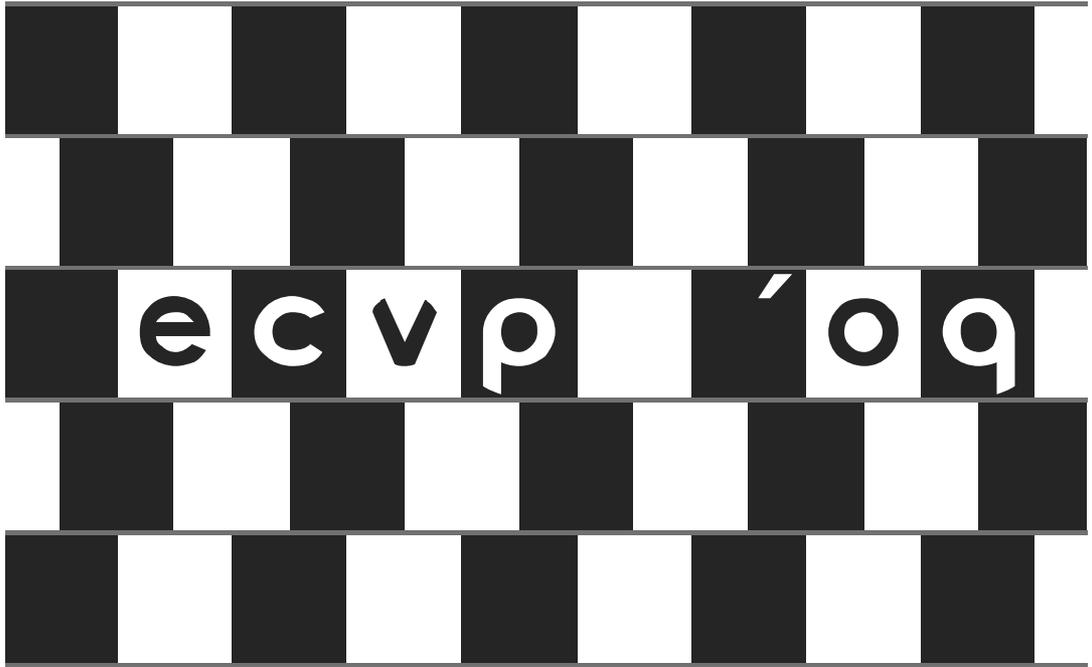


PERCEPTION

VOLUME 38 SUPPLEMENT



32nd European Conference

on Visual Perception

Regensburg, 24–28 August 2009

Abstracts

Thirty-second European Conference on Visual Perception

Regensburg, Germany

24 – 28 August 2009

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ECVP '09 Abstracts

MONDAY

SATELLITE WORKSHOP

MODELS OF VISION AND DECISION-MAKING: FROM FEATURES TO BEHAVIOUR AND PERCEPTUAL ROBOTICS

◆ **Neural mechanisms of motion integration and segregation: perception and modeling**

H Neumann (Faculty of Engineering and Computer Sciences, Institute of Neural Information Processing, University of Ulm, Germany; e-mail: heiko.neumann@uni-ulm.de)

Different behavioural tasks necessitate the perceptual combination of raw items to form task-relevant prototypical objects and to segregate them from the background. Evidence suggests that the processing is based on neural mechanisms of hierarchical computation of motion and form and on their interaction at different stages along the cortical dorsal and ventral pathway. In a neural modeling approach we investigate how form–motion interactions at early and intermediate stages involving cortical areas V1, MT, MST, and V2 achieve seemingly conflicting tasks of item integration and, at the same time, of segregating object fragments apart. We demonstrate this for different examples, namely the integration of ambiguous motion estimates and the segregation of multiple target objects, the segregation of transparent motions into distinct layers, and figure–ground segregation from motion. Attention signals can be deployed for spatial locations and for features at different stages to improve perceptual performance. We show that the combined action of feedforward and feedback signal processing as well as lateral modulating interaction can explain the main experimental findings in one common model framework. It is predicted that attention and decision-making mechanisms can be observed as delayed response amplification in the neural representations, which is in accordance with recent physiological findings.

[*Joint work with Cornelia Beck and Florian Raudies. Supported by European Union (projects Decisions-in-Motion and SEARISE) and BMBF.]

◆ **Mechanisms and dynamics of visual attention in primates**

S Treue (German Primate Center, Cognitive Neuroscience Center, Bernstein Center for Computational Neuroscience, Georg August University, Göttingen, Germany; e-mail: treue@gwdg.de)

Attentional modulation is a powerful influence on the processing of visual information in primate cortex. I will present experimental findings focussing on the influence of attention on area MT in macaque visual cortex. Here electrophysiological recordings have demonstrated the influence not only of spatial attention but also the neural correlates of attention to stimulus features and of object-based attention. The attentional modulation appears to have a multiplicative influence on neural responses but it is still able to create non-multiplicative changes in receptive field profiles in population responses and to complex multi-component stimuli.

◆ **Active segmentation**

Y Aloimonos (Institute for Advanced Computer Studies, Computer Vision Laboratory, University of Maryland, College Park, USA; e-mail: yiannis@cs.umd.edu)

The human visual system observes and understands a scene/image by making a series of fixations. Every 'fixation point' lies inside a particular region of arbitrary shape and size in the scene which can either be an object or just a part of it. We define as a basic segmentation problem the task of segmenting that region containing the 'fixation point'. Segmenting the region containing the fixation is equivalent to finding the enclosing contour—a connected set of boundary edge fragments in the edge map of the scene—around the fixation. I present here a novel algorithm that finds this bounding contour and achieves the segmentation of one object, given the fixation. The proposed segmentation framework combines monocular cues (color/intensity/texture) with stereo and/or motion, in a cue independent manner. The performance of the proposed algorithm is evaluated on challenging videos and stereo pairs. Although the proposed algorithm is more suitable for an active observer capable of fixating at different locations in the scene, it applies to a single image as well. It is shown here that even with monocular cues alone, the introduced algorithm performs as well or better than a number of image segmentation algorithms, when applied to challenging inputs.

[*Joint work with Ajay Mishra and Cornelia Fermüller. Supported by the EU Program on Cognitive Systems, (project POETICON).]

Monday

◆ **Neural model of visually-guided navigation in a cluttered world**

E Mingolla (Center for Adaptive Systems, Center of Excellence for Learning in Education, Science, and Technology (CELEST), Boston University, USA; e-mail: ennio@cns.bu.edu)

Visually guided navigation through a cluttered natural scene is a challenging problem that animals and humans accomplish with ease. A neural model proposes how primates use motion information to segment objects and determine heading for purposes of goal approach and obstacle avoidance in response to video inputs from real and virtual environments. The model produces trajectories similar to those of human navigators by use of computationally complementary processes in its analogs of cortical areas MT-/MSTv and MT+/MSTd to determine object motion for tracking and self-motion for navigation, respectively. The model retina responds to transients in the input stream. Model V1 generates a local speed and direction estimate that is ambiguous due to the neural aperture problem. Model MT+ interacts with MSTd via an attentive feedback loop to compute accurate heading estimates in MSTd that quantitatively simulate properties of human heading estimation data. Model MT- interacts with MSTv via an attentive feedback loop to compute estimates of speed, direction and position of moving objects. This object information is combined with heading information to produce steering decisions wherein goals behave like attractors and obstacles behave like repellers. These steering decisions lead to navigational trajectories that closely match human performance.

◆ **Multisensory integration for perception and action in virtual environments**

H H Bülthoff (Department of Human Perception, Cognition and Action, Max Planck Institute for Biological Cybernetics, Tübingen, Germany; e-mail: hhb@tuebingen.mpg.de)

Understanding vision has always been at the centre of research in perception and cognition. Experiments on vision, however, have usually been conducted with a strong focus on perception, neglecting the fact that in most natural tasks sensory signals are not ultimately used for perception, but rather for action. The effects of the action are sensed by the sensory system, so that perception and action are complementary parts of a dynamic control system. Additionally, the human sensory system receives input from multiple senses which have to be integrated in order to solve tasks ranging from standing upright to controlling complex vehicles. In our Cybernetics research group we use psychophysical, physiological, modeling, and simulation techniques to study how cues from different sensory modalities are integrated by the brain to perceive, act in, and interact with the real world. In psychophysical studies, we could show that humans integrate multimodal sensory information often, but not always, in a statistically optimal way such that cues are weighted according to their reliability. In this talk, I will present results from our studies on multisensory integration of perception and action in both natural and simulated environments for different tasks using our latest simulator technologies, the Cyberwalk omnidirectional treadmill and the MPI Motion Simulator based on a large industrial robot arm.

◆ **Cortical mechanisms for generating multi-sensory spatial representations in guiding actions**

F Bremmer (Department of Neurophysics, Philipps-University Marburg, Germany; e-mail: frank.bremmer@physik.uni-marburg.de)

The neural circuits underlying normal spatial vision and attentive sensorimotor behaviour of primates have been most intensively studied in macaque monkeys. Both electrophysiological and anatomical studies have highlighted the importance of the posterior parietal cortex for the integration of neural signals from different sensory modalities and its use for guiding and controlling action in space. In the monkey, a highly modular structural and functional specialization has been demonstrated within this part of the brain. One such functionally specialized area is the ventral intraparietal area (VIP) located in the fundus of the intraparietal sulcus (IPS). I will review a number of recent studies where we have shown that area VIP contains many neurons that show multisensory directionally selective discharges, ie these neurons respond to moving visual, tactile, vestibular or auditory stimuli. The functional properties imply that area VIP is involved in the encoding of self- and/or object motion in near-extraperpersonal space. In addition, many VIP neurons also encode sensory information from different modalities in a common, probably head-centered, frame of reference.

◆ **Vision to action: Neurophysiology and modelling of the visual properties of mirror neurons**

M A Giese (Section for Computational Sensorimotorics, Hertie Institute for Clinical Brain Research and Center for Integrated Neuroscience, University Clinic Tübingen, Germany; e-mail: martin.giese@uni-tuebingen.de)

The visual recognition of goal-directed movements is central for imitation learning and action understanding. It is completely unknown whether action recognition in the brain is based on simple image-based visual processes, or on a full reconstruction of the 3-D geometry of the effector and goal object (as implicitly assumed by many existing models in robotics). We present

a neurophysiologically-inspired model for the recognition of goal-directed grasping movements from real video sequences. It is based on physiologically plausible mechanisms and proposes a new mechanism that integrates the information about goal objects and the effector. Core elements are: (i) A hierarchical neural architecture for the recognition of hand and object shapes that realizes partial positional invariance by nonlinear pooling; the retinal positions of goal object and effector can be read out from this hierarchy by a population code. (ii) Simple recurrent neural circuits that make recognition dependent on the temporal sequence of the occurring effector shapes. (iii) A novel neural mechanism that combines information about object shape and affordance and the effector posture and position, exploiting a gain field-like mechanism that implements the relevant coordinate transformations. The model shows that a robust recognition of goal-directed hand actions from unsegmented real video sequences can be accomplished by well-established physiologically plausible principles. In addition the model predicts and reproduces critical visual tuning properties of mirror neurons in area F5 of premotor cortex.

[*Joint work with Falk Fleischer, Vittorio Caggiano, and Antonino Casile. Supported by DFG (SFB 550), EC (projects COBOL and SEARISE), and the Hermann und Lilly Schilling Foundation.]

◆ **From 3-D sensing to recognition to shape understanding: A viewpoint from robotics**

U Hillenbrand (Institute of Robotics and Mechatronics, German Aerospace Center (DLR), Oberpfaffenhofen, Germany; e-mail: Ulrich.Hillenbrand@dlr.de)

For an autonomously acting robotic agent, it is essential to acquire both a geometric and a functional understanding of its environment. A principled way to achieving both goals is through the acquisition and processing of range data. I will briefly describe the various range sensing technologies we use and some approaches to object recognition from range data we have taken. Of particular interest is recognition not just of specific shapes, but of generic shape categories, so as to allow segmenting and interpreting objects even when seen for the first time. By establishing detailed correspondences between known shapes and new shapes of the same category, task-relevant knowledge can be transferred to novel situations involving unknown objects.

◆ **Perception of space and time during saccades**

M C Morrone (Faculty of Medicine, Pisa Vision Lab, University of Pisa and Scientific Institute Stella Maris, Italy; e-mail: concetta@in.cnr.it)

Vision is always clear and stable, despite continual saccadic eye movements, ballistic movements of the eyes that reposition our gaze, two to three times a second. The world seems to stay put, while comparable image flow produced externally, rather than by movements of the observer's own eyes, has an alarming effect on the observer's sense of stability. The perceptual and neuronal mechanisms mediating stability are still mostly unknown, although much evidence points to the existence of an eye-positional signal that becomes active before the actual eye movement. Before the onset of saccades, briefly presented stimuli are grossly mislocalized in space and in time: visual stimuli appear mislocalized in space, usually in the direction of the saccade, and delayed in time; and both relative distances and durations appear strongly compressed (Ross et al., 1997 *Nature* **386** 598–601; Morrone et al, 2005 *Nature Neuroscience* **8** 950–954). The temporal distortions also depend on perceived spatial position: the amount of perceived perisaccadic spatial displacement correlating with the magnitude of temporal distortion, but not with the physical position of the target. The perceptual errors are greatly reduced for multisensory (audio-visual) stimuli (Binda et al, 2007 *Journal of Neuroscience* **27** 8525–8532) and for localization by blind pointing (Burr et al, 2001 *Current Biology* **11** 798–802; Morrone et al, 2005 *Journal of Vision* **5**(9):7, 741–754). All the data are consistent with the idea that the perceptual localization of visual events in space and in time is mediated by visual neurones with craniotopic receptive fields that commence to compensate for the gaze shift before the actual eye position.

◆ **A behavioural model for vision-based navigation of robots**

A Frisoli (Virtual Reality and Telerobotic Systems Division, PERCRO Lab, Scuola Superiore Sant' Anna, Pontedera, Italy; e-mail: a.frisoli@sssup.it)

Humans and many animals can estimate the optic flow in their surrounding. By knowing their translational speed, they can improve their performance in object-reaching and obstacle-avoidance tasks. Different kinds of information can be extracted from optic flow, eg, speed, traveled distance, time to contact, heading. Small animals like insects can easily navigate in their natural environment, avoiding obstacles that are in their way. In this presentation, we report on analytical and experimental performance evaluation of different models of neuromorphic architectures for robot navigation that make use of optic flow estimation as well as on a reactive behavioural module for robot navigation. The latter is an extension of a behavioural model, based on a simplified dynamics of human behaviour, observed in humans during navigation tasks. Its implementation in an algorithm for robot navigation allowed us to study the effect of speed estimation on human performance in reaching and avoidance tasks.

Monday

◆ **Modeling the role of task in the control of gaze**

D H Ballard (Department of Computer Science, Center for Perceptual Systems, University of Texas at Austin, USA; e-mail: dana@cs.utexas.edu)

Gaze changes and their resultant fixations that orchestrate the sequential acquisition of information from the visual environment are the central feature of primate vision. How are we to understand their function? For the most part, theories of fixation targets have been image-based: the hypothesis being that the eye is drawn to places in the scene that contain discontinuities in image features such as motion, color and texture. But are these features the cause of the fixations or merely the result of the fixations that have been planned to serve some visual function? We examine the issue and review evidence from various image-based and task-based sources. Our conclusion is that the evidence is overwhelmingly in favor of fixation control being essentially task-based.

◆ **Using neurally inspired robots to study brain function: Principles and mechanisms**

J L Krichmar (Department of Cognitive Sciences, University of California, Irvine, USA; e-mail: jkrichma@uci.edu)

Organisms whose behaviors are guided by a nervous system are by far more sophisticated than current artificial agents. Thus, the construction of behaving devices based on principles of nervous systems may have much to offer. Our group has built series of neurobiologically inspired robots to provide a heuristic for studying brain function by embedding neurobiological principles on a physical platform capable of interacting with the real world. These neurorobots have been used to study attention, action selection, perception, operant conditioning, episodic memory, and motor control through the simulation of brain regions such as the visual cortex, the neuromodulatory system, the hippocampus, and the cerebellum. Following the brain-based model, we argue that an intelligent machine should be constrained by the following design principles: (i) it should incorporate a simulated brain with detailed neuroanatomy and neural dynamics that controls behavior and shapes memory, (ii) it should organize the unlabeled signals it receives from the environment into categories without a priori knowledge or instruction, (iii) it should have a physical instantiation, which allows for active sensing and autonomous movement in the environment, (iv) it should engage in a task that is initially constrained by minimal set of innate behaviors or reflexes, (v) it should have a means to adapt the device's behavior, called value systems, when an important environmental event occurs, and (vi) it should allow comparisons with experimental data acquired from animal nervous systems. Like the brain, these devices operate according to selectional principles through which they form categorical memory, associate categories with innate value, and adapt to the environment. Moreover, this approach may provide the groundwork for the development of intelligent machines that follow neurobiological rather than computational principles in their construction.

THE PERCEPTION LECTURE

◆ **Distributed processing and temporal codes in cortical networks**

W Singer (Frankfurt Institute for Advanced Studies (FIAS), Max Planck Institute for Brain Research, Frankfurt am Main, Germany; e-mail: singer@mpih-frankfurt.mpg.de)

The cerebral cortex presents itself as a distributed dynamical system with the characteristics of a small world network. The neuronal correlates of cognitive and executive processes often appear to consist of the coordinated activity of large assemblies of widely distributed neurons. These features require mechanisms for the selective routing of signals across densely interconnected networks, the flexible and context dependent binding of neuronal groups into functionally coherent assemblies and the task and attention dependent integration of subsystems. In order to implement these mechanisms, it is proposed that neuronal responses should convey two orthogonal messages in parallel. They should indicate (i) the presence of the feature to which they are tuned, and (ii) with which other neurons (specific target cells or members of a coherent assembly) they are communicating. The first message is encoded in the discharge frequency of the neurons (rate code) and it is proposed that the second message is contained in the precise timing relationships between individual spikes of distributed neurons (temporal code). It is further proposed that these precise timing relations are established either by the timing of external events (stimulus locking) or by internal timing mechanisms. The latter are assumed to consist of an oscillatory modulation of neuronal responses in different frequency bands that cover a broad frequency range from < 2 Hz (delta) to > 40 Hz (gamma) and ripples. These oscillations limit the communication of cells to short temporal windows whereby the duration of these windows decreases with oscillation frequency. Thus, by varying the phase relationship between oscillating groups, networks of functionally cooperating neurons can be flexibly configured within hard-wired networks. Moreover, by synchronizing the spikes emitted by neuronal populations, the saliency of

their responses can be enhanced due to the coincidence sensitivity of receiving neurons in very much the same way as can be achieved by increasing the discharge rate. Experimental evidence will be reviewed in support of the coexistence of rate and temporal codes. Evidence will also be provided that disturbances of temporal coding mechanisms are likely to be one of the pathophysiological mechanisms in schizophrenia.

Tuesday

TUESDAY

TALK SESSION A

ATTENTION AND VISUAL SEARCH

◆ **Spatial attention modulates the spatiotopicity of human MT complex**

S A Crespi, L Biagi¶, D C Burr§, G d'Avossa#, M Tosetti¶, M C Morrone‡ (Department of Psychology, Università Vita-Salute San Raffaele, Milan, Italy; ¶ Scientific Institute Stella Maris, Pisa, Italy; § Department of Psychology, Università degli Studi di Firenze, Italy; # School of Psychology Adeilad Brigantia, Bangor University, UK; ‡ Department of Physiological Sciences, Università di Pisa, Italy; e-mail: s.crespil@campus.unimib.it)

Previously (d'Avossa et al, 2007 *Nature Neuroscience*), we reported that the visual BOLD response of human motion area MT+ is spatially selective in external (spatiotopic) not retinotopic coordinates. However, Gardner et al (2008 *Journal of Neuroscience*) reported the opposite result, claiming that MT+, like other occipital visual areas, is retinotopic rather than spatiotopic. One major difference between the two studies is that Gardner et al required subjects to perform an attentive task centred at the fovea. We therefore studied spatiotopicity in MT+ by measuring visually evoked BOLD responses (Phillips 3T) under two attentive conditions, one where subjects performed a contrast discrimination task at the fixation point, and one with passive fixation in the absence of an active task. As before, stimuli were presented in four possible positions ($\pm 5^\circ$ and $\pm 15^\circ$ eccentricity), with three different fixations (0° and $\pm 10^\circ$). During the passive viewing condition, the BOLD response was primarily spatiotopic, depending on the stimulus position in space rather than on the retina, replicating d'Avossa et al (2007). However, when subjects performed the foveal task, the response became more retinotopic. These results confirm previous fMRI evidence for spatiotopicity in human MT+, and suggest that spatial attention may affect spatiotopic selectivity. The results also suggest a neural substrate for cross-saccadic integration of motion (Melcher and Morrone, 2005 *Nature Neuroscience*).

◆ **Behavioral studies support the normalization model of attention**

K Herrmann, L Montaser Kouhsari, M Carrasco¶, D J Heeger¶ (Department of Psychology [§ and Center for Neural Science], New York University, USA; e-mail: katrin.herrmann@nyu.edu)

Attention has been shown to affect neuronal responses in visual cortex through either contrast gain or response gain. The normalization model of attention (Reynolds and Heeger, 2009 *Neuron*) reconciles these disparate findings by proposing that stimulus size and attention field size determine the effect of attention on contrast response functions and, consequently, on psychometric functions. We tested this key prediction for exogenous (involuntary) and endogenous (voluntary) attention. Observers performed a 2AFC orientation-discrimination task on one of two tilted Gabor stimuli. Attention was directed by a pre-cue. A response-cue at stimulus offset indicated the target location, yielding three cue conditions: valid (pre-cue matched response-cue), invalid (mismatched) and neutral (both stimulus locations pre-cued). Smaller stimuli were paired with larger attention fields and vice versa. Attention field size was enlarged by introducing spatial uncertainty and decreased by surrounding stimuli with distracters. As predicted by the normalization model of attention, exogenous and endogenous attention had similar effects on psychometric functions: response gain (change in asymptotic performance at high contrasts) emerged for large stimuli paired with small attention fields, and contrast gain (change in the contrast yielding half-maximum performance) emerged for small stimuli paired with large attention fields.

◆ **Reward modulates the signal-to-noise ratio of orientation-tuned channels**

S Baldassi, C Simoncini¶ (Department of Psychology, University of Florence, Italy; ¶ Institut de Neurosciences Cognitives de la Méditerranée, CNRS, Marseilles, France; e-mail: stefano.baldassi@unifi.it)

Rewarding improves performance. Does it depend only on sharper responses or are there mechanisms favoring more 'generous' input? In this study, we address this issue with a psychophysical dual task consisting of a foveal counting task to control attention while orientation discrimination thresholds for peripheral targets associated to different levels of reward are measured. We found that different reward rates improve orientation discrimination, sharpens the internal response distributions and decreases off-orientation looking. This occurred independently of the attentional load and when the effect of feature-based attention was considered. We have successfully modeled the data in a simulation in which orientation discrimination is performed by comparing the output of independent orientation-tuned filters and by choosing the direction of the loudest. Simply increasing the signal-to-noise ratio (SNR) of each relevant channel to simulate the positive modulation of reward reproduces thresholds improvement, response distribution sharpening,

and the reduction of off-orientation looking. This suggests that reward may act independently on attention by modulating the activity of early sensory stages, perhaps V1, through a SNR improvement of task-relevant channels. Reward acts like attention, but using separate channels.

◆ **Optimal adaptation of visual search strategies to utility: Empirical evidence and computational model**

Y-C Tseng[¶], A Howes (Manchester Business School, The University of Manchester, UK; [¶]Human Factors Division and Beckman Institute, University of Illinois at Urbana-Champaign, USA; e-mail: yctsensg@illinois.edu)

Studies suggest humans have a tendency to shift attention to the location that maximises information gain. However, it is unclear whether people maximise information gain in circumstances where the cost of gaining information is likely to reduce its utility. An ecologically motivated visual search paradigm with a well-defined cost/benefit structure was proposed to investigate the adaptation of visual search strategies to the utility payoff of an environment. Empirical findings supported the hypothesis that the micro-structure of the visual search process is adapted to a desire to maximise utility. The results showed that participants trade time for value, and adjust gaze duration and targeting to the distribution of reward. A signal detection based model successfully predicted that adaptation generates optimal utility given the perceptual system and task constraints. The model also predicted that an information maximisation strategy would have been too expensive as a means to maximise utility. These results demonstrate the extreme flexibility of the human visual search system in response to top-down representations of local task utility. The model, in which the best fitting strategy is also the strategy that generates the highest utility, supports the idea that people do not merely adapt, but rather that they adapt optimally.

◆ **Modulation of attentional capture by display probabilities in visual search**

B Sayim, A Grubert[¶], J Krummenacher[¶], M H Herzog (Laboratory of Psychophysics, Brain Mind Institute, Ecole Polytechnique Fédérale de Lausanne, Switzerland; [¶]Department of Psychology, University of Fribourg, Switzerland; e-mail: bilge.sayim@epfl.ch)

Attentional capture is often thought to be automatic and not modulable. For example, visual search experiments showed that salient distractor singletons strongly capture attention even when they had to be ignored by the observers. Recently, however, it was shown that attentional capture can be modulated by varying the display probability of distractors. Thus, attentional capture is not completely automatic. Distractor singletons in these studies were defined by salient colour differences and, hence, the parvocellular system may have been primarily involved. Here, we aimed at involving the magnocellular system by presenting onset distractors—ie, distractors displayed after the onset of the other search items—which are known to strongly capture attention. Eye movements were recorded. The results clearly show that attentional capture by the onset distractors strongly depended on their display probability: The higher the display probability, the lower the proportion of saccades to the onset distractors. This result provides further evidence that attentional capture is not completely automatic.

◆ **Critical differences in flicker rate capture attention**

J R Cass, E Van der Burg[¶], D Alais (School of Psychology, University of Sydney, Australia; [¶]Department of Cognitive Psychology, Vrije Universiteit, Amsterdam, The Netherlands; e-mail: johnc@psych.usyd.edu.au)

Does visual flicker capture attention, and if so, are faster flicker rates more effective? This study used a speeded visual search task involving horizontal and vertical target singletons amongst oblique distractors, all equidistantly located around fixation. Oriented elements were surrounded by a luminance modulating annulus. In Experiment 1 distractor annuli all flickered at 1.3 or 12.1 Hz while the target temporal rate varied between 1.3 and 12.1 Hz. Set size was either 4, 7, or 10 items. Search improved monotonically with increasing temporal frequency separation between target and distractor annuli, producing parallel search performance at separations ≤ 5 Hz. Results were symmetrical with respect to temporal frequency (low frequencies pop out from high; and vice versa). These results are closely predicted by the profiles of human temporal frequency filters. In Experiment 2 we find performance costs when the unique temporal frequency corresponded with a distractor location. The combination of pop-out and attentional costs indicates that low and high flicker frequencies can capture attention. We also examine the effects of combining auditory flutter at target or distractor frequencies. Our results indicate that additional auditory cues only provide benefits in search efficiency under impoverished visual conditions.

Tuesday

◆ **Masking effects in visual feature binding**

S Jaswal, R H Logie (Human Cognitive Neuroscience, Department of Psychology, University of Edinburgh, UK; e-mail: S.Jaswal@sms.ed.ac.uk)

What happens to irrelevant features in binding from 0–2500 ms? Stimuli were conjunctions of shape, colour, and location. Participants had to detect swaps in shape–colour bindings with location either unchanged, or made irrelevant by randomizing it from study to test, in a change detection task with study-test intervals ranging from 0–2500 ms. Performance differences between unchanged and randomised location conditions were expected at shorter but not longer study-test intervals. Results of Experiment 1 confirmed this expected interaction. Experiment 2 presented a pattern mask immediately after the study display to eliminate the effect of iconic memory. The mask reduced, but did not completely eradicate, the gap between unchanged and randomized location conditions at shorter study-test intervals. Experiment 3 used the mask after a delay of 300 ms to study encoding efficiency following Vogel et al [2006 *Journal of Experimental Psychology: Human Perception and Performance* **32** 1436–1451], and Woodman and Vogel (2008 *Psychonomic Bulletin and Review* **15**(1) 223–229]. The mask disrupted, and thus confirmed the existence of the central processes of consolidation as well as inhibition happening at 300 ms. Across experiments, results allowed the conclusion that while bindings of relevant features are consolidated with the aid of iconic memory, there is also ‘active inhibition’ of irrelevant features.

◆ **Attention helps generalize learning across locations**

M Carrasco, A Giordano¶ (Department of Psychology and Neural Science [¶ Department of Psychology], New York University, USA; e-mail: marisa.carrasco@nyu.edu)

Perceptual learning is considered to be highly specific for basic stimulus attributes, such as orientation and spatial location. We investigated how exogenous attention affects perceptual learning with regard to spatial locations. Observers trained for five consecutive days with an orientation discrimination task (left vs right) using two Gabor stimuli on the horizontal meridian. For some observers each trial began with a spatially neutral cue. For other observers an uninformative spatial cue preceded either the target (valid cue) or the distractor (invalid cue). For a third group of four observers, a spatial cue always preceded the target. The transfer task was identical to the training, except that for five consecutive days observers reported the orientation of Gabors that were either at the original location or were shifted to neighboring locations (transfer task). During the transfer task, observers’ performance levels dropped back to the initial training level, thus showing the signature of perceptual learning. The performance decrement diminished significantly for observers who trained with valid and invalid cues and was absent for observers who trained only with valid cues. The results suggest that exogenous attention transfers to new stimulus locations, thus helping generalize learning.

TALK SESSION B

MOTION MECHANISMS, ADAPTATION, AND ILLUSIONS

◆ **Biphasic temporal response of low-level motion detectors in human vision revealed by a direction discrimination task**

K L Challinor, G Mather (Department of Psychology, University of Sussex, Brighton, UK; e-mail: K.Challinor@sussex.ac.uk)

Current models of low-level motion detectors assume that their temporal impulse response is bipolar, with an initial positive phase and a later negative phase. However, it is difficult to test this assumption using a task that isolates motion detector responses. We devised a psychophysical direction discrimination task to investigate the shape of the temporal response function. The stimulus contained eight animation frames in which square-wave luminance gratings alternated with saw-tooth luminance gratings, separated by blank interstimulus intervals. Each grating type underwent a half-cycle phase-shift at each re-appearance (alternate frames). But when quarter-cycle edge displacement in adjacent frames is considered, two possible directions were available. One direction corresponded to matches between like-signed luminance edges, and the opposing direction corresponded to matches between opposite-signed edges. We found that at very short ISIs apparent direction was determined by like-signed edges, reflecting the initial positive phase of the temporal response. But at intermediate ISIs (33–100 ms) apparent direction was determined by opposite-signed edges, reflecting the later negative phase of the temporal response. These results are consistent with predictions computed from a standard motion energy sensor fed by filters with a biphasic temporal impulse response.

◆ **Surround motion affects speed encoding at an early stage of processing**

D H Baker, E W Graf (School of Psychology, University of Southampton, UK;
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Surround motion can strongly modulate the perceived speed of a central stimulus, yet the mechanisms behind this process are unknown. Using translating gratings (1 cycle deg⁻¹, 1 deg s⁻¹) surrounded by filtered noise textures, we conducted experiments to measure spatiotemporal tuning, contrast dependency and envelope properties of surround modulation in two directions. Plotted in terms of relative surround speed, perceived (matched) speed followed a sigmoidal function, saturating at the fastest speeds, ruling out a simple differencing process. Effect size increased with temporal frequency (speed * SF) and showed some spatial frequency tuning. Reductions in perceived speed saturated as a function of surround contrast and were constant with envelope blur. Perceived speed increases were weaker for sharper envelopes, but increased with surround contrast. We then asked whether surround effects occur before or after pattern motion computation. Using plaid stimuli with components $\pm 45^\circ$, we measured the PSE for global plaid direction with and without surrounds drifting along the motion axis of one component. We observed substantial shifts (up to 20°) in the perceived plaid direction, consistent with surround-induced perceived speed changes. No effect was found for a grating drifting in the pattern direction. This suggests that surround effects occur before pattern integration in extrastriate areas (MT).

◆ **The role of striate cortex (V1) in conscious and unconscious motion perception**

M Koivisto, T Mäntylä, J Silvanto¶ (Department of Psychology, University of Turku, Finland;
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A 'late' period of activity in striate cortex (V1) in response to extrastriate feedback has been proposed to act as a gatekeeper to visual awareness. Although there is evidence to suggest that this feedback activity in V1 plays a role in visual perception, it is not clear whether it is exclusively associated with visual awareness. Here we investigated the role of this 'late' V1 activity in conscious and unconscious motion perception. Participants were asked to make forced-choice direction discrimination judgments (left vs right) on coherently moving dots and to rate their subjective awareness of motion on each trial. Transcranial magnetic stimulation was applied over the early visual cortex at either 20, 40, 60, 80, or 100 ms after motion offset. Consistent with previous studies, visual awareness was impaired at an 'early' (20 ms) and a 'late' (60 ms) time window, the latter presumably reflecting feedback activity. Importantly, unconscious perception (ie discrimination performance in the absence of awareness) was also impaired at the late time window. These results therefore suggest that the 'late' period of V1 activity is necessary for visual perception in general rather than for conscious perception in particular.

◆ **Orientation-tuned masking and adaptation caused by motion streaks**

D Apthorp, J R Cass, D Alais (Department of Psychology, University of Sydney, Australia; e-mail: deboraha@psych.usyd.edu.au)

The oriented trail of blur left by fast-moving objects ('motion streaks') could be used by the visual system, in combination with motion information, to help judge direction of motion (Geisler, 1999). If fast motion were 'deblurred' very early in the motion perception process, however, streaks would be unavailable at the cortical level to combine with motion signals. Here we show that fast-moving arrays of Gaussian blobs cause monoptic contrast masking of static gratings. This is tuned for both orientation and spatial frequency, with similar bandwidths to masking functions for static stimuli (Phillips and Wilson, 1984). Dichoptic masking shows little orientation tuning, but dichoptic presentation at low mask contrasts results in tuned facilitation. We explore masking as a function of dot mask contrast, thus establishing the effective contrast of the motion streak signal. Interestingly, repeating the experiment in an adaptation paradigm (adapting to drifting dots and testing thresholds for low-contrast gratings), we show broad orientation-tuned threshold elevation in the adapted eye; interocular functions show very little threshold elevation, but distinct facilitation at orientations away from the adapting direction of motion. Binocular threshold elevation tuning is much narrower, and this is discussed in terms of a model of interocular suppression.

◆ **Modelling contrast sensitivity of the motion aftereffect**

W A van de Grind (Helmholtz Institute and Functional Neurobiology, Utrecht University, The Netherlands; e-mail: w.a.vandegrind@uu.nl)

A previously described neural gain-control model explained the phenomenon of storage of motion aftereffects (MAE) (van de Grind et al, 2004 *Vision Research* **44** 2369–2384). The model contains no other 'storage' mechanism than a single adaptation-dependent gain-control per direction-

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tuned channel. An adequate test stimulus is presumed to stimulate all direction channels about equally and thus it tends to restore the balance between these channels. One counter-intuitive qualitative prediction of the model was that a MAE will last longer for weak tests and shorter for strong test stimuli. Such a result has indeed been reported in the literature (eg Keck et al, 1976 *Vision Research* **16** 187–191; Keck and Penz, 1977 *Perception* **6** 719–725), that is, if we interpret ‘stimulus strength’ in the model as ‘contrast’ in psychophysics. To quantitatively describe the psychophysical results a mapping from contrast to model input-values was required. Here I report the results of such an extension with a physiologically plausible front-end stage. The expanded model proves to describe both the psychophysically measured influence of adaptation contrast, of test contrast, and of their interactions, in great detail. The model is simple and powerful, making it an attractive candidate for broader application in studies of aftereffect phenomena.

◆ **Mixing slow and fast speeds fools the colour-motion asynchrony illusion**

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When a stimulus changes colour and motion direction in synchrony, we perceive that the motion change is delayed relative to the colour change: the colour-motion asynchrony (CMA) illusion. As the asynchrony is larger when opposite directions are used (Arnold and Clifford, 2002 *Proceedings of the Royal Society of London, Series B* **269** 579–583), opponency mechanisms between motion channels might be implicated. On the other hand, it is believed that the visual system processes low and fast speeds partially independently (van der Smagt et al, 1999 *Nature Neuroscience* **2** 585–596). Assuming that this independency affects how opponency mechanisms are engaged, we expect a reduction of the perceived delay of motion by using speeds with different modules (slow/downwards and fast/upwards). To test this, we displayed plaids that changed colour (red/green) and motion direction (up/-down) every 300 ms at different relative phases. Consistent with the illusion observers paired colours with early motions for both slow (3.5 up and 3.5 deg s⁻¹ down) and fast speeds (11 up and 11 deg s⁻¹ down). Critically, when the speeds were intermixed (eg 11 up and 3.5 deg s⁻¹ down) the perceived asynchrony was reduced by about 40 ms, which supports the role of motion opponency in the CMA illusion and adds further evidence for segregation of slow and fast speed processing.

◆ **Optic flow perceived from illusory disk motion**

J M Zanker (Department of Psychology, Royal Holloway, University of London, UK;

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Op art paintings and other static images can elicit strong motion illusions, which are attributed to eye movements that lead to image shifts generating local motion signals (Zanker and Walker, 2004 *Naturwissenschaften* **91**). Similar phenomena can be generated without any displacement of the image, for instance in the ‘Spinning Disk Illusion’ where disks filled with greylevel gradients appear to move when the background luminance changes. A biologically plausible motion detector, the 2-DMD model, can account for the perceived shift of a static gradient disk under these conditions (Zanker, 2007 *Perception* **36** Supplement, 64). When randomly distributed sets of disks with radial or tangential orientation of the greylevel gradient are presented in front of a luminance-modulated background, a strong percept of translational and rotational optic flow is perceived by human observers. The 2-DMD model predicts that the strength of the flowfield information depends on stimulus parameters such as the number and the size of the disks, or the slope of the greylevel gradient. Corresponding to the modelling results, we found in psychophysical experiments that the ability to detect illusory flow patterns depends on the density and strength of local motion signals generated by the dynamic contrast changes at the edges of the greylevel gradients.

◆ **Buildings drawn in perspective on large billboards appear to rotate: An explanation**

T V Papathomas, Z Kourtzi[¶], A E Welchman[¶] (Biomedical Engineering and Laboratory of Vision Research, Rutgers University, New Brunswick, USA; [¶]School of Psychology, University of Birmingham, UK; e-mail: papathom@rci.rutgers.edu)

In a variant of the ‘following’ or ‘pointing-out’ illusion, a building drawn in linear perspective on a huge flat billboard appears as a 3-D volumetric structure that ‘moves with’ viewers who move in front of it, especially if they move fast. Stereo and motion parallax provide bottom–up signals to perceive the flat billboard as such (ie, a flat surface). As a result, because of the strong perspective cues, the painted building’s 3-D shape is perceived to be invariant under changes in the vantage point (Kubovy, 1986). We provide a simple qualitative explanation for this motion that relies on the fact that any point on the building is perceived to lie in depth along its line of sight. Because of perspective, different points on the building are perceived to lie at different

depths in accordance with the perspective cues, rather than in accordance with the flat billboard surface. Thus, every physical point on the painted building acts as a ‘pivot’ that connects the moving eye to the misperceived depth of the corresponding point; this produces the illusory motion. This explanation runs contrary to alternative ‘high-level’ theories and explains the illusion as a straightforward consequence of pictorial 3-D interpretation.

SYMPOSIUM

PERCEPTUAL LEARNING

◆ **Reinforcement, associative, and perceptual learning in a visual decision task**

J Gold (Department of Neuroscience, University of Pennsylvania, Philadelphia, USA;
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Many perceptual tasks require the brain to weigh noisy evidence from sensory neurons to form categorical judgments that guide behavior. In my talk I will discuss recent experiments combining neurophysiology and behavior in monkeys that have begun to identify how experience can shape these decision mechanisms. For a visual motion discrimination task, improvements in perceptual performance, a phenomenon known as perceptual learning, does not appear to involve changes in the response properties of neurons that represent the sensory evidence. Instead, perceptual learning results from changes in how the sensory evidence is selected and weighed to form the decision. These changes are consistent with a reinforcement-driven process that first establishes the association between the neurons that represent the sensory evidence and those that prepare the behavioral response, and then further refines that association so that only the most informative sensory neurons drive the decision. I will discuss predictions, implications, and the generality of this scheme.

◆ **Functions and mechanisms of perceptual learning**

Z-L Lu (Department of Psychology, University of Southern California, Los Angeles, USA;
e-mail: zhonglin@usc.edu)

Perceptual learning—the improvement of performance through practice or training—has been observed over a wide range of perceptual tasks in adult humans. The high degree of plasticity of the adult perceptual systems suggests that perception and perceptual learning cannot be studied separately. In this talk, I will review some major functions and mechanisms of perceptual learning, including specificity of perceptual learning, the law of practice in perceptual learning, mechanisms of perceptual learning, the level and mode of perceptual learning, optimal training procedures, and computational models of perceptual learning. Studies of these various aspects of perceptual learning have greatly enhanced our understanding of the information processing limitations of the human observer, and how the state of the observer changes with training, with strong implications for the development of potential noninvasive training methods for perceptual expertise in normal populations and for the amelioration of deficits in challenged populations.

◆ **Explaining training-induced performance increments and decrements within a unified framework of perceptual learning**

D Sagi, N Censor (Department of Neurobiology, Weizmann Institute of Science, Rehovot, Israel; e-mail: Dov.Sagi@Weizmann.ac.il)

Practicing sensory tasks could result in two main perceptual outcomes. The first, and more widely documented, is perceptual learning referring to long-lasting improvement of perceptual thresholds. The second is perceptual deterioration, observed when the number of trials is increased within a training session or between closely spaced sessions. Recent results with visual texture discrimination show that these two processes inversely affect each other: decremental effects interfere with further learning, while efficient short practice results in a long-term learning effect where performance deterioration is practically eliminated. Further results show that sleep is necessary to preserve learning effects following short training and to minimize deterioration that normally follows extensive training. We suggest a theoretical link between perceptual deterioration and learning, assuming a system with saturating connectivity, in which continuous learning leads to saturation unless connectivity is efficiently consolidated. Thus, best learning is achieved with short training sessions. Resistance to saturation is achieved by sleep-dependent consolidation of unsaturated connectivity. The different transfer properties of increased/decreased performance allow us to identify local and global components of perceptual learning and their interactions. This suggests sleep-dependent consolidation mechanisms that induce modifications in higher brain areas interacting with local early visual networks to enable improvement of perceptual abilities.

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◆ **Perceptual learning and brain activation**

Y Sasaki (Department of Radiology, Athinoula A Martinos Center for Biomedical Imaging, Massachusetts General Hospital, Boston, USA; e-mail: yuka@nmr.mgh.harvard.edu)

Practice and sleep improve perceptual learning (PL). However, the brain activation associated with practice and sleep has yet to be entirely clarified. Here, I will discuss our recent findings regarding brain activation related to PL of a texture discrimination task (TDT, Karni and Sagi, 1991) during practice and sleep, using fMRI. First, we investigated whether activation of the primary visual cortex (V1) correlates with performance improvement of TDT. For the first week, we found that the activation increased as the performance improved. However, later, while the performance improvement retained, the increased activation disappeared. Second, we investigated whether V1 activation is modulated during sleep. We found that the trained-region of V1 was enhanced compared to the untrained-region during sleep after TDT-practice. However, such regional difference was not found during sleep when TDT-practice did not precede sleep. These results indicate two distinctive states of brain activation in different phases of the time course of PL. The first phase is characterized as gradual enhancement in both V1 activation and TDT performance. This occurs during both practice and the subsequent sleep. The second phase is characterized as retention of the enhanced performance without accompanying V1 activation.

◆ **Perceptual learning as a result of an exposed feature being internally enhanced**

T Watanabe (Department of Psychology, Boston University, USA; e-mail: takeo@bu.edu)

While it was once believed that no perceptual learning (PL) occurs without focused attention to a visual feature, we found that PL occurs on a feature that is task-irrelevant and subthreshold. (Watanabe et al, 2001 *Nature*). We call this type of PL task-irrelevant PL. Later we found that task-irrelevant PL occurs particularly when subjects are engaged in a task (Seitz and Watanabe, 2003 *Nature*). Here we present recent lines of research that has indicated that if a task-irrelevant feature is paired with reward, PL on the feature occurs without any task engagement (Seitz et al, 2009 *Neuron*) and when task-irrelevant PL occurs only on a weak feature (Tsushima et al, 2008 *Current Biology*). Thus, there are at least three conditions in which PL on a feature occurs; (i) when the feature is task-relevant and subject to focused attention (Ahissar and Hochstein, 1992 *Proceedings of the National Academy of Sciences of the USA*), (ii) when the feature is task-irrelevant and weak and, therefore, is not subject to attentional suppression (Tsushima et al, 2006 *Science*) and (iii) when the feature is reinforced by reward. We conclude that irrespective of whether a feature is task-relevant or task-irrelevant, PL occurs when the feature is internally enhanced/reinforced.

TALK SESSION C

BRIGHTNESS, LIGHTNESS, AND COLOUR

◆ **Probe disks reveal lightness computation in complex images**

A L Gilchrist, A Radonjic (Department of Psychology, Rutgers University, Newark, USA; e-mail: alan@psychology.rutgers.edu)

Observers made Munsell matches to 13 identical gray probe disks embedded at different locations in a CRT image of a complex scene containing regions of sunlight and shadow. Disk lightness was relatively uniform within either sunlight or shadow framework, with a 2.9 Munsell unit step function at the shadow boundary. Viewing the scene through a pinhole (fifteen observers), known to enhance perceived depth in a photo, increased the size of the framework effect (difference between average disk lightness in the two frameworks) to 4.0 Munsell units. The use of paper disks (identical in luminance and size) pasted onto the front glass surface of the screen, with a perceptible depth difference, reduced the framework effect to 1.5 Munsell units ($N = 15$). Successive presentation of probe disks ($N = 15$) increased the framework effect one Munsell unit over simultaneous presentation. Finally, when global anchoring was prevented by covering the entire sunlight region with black paper ($N = 15$), all disks were perceived as white, with mean disk Munsell values between 8.4 and 9.1. In sum, framework effect size depends on perceived embeddedness of the disks. These differences are expressed only in the shadow framework because, we believe, disks in the shadow have different local and global anchors.

◆ **The role of mid-range luminance context in lightness induction**

M E Rudd (Howard Hughes Medical Institute, University of Washington, USA; e-mail: mrudd@u.washington.edu)

Luminance relations play an important role in lightness induction. For example, the intensity of a highest luminance surround has a big effect on target appearance while the intensity of a lower luminance surround has little or no effect. Recently, a number of studies—employing stimuli ranging in complexity from Bressan's dungeon display to concentric ring patterns—have examined the effect of introducing into the target's surround elements whose luminance lies intermediate

between a low target luminance and a remote highest luminance. These ‘mid-range’ contextual elements tend to block contrast induction from the remote highest luminance and may induce lightness assimilation in the target. This pattern is not usually observed when the target is the highest luminance and the remote context is dark. Here I argue for a theory of these effects in which lightness and darkness induction derive from edges. Blockage and assimilation occur because edges compete for salience based on their relative contrasts and positions, with darkness-inducing edges having an inherently stronger relative salience than lightness-inducing edges. For some ambiguous stimuli, the salience of lightness-inducing edges can be increased by voluntary attention, eliciting blocking and assimilation even when the target is the highest luminance and the background is dark.

◆ **Stretching of the relief makes Lambertian surfaces appear glossy**

M W A Wijntjes, S C Pont (Industrial Design Engineering, Delft University of Technology, The Netherlands; e-mail: m.w.a.wijntjes@tudelft.nl)

It has previously been shown that height increases of surface reliefs increases glossiness perception and vice versa (Ho et al., 2008, *Psychol Sci* 19: 196-204). However, the grounds on which this interaction is based are not understood. To investigate this issue, we studied the perceived material properties of Brownian rough surfaces under different illumination and relief range conditions. We generated stimuli with a Lambertian BRDF which were illuminated from elevations that ranged between 0 and 60 degrees. Participants had to judge the glossiness of each sample using a continuous slider presented next to the stimulus. For all observers, the relief range and illumination direction influenced the illusory glossiness percept. Statistical analysis showed that the skewness of the intensity distributions is influenced in a way that is predicted by Motoyoshi et al (2007 *Nature* 447 206–209). We also investigated the relation between glossiness and the transition between first and second-order shading regimes by calculating the coherence of the illuminance flow. We found evidence that this metric also predicts glossiness perception. As opposed to skewness, we argue that second-order shading is a more plausible perceptual diagnostic for material appearance because skewness is invariant to a scrambling of pixels, while second-order shading is not.

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◆ **Contrast suppression regulates perceived transparency**

T L Peromaa (Department of Psychology, University of Helsinki, Finland; e-mail: tarja.peromaa@helsinki.fi)

It has been argued that perceived transparency corresponds to the ratio of perceived contrasts in the centre and surround of the stimulus. However, the perceived contrast of the stimuli has not been independently measured. Neither has the contrast of the background been systematically varied. The method of constant stimuli was applied to measure both perceived transparency and contrast of the central patch of a sinusoidal 2 cycles deg^{-1} equiluminant centre-surround stimulus. In the transparency measurement the comparison stimulus was a modified Metelli-stimulus, the transparency index α of which was varied (background luminances and the reflectance of the transparent layer fixed). Under this condition, perceived transparency is known to be linearly related to α . In the contrast measurement, the Michelson contrast of a sinusoidal comparison stimulus was varied. Measurements were made as a function of (i) the centre contrast (0.15–0.60, surround contrast 0.75) and (ii) the surround contrast (0.35–0.95, centre contrast 0.25). The results show that perceived transparency is linearly related to the ratio of perceived contrasts in the centre and surround. Moreover, despite of the fairly large individual differences in the levels of contrast suppression, the results of different subjects overlap when the results are expressed in terms of perceived contrasts.

◆ **Focal colours attract visual attention**

T Hansen, S Weis, K R Gegenfurtner (Department of General Psychology, University of Giessen, Germany; e-mail: Thorsten.Hansen@psychol.uni-giessen.de)

Focal colours, the best sample colours of a colour category, are highly consistent in different populations (Regier et al 2005). Here we investigate whether focal colours are also more salient. Four uniformly coloured discs were shown on a medium gray background for 1000 ms. The colours of two discs were randomly drawn from a set of focal colours, the other two colours randomly drawn from a set of non-focal colours. Eye movements were recorded during free viewing. There was a significant main effect of fixation preference for the three groups of focal unique, focal-nonunique and non-focal colours ($p < 0.05$). Multiple regression revealed a significant correlation of the number of fixations with luminance and saturation ($r = 0.77$, $p < 0.018$); however, focal colours were on average fixated more often than predicted by their luminance and saturation. We conclude that focality as a high level aspect of a colour attracts eye movements, providing further evidence for the role of colour in perception and action.

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◆ **Evolution of highly chromatic signals**

L Wilkins (Department of Neuroscience, University of Sussex, Brighton UK;
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Colour plays an important role in biological signaling, with 'strong' colours being often associated with prey with some kind of defense mechanism. Recent studies have suggested that these aposematic signals are of the result of a co-evolutionary chase between palatable (mimic) and non-palatable (model) species. In this light, a model of mimicry was used to explore the reasons for high chromacity in aposematic signaling. The prey are assumed to have reflectance spectra based on the chromophores which they present, the parameters of which are allowed to evolve under pressure from predation. The predator (modeled as a multi-layer perceptron) perceives the reflectance spectra of a prey organism as a colour. It then uses this colour (and past experience) to decide whether or not to eat it. The mapping between the parameters defining the chromophores and the perceived colour creates a complex, non-uniform space in which the prey species evolve. The simulations demonstrate that stable situations can only occur where the predator perceives the model as highly chromatic, in agreement with theoretical considerations. It would seem that the properties of perceptual space of the predator provides an essential part of the mechanism by which aposematic signals are formed.

◆ **Fusion of sequential colour stimuli in response priming?**

T Schmidt, L Vorobyova¶ (Department of Psychology 1, University of Kaiserslautern, Germany; ¶ Department of General Psychology, University of Giessen, Germany;
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We tried to determine whether the visuomotor system can disentangle the single colours in a stimulus changing so rapidly from red to green (or vice versa) that it appears yellow. In a series of experiments, participants rapidly indicated the colour of a target stimulus (eg, red vs yellow, green vs yellow) by pressing a response key. Responses were strongly influenced by red, green, and yellow primes, so that primes mapped onto the same response as the target slowed responses while primes mapped onto the opposite response prolonged them. Surprisingly, yellow-appearing fusion primes only sometimes acted like true yellow primes, and more often like red or green primes, depending on the order of colours in the fusion primes. We suggest that the fusion primes can activate motor responses associated with single colours in the prime, even if these colours are fused in conscious vision.

◆ **Categorical reaction times for equally discriminable colours**

C Witzel, T Hansen, K R Gegenfurtner (General Psychology, Justus-Liebig-Universität Giessen, Germany; e-mail: Christoph.Witzel@psychol.uni-giessen.de)

The classical question concerning the interaction of colour perception and colour categorisation is still debated. Many studies have shown that colour discrimination is faster across categories. The blue–green boundary has become the prime example for this effect. However, in order to prove this effect, colour pairs within and across boundaries must be comparable, ie, their differences must be perceptually equal. The problem is that there is no definite colour space that guarantees perceptual equality. To solve this problem we used stimuli that were equally discriminable for each subject. For this purpose, we first measured discrimination thresholds along the isoluminant colour circle in Derrington–Krauskopf–Lennie colour space as well as the category boundaries for basic colour terms. We then determined for each subject equally discriminable colour pairs around the centre (within), across the boundary (across), and close to the boundary (transitional) of all categories existing within the isoluminant colour circle (pink, orange, yellow, green, blue, and purple). In the main experiment, we measured reaction times in a colour identification task for each of these pairs. We found categorical effects at some, but not all category boundaries. The transitional colours between blue and green revealed a particularly marked reduction of reactions times.

◆ **Enhanced colour discrimination at a category boundary**

M V Danilova, J D Mollon¶ (Laboratory of Visual Physiology, I. P. Pavlov Institute of Physiology, St Petersburg, Russia; ¶ Department of Experimental Psychology, Cambridge University, UK; e-mail: mvd1000@cam.ac.uk)

Can the boundaries of phenomenological colour categories be revealed by enhanced performance in a colour discrimination task? To answer this classical question, performance in the discrimination task must be measured in a metric that is not itself phenomenological. Using cone ratios as our metric and requiring observers to make a two-alternative spatial forced choice, we measured thresholds for discriminating simultaneous, 100-ms targets presented on a neutral field of 10 cd m^{-2} . The luminances of the two targets were independently jittered to ensure discrimination depended on chromatic signals. We worked in an analogue of MacLeod-Boynton space

scaled so that the line running from unique yellow to unique blue (576–476 nm) was at –45 deg. In each experimental run, measurements were made for several referent stimuli located along a line orthogonal to the yellow–blue line: these referents vary in quality from reddish to greenish. Such measurements were repeated at different points along the yellow–blue line. In separate experiments, we made measurements in the parafovea and in the fovea. In both cases we found a region of enhanced discrimination that is close to, but not coincident with, the phenomenal transition from reddish to greenish, independently estimated for our own observers.

◆ **The role of chromatic texture in object classification: pocked yellow equals lemon yellow**

A Hurlbert, I Pietta¶, Y Ling (Institute of Neuroscience, Newcastle University, UK;

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The role of colour in object recognition is controversial. Many natural objects possess distinctive chromatic textures which may be as diagnostic as shape or average colour: mottled yellow indicates banana whereas pocked yellow indicates lemon. Here we investigate the roles of colour and texture in a speeded object classification task. Stimuli were patches derived from trispectral-calibrated images of familiar natural objects. Three types of patches were used: luminance texture alone; average colour alone; and combined-cue (both ‘incongruent’—eg banana texture with carrot colour—and ‘congruent’). Eight observers performed a three-way speeded classification task for 3 different groups of each type at 2 presentation times (40 ms and 250 ms) (example classification: potato, lime, or carrot). Observers tended to classify according to texture for combined-cue patches, although reaction times were faster for uniform colour alone than for luminance texture alone. Classification of incongruent patches was slower than for congruent patches. The ‘Stroop effect’ (slowing) of incongruent texture on classification by colour was more pronounced at shorter presentation times, whereas slowing by incongruent colour on texture showed the opposite pattern. The results strongly suggest that texture and mean colour interact in object recognition, and that texture dominates but is slower.

RANK LECTURE

◆ **The position sense**

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How is position coded in the visual system? Many of the visual areas in the brain are organized as retinotopic maps where adjacent neurons respond to adjacent locations on the retina. An object’s position, at least for the fronto-parallel (XY) plane, is therefore naturally carried by its retinotopic coding throughout the visual areas. Clearly, this retinotopic information must be corrected for eye, head, and body movements (to reference locations in the world), but recent physiology suggests this is feasible. In comparison, position in depth must be constructed from multiple cues and lacks an explicit dimension for representation. Errors in depth perception are common, including depth reversals, whereas there are few such dramatic errors in XY location. Nevertheless, there are some—saccade-induced compression and mislocalization, and motion induced shifts, for example—where the perceptual and retinotopic locations of a stimulus disagree and these force us to reject retinotopy as the underlying code for position. Our studies suggest that position is constructed on one map and that target locations on this map attempt to follow and, where possible, predict target locations but occasionally lag or miscalculate in the attempt. These errors in construction underlie several perceptual mislocalizations and reveal possible mechanisms used to follow and predict target locations.

POSTER SESSION

ATTENTION

◆ **Target-mask spatial separation influences the extent of object substitution masking**

D Guest, A Gellatly, M Pilling (Department of Psychology, Oxford Brookes University,

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Lleras and Moore (2003) reported strong masking when their stimuli (C’s with the gap appearing left, right, up or down) were replaced by a single dot at their centre. Such strong masking was unexpected and their proposed explanation emphasised updating of object tokens. According to the token updating account of object substitution masking, type information about the mask gets bound to the same perceptual token that was previously bound to type information about the target, thus overwriting target information. However, another possibility is that masking resulted from limitations in the spatiotemporal resolving power of visual attention. Masks were a third of the size of targets, perhaps making it difficult to selectively attend to the fading trace of the target when a new candidate for attention was presented in too close spatiotemporal proximity. In a series of experiments we manipulated mask size, mask type (a hollow square or a

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four-dot mask) and whether the mask was larger or smaller than the target (a square with one side missing). As predicted by the attentional acuity account, masking increased the greater the similarity between target size and mask size.

◆ **The identity of a target is rapidly available in the attentional blink**

F Hilkenmeier, I Scharlau (Department of Psychology, Universität Paderborn, Germany; e-mail: frederic.hilkenmeier@uni-paderborn.de)

How fast is the identity of a first target (T1) in a rapid serial visual presentation available to top-down processes? A valid cue about the temporal position of a second target (T2) was integrated into T1. Using it required identification of T1. The data show that already 50 ms after T1 onset, T2 was identified significantly better than without cue, attenuating the attentional blink. Moreover, the correct temporal order of the two targets was reported more often. T1 apparently elicits a transient facilitative effect of attention known from other paradigms such as peripheral cueing. This supports the assumption that attentional blink and cueing rely on the same attentional mechanisms.

◆ **Object substitution masking with a single peripheral dot: evidence of object updating or attentional capture?**

M Pilling, A Gellatly (Department of Psychology, Oxford Brookes University, Oxford, UK; e-mail: mpilling@brookes.ac.uk)

Object substitution masking (OSM) is a phenomenon in which a briefly presented target which is not the focus of attention is rendered imperceptible by the presence of a sparse mask. Lleras and Moore (2003, "When the target becomes the mask" *Journal of Experimental Psychology: Human Perception and Performance* **29** 106–120) showed that a peripherally located single dot was enough to mask a target's features providing that the inter-stimulus timings were short enough to generate the perception of apparent motion between target and mask. From such evidence it was concluded that OSM is a consequence of situations in which the visual system represents the target and mask stimulus with a single object token and the trailing mask comes to overwrite the features of the target within this token representation. Experiments test whether the perception of target and mask as a single object is necessary to produce OSM. Results show that OSM still occurs even under conditions where target and mask are perceived as distinct objects. The data suggests that OSM occurs because of attentional capture by the mask; however interference at the level of object tokens is not necessarily ruled out as an additional mechanism.

◆ **Serial, parallel, and coactive processing of double stimuli presented with onset asynchrony**

M Gondan, V Fischer (Institute for Psychology, University of Regensburg, Germany; e-mail: matthias.gondan@psychologie.uni-regensburg.de)

In divided attention tasks with two classes of target stimuli, participants are frequently observed to respond faster if both targets are presented simultaneously, compared to single target conditions (redundant signals effect, RSE). Different explanations exist for the RSE including serial, parallel, and coactive models of information processing. Based on earlier work by Townsend and Nozawa (1995 *Journal of Mathematical Psychology* **39** 321–359), we show how processing architectures and stopping rules are distinguished by the distribution function interaction contrast for double stimuli presented with onset asynchrony. The predictions enable strong tests of different processing architectures by using data from experiments in which only the temporal onset of the stimuli is manipulated. We illustrate the technique using data from auditory–visual redundant signals experiments and visual search tasks.

◆ **The effect of spatial attention on pupil dynamics**

L Daniels, H S Hock, D Nichols[¶], A Huisman (Department of Psychology, Florida Atlantic University, Boca Raton, USA; [¶] Department of Psychology, York University, Toronto, Canada; e-mail: lbukowsk@fau.edu)

Although it is well known that the pupil responds dynamically to changes in ambient light, we show for the first time that the pupil also responds dynamically to changes in spatially distributed attention. Using a variety of orientating tasks, subjects alternated between focusing attention on a central stimulus and spreading attention over a larger area. It was found that broadly spread attention results in pupil dilation, whereas narrowly focused attention results in pupillary constriction. Given that broadly spread attention increases the activation of relatively large receptive fields and narrowly focused attention increases the activation of relatively small receptive fields (Balz and Hock, 1997), the results of this study indicate that these attentional effects on receptive field sensitivity can be mediated by the spherical aberration produced by pupil dilation. That is, broad attention decreases the sensitivity of small receptive fields because pupil dilation

increases the blur caused by spherical aberration, whereas narrowly focused attention increases the sensitivity of small receptive fields by decreasing the blur caused by spherical aberration.

◆ **An unmasked attentional blink for bandpass filtered letters**

B J Wolfgang, Q Bucklach, W Heywood, P L Smith (Human Sciences, Defence Science and Technology Organisation; also Department of Psychology, University of Melbourne, Australia; e-mail: bwolf@unimelb.edu.au)

When two suprathreshold letter stimuli are presented within 100–500 ms of one another, second target perceptibility is markedly reduced following first target identification. This ‘attentional blink’ (AB) depends critically on second target backward masking (Giesbrecht and DiLollo, 1998). Two recent studies have shown that an AB can be obtained in the absence of visual masking if stimuli are (i) not ‘over-learned’ (ie, alphanumeric) (Kawahara et al, 2003), or (ii) narrowband and low spatial frequency (Wolfgang, 2005). We investigated whether the over-learned status of letters or their spatial frequency composition drives the need for masking in the AB. In separate experiments, observers performed a letter orientation discrimination task about two temporally separated low (1.8 cycles deg⁻¹) or high (5 cycles deg⁻¹) spatial frequency filtered letters. Target pairs were presented at the same or different display location with equal probability. Neither target was masked. An AB of similar magnitude and form was found across both spatial frequency and target location. Further analysis revealed that the unmasked AB was limited to mirror-reversed stimuli: letters presented in their canonical orientation were immune from the AB. We suggest that mirror-reversed letters are processed more slowly than their unrotated counterparts and implicate over-learning as a key factor in determining the need for masking in the AB.

◆ **Strategic influences on visual prior entry**

K Weiß, I Scharlau (Department of Psychology, University of Paderborn, Germany; e-mail: katharina.weiss@upb.de)

Prior entry denotes the misperception that attended stimuli are perceived earlier than unattended stimuli (eg Shore, Spence, and Klein, 2001). This misperception is usually assessed by a temporal order judgment (TOJ) task. Observers indicate which of two targets, presented with variable SOAs, was the first. In experimental trials, attention is directed to one of the two targets. In consequence, the probability of misperception of temporal order is enhanced: observers tend to report the attended target as seen first, if actually both targets are presented simultaneously, or the unattended target was leading. We investigated, if prior entry can be voluntarily reduced. To this aim one group received information about prior entry and, additionally, continuous feedback about the correctness of their TOJs, whereas the other group did not. Note that a higher amount of correct TOJs will reduce prior entry. As motivation to reduce prior entry observers gained points for correct TOJs or lost points for incorrect TOJs. Results showed that prior entry can be strategically reduced: The temporal advantage for the attended target was reduced from 54 ms to 44 ms. Nevertheless, the remaining effect was substantial, indicating a strong attentional basis of prior entry.

◆ **Attention and conscious decisions**

A Stemme, G Deco[¶] (Institute of Biophysics, University of Regensburg, Germany; [¶]Department of Theoretical and Computational Neuroscience, Universitat Pompeu Fabra, Barcelona, Spain; e-mail: anja.stemme@gmx.de)

This review considers a range of contradictory results with respect to the question of ‘decision making’: A recent study of Soon et al (2008 *Nature Neuroscience* **11** 543–545) detected a delay of several seconds between the decision of a brain and the actual action upon this decision (a finger movement); however in a range of other studies no corresponding delay showed up (eg Wang, 2008 *Neuron* **60** 215–234). These differences led us to ask a more fundamental question: What do we actually mean by a ‘decision’? By considering a range of findings we were able to substantiate the hypothesis that the brain activation underlying the famous ‘readiness potential’ or recent fMRI measurements (Soon et al 2008) represent the outcome of increased attention and must be separated from concrete decision. However, a consistent view of a decision implies that ‘decision making models’ are more about the ability to discriminate between stimuli than about actual decision making. Overall the experimental results demonstrate the necessity to differentiate carefully between attention, consciousness, and decisions.

◆ **How do we look at the world? Perceptual learning creates two kinds of observers**

T Albrecht, U Mattler (Georg-Elias-Müller Institute for Psychology, Georg-August University Göttingen; e-mail: Thorsten.Albrecht@biologie.uni-goettingen.de)

Backward masking is a technique often used in visual science to prevent participants becoming aware of target stimuli. Individual differences in masking effects are often deemed undesirable

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complications. However, individual differences might provide a tool for studying the mechanisms of perceptual learning and the access to visual consciousness. Here we report on the development of stable individual differences in a meta-contrast paradigm. Participants performed a discrimination task on targets that were followed by a meta-contrast mask at different stimulus onset asynchronies (SOA). After two days of training two groups of participants could be distinguished due to their masking functions: Performance either increased or decreased with increasing SOA. Although the difference between groups was negligible at the beginning of the experiment, it became more marked over the course of training, remained unchanged after several weeks, and could not be reversed by training under different conditions. Findings suggest that participants differ in their ability of directing their attention to certain aspects of the stimulus display so as to extract the information required. We think this top-down guidance determines the level in the physiological hierarchy of visual operations where perceptual learning takes place.

◆ **How does sound improve vision? A classification image study**

D Pascucci, N Megna, M Panichi, S Baldassi (Department of Psychology, University of Florence, Italy; e-mail: chareste@gmail.com)

A non-informative sound synchronous with a visual target improves contrast detection thresholds (Lippert and Logothetis, 2007 *Brain Research* **1173** 102–109). We investigated the spatiotemporal characteristics of the mechanisms underlying this crossmodal effect by using a classification image paradigm very similar to that used by Neri and Heeger (2002 *Nature Neuroscience* **5** 812–816). A bright bar was embedded in 2-D (space-time) dynamic noise to measure 1st and 2nd order kernels in two conditions: unimodal (vision) and bimodal (vision-hearing). Our results show that the crossmodal facilitation of detection consists in a reduction of visual noise at the early stages of visual processing. In fact, the sound reduces the activity of the 2nd order kernels involved in target detection, before the target, while it does not influence the 1st order kernels, probably involved in target identification. This fits with a model in which the sound provides a weight that is linearly combined to the time coding visual mechanisms in a detection task, reducing temporal uncertainty and decreasing the activity of contrast energy extractor filters temporally uncorrelated with the target.

◆ **Difficulty of change detection influences attentional allocation between foreground and background**

T Kabata, E Matsumoto (Graduate School of Intercultural Studies, Kobe University, Japan; ¶Graduate School of Intercultural Studies, Kobe University, Japan; e-mail: kabata@stu.kobe-u.ac.jp)

Recent studies on change detection with foreground-background segmentation have reported that changes in the background were often missed, while those in the foreground were detected easily. However, in those previous studies, the effect of stimulus arrays on difficulty in detecting changes was unclear. In the present study, we investigated whether difficulty of foreground change detection influences detection performance on background changes by manipulating the presentation range and the changing features of the foreground stimuli. In Experiment 1, we investigated the effect of spatial extent of attention with changing the diameter of stimulus array (ranging from 3.25 deg to 13.0 deg). In Experiment 2, we manipulated the combinations of changing features. As the results, the foreground change detection performance was influenced by the range of the foreground stimulus array. On the other hand, attribute required the foreground change detection did not influence attentional allocation. In addition, in spite of the foreground conditions, the background change detection performance was not influenced. These results suggest that the cognitive load for the foreground does not influence attention to the background and the cognitive resources for both segments are to some extent independent.

◆ **Attention bias to emotional face expression: level of subjective anxiety and sympathetic nervous activity affects on a threat superiority effect**

E Matsumoto (Graduate School of Intercultural Studies, Kobe University, Japan; e-mail: ermatsu@kobe-u.ac.jp)

Emotionally significant objects tend to attract attention and be detected efficiently; in particular, threatening facial expressions have priority over other emotional expressions. Several studies reported that social anxiety was associated with an attentional bias towards threatening information. In previous studies, the anxiety level was measured by using the participants' subjective answers. In this study, we evaluated the participants' level of neurophysiological mental strain with R-R interval of electrocardiogram to find out what properties of individuals affect threat superiority. A visual search paradigm was used in which participants were asked to search for a discrepant facial expression among otherwise homogeneous faces. Results confirmed the anger superiority effect in the detection of an angry face among neutral faces. Furthermore, it was

found that the high mental strain group exhibited an obvious threat superiority effect. To investigate the relationship between the threat superiority effect and sympathetic nervous activity, we used R-R interval as an index of mental strain. In contrast to previous results, the high mental strain group were quicker in detecting not only angry but also happy faces. This suggests that increased sympathetic nervous activity is associated with the detection of emotional expressions generally, and not necessarily just with threatening information.

◆ **Attention increases input gain when processing motion coherence**

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Several alternative models try to explain how attention affects sensory processing. Attention is thought to enhance the representation of attended stimuli by increasing the stimulus strength (input gain model) or by multiplying the neuronal response (output gain model) or by stimulus-unspecific activity increase (baseline shift model). We used high-field functional magnetic resonance imaging (fMRI) at 4T in seven participants to test how attention affects the blood-oxygen-level dependent (BOLD) signal in middle temporal (MT) and medial superior temporal areas (MST) to attended or ignored low-contrast moving dots in the periphery. In an event-related design participants either judged the predominant direction of the dots or they were engaged in a central task. In both tasks moving dots were present and coherence was parametrically varied. Behavioural results produced clear coherence-response functions. BOLD responses showed that only intermediate motion coherence levels (25% and 50%) profited from attention, while the lowest (12.5%) and the highest (100%) levels did not. This suggests that attention increases behavioural performance in motion processing by increasing the input strength of motion signals.

◆ **Making waves in the stream of consciousness: Eliciting predictable oscillations in visual awareness with visual entrainment at 12 Hz**

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In order to investigate the possibility that exogenously driven temporal attention can influence the level of consciousness elicited by a given stimulus, we experimentally entrained temporal attention with rapid presentation of stimuli at 12 Hz, and then manipulated the lag between the onset of the final pre-target entraining stimulus and the target. The target itself was followed by a metacontrast mask at a constant SOA to limit access time to target information and to minimize contributions from trace processing of post-target visible persistence activation. As predicted, sensitivity was best for masked targets presented at the moment that the next visual entrainer would have arrived, and decreased to a minimum when targets were presented earlier or later, in counterphase to the preceding entrainers. Further, the effect of entrainment was graded by the number of entrainers presented prior to the target and could not be explained by warning effects. Our results show that in the presence of rapid, periodic visual events, visual processing is exogenously synchronized to the frequency of visual stimulation to produce phase-locked peaks of visual sensitivity in anticipation of imminent visual events, at the cost of processing out-of-phase visual events.

◆ **Accumulation of salience: Modeling the effects of target distractor similarity in visual search**

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When a target differs significantly from homogeneous distractors, search is very efficient. Search gets harder as target-distractor (TD) similarity increases. Several models such as feature integration theory, guided search, or visual similarity theory predict that the effect of increasing TD similarity will be manifest as a decrease in search efficiency; an increase in $RT \times$ set size slopes. Here, we present data demonstrating that, as TD similarity increases, the intercepts of $RT \times$ setsize functions increase with no increase in slope until TD similarity is further increased. Additionally, search performance (slope, intercept, and miss rate) for targets of one level of TD similarity depends on the context in which this search is carried out, that is, whether the majority of other trials are of high or low TD similarity. These patterns of responses to TD similarity can be modeled using a salience map that accumulates salience signals with one leaky accumulator for each item in the display with drift rates depending on TD similarity. This model can account for the range of behavior with a fixed set of stimulus parameters constant, changing only observer-based parameters related to search strategy.

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◆ **Optimal visual search: combining what you expect with what you see**

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Are we optimal in conducting visual search? In searches where target location is partially predictable, one can potentially use spatial expectations and visual feature cues to guide visual search. A Bayesian optimal observer would not use one or the other, but combine both expectation and visual feature observations to make the best guess of target location. I tested if this was the case in human participants using a spatial-forced-alternative-choice visual search task for oriented lines. Spatial expectations were varied by either manipulating cue validity, or through spatial probability of target location. Results could not be accounted for by using either features or spatial expectations alone, nor by probability matching. Results were consistent with predictions of a 1-parameter Bayesian optimal observer that constructs spatial expectations and combines them with visual feature information. Notions of finite attentive capacity or selective bottlenecks were not required in order to explain the results. Manipulations of cue-validity or of spatial probability are very different mediums of providing information of upcoming target location, but despite this subjects utilized information optimally resulting in identical performance in both conditions. The results provide further support for the wider notion that visual search phenomena are by-products of optimal inference of target location

◆ **Positive affect in the additional singletons paradigm: Initial global dimensional attention mode and intact top-down control**

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Positive affect is known to broaden the scope of spatial (and semantic) attentional filters, thus reducing their selectivity and increasing distraction by goal-irrelevant stimulation. The present study investigated whether such mood-induced modulations of attentional functions also extend to dimension-specific attention. In visual search, an additional singleton (AS) from a dimension different than the target is known to capture attention. Recent work suggests that attentional capture is not a purely bottom-up phenomenon, but strongly modulated by top-down control: interference from AS decreases with increased application of dimension-specific inhibition. Therefore, we examined whether affect would also influence this form of top-down control. We found that positive affect strongly enhanced attentional capture as compared to negative affect (142 vs 78 ms). Also as expected, the capture effect decreased as a function of practice, ie, from the first to the second block of 32 trials (163 vs 59 ms). However, affect did not influence the down-regulation of the weight for AS-defining dimension, as mood-induced differences were eliminated in the second 32 trials. These results represent first evidence that positive affect increases attentional capture and suggest that experiencing positive affect induces a more global and less selective dimensional attention mode, but does not impair the general ability to inhibit task-irrelevant dimensions.

◆ **The role of the gaze direction of a crowd on the orientation of attention**

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Social signals such as eye gaze can cue our attention to specific spatial locations (Driver et al, 1999 *Visual Cognition* 6 509–540; Friesen and Kingstone, 1998 *Psychonomic Bulletin & Review* 5 490–495). The aim of our study was to investigate whether the eye gaze of a crowd is an effective attentional cue and determine what proportion of a crowd must be looking in the same direction to cue our attention. We conducted two experiments in which we used a modified central cueing task (Posner, 1980 *Quarterly Journal of Experimental Psychology* 32 3–25). A trial began with either a static (Experiment 1) or a dynamic (Experiment 2) image of a crowd, a proportion of which were looking to the left, right, or straight ahead. Using SOAs of 700 or 1000 ms a target letter appeared in a position that was valid or invalid or neutral with gaze direction, and participants were required to discriminate the letter. We found that valid eye gaze directions of the crowd facilitated target location but only when relatively large proportions of the crowd gazed in one direction. Moreover, dynamic eye gaze of a crowd facilitated target detection more than static eye gaze. Our findings suggest that the eye gaze of a crowd can be used as an efficient social cue for orienting spatial attention.

◆ **Keep it big for the small ones! The development of attentional resolution**

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Attentional resolution (He, Cavanagh, and Intriligator, 1997; Cavanagh and Intriligator, 2001) is defined as the smallest region in space that can be selected by visual attention. In the present study, we investigated the development of attentional resolution of children with grades 1, 3, 5, and 7 as compared to an adult sample. Using a tracking paradigm with one target the distance between target and distractors was varied between 2 and 10 min of arc. Whereas the performance of children and adults was comparable at very small and large distances between objects, significant differences emerged in intermediate distances. More specifically, children reached optimal performance later, ie at larger distances, the more so the younger they were. In a control experiment, visual acuity was measured by a dynamic gap detection task with varying distances between two dots. Children performed similar to the adult sample in this task. Therefore, the increase in attentional resolution cannot be explained by a concurrent development in visual acuity. The results indicate that the resolution of attention develops dramatically during childhood, especially between the age of 6 and 8. This contradicts theories of development in the attentional networks as proposed by Posner (2007).

◆ **Irrelevant words trigger an attentional blink**

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It has been argued that salient distractor items displayed during rapid serial visual presentation (RSVP) trigger an attentional blink (AB) when they share features with the target item. Here we demonstrate that salient distractor words induce an AB independently of feature overlap with the target. In two experiments a color-highlighted irrelevant word preceded a target by a variable lag in an RSVP series of false font strings. Target identification was reduced at short relative to long temporal lags between the distractor word and the target, irrespective of feature sharing with the distractor word. When the target shared features with the distractor word, target accuracy was reduced across all lags. Accordingly, feature sharing between the distractor word and the target did not amplify the AB, but had an additive effect on attentional capture by the distractor word.

◆ **Orienting to gaze and arrow cues: independent or partially overlapping processes?**

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There is evidence that both irrelevant gaze and arrows can orient visuospatial attention. There is no agreement, however, as to whether biological and symbolic cues are processed by independent or partially overlapping mechanisms, and whether they engage different attentional orienting processes. A possible reason for this is the variety of symbolic stimulus designs used, with the underlying assumption that they are equally powerful in orienting spatial attention. We investigated the role of symbolic stimulus design by comparing the effectiveness of three types of arrows (Experiment 1). We then contrasted in a discrimination task the most effective arrow design, as found in Experiment 1, with schematic and real faces, with arrows and faces being central irrelevant cues (Experiment 2). Manual RTs indicated that arrow designs were not processed at equal speeds; moreover, response times for the most effective arrows differed from biological cues, being overall slower. The time course of the cueing effects was different across cues, emerging earlier for arrows and lasting longer for biological cues. Conversely, no difference between schematic and real faces was found. In conclusion, there are both quantitative and qualitative differences among various symbolic and biological cues in orienting visual attention.

◆ **Object-based attention: Evidence for sensory enhancement**

Z Chen, K Cave¶, O Shevchouk (Department of Psychology, University of Canterbury, New Zealand; ¶ Department of Psychology, University of Massachusetts, Amherst, USA; e-mail: zhe.chen@canterbury.ac.nz)

When attention is paid to a specific location in space, the attentional facilitation can be greater for locations that are in the same object as the cued location than for locations that are equally distant but at a different object, suggesting that attention can select an entire object. In prior research, object-based effects have been explained in terms of improved quality of an early sensory representation of the selected item or its region (the sensory enhancement account), or in terms of higher priority that the selected item or its region receives during search (the

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prioritization account). In several experiments, we distinguished these two accounts by asking participants to perform a letter discrimination task under data-limited conditions (Norman and Bobrow, 1975). Participants saw stimuli that were presented very briefly, and there was no speed pressure to respond. The target, which always appeared at a location indicated by an arrow cue, was equally likely to be within the same object as the cue or within a different object from the cue. Our results showed a same-object advantage. Because performance differences under data-limited conditions reflect how well information can be extracted, our finding supports the sensory enhancement account.

◆ **Attentional effects on drift eye movements before and after microsaccades**

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Recent studies have demonstrated the important roles of involuntary fixation eye movements in visual perception. Microsaccades and drift eye movements during the maintenance of fixation are modulated by the visual attention system, and emphasize high spatial-frequency components of the visual information. However, there are no studies that discuss attentional effects on drift eye movements during attentive or inattentive fixation. In this study, we analyzed the characteristics of frequency-domain properties of drift eye movements, using a parametric approach based on statistical autoregressive models. Microsaccades were classified into two types: corrective catch-up movements and parts of square-wave jerks. Short-term fixation eye movements before and after these two types of microsaccades were analyzed statistically. The results revealed that the low-frequency components of the drift eye movements were reinforced immediately after microsaccades, especially for the lagging edges of square-wave jerks. This tendency was more prominent when visual attention was dispersed over the parafoveal visual field to detect weak color changes of peripheral targets. These results suggest that microsaccades and microsaccade-driven drift eye movements are both controlled by higher-order brain functions for the acquisition of details of visual information from peripheral vision.

◆ **The processing of visual salience in parietal patients**

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Saccadic target selection has been demonstrated to vary substantially as a function of eye movement latency. Short latency saccades are salience-driven, whereas long latency saccades are unaffected by salience [see eg van Zoest et al, 2004 *Journal of Experimental Psychology: Human Perception and Performance* 30(4)]. Here we investigate the role of parietal lobe functioning in this time course of visual salience. We systematically varied the salience of stimuli presented to either one or both hemifields of a number of parietal patients suffering from extinction or neglect (as well as healthy aged matched controls). Patients with mild to severe neglect did not process visual salience in their affected hemifield at all, while saccadic target selection followed a normal time course in their unaffected hemifield. This would be consistent with a failure to engage at all onto contralesional stimuli. For patients with extinction, salience information was initially represented in the affected field but then rapidly declined (relative to control subjects), whereas in their unaffected field, the effects of salience were more sustained across time. This latter pattern is more consistent with a mechanism that fails to disengage from strong ipsilesional stimuli.

◆ **The effect of spatial distortion distributions on human viewing behaviour when judging image quality**

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In wireless communication, distortions are induced into an image through both lossy source coding and an error prone channel. The combination thereof causes complex distortion patterns in the visual content which vary strongly in their spatial distribution, some being uniformly spread and others being locally clustered. In the context of image quality, it is of interest to identify how the distribution of distortions impact on visual attention of human observers and thus on perceived quality. For this reason, we conducted an experiment in which fifteen participants were asked to rate the quality of 80 distorted images and their corresponding reference images, while we recorded their gaze patterns using an eye tracker. The test images contained a wide range of artifact magnitudes, both locally and globally distributed, and were created using a wireless channel simulation model. We then correlated the visual gaze patterns of the human

observers with local energy measures of the distortions in order to identify the effect of distortion distributions on the viewing behaviour of human observers when judging image quality. The outcomes serve to improve the prediction performance of objective image quality metrics that we previously proposed.

◆ **Eye movement analysis of tilt illusions**

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According to the phenomenal model proposed by Kitaoka et al (2004) to explain the Café Wall Illusion, the contrast polarities of the solid square and its adjacent line segment determine the direction of tilt. An alternative explanation is that the tilt is due to slight shifts between the edges of the same contrast polarity (Kitaoka et al 2001, 2004). However, there is no empirical data on whether viewers actually fixate on these regions of contrast polarity. The goal of this experiment was to study eye-movement fixation patterns by varying contrast polarities of the tilt illusion. We took two versions of the fringed-edge illusion and created four alterations of each version by systematically removing coloured squares: (a) original Illusion with both dark and light squares intact; (b) darker squares removed; (c) lighter squares removed, and (d) both squares removed. Eye-movement data for 10 s and illusion-strength rating on 1–5 Likert scale were collected. Results show a steady increase in the average fixation time and a steady decrease in the number of fixations with decrease in illusion strength. In accordance to the phenomenal model, significantly large number of fixations are located at the regions of contrast polarity.

◆ **Comparing eye movements for perception and communication: Changes in visual fixation durations and saccadic amplitudes**

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Eye movements are crucial for visual perception but also essential for establishing joint attention. Although their supportive implications in technical applications have already been demonstrated (Velichkovsky, 1995), it remains open how using gaze for communicational purposes affects those eye movements themselves. In two studies we examined relationships between fixations and saccades as a function of their communicative use. Participants either explored images to perceive their content or communicated this content to a partner through their eye movements. In the latter condition their gaze position was transferred to their partner's screen as a cursor pointing to different objects, which the partner had to verbally interpret. In Experiment 1 subjects could freely explore the images, whereas in Experiment 2 the observed areas were closely matched in both conditions. In both experiments we obtained not only basic differences in fixation durations and saccadic amplitudes between the perception and communication condition but also changes in the fixation-saccade interplay: In the communication condition the proportion of ambient visual processing (short fixations, long saccades) decreased while indications of focal processing (long fixations, short saccades) increased. We conclude that using gaze to communicate changes eye movement patterns similar to situations requiring deeper levels of visual processing.

◆ **Using eye tracking to assess the task effect on viewing behaviour**

H Alers, H Liu, L Bos, I Heynderickx¶ (Delft University of Technology, The Netherlands; ¶ Philips Research Laboratories, Eindhoven, The Netherlands; e-mail: hani.alers@googlemail.com)

Most image quality experiments use some subjective quality scores. To collect such scores, observers are given the task to assess the quality of a set of images. This makes it important to have an understanding of how the given task influences the way people look at the image material. This paper shows that the quality assessment task actually changes the behaviour of the observers. We exposed two groups of observers to the same set of images presented in different quality levels. One group looked freely at the images while the other was given the task of scoring the image quality level. By tracking the gaze location of the observers, it was possible to measure the effect of the given task on the viewing behaviour through a wide range of image quality. The data indicates that changing the quality level does not affect the viewing behaviour for the free looking group, while it has significant effect on how participants look at the image while evaluating its quality. Since the quality assessment task affects how the images are viewed, it is likely that the gathered subjective quality scores are also affected. This is something researchers should consider when using these scores.

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◆ **The effect of terrain on eye movements while walking in the real world**

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Under natural conditions, humans continuously allocate their gaze according to task demands and environmental constraints. Despite nearly a century of eye-movement research in laboratory conditions, gaze control during truly real-world behaviour is far from being understood. With the advent of mobile eye-tracking systems, measuring eye movements during free behaviour is now feasible. Early studies in this field focused either on very specific tasks in restricted environments (sports, food preparation, etc) or on the environment's effect with little or no control of the task ('free exploration'). We investigated natural gaze control in an everyday situation—ascending and descending a hill in an urban environment. Rather than varying the instruction, we had participants implicitly adapt to their task by varying terrain difficulty—a street of constant slope as compared to the adjacent irregularly spaced sidewalk steps. We found marked differences in gaze parameters: while eye positions when walking the sidewalk exhibited a clearly bimodal distribution, eye positions on the street were unimodal. This difference held for all individual, irrespective of the unimodal distribution's mean. This effect of navigated terrain on eye movements suggests that the set task strongly affects gaze control even when instructions and environment are kept identical.

◆ **Does the shift of another person's gaze direction enhance the reflective attentional shift?**

M Takahashi, H Yoshida, H Yamada (Department of Psychology, Nihon University, Japan; e-mail: kinocol2@gmail.com)

Recent studies have demonstrated that the perception of gaze direction causes reflexive attentional shift. Those studies typically used static gaze stimuli, for example, a still facial picture with eyes gazing at the left or the right appeared as a gaze cue. However, in interpersonal communications, we have all experienced looking where another person is looking when he/she suddenly gazes in another direction. Therefore we hypothesized that such a dynamic gaze cue would have a stronger effect on attentional shift than a static one. The experiment consisted of two blocks where static gaze cues were presented in the first block, and dynamic gaze cues, which made the gaze shift, in the second block. The task for participants was to localize targets following the gaze cues with 105 ms, 300 ms, or 600 ms SOA, but one third of all trials were catch trials (no target). Reflexive attentional shift was observed in 105 ms and 300 ms SOA conditions with the first block and in all SOA conditions with the second block. However the expected differences in the effect on attentional shift between the static cues and the dynamic ones were not obtained. We will discuss these results.

PERCEPTUAL ORGANIZATION

◆ **Searching for fragmented objects: An ideal observer analysis of human eye movements**

L Holm, P Schrater, A Yuille¶, S Engel (Department of Psychology, University of Minnesota, Minneapolis, USA; ¶ Department of Statistics, University of California at Los Angeles, USA; e-mail: linus.holm@psy.umu.se)

An essential component of object recognition is selecting relevant object information. However, the image typically offers a confusion of potentially important features. To facilitate recognition selection humans may be guided by prior object knowledge. On that account, they should forecast where the best information can be found. To infer use of prior knowledge by humans, we derived a model that makes optimal use of object knowledge. The model acquires information about the objects' location through image fixations which are guided by object knowledge. If human observers select similarly informative fixations as the model, it would imply use of prior object knowledge. To test the effect of prior knowledge on selection, we registered eye movements of seventeen subjects as they searched for fragmented object contours embedded in noise. A few fixations were sufficient for the ideal observer to determine the object's location in those images, whereas human observers required an average of 32.5 fixations to locate the object.

◆ **The role of orientation and position in shape perception**

G Loffler, M Day (Vision Sciences, Glasgow Caledonian University, UK; e-mail: gloe@gcal.ac.uk)

Interactions between orientation and position information in shape processing can be investigated using Gabor patches positioned on a circle but with orientations sampled from a noncircular shape. As a measure of perceived shape, we determined points-of-subjective-equality (PSEs) between reference shapes made in this way and test shapes with element position and orientation sampled from radial frequency patterns of varying amplitudes. PSEs exhibit a band-pass relationship with respect to number of elements. For sparse (15) and numerous (50) elements, element position determines the perceived shape. For intermediate numbers (20-40), patterns take on the shape

carried by element orientation. This striking illusion—in which elements placed along a circle are perceived as eg a pentagon—is scale invariant. Increasing the carrier frequency or envelope size increases PSEs, suggesting that the two factors interact non-linearly. Element position is always dominant when elements are second-order. These results suggest that the computation responsible for processing contour shapes can be dominated by either local orientation or local position alone or in combination. Which of these drives the percept depends on factors such as the number of elements, their separation and their characteristics (carrier and envelope, first-versus second-order).

- ◆ **Effect of orientation on depth-order and lightness perception in perceptual transparency**
Y Kiyohisa, H Ito[¶], S Sunaga[¶] (Graduate School of Design [[¶] Faculty of Design], University of Kyushu, Japan; e-mail: ds208017@s.kyushu-u.ac.jp)

Overlapping two thick bars in a '+' configuration produced Metelli's perceptual transparency. The bars were in the same mid-grey colour on a light-grey background, while the perceptually overlapped centre area was dark grey. The two bars were perceived as translucent and overlapped but with ambiguity in their depth order. We have observed a tendency for the vertical bar to be perceived in front. We evaluated the effect of orientation on the perceptual depth order of the two bars, varying the orientation of the cross shape that they formed. The results indicated that the inclination of the cross stimuli affected the perceptual depth order and the lightness of the two bars. There was a perceptual bias toward seeing the vertical bar in front. At the same time, correlated with the perceptual depth order, the vertical bar tended to be perceived as darker than the horizontal bar (in higher contrast to the background brightness). Although the causal relationship between the perceived depth order and the perceived lightness change is not clear at present, the biases may indicate that a vertical visual object tends to be perceived as a figure, while a horizontal one tends to be perceived as a ground.

- ◆ **Texture and contour integration in normal ageing and Alzheimer disease: a VEP study**
F Pei, G Gattulli[¶], A Mangiabene[¶], S Baldassi[¶] (AISV, Pisa, Italy; [¶] Department of Psychology, University of Florence, Italy; e-mail: fp32@nyu.edu)

Ageing implies a deterioration of the visual system both in its optic components and in the neural systems from the retina onward. It has been found that VEP amplitude is reduced and the perception of motion and complex stimuli including contours and texture becomes poorer, suggesting changes at the cortical level. This occurs both in normal ageing and, more severely, in clinical conditions such as the Alzheimer disease (AD). We measured VEPs to Gabor-defined texture and contour stimuli as a probe to investigate the neural correlates of the ageing process in two groups of normal subjects aged 57–86 years and in a small pilot group of six AD patients. In the normal group we also measured texture-coherence thresholds. The results show a general decrease of VEP amplitude with age. The neural signature for texture integration is present in all groups, although the older group evidences higher thresholds. On the other hand the signal for contours is strongly reduced both in the older group of normal observers and in AD patients. The possibility of using middle-level perceptual tests for early detection of different forms of senile dementia will be discussed.

- ◆ **Integration of contour features into a global shape: A classification image study**
I Kurki, J Saarinen[¶], A Hyvärinen (Department of Computer Science and HIIT [[¶] Department of Psychology], University of Helsinki, Finland; e-mail: ilmari.kurki@helsinki.fi)

What are the most important features for recognition of a shape of a contour? Some studies suggest locations of maximum curvature (corners), others the sides of the shape. We used psychophysical reverse correlation or classification images (CI) to estimate the parts of the radial frequency (RF) contour (a sinusoidally modulated circle) used for shape discrimination. Stimuli were composed of difference-of-Gaussian patches (center SD = 5.6 min of arc min, $N = 32$) in an RF contour ($r = 1.5$ deg; $f = 4$ cycles/radius). Position noise (jitter) along the radial axis was added. The standard RF contour had zero modulation amplitude (circle). The modulation amplitude of the test ('square') was adjusted to keep the proportion of correct detections at 75%. A one-interval shape discrimination task was used with 4-point rating scale. CIs were computed from the position noise. CIs reveal that both peaks and troughs of the radial modulation are used for shape recognition, suggesting that sides and corners of the stimulus have about the same importance. All parts of the stimulus are used, suggesting global processing. However, modulation amplitude of the CI is not constant; suggesting that computation of the shape in the task is not purely global process.

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- ◆ **Probing the spatial extent and selectivity of mechanisms that pool orientation signals across space**
B S Webb, N W Roach, P V McGraw (Visual Neuroscience Group, School of Psychology, University of Nottingham, UK; e-mail: bsw@psychology.nottingham.ac.uk)

To extract global structure, the visual system must combine ('pool') local visual information across space. Yet we know very little of the algorithms presiding over the combinatorial process. We have previously shown that adapting global form mechanisms (with complex patterns containing circular or radial structure) actively modulates the local orientation detectors over which they pool. Here we first employed circular patterns containing different proportions of signal and noise orientations to map out the spatial extent of these reciprocal interactions. Signal and noise were either randomly distributed throughout the adapting pattern or segregated into two circumscribed regions, proximal and distal to the local target. Our results suggest a pooling mechanism which accumulates orientation signals over a large (at least 40 degrees) region of the visual field. We next probed the selectivity of this mechanism with adapting stimuli containing different forms of global structure and orientation variance. The effects revealed that spatially extensive pooling of orientation signals is not specific to polar form per se, but rather is a flexible process capable of extracting any systematic change in orientation structure across the visual field.

- ◆ **Corner enhancement effect: comparing convex and concave corners**
M Bertamini, M Mohamed Helmy, P A Skarratt¶, G G Cole§ (School of Psychology, University of Liverpool, UK; ¶ Department of Psychology, University of Hull, UK; § Department of Psychology, University of Durham, UK; e-mail: m.bertamini@liv.ac.uk)

The appearance of an object initiates a redistribution of attentional resources across visual space. Based on reaction time data, it has been suggested that greater attentional resources are directed to corners: the corner enhancement effect (Cole et al, 2001 *Journal of Experimental Psychology: Human Perception and Performance* 27 1356–1368). We conducted two experiments to compare the size of the effect for convex and concave corners. The object was defined by change of texture but not average luminance, and it appeared behind a grid. Although a corner effect was present for convex corners no such effect occurred for concave corners. The corner effect for the convex corner was present for a simple reaction time task (Experiment 1) and also a choice reaction time task (Experiment 2). In Experiment 2 there was an onset in the testing location (probe) as well as in the other possible locations (placeholders). Therefore a unique luminance transient is not necessary for the corner enhancement effect to occur.

- ◆ **Detection, categorization, and identification are separable component processes of object recognition**

S de la Rosa, R Choudhery, A Chatziastros (Human Perception, Cognition and Action, Max Planck Institute for Biological Cybernetics, Tübingen, Germany; e-mail: stephan.delarosa@gmail.com)

Are detection, categorization, and identification of upright images of natural objects mediated by the same or different visual processes? Surprisingly, previous studies found that object detection is as fast as object categorization while object identification takes significantly longer. This suggests that object detection and categorization are mediated by the same visual processes while object identification is mediated by different visual processes (eg Grill-Spector and Kanwisher, 2005 *Psychological Science* 16(2) 152–160). We compared (a) the time course of object detection, categorization, and identification of upright object images using a higher temporal resolution than in previous studies (Experiments 1 and 2); and (b) the sensitivity of these three recognition processes (Experiment 3). Participants saw two consecutive image presentations of which one contained an object image and the other a patch of visual noise. On every trial participants reported the object interval (detection), the object's category (categorization), and the object identity (identification). We measured participants' accuracy to conduct each of these tasks as a function of presentation time (Experiments 1 and 2), and signal-to-noise ratio (Experiment 3). We found significant differences between the psychometric functions of object detection, categorization, and identification in all three experiments. We conclude that detection, categorization, and identification are separable component processes of object recognition.

- ◆ **Visuo-tactile contributions to the perception of naturalness: an fMRI study**
T Whitaker, C Simões-Franklin, F N Newell (School of Psychology/Institute of Neuroscience, Trinity College Dublin; e-mail: whitaket@tcd.ie)

The ability to readily discriminate between natural things and synthetic mimics is not only important for survival but also has significant consumer value. This ability relies on the acuity of the different senses, the material characteristics of the stimuli, past knowledge and experience and the goal of the behaviour. In a behavioural study we investigated the relative contribution of vision and touch to the perception of a set of fabric stimuli in terms of naturalness, and whether

this correlated with ratings of pleasantness, familiarity, softness, roughness, value and hedonics using a 7-point scale. The stimuli comprised of 44 fabric samples, which varied systematically from natural to synthetic. Overall, we found that perceived naturalness was strongly correlated with value and hedonics. Specifically, natural stimuli were rated as more valuable and were liked more. In a second experiment, we examined the brain activations associated with the perception of naturalness using a subset of these stimuli and compared these with activations elicited by hedonics perception. Preliminary results suggest both independent and multisensory contributions to the perception of naturalness. These results have implications on our understanding of how the senses contribute to more higher-order decisions related to the perception of texture.

◆ **One possible model for illusory motion perception in still figure**

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Illusory motion perception in a still figure is a fascinating topic in human vision study (Fraser and Wilcox, 1979 *Nature* **281** 565–566; Kitaoka, 2002, <http://www.psy.ritsumei.ac.jp/~akitaoka/rotsnakee.html>; Murakami et al, 2006 *Vision Research* **46** 2421–2431). Kitaoka reported an essential and simple design rule: in which strong effect can be produced by repeating the picture element with asymmetric four different lightness regions in systematic order such that black, dark gray, white, and light gray. The perceived motion was as vigorous as real motion. Several models for explaining this phenomenon have been tried and proposed, however, no effective model has been proposed. We proposed one possible model by speculating the neural image shift produced in the filtering process such as lateral inhibition and the reset and/or suppression of image information such as one accompanying with eye movement. The image shift was simulated by introducing time varying factor into filtering process, and the visual reset was simulated externally by inserting flashing or blanking frame; then, the continuous motion perception was realized successfully with their combination. The speculated neural filtering process and the reset and/or suppression of image information were physiologically plausible; we believe that similar mechanism may exist in human visual system.

◆ **Temporal priming of figural information and relations**

F Bauer, M Conci, H J Müller (General and Experimental Psychology, Ludwig Maximilian University, Munich, Germany; e-mail: fbauer@lmu.de)

Within a 3×3 matrix of 90° corner junctions, detection of a Kanizsa-type square is facilitated when the target display is preceded by a 40-Hz flickering premask of 3×3 crosses, with 4 crosses synchronously oscillating at the subsequent target location. A series of experiments examined whether this 'synchrony priming' (eg, Elliott and Müller 1998) can become manifest only when a figural target follows the synchronous prime. That is, the question was whether the priming effect is figure-specific or whether any arbitrary stimulus would be primed, as it would be the case if spatial attention would be the underlying mechanism of the priming effect. Figural targets were found to be facilitated by the prime, replicating previous studies. By contrast, detection of non-figural dot-probe targets was not expedited by the synchronous prime. However, priming was found to be effective when observers were required to judge the spatial relation of a non-figural dot probe relative to a Kanizsa square. Taken together, these results show that synchrony priming depends largely on target-figure information. However, if the relation of a non-figural target needs to be evaluated, the temporal prime facilitates performance. Thus, in addition to figural information, relational information may also be encoded by synchrony priming.

◆ **The earliest neural correlate of visual awareness: Motion precedes colour**

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Binocular rivalry causes perceptual awareness to fluctuate between two dissimilar monocular images. Colour and motion are processed in two distinct visual pathways. We investigate whether this difference in the processing stream influences the temporal course of the first neural correlate of visual awareness. Observers tracked either colour rivalry between red/black and green/black radial frequency patterns or motion rivalry between concentric and excentric movements within these patterns. We measured event-related potentials (ERPs) to stimulus transitions from binocular colour or motion rivalry to binocular fusion (same colour or motion in both eyes). Depending on the observer's prevailing percept when such a physical change happened, the observer became aware of the stimulus transition (incompatible transitions) or remained unaware (compatible transitions). We found similar but attenuated neural responses for compatible as compared to incompatible transitions. Importantly, this awareness-related difference occurred earlier following motion rivalry (P2; 220–240 ms) than following colour rivalry (N2; 245–275 ms). We take our finding as evidence that changes in stimulus colour and stimulus motion impact on the neural mechanisms of visual awareness at different stages of visual processing.

Tuesday

3-D PERCEPTION

◆ **Monocular viewing prolongs interval of perceptual reversal**

K Ukai, S Tanahashi, K Segawa, M Zheng ¶, J Kuze § (Department of Applied Physics, Waseda University, Japan; ¶ Department of Psychology, Tsinghua University, Japan; § Faculty of Health Science, Nihon Fukushi University, Japan; e-mail: ukai@waseda.jp)

This study examines whether the perceptual reversal rate is changed under monocular versus binocular viewing conditions. Results show that the perceptual reversal interval increases during monocular viewing. The ratio of the reversal rate ($1/\text{interval}$) for the two viewing conditions (binocular/monocular) is 1.28 over a wide range of the pattern luminance levels, whereas it is 1.40 when the luminance is high. The observed ratio of 1.40 parallels the value of a well-known binocular summation index ($\sqrt{2}$), which was observed in the various measurements and also derived from signal detection theory. The present study also revealed that reversal interval shortened by a factor of 1.20 for increase of 1.0 log luminance of the pattern. As the binocular summation index has shown, the strength of an input signal is enhanced by binocular viewing. However, how binocular summation shortened perceptual reversal interval is unclear. This issue will be resolved if perceptual reversal is derived by integration of the strength of unconscious image signal. Thus classically well-studied two phenomena, binocular summation and perceptual switch, are combined here and a clue for understanding mechanism of perceptual switch is obtained.

◆ **How embedding prior constraints improves coding and decoding strategies in a neural distributed architecture for depth perception**

S P Sabatini, M Chessa, F Solari (Department of Biophysical and Electronic Engineering, University of Genoa, Italy; e-mail: silvio.sabatini@unige.it)

The energy-based distributed coding approaches for the estimation of binocular disparity can intrinsically embed adaptive mechanisms both at coding and decoding levels. We investigated to what extent prior knowledge of constraints on the local disparity can improve the estimated reliability of a population of binocular energy units, based on a generalization of the phase-shift model (Fleet et al, 1996 *Vision Research* **36** 1839–1857) sensitive to 2-D disparities along different orientations. Population activity can be adapted to specific feature constraints by changing the distribution of units, thus minimizing the necessary resources while preserving the reliability of estimates. We assessed the proposed approach by using the ground truth disparity map of a set of image stereo pairs (Scharstein and Szeliski, 2004 *International Journal of Computer Vision* **47** 7–42). Knowledge of the disparity values was used to redistribute the sensitivity coverage of the cells' population and its density by properly choosing the phase-shifts, while keeping the other parameters fixed. In particular, we proved that the same reliability is obtained by halving the units of the population. Similarly, the constraints can affect the decoding strategy by properly selecting the cells' responses so as to minimize uncertainty of the estimates.

◆ **Cast shadows in perspective**

S C Pont, M W A Wijntjes, S Oomes ¶, A J van Doorn, H de Ridder, J J Koenderink ¶ (Industrial Design [¶ Electronics, Mathematics and Informatics], Delft University of Technology, The Netherlands; e-mail: s.c.pont@tudelft.nl)

The geometry of shadows in perspective images has been a basic topic in arts and graphics education for centuries [Descargues, 1982 *Perspective: History, Evolution, Techniques*] and sciagraphy might be assumed to form common knowledge. We investigated the apparent spatial layout of cast shadows in very wide field of views. We presented 130 degrees wide images in which two 'flat poles' were standing on a green lawn under a cloudless blue sky on a sunny day. Thus, the poles throw sharp cast shadows on the green. The shadow of one of the poles was fixed. The observer's task was to adjust the azimuth of the shadow of the other pole such that it fitted the scene. The source elevation was kept constant. The two cast shadows are of course parallel in physical space, but generically not in the picture plane. Cast shadows at different visual directions subtend different angles with those visual directions, due to the divergence of visual directions from the eye. We found that observers made systematic huge errors in the comparison of cast shadows of poles seen far apart in the visual field, indicating that generically they fail to account for the divergence of visual directions.

◆ **Shape from smear**

D N Holtmann-Rice, R W Fleming (Human Perception, Cognition and Action, Max Planck Institute for Biological Cybernetics, Tübingen, Germany; e-mail: daniel.holtmann-rice@tuebingen.mpg.de)

Recent work indicates that the patterns of scales and orientations in an image ('orientation fields') may play an important role in 3-D shape perception. If true, it should be possible to elicit percepts of specific 3-D shapes using stimuli containing only an appropriate orientation field.

To investigate this, we use line-integral convolution to ‘smear (coerce) 2-D noise patterns to have a geometrically ‘correct’ orientation field (ie, as similar as possible to the orientation field present in the rendering of some object). The spatial scales are also modulated to be physically accurate. Importantly, the image generation process is entirely based on 2-D filtering operations, and is fundamentally different from a physically realistic rendering. Despite this, the resulting pattern elicits almost as vivid an impression of the object’s 3-D shape as a true rendering. Such images were used in depth comparison and gauge figure tasks to assess the relative contribution of spatial scales and orientation fields to shape perception; as well as the dramatic breakdown of shape perception resulting from physically unrealistic orientation and scale configurations. By examining the accuracy with which subjects are able to make metric judgments (relative depth and surface orientation) about the shape percepts evoked by these patterns, we demonstrate that the continuous variations of orientation and spatial scale across an image can play a key role in 3-D shape inference.

◆ **Dynamic interactions between the dorsal and the ventral visual subsystems during the perception of 3-D structure from 2-D motion**

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Two-dimensional optic flow is an important cue to perceive 3-D structure of objects. Recent neuroimaging studies suggest the involvement of both the ventral and the dorsal visual pathways in the perception of 3-D structure from motion (3-D-SFM), though the neural dynamics underlying the 3-D-SFM is not fully understood. Here, we combine magnetoencephalography (MEG) and fMRI to detect the dynamic brain responses to 3-D-SFM. We manipulated the coherence of randomly moving dots to create different levels of 3-D perception and investigated the associated changes in brain activity. Results of the fMRI analysis were used to impose plausible constraints on the MEG inverse calculation to improve spatial resolution of the spatiotemporal activity estimates. The infero-temporal (IT), parieto-occipital (PO), and intraparietal (IP) regions showed increased neural activity at different latencies during highly coherent motion conditions in which subjects perceived a robust 3-D object. Causality analysis between the estimated neural activities in these regions indicated a significant causal influence from IP to IT and from IT to PO only in conditions where subjects perceived a robust 3-D object. Current results suggest that the interactions between the dorsal and ventral visual subsystems are crucial for the perception of 3-D object from 2-D optic flow.

◆ **Effects of surface material on perceived 3-D shape: comparing velvet and matte reflectances**

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The appearance of an object is the result of an interplay of several factors: its 3-D geometry, the distribution of incident illumination and its material. Previous research indicates that changes in illumination lead to linear and nonlinear changes in perceived 3-D shape (Koenderink et al 1996; Nefs et al 2005). Conversely, a change of surface reflectance properties of an object will produce characteristic shading patterns for a given material. Here we investigate whether these changes will affect the perceived 3-D shape of the object. Stimuli were computer-rendered sinusoidally modulated spheres with either one of two, physically realistic bi-directional reflectance distribution functions (BRDFs): Lambertian and surface scattering (Pont et al 2006), resulting in matte or velvety appearance, respectively. Objects were illuminated by a mixture of a point and ambient light source. We measured observers’ judgments of local surface attitude using a gauge-figure probe (Koenderink et al, 1992). From these local measurements, for each object, perceived 3-D surfaces were reconstructed and compared across BRDFs. Regression analysis revealed that velvety objects appeared compressed in depth compared to their Lambertian-shaded counterparts. Furthermore, initial results indicate non-linear effects, ie velvety surfaces were perceived as less curvature-modulated.

◆ **Depth perception in depth-fused 3-D (DFD) display when both eyes have different visual acuity**

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It is well known that depth is difficult to perceive when both eyes have different visual acuity. In stereoscopic display, it is reported that depth cannot be perceived when visual acuity of the dominant eye is less than 0.1. However, in DFD display, depth can be perceived when both eyes

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have different visual acuity. DFD display was proposed by Suyama et al (2004 *Vision Research* 44 785–793), suggesting that depth is continuously perceived between the front and rear 2-D images when luminance ratio of two images is changed. In this paper, we examined perceived depth change in DFD display, as well as in stereoscopic display, when the difference of visual acuity between both eyes is increased. Stimuli were three squares with different depths. In various visual acuity of dominant eye, subject was asked to answer a middle depth square in three squares. We found that a correct answer ratio slowly decreases in DFD display when visual acuity of dominant eye is decreased from 0.1 to 0.05. Thus, in DFD display, depth is considered to be perceived partially at visual acuity from 0.1 to 0.05.

◆ **Comparing audiovisual distance perception in various ‘real’ and ‘virtual’ environments**

J S Chan, D Lisiecka, C Ennis¶, C O’Sullivan¶, F N Newell (School of Psychology, Institute of Neuroscience [¶] Department of Computer Science), Trinity College Dublin, Ireland; e-mail: jason.chan@tcd.ie)

Veridical representation of absolute distance is still a significant challenge in virtual reality. It has been shown that consistent underestimations of a target’s distance are made when perceived using vision and hearing alone. This is further compounded in virtual reality by the perceived ‘compression of space’. In this study, we examine if audiovisual stimuli can reduce perceived underestimations in real and virtual environments. We conducted a $5 \times 3 \times 2 \times 2$ mixed-measures design with location (25 m, 22.5 m, 20 m, 17.5 m, 15 m) and modality (vision only vs auditory only vs audiovisual) as within-subjects factors, reality (real vs virtual) and environment (small vs large) as between-subjects factors. Participants saw, heard, or saw and heard, a target for 10 s. Their task was to bisect the distance between the start position and the target’s location while wearing a blindfold. In the real environments, participants saw the real target with sounds emanating from loudspeakers on that target. In the virtual environments, the visual stimuli were presented via a head-mounted display. The auditory stimuli were probe microphone recordings of the target at various locations and played back via headphones. Results show a clear underestimation of perceived distance in both unimodal conditions, with larger underestimations on the auditory conditions. Performance in the multisensory condition followed the vision-only condition. There was also a qualitative difference in the type of errors between the two environmental conditions. The implications for virtual reality will be discussed.

◆ **Wideangle or telefoto pictures and perceived shape**

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It is frequently remarked that photographs taken with wide-angle lenses look ‘distorted’ and that those taken with tele-lenses look ‘flat’. Textbooks often ascribe this to (typically) incorrect viewing. For instance, wide-angle shots tend to be seen from too large, tele-shots from too short a distance. We test this hypothesis empirically. A low relief sculpture and a sculpture ‘in the round’ were photographed with wide-angle lenses and tele-lenses. A gauge figure task was used to determine perceived pictorial relief. Wide-angle shots were viewed at the correct distance and at a distance actually appropriate to a telefoto shot, telefoto shots were viewed at the correct distance and at a distance actually appropriate to a wide-angle shot. The resulting pictorial reliefs are analyzed in detail for four observers. We find that pictorial relief is conserved over a huge range of (‘incorrect’) viewing distances. Apparent distortions are due to size variations in the visual field.

◆ **The influence of a visible reference on judging egocentric distance**

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When a sphere is presented binocularly at various distances in complete darkness the range of distances is usually underestimated. We examined whether adding a stable reference improves judgments of distance. Subjects had to point with their unseen index finger to a small virtual sphere. In one condition ocular convergence was the only informative cue. Two additional conditions tested whether adding an object improves performance. In those conditions a cube was visible. In one condition the cube remained visible at a fixed position. In the other condition a similar cube was shown, but its position varied at random across trials. We found that adding a reference yielded a larger range of indicated distances, even if the reference changed position whenever a new sphere was presented. This suggests that having an additional visible structure provides information that can be used to scale the visual information even if this structure is not always at the same position.

◆ **Misestimation of lightness under changes in light source elevation**

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Lightness perception is an underconstrained problem because it is in principle impossible to ‘unmultiply’ the effects of lighting and geometry in a single image. Yet, people are remarkably good at this task, albeit not perfect. Subjects adjusted the reflectance of the central face of a dodecahedron using the rest of the sides as reference, whilst the elevation of illumination was varied. The adjusted reflectance was systematically different from veridical. Reflectance was overestimated for vertically eccentric illuminant angles and underestimated for angles close to the horizontal plane. We provided additional information about the light source direction by adding Lambertian and specular spheres to the scene. Inconsistent cues were also tested—spheres with illumination angle offset of 8 and 15 degrees. Context did not enhance accuracy or shift perception. To increase depth salience we added rotational motion, and to reduce depth salience, γ -junctions and edges were masked. Neither manipulation altered the reflectance settings. The systematic errors in reflectance setting appear to result from a bias in the assumed direction of illumination. These errors are robust to changes in context. This implies that people might ignore useful cues or alternatively that only the relative information within an area perceived as a single object is used in lightness estimation. Removing local features did not result in reduced accuracy, which implies that lightness estimation in this case is not extracted from local information of edges or γ -junctions.

◆ **Perceived size and distance are not internally consistent**

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It has been argued that judgments of an object’s perceived size, shape and distance are ‘quite independent’ and not based on a single estimate of distance (Brenner and van Damme, 1999 *Vision Research* 39 975–986). Here we test this hypothesis directly for size and distance in a context where both judgments can be severely distorted. In an immersive virtual reality environment, observers judged whether a comparison square in the second interval had changed either in size or distance with respect to the reference square presented in the first interval. The virtual room was visible throughout the trial and increased in size by a factor of 4 between intervals (expanding around the cyclopean point). On some trials, a vertical ribbon provided a strong distance cue (but no information about the correct size match). Its effect was greater on distance matches than on size matches. Without the ribbon, reference and comparison stimuli with the same perceived distance and matched retinal size were perceived as approximately the same size, as expected. However, in the presence of the ribbon, perceived sizes were very different. This demonstrates, more directly than in the past, the lack of internal consistency between judgments of size and distance.

◆ **The Mona Lisa effect: Is it confined to the horizontal plane?**

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As an observer views a picture from different viewing angles, objects in the picture appear to maintain orientation relative to the observer, but for some objects this constancy is better than for others—differential rotation effect (DRE) (Goldstein *Journal of Experimental Psychology: Human Perception and Performance* 1979 5 78–87; 1987 13 256–266). The DRE occurs also for pictures of faces: the eyes of a portrait appear to follow the observer as he or she views the image from different angles—also called the Mona Lisa effect. Empirical studies of this effect were, however, based on and limited to gaze directions and observer displacements in the horizontal plane only (right and left from the centre). We report an experiment that first replicates the differential rotation effect for gaze shifts and observer displacements in the horizontal plane. A portrait photograph was used at all times. To rule out computer artifacts, actual photographs were presented. Then we used the same methodology but this time varied gaze direction and observer displacement in the vertical and diagonal. The perceptual distinction of the horizontal plane in picture perception will be discussed.

◆ **The changes in perception of visual illusions during long-term isolation**

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We investigated changes in human susceptibility to selected visual illusions during long-term isolation. Six crew members took part in a ground-based experiment simulating manned flight to Mars. For the period of 105 days (starting 31 March), the crew was confined in a special isolation

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facility where they could not view objects or surfaces more than a few metres away. As a result we expected that the subjects' sensitivity to perspective would change and may also lead to a decrease in susceptibility to visual illusions of size. Indeed, the data from the first half of the isolation experiment already show such a trend. However no definite conclusions can be made before the end of the experiment, but interim results are presented.

◆ **Focus position's effect in depth perception**

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When we see a photograph, we can see the area in focus clearly. But the out of focus area is seen unclearly. We can use blur as depth cue. On seeing two images where focus position is different (one focused on the near area, the other on the far area), does the depth perception differ? The aim of our study was to examine that question. Two images were displayed on an LCD display, top and bottom. All images used in the experiment contained two targets and the ground. Targets were positioned at different depth and horizontally in virtual space. They were produced by 3-DCG software (POV-Ray). One image was focused on the near target, the other on the far target. The subjects' task was to choose the image where the distance between near target and far target appeared greatest. Our results show that the distance in the image focused on the near target was thought to be the longest. This indicates that depth perception varies with focus position when looking at photographs.

◆ **A virtual reality tool for disparity statistics in the peripersonal space**

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In stereoscopic vision research, attempts of assessing the disparity cues in natural settings during active vision tasks yield to several studies on the disparity statistics (Liu et al, 2008 *Journal of Vision* 8 1–14). Though systematic analyses of this issue in the peripersonal space (large vergence angles) in real-world situations (ie, 3-D exploration of a real environment) are still lacking, a tool has been developed that uses the virtual reality to simulate the actual projections impinging upon the retinas of an active visual system rather than render 3-D visual information for stereoscopic display. The simulator works on the 3-D data acquired by a laser scanner and performs the version and vergence movements following the strategies adopted by different active stereo vision systems, including biomimetic ones. The ground truth disparities of the projections of the scene points can be computed for each different fixation point, thus enabling disparity statistics in real-world situations. Moreover, the corresponding stereo image pairs, together with the actual position and orientation of the eyes, are available and can be used to assess and benchmark neural models for depth estimation and control strategies of the active vision systems.

◆ **Visual search in 2-D and 2½-D surfaces: differential eye movement patterns and effects of writing direction**

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Languages use different writing system directions: left to right, right to left, or top to bottom. Reading/writing is important in how humans gain and convey information. Thus, spatial routines humans engage while reading/writing affect spatial organization of various cognitive and motor functions. We tested the effects of writing system direction on eye-movement patterns during conjunctive visual search, using ten Russian (left–right) and ten Hebrew (right–left) mother-tongue speakers/readers. A white '+' shaped target between green '+' and white 'O' shaped 'distractors' comprised 2-D-fronto-parallel display surface. Corresponding 2½-D display included similar shaded cue volumetric elements arranged on subjective perspective surface, as if viewed from elevated viewpoint. Elements from 'near' to 'far' became smaller and dense. Controlling eye-dominance and handedness, eye-movement patterns were coherently affected by writing orientations, searching the 2-D display. Conversely, all subjects showed similar search patterns in 2½-D search, where embarking of first saccades occurred at the perspective 'vanishing point'. Detecting 'far' targets elicited shorter RT's than 'near' targets. Subjects' eyes tended to diverge/converge when searching for 'far'/'near' 2½-D elements. Results suggest that 2-D conjunctive visual search patterns reflect engrained reading/writing orientation system, but different mechanisms underlie visual search patterns in volumetric environments. Results also support cognitive-driven vergence control mechanisms.

◆ **Inclination bias in near 3-D visual space**

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Our visual system has evolved to process proximal stimulation with respect to distal objects in the world. Meanwhile modern technology allows for the generation of proximal stimulation in the absence of distal objects. Goal-directed movements in virtual environments, however, lack the ease and automaticity which characterise those in natural settings. The purpose of the present study was to shed some light on the origins of these difficulties. In particular we were interested in whether the movements reflect known visual distortions and whether their characteristics match those that are observed in more natural settings. We asked our subjects to point to eight randomly presented targets located on a circle around a central start position, all lying on a horizontal plane. Visual feedback was absent during pointing. Whereas we found no evidence for a contraction bias in this open-loop 3-D task, we found strong evidence for an inclination bias and its persistence even after closed-loop calibration trials. We present evidence that this effect is of visual rather than of motor origin and discuss the importance of more or less continuous calibration for accurate goal-directed movements in 3-D space.

◆ **Visual rather than proprioceptive information contribute more to shape-from-shading when the light-source was actively moved**

T Sato, K Hosokawa (Department of Psychology, University of Tokyo, Japan; e-mail: satotak8@gmail.com)

Knowledge about light-source position is theoretically indispensable for shape-from-shading. Thus, it is expected that the perceptual performance improves if we hold a light-source such as a flashlight and move it ourselves. We investigated the contribution of proprioceptive input in such a situation. In our experiments, participants observed a circular stimulus simulating either a convex or a concave surface. In the active condition, the luminance distribution changed according to the observers' hand movement as if a light-source was placed at the position of the hand, and observers judged the 3-D shape of the stimulus (concave/convex). In the passive condition, the experimenter moved his hand and the display changed according to the hand movement. Finally, in the control condition, the light source position was moved automatically and subjects simply looked at the display. Performance was better in both passive and active conditions rather than in the control condition. In addition, performance was almost the same when the observer or experimenter held a real flashlight in their hand to enhance the relationship between the hand and light-source positions. These results indicate that visual rather than proprioceptive information is important in obtaining shape-from-shading perception.

HAND MOVEMENTS

◆ **The role of body and tool-based information in joint action coordination**

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Influential theories (eg common coding theory) suggest that visual body information about the interaction partner is critical when two people physically interact (joint action). Evidence supporting this idea comes from studies investigating computer mediated joint actions. Surprisingly, this hypothesis has not been examined in a real-life joint action task. To test this hypothesis, participants cooperatively played table tennis in complete darkness with the ball, net, and table illuminated with fluorescent markings (Experiment 1). In different conditions we added different types of visual information by placing glowing point markers on the players' body (body information) and/or marking the paddle's rim with fluorescent paint (tool information). We found a significantly reduced error rate when body and/or tool information was available. In Experiment 2 the same types of visual information were available to only one player at a time. The error rate was measured in every condition for each player separately. We found improved performance when the player saw his/her own body or the other player's tool but not when he/she saw his/her own tool or the other player's body. These findings challenge the view that information about the body of an interaction partner is critical in a joint table tennis task.

◆ **Trajectory formation affects grasping kinematics**

C Hesse, H Deubel (Experimental Psychology, Ludwig-Maximilians-Universität, Munich, Germany; e-mail: constanze.hesse@psy.lmu.de)

It was proposed that the components of grasping, namely transport and grip, are controlled by two independent visuomotor channels [Jeannerod, 1981, in *Attention and Performance, Volume IX* Eds J Long A Baddeley (Hillsdale, NJ: Lawrence Erlbaum Associates) pp 153–168]. Both channels were assumed to be sensitive to different kinds of information and to share only little of it.

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According to this view, the pre-shaping of the hand is a stable motor pattern which is mainly pre-determined by the object related visual input. In our experiments participants had to execute different types of curved movements in order to reach and grasp a target object. Simply varying the curvature of the transport path resulted in a delayed pre-shaping of the grip. When participants additionally had to either stop at, or pass over a certain via-position the grip became segmented into two movement parts meaning that the pre-shaping was not started until the via-position was reached. The more difficult it was to pass over the via-position correctly, the stronger became the observed dissociation between transport and grasp components. In summary, changes in the transport path resulted in a disruption of the stereotyped grip pre-shaping pattern giving further evidence that both channels are interrelated. Moreover, our findings suggest a sequential scheduling process occurring when the motor pattern becomes more difficult.

◆ **Feature-based attention modulates priming effects in a primed-pointing paradigm**

F Schmidt¶, T Schmidt¶ (Sozialwissenschaften, Technische Universität, Kaiserslautern, Germany; ¶ also Allgemeine Psychologie I, Justus-Liebig Universität, Giessen, Germany; e-mail: filipp@onlinehome.de)

We introduced two experiments to study the influence of feature-based attention with colour and shape on the time course of speeded primed pointing responses. Colour or shape targets were preceded by prime stimuli that triggered either the same or opposite response as the targets on the same location. Before each trial the relevant target pair was indicated by an attentional cue stimulus. Time intervals between presentation of cue and prime as well as prime and target stimuli were varied systematically. Prime visibilities were explored in separate behavioral tasks. Pointing trajectories showed strong priming effects that were amplified by attentional direction on the relevant feature at optimal cue-prime intervals. In conclusion, visual feature-based attention seems to modulate the earliest phases of visuomotor processing. This modulation was independent of visual awareness of the primes, strongly supporting the notion of distinct processes underlying visual awareness and attention.

◆ **Learning to intercept targets driven by force fields: effects of modulus and orientation variability**

A Sciutti¶, F Nori, G Metta¶, T Pozzo§, G Sandini (RBCS Lab, Istituto Italiano di Tecnologia, Genoa, Italy; ¶ also Dipartimento di Informatica Sistemistica e Telematica, University of Genoa, Italy; §INSERM U887, Motricité-Plasticité, Dijon, France; e-mail: alessandra.sciutti@iit.it)

In previous studies we observed that intercepting a target may also require modeling the force field which drives its motion. A question which is still open is to determine what force field parameters are to be modeled. Therefore, we performed an experiment to understand whether force field direction and modulus are both involved in the modeling process. Subjects were required to intercept a virtual target moving on a screen by pointing at it with their finger, while the movement of the finger was recorded with an Optotrak system. Performance was assessed evaluating the spatial interception error and the kind of motion adopted in catching (one-shot movement or multiple adjustments). We compared interception of targets driven along parabolic trajectories by different force fields. Forces could either (i) be constant during the whole task (oriented along one of two opposite vertical directions) or vary, on each trial, (ii) their modulus and direction, or (iii) their modulus only. The results show greater learning (the error is reduced across trials) when both force field modulus and direction were kept constant, thus indicating that they both play a role in the modeling process. Moreover different kinds of motion were preferentially adopted in the various conditions.

◆ **Spontaneous blinks are entrained by finger tapping**

M Sharikadze, D-K Cong, G Staude, H Deubel¶, W Wolf (Institute of Communication Engineering, University of Federal Armed Forces, Munich, Germany; ¶ Department of Psychology, Ludwig Maximilians University, Munich, Germany; e-mail: msharikadze@yahoo.com)

Human eyeblink behaviour was mostly studied under psychological and perceptual aspects, whereas motor aspects were rarely considered (eg, blink behaviour during walking). On the other hand, blink control shares neural resources with limb motor control, suggesting an interaction between both. In this study, a synchronization-continuation index finger tapping task was used to test this hypothetical coupling of both motor activities with regard to their time-structure. The mutual 'cross-talk' between blink control and tapping motor commands for unimanual and bimanual tapping (the latter requires hemispheric cooperation), and the effect of more pronounced motor commands (strong and impulse-like tapping) were studied. The data obtained revealed essential modulation of blink control: in this regard, bimanual tapping was more effective than unimanual, with strong and impulse-like tapping showing the largest effects. In contrast, the tapping process was not significantly disturbed by the eyeblinks across all experiments. Although the

characteristic of the interaction conspicuously varied by individuals, its generic appearance was clearly demonstrated.

- ◆ **Relative contributions of non-visual information to the position estimates of a moving hand**
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Vision functions as an adjust mechanism continually tuning proprioceptive localization of the hand in space. Without vision, proprioceptive estimates of hand position become more erratic as an unseen hand moves. We investigated whether accuracy of the position estimates of a moving hand can be improved without vision. Seventeen subjects performed a manual tracking task in which a target moved horizontally on a level screen at a constant velocity and then disappeared. The moving limb was covered by the screen and subjects were asked to judge the position of their unseen hand during tracking the unseen target. Half of the subjects participated in a moderate training session for manual tracking with augmented visual feedback, but the other half did not. The training significantly decreased not only errors of the manual tracking, but also errors of the judgement of the unseen hand position. However, the judgement errors were larger than that under a visual condition in which a cursor representing the hand position was always visible. These results suggest that subjects could become to consciously perceive dynamic hand positions by relying on non-visual information, even though vision is a major source for error corrections.

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COLOUR VISION

- ◆ **Modelling of RGB colour contribution to visual acuity in conditions of fog evoked decrease of luminance and contrast**

D Lauva, M Ozolinsh, S Fomins (Department of Optometry and Vision Science, University of Latvia, Riga, Latvia; e-mail: ozoma@lu.lv)

This report builds on the results of previous mesopic vision studies done in a fog chamber where three parameters—luminance, contrast, and light scattering—evoked ‘effective’ modulation transfer function (MTF) undergo correlated changes with increasing fog density [Ozolinsh et al, 2009 *Perception* **38** 466 (abstract)]. Now we studied the decrease of visual acuity (VA) dependent on two orthogonal dimensions—stimuli luminance L (Y in CIE xYz colour space) and Michelson contrast C . Our aim was to determine their specific contribution for three basic colours: red, green, and blue, and study the effects on VA with changes in MTF. An optotype set of different size and contrast was prepared using print technology. A LCD projector was used for selective red, green, and blue illumination covering mesopic illumination range of $0.1\text{--}10\text{ cd m}^{-2}$. We obtained a good agreement between VA for red and green optotypes for isoluminant conditions at different stimuli contrast. We found the following relationship between visual acuity and luminance $VA^k = \text{const}$ ($k = 0.18\text{--}0.30$ for stimuli contrast $C = 0.15\text{--}1.0$) for all basic colours within this range of transition from cone to rod vision. Using spectral data of red, green, and blue illumination results are analyzed in the LMS cone space.

- ◆ **Mesopic luminance defined by minimum motion**

S Raphael, D I A MacLeod¶ (L-LAB, Universität Paderborn, Germany; ¶ Department of Psychology, University of California, San Diego, USA; e-mail: Sabine.Raphael@gmx.de)

The method of nulling the apparent motion of a stimulus composed of homochromatic and heterochromatic sinusoids has been used to determine individual isoluminance ratios between two colors under photopic conditions. Here we employ a minimum motion technique over a wide intensity range to assess changes in the relative contribution of rods and cones for annular fields in the near fovea and periphery. Results show that near foveal vision ($\pm 1^\circ$) can be described with only the cone response at all intensities where settings are possible. From 2° off-axis to 18° off-axis the point of equal rod and cone contribution to luminance shifts from 0.02 cd m^{-2} to 0.7 cd m^{-2} . Motion settings using differently colored adaptation fields with the same S:P ratio (ratio of scotopic to photopic luminance) show no differences in isoluminance ratio. This suggests that the scotopic and photopic CIE standard luminosity functions $V'(\lambda)$ and $V10(\lambda)$ are sufficient to describe achromatic luminance at low light levels when the rods get involved. Besides eccentricity the mesopic luminance determined by minimum motion also depends on the spatial frequency of the sinusoidal stimulus and the S:P ratio of the adaptation background. An increase in S:P ratio is associated with a decreased effectiveness of rods relative to cone stimulation at mesopic levels. This effect is also found under photopic levels for far peripheral stimuli.

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◆ **Quantification and formulation of age-related changes in color appearance**

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In order to compare and relate the color appearance as seen by elderly and young people, we conducted an experiment where young and aged subjects responded to the color appearance of color patches using an elemental color scaling method. The results showed that there was no significant difference in color appearance between the two age groups, suggesting that the neural mechanism of color vision in elderly people may overperform on color appearance constancy to compensate for age-related changes of the crystalline lens. However, there were systematic differences in the elemental color response between the two age groups depending on hue and saturation of the color patches, indicating that the compensation mechanism is not perfect. We formulated a conversion equation as a function of colorimetric values to calculate equivalent colors between young and elderly subjects taking into account age-related changes of brightness, and can confirm that the color conversion is quite precise. Finally, we developed a color vision simulator which enables young observers to perceive color appearance as seen by the elderly in real time by using our color conversion method and dynamic image processing techniques.

◆ **Influences of surround hue on colour appearance**

T Wachtler ¶, S Klauke¶ (Department of Biology, Ludwig-Maximilians-Universität München, Germany; ¶ Department of Neurophysics, Philipps University, Marburg, Germany; e-mail: susanne.klauke@physik.uni-marburg.de)

Most studies of colour induction investigate induction effects around equilibrium points such as the achromatic point. Little is known about induction along other directions in colour space. We measured changes in hue, expressed as azimuth angle in cone-opponent colour space, induced by chromatic surrounds. In one experiment, subjects performed asymmetric matching of 2-degree chromatic patches across different isoluminant backgrounds. Induced hue shifts depended on the hue angle difference between test and surround, with a maximum for hue angle differences around 41 degrees. Qualitatively, induction effects for different surrounds were similar, but the amount of induced hue change depended on the hue of the surround. To test whether the induced hue changes are task-dependent, in a second experiment we measured the influence of surround hue on unique hue settings. Induced hue angle changes were qualitatively similar to those in the first experiment, but showed quantitative differences. While hue shifts were largest along a red–green axis and smallest along a blue–yellow axis in the asymmetric matching task, we found the opposite for the unique hue setting task. This may indicate a special role of the unique hues for judging colour appearance.

◆ **Colour categories boundaries are better defined in contextual conditions**

R Benavente, C Parraga¶, M Vanrell¶ (Computer Vision Center [¶ Computer Science Department], Universitat Autònoma de Barcelona, Spain; e-mail: maria.vanrell@uab.cat)

In a previous experiment [Parraga et al, 2009 *Journal of Imaging Science and Technology* 53(3)] the boundaries between basic colour categories were measured by asking subjects to categorize colour samples presented in isolation (ie on a dark background) using a YES/NO paradigm. Results showed that some boundaries (eg green–blue) were very diffuse and the subjects' answers presented bimodal distributions, which were attributed to the emergence of non-basic categories in those regions (eg turquoise). To confirm these results we performed a new experiment focussed on the boundaries where bimodal distributions were more evident. In this new experiment rectangular colour samples were presented surrounded by random colour patches to simulate contextual conditions on a calibrated CRT monitor. The names of two neighbouring colours were shown at the bottom of the screen and subjects selected the boundary between these colours by controlling the chromaticity of the central patch, sliding it across these categories' frontier. Results show that in this new experimental paradigm, the formerly uncertain inter-colour category boundaries are better defined and the dispersions (ie the bimodal distributions) that occurred in the previous experiment disappear. These results may provide further support to Berlin and Kay's basic colour terms theory.

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◆ **Processing bimodal line stimuli: Contributions of colour and orientation**

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How do two distinct stimulus attributes, colour and orientation, interact as contributions to global dissimilarity? Line stimuli ($N = 30$) that varied in hue (four cardinal colours, plus white) and orientation (six angles at intervals of 30 deg) were presented pair-wise to five subjects who judged their global dissimilarity. An exploratory analysis with multidimensional scaling showed that a minimal representation of the data required two dimensions to accommodate the circular sequence of the angular attribute, and two more, colour-opponent dimensions for the hue attribute. A 5th 'desaturation' dimension improved the fit by accommodating the qualitative gap between white and chromatic stimuli. For these complex stimuli, colour and orientation modalities proved to behave as integral rather than separable dimensions. We obtained independent spatial models for the colour parameter and the orientation parameter, and used multivariate regression to estimate subject-specific contributions to dissimilarities from colour differences and angle differences. Overall, colour dominated orientation marginally, but the relative weights varied among subjects in a reproducible way. We discuss a synergistic relationship between the low-level vision attributes of colour and orientation, involved in image segmentation.

◆ **The effect of contrast polarity, contrast ratio and colors on neon**

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Two experiments were conducted to investigate the impact of contrast polarity, contrast ratio and color of segments on neon color spreading (NCS). The stimulus was a modification of the Ehrenstein figure used by Redies and Spillmann (1981); the inner and outer segments were achromatic and the middle segment was changed into four colours (eg, red, green, blue, and purple) depending on conditions. In Experiment 1, background and inner/outer color were selected, either white or black, to test the impact of contrast polarity. And the effect of color was also tested via changes of colors in the middle segments. In Experiment 2, the impact of contrast ratio between background and inner/outer segments and color of middle segments were tested. The results showed that the higher the contrast ratio, the clearer the NCS was. This is consistent with previous studies. In addition, the NCS was stronger when the background color was white and the inner/outer segments were black than in the opposite case. The effect of color was strongest when the middle segments were blue. The only exception was green segments with black background. These results suggest that the occurrence of NCS could be involved in the early visual information process.

◆ **Selectivity of local field potentials to natural images in primate V4 and prefrontal cortex**

S Liebe, N K Logothetis, G Rainer (Physiology of Cognitive Processes, Max Planck Institute for Biological Cybernetics, Tübingen, Germany; e-mail: sliebe@tuebingen.mpg.de)

Both the extrastriate area V4 and the prefrontal cortex (PF) play an important role in the processing of visual information. Their role can be understood by examining single unit activity as well as local field potential responses that are indicators of dendro-somatic events. Here we studied the interaction between luminance- and colour-based structural information in natural images on the tuning properties of local field potential responses in both cortical areas while monkeys were performing a visual recognition task. Our analyses focused on the stimulus-locked LFP waveforms (or visually evoked potential, VEP). In both areas, a majority of sites showed significant VEPs to natural images. In addition, our analysis revealed that VEP amplitudes in V4 were strongly modulated by colour, but not by structural content of the image. In contrast, amplitudes in prefrontal cortex were strongly modulated by image structure, irrespective of colour. These results suggest, that V4 is a highly colour sensitive area as measured by the LFP, whereas the LFP in PF cortex reflects the informational content of natural images.

◆ **Multispectral analysis of the colour deficiency tests and modelling of cones influence on test perception**

M Ozolinsh, S Fomins (Department of Optometry and Vision Science, University of Latvia, Riga, Latvia; e-mail: sergejs.fomins@gmail.com)

Visual stimuli for colour deficiency tests are designed either for trichromatic computer-controlled CRT or LCD displays and projectors, or by means of print technologies. Nevertheless, the standard characteristics of these tests fail, thus preventing unambiguous diagnosis of the degree of different colour deficiency. We use multispectral colour analysis scanning the image by use of tuneable liquid crystal LC filters (Nuance II spectral imaging system) to obtain measurable quantities of different colour deficiency tests. Different Ishihara plates from Rabkin polychromatic colour

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deficiency test book (PSM) were analyzed. Spectral images were taken in the range of 420 to 720 nm with the 10 nm step under typical and widely available light sources. Subsequently cone colour space (LMS space) images were calculated based on the cone spectral sensitivity functions. The difference between the L and M cone signals is the basic perception source for the protan and deutan tests. Changes in the signals and spectral sensitivities of these cone types have the greatest impact on colour perception. The distribution of CIE (x,y) chromatic coordinates were analyzed.

◆ **The influence of color on visual performance**

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We measured the reaction time (RT) as a function of luminance contrast (C)—up to ± 40 —for a set of colors belonging to red–green or yellow–blue axes with different purity excitations (RMSi). A range of size (0.129 – 1.045°) and two values of luminance (5 cd m^{-2} and 40 cd m^{-2}) were considered. Results show that for low values of luminance contrast, the presence of color information in the stimulus improves visual performance. This effect is stronger for colors modulated on the red–green (RG) mechanism and weaker for colors on the yellow–blue (YB) mechanism. For higher contrasts, results from chromatic and achromatic stimulus become indistinguishable. We propose an empirical model based on a modification of Pieron's Law: $RT = RT_0 + \{k/[bC^n + (1-b)RMS_i^n]\}$. The parameter n is around 2 and is independent on stimulus' parameters, k represents a shared gain mechanism, and is higher for stimuli modulated on the RG than on the YB axes; it also reflects the effect of size and luminance on the RT. Interestingly, the parameter b only depends on color and results show two very well differentiated groups, corresponding to colors modulated on the RG and on the YB axes, which suggests that b would be measuring the relative weight of color and luminance in the RT. [Supported by ANPCyT PICT 2006, No.1920/CIUNT 26/E410.]

◆ **Spacing constraints in the watercolour effect**

F Devinck, L Spillmann¶ (Department of Psychology, University of Rennes, France; ¶Neurozentrum, University of Freiburg, Germany; e-mail: frederic.devinck@uhb.fr)

The watercolour effect (WCE) is a long-range colour assimilation phenomenon. When a dark chromatic contour surrounds a lighter chromatic contour, the lighter colour will assimilate into the entire enclosed area. We studied the effects of chromatic modulation of the WCE for different kinds of spacing between and within the inducing contours, using a hue cancellation method. The mean colour directions of the settings were always opposite to that of the inner contour consistent with assimilation. In the first experiment, four interspaces were inserted in between the two inducing contours (radial spacing). Results show that the hue shift required to null the induced coloration rapidly decreased with increasing spacing between the two contours. In the second experiment, the continuous contours were replaced by dotted contours (lateral spacing). One pattern was composed from paired dots ('in-phase' condition) and the other from unpaired dots ('out-of-phase' condition). Four different dot interspaces were used. The shift in chromaticity required for nulling quickly decreased with increasing distance between the dots. The decrease was approximately the same for paired and unpaired dots. Results demonstrate that the WCE is strongest when the two inducing contours are spatially contiguous and continuous.

◆ **Subtractive Land Effect**

K Brecher (Department of Astronomy and Physics, Boston University, USA; e-mail: brecher@bu.edu)

The Land Effect provides one of the most striking demonstrations in color vision. In the original presentation method, two black and white photographic transparencies of a full color scene are made: one through a long wavelength (red) filter, the other through a short wavelength (green filter). The long wavelength image is then projected onto a screen through a red filter, and the short wavelength image is projected either through a green filter or through a neutral density filter. The additively mixed image appears to include a surprising palette of colors from the original scene. In this presentation, we will show several ways to demonstrate the Land Effect subtractively. In one method (originally devised by Joe Huck of Austin, Texas, USA), the long wavelength image is printed in red on plain white paper and the short wavelength image is printed in black on a transparency. When overlaid and viewed in subdued low temperature incandescent light, most observers report seeing a wide range of colors—including reds, oranges, yellows, browns and greens, with some viewers even reporting the appearance of blue. Such subtractive techniques may prove useful in further investigations of the Land Effect, simultaneous color contrast and other color phenomena.

◆ **Colour discrimination in coral reef fish**

U E Siebeck, G Wallis¶, M Vorobyev§ (ARC Centre for Excellence in Vision Science and School of Biomedical Sciences [¶ Perception and Motor Systems Laboratory, School of Human Movement Studies], University of Queensland, Brisbane, Australia; §Department of Optometry and Vision Science, University of Auckland, New Zealand; e-mail: u.siebeck@uq.edu.au)

Many coral reef fish are brightly coloured and display complicated colour patterns. As many of these fish possess multiple photoreceptor types with different sensitivities, it seems likely that their colouration plays an important role in their lives. In fact, little is known about the pattern and colour discrimination ability of reef fish. We report studies of the damselfish, *Pomacentrus amboinensis*, aimed at uncovering these abilities. Sixteen freshly caught fish were trained to tap a colour stimulus before receiving a food reward, and then tested against a second stimulus using a two-alternative-choice paradigm. Three colours were used to create two sets of colour and two sets of pattern stimuli. Four fish were tested with each set of stimuli. Within four days all fish had learned the initial task. The fish trained on a colour (blue or green) and tested against another colour that differed in either chromaticity or brightness, reached a level of 80% correct choices. The fish trained on a pattern (blue–green or two greens) were able to distinguish stripes from chequers to a level of over 75% correct when the pattern provided brightness contrast, but not when it provided chromaticity contrast alone. Damselfish are able to learn and discriminate colours that differ in chromaticity or brightness, but it appears that brightness difference is required for pattern discrimination.

◆ **Colorimetry is coarse-grained spectroscopy**

J J Koenderink (EEMCS, Delft University of Technology, The Netherlands; e-mail: jan.koenderink@telfort.nl)

The object colours of Lambertian “Mondrian patches” (thus only the spectral reflectance factors matter) illuminated with natural daylight are contained in the corresponding Schrödinger colour solid. Split the spectral range into three parts, having the ‘primary’ colours L, M, S (say). Add the ‘secondary’ colours $P = L + M$, $Q = M + S$, and $R = S + L$, ‘white’ $W = L + M + S$, and ‘black’ (darkness). By construction these are the vertices of a parallelepiped inscribed inside the colour solid. Find the cut loci that maximize its volume, then the three bins are those of the optimum coarsegrained spectrum, Schopenhauer’s “Parts of Daylight”. With L, M, S as primaries and an obvious choice of metric one obtains the ‘RGB-cube’ as an optimum approximation of the colour solid. I explore the use of this construction as a particularly intuitive and convenient system of colorimetry. ‘Colorimetric coordinates’ double as ‘spectral samples’ (physical meaning) and as RGB colours (intuitive meaning, immediately useful in applications).

◆ **Shaping the universality hypothesis to the Italian language**

G Paggetti, G Bartoli¶, G Menegaz§ (Department of Computer Science, University of Verona, Italy; ¶ Department of Information Engineering, University of Siena, Italy; § Department of Computer Science, University of Verona, Italy; e-mail: giulia.paggetti@univr.it)

A monolexic colour naming experiment has been performed on a sample of 1014 colours obtained extending the OSA-UCS colour system (E-OSA). The 11 universal categories proposed by Berlin and Kay (1969) were considered. Colours were rendered on a Mitsubishi Diamond Pro 2070 monitor as patches subtending 10 degrees of visual angle in a completely dark room. Consensus and consistency colours were identified and the coordinates of centroids and focal colours were evaluated for each category. Out of the 1014 samples, 404 are among the 424 colour samples used by Boynton and Olson in 1987. Results show that despite the difference in the experimental conditions, a good overlap can be observed among the locations of the consensus colours in the Ljg colour model, as well as a close proximity among the centroids of homologue regions. However, the observed differences suggest the use of the colour space partitioning resulting from the proposed paradigm as a more suitable basis for the development of multimedia applications. Furthermore, a second experiment aiming at identifying focal colours was conducted. Results suggest that a basic colour category could be missing in the blue region for the Italian language.

◆ **Comparison of models for chromatic discrimination**

M Giesel, T Hansen, K R Gegenfurtner (Department of Experimental Psychology, Justus Liebig University, Giessen, Germany; e-mail: Martin.Giesel@psychol.uni-giessen.de)

Cardinal models of chromatic discrimination assume that chromatic discrimination is mediated by 4 mechanisms lying along the cone-opponent axes. They predict that discrimination ellipses measured at locations intermediate to the cardinal axes are either circular or elongated along

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one of the cardinal axes. Previously, we presented data showing discrimination ellipses that were elongated along non-cardinal directions. A model with 8 mechanisms provided a good fit to the data (Giesel et al, 2008 *Perception* Supplement, 106). Here we fitted various variants of a model with 4 and with 8 mechanisms to this data set. Each mechanism has a differently tuned half-wave-rectified cosine-shaped sensitivity profile. The excitation of the mechanisms is computed as the product of each pixel's chromatic amplitude and the sensitivity of the mechanisms to the chromatic direction of the pixel. The resulting excitation is then passed through a non-linear response function. A model with 4 mechanisms predicted discrimination ellipses elongated along intermediate directions if the mechanisms were more narrowly tuned than given by a linear combination of cone inputs. However, the 4-mechanisms model did not predict the different discrimination ellipses at locations intermediated to the cardinal axes for stimuli chromatically variegated along orthogonal directions.

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◆ **Decomposition of dimension-specific intertrial effects: separate weighting systems modulate visual selection and identification processes**

D Rangelov[¶], H J Müller[¶], M Zehetleitner[¶] (Graduate School of Systemic Neurosciences [¶] also General and Experimental Psychology), Ludwig Maximilian University, Munich, Germany; e-mail: rangelov@psy.lmu.de)

Singleton item selection is faster when its dimension of distinction repeats across consecutive trials relative to when dimension changes. The dimension weighting account (eg Müller and Krummenacher, 2006 *Visual Cognition* **14** 490–513) assumes that this dimension repetition benefit (DRB) originates from the modulation of feature contrast (FC) computation. However, Mortier et al [2005 *Journal of Experimental Psychology: Human Perception and Performance* **31**(3) 542–557] observed DRB in displays containing only one item, ie without feature contrast (FC absent). Here, we argue that the DRBs can rise from different sources, one involved with feature contrast computation, another related to the identification processes. Experiment 1 mixed singleton detection and localization tasks randomly within a block of trials (FC present in both tasks). Similarly, in Experiment 2 singleton detection (FC present) and stimulus identification (FC absent) tasks were used. Experiment 3 mixed stimulus identification and feature discrimination tasks (FC absent in both tasks). Significant DRBs were observed across consecutive trials of detection and localization tasks, and across identification and discrimination tasks. There was no significant DRB across trials of detection and identification tasks. Thus, significant DRBs between tasks that rely either on feature contrast computation or stimulus identification (Experiments 1 and 3), but not across tasks that rely on different processes (Experiment 2) argue in favor of our multiple weighting systems hypothesis.

◆ **Brave upside-down world: verbal judgments versus matching task in distance perception**

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Recently, using verbal judgments, Higashima showed that distances observed between the legs are perceived as shorter than distances viewed from upright position. However, using distance matching task, we showed that distances in a horizontal direction are being perceived as shorter than physically identical distances in a vertical direction. The aim of this research was to determine how would perceived distance change if we estimate distances by looking between the legs, and if we use distance matching task. The experiment was performed on a field in daylight, with twenty participants. The task was to equalize the distances of two stimuli, one of which was placed in front of the observer, and the other one behind, on three distances, 1 m, 3 m, and 5 m. Participants observed one of the stimuli by standing, and the other one by looking between the legs. Results showed significant effect of body position ($F_{1,19} = 6.88, p < 0.05$) and distance of the standard ($F_{2,38} = 864.71, p < 0.01$), and no significant interaction between the two. Distances viewed between the legs were perceived as larger than the distances viewed from upright position. Results might be opposite from those obtained by Higashima because the matching task leaves less possibility for higher cognitive processes to be involved.

◆ **Low-Level visual deficits in normal ageing dissociation of magnocellular and parvocellular visual pathways in a luminance forced choice pedestal discrimination**

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The study aimed at evaluating the psychophysical correlates of the magnocellular (MC) and parvocellular (PC) visual pathways and their evolution with normal ageing. Ten young (mean age

of 24.2) and 10 old (mean age of 71.4) participants were shown with a short version of the psychophysical paradigm proposed by Pokorný and Smith (1997 *Journal of the Optical Society of America*), to bias processing toward MC or PC. Observers had to discriminate the location of the higher luminance square within a four square stimulus array presented for 33 ms. In the steady pedestal condition (MC-bias), the array was preceded and followed by a four-identical-squares pedestal whereas, in the pulse pedestal condition (PC-bias), the array was presented alone. Two target luminance discrimination thresholds were collected for each experimental condition (3 pedestal-contrasts \times 2 conditions) using an adaptive staircase procedure. The results showed a higher increase of threshold with pedestal contrast in the pulse relative to the steady condition. Moreover, a double interaction between group, pedestal contrast, and condition was observed: the rise in discrimination threshold found for old relative to young participants was higher in the pulse than in the steady pedestal conditions, especially for high pedestal contrasts. These results replicate the dissociation between the two low-level visual systems and demonstrate both a slight MC and a large PC impairment with normal ageing.

◆ **The time course of similarity effects in visual search**

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It is well established that visual search becomes harder when the similarity between the target and distracting items is increased. However, in models of visual search similarity is typically treated as a static, time invariant property of the relation between objects. This contrasts with data from other perceptual tasks (eg perceptual categorisation) demonstrating that similarity is dynamic and changes over time as perceptual information is gradually accumulated (Lamberts, 1998 *Journal of Experimental Psychology: Learning, Memory, and Cognition* **24** 695–711). In this experiment we examine the time course of target-distractor similarity effects. Consistent with the notion that similarity is dynamic, target-distractor similarity effects increase as display duration is lengthened. A model incorporating the notion of dynamic similarity was developed to fit this time course data. The model provided a good account of the time course of similarity effects as well as accounting for display size effects. The implications for models of search will be discussed.

◆ **Visual search for targets on natural textured backgrounds**

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Little is known about visual search for targets on natural, textured backgrounds, or about the capacity of biological camouflage patterns to provide protection across a range of backgrounds. The experiments described address both these problems. Observers searched under diffuse daylight for a camouflaged target on a flat, natural surface, subtending approximately $35 \times 20^\circ$, while wearing a lightweight portable eye tracker. The targets were life-size images of four different moth species, varying in luminance contrast and size of pattern elements. They were printed on paper and cut out. Two backgrounds were approximately uniform in colour (paving slabs, stucco wall), while two consisted of distinct objects varying in colour (stone chips, dead leaves). The identity, position, and orientation of the target varied randomly between trials. The background had a significant effect on search time, which was longest for the stucco wall, and shortest for the paved surface. The rank ordering of difficulty of search on the four backgrounds could not be explained by differences in first-order properties (mean luminance, contrast) between their images and those of the moths, nor by the strength of luminance gradients at the outlines of the moths. The results suggest that search follows segregation of a scene into distinct solid elements.

◆ **Object segregation and local gist vision using low-level geometry**

J A Martins, J Rodrigues¶, H du Buf (FCT [¶ ISE], Institute for Systems and Robotics, Vision Laboratory, University of the Algarve, Portugal; e-mail: jamartins@ualg.pt)

Multi-scale representations of lines, edges and keypoints on the basis of simple, complex, and end-stopped cells can be used for object categorisation and recognition (Rodrigues and du Buf, 2009 *BioSystems* **95** 206–226). These representations are complemented by saliency maps of colour, texture, disparity and motion information, which also serve to model extremely fast gist vision in parallel with object segregation. We present a low-level geometry model based on a single type of self-adjusting grouping cell, with a circular array of dendrites connected to edge cells located at several angles. Different angles between active edge cells allow the grouping cell to detect geometric primitives like corners, bars and blobs. Such primitives forming different configurations can then be grouped to identify more complex geometry, like object shapes, without much additional effort. The speed of the model permits it to be used for fast gist vision, assuming that edge cells respond to transients in colour, texture, disparity and motion. The big

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advantage of combining this information at a low level is that local (object) gist can be extracted first, ie, which types of objects are about where in a scene, after which global (scene) gist can be processed at a semantic level.

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◆ **Top – down modulations of visually guided pointing movements**

M Hegenloh, M Zehetleitner, H J Müller (Department of General and Experimental Psychology, Ludwig Maximilian University, Munich, Germany; e-mail: michael.hegenloh@gmail.com)

In detection tasks, search performance is improved, if the target defining dimension either repeats or is semantically cued before the trial. According to the dimension weighting account (DWA) these effects are due to modulation of feature contrast signals by dimensional weights before they are integrated into a master saliency map. On that account, dimensions with higher weights have a greater impact on saliency map and subsequent selection processes are faster. However, alternative accounts argue that there are two different processing routes according to the task requirements (spatial vs nonspatial). These accounts attribute dimension weighting only to the nonspatial route of singleton detection, whereas the salience map is supposed to be processed in an unweighted fashion impenetrable by top–down control. In the current study, the observers' task was to point at a feature singleton, the dimension of which was semantically cued. We found faster reaction times for valid dimensional cues over neutral or invalid cues. A greater benefit of the cueing was observed in the lift-off time, while there was almost no benefit of cueing in the movement time. These results are in line with the dimension weighting account and contradict dual-route models which propose no top–down or weighting modulation of the salience map.

◆ **Contextual memory and association across successive contextual layouts**

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Contextual cueing refers to improved visual search performance as a result of the repetition of the same displays. Previous researches have usually employed 12 repeated displays in a single session of training. It has been reported that when a search display presented on one trial is predictive of the target's location on the next trial, reaction time (RT) for the next trial is improved. Here, we studied the effect of association across consecutive visual search trials on number of contexts which one can learn in a single session of training. We trained subjects to learn 12, 18, or 24 repeated displays in a single session, in which the spatial context on trial $N - 1$ was reliably followed by a specific target location on trial N . Results showed subjects' RT became significantly faster in all groups as the experiment. There was a significant difference between mean RTs of the experiments in which context $N - 1$ was predictive of target location on trial N and the control groups in which there was no association between trials, during training phase. We conclude that spatial contextual memory may benefit from the association across consecutive spatial contexts to improve context learning.

◆ **Two mechanisms for detecting spatial contours defined by motion**

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We measured the discriminability of the linear motion trajectory of a line embedded in a random-line kinematogram. The signal line orientation was either parallel (iso-) or orthogonal (ortho-) to its motion direction and it was identical in all respects to the noise (orientation, length, baseline step size, frame rate) except for motion direction, rendering the signal line indistinguishable from the noise lines on a frame-to-frame basis. Our results show better discrimination of ortho-trajectories in most conditions, which (i) improved with duration up to 150–450 ms, (ii) was relatively independent of the speed, and (iii) whether the trajectory was straight or jittered each frame. However, discrimination of ortho-trajectory dropped when step size was high and lines were longer than 30 min of arc. Discrimination of iso-trajectory improved with increasing signal line speed and length, but was not affected by duration and was severely impaired by jitter. These results strongly suggest that discrimination of the signal line's trajectory is modulated by its orientation, and that iso- and ortho-trajectory discrimination relies upon at least two distinct mechanisms: an orientation-selective static detector that responds to iso-trajectories and a network of primary motion units that integrate local motion signals orthogonal to line orientation.

◆ **Spiders capture attention especially when you are afraid of them**

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Recent studies suggested that fear-related stimuli (such as spiders or snakes) are prioritized during visual selection. However, it remains unclear whether such stimuli capture attention in a bottom-up fashion when they are irrelevant for the search task. To investigate this issue we used the additional singleton paradigm (Theeuwes, 1992 *Perception & Psychophysics* **51**(6) 599–606), in which participants had to search for a shape singleton (a circle among diamonds) while either a fear-related stimulus (a spider) or a fear-unrelated stimulus (a butterfly) was also present in the display. To determine whether the capture was modulated by the degree of actual fear evoked by the stimuli we compared performance of participants that scored high or low on the Fear of Spiders Questionnaire (Szymanski and O'Donohue, 1995 *Journal of Behavior Therapy and Experimental Psychiatry* **26** 31–34). Results indicate that both task-irrelevant spiders and butterflies capture attention. More importantly, however, for high-fear participants the interference caused by spiders was larger than that caused by butterflies, signifying the role of fear as a factor in the capture of attention by fear-related objects.

◆ **Task efficiency mediates the effects of movement in visual search**

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Intrigued by contradictory findings in the literature, we examined whether smooth motion of items in visual search displays influences search behaviour. Subjects searched for a target in two display types: static (stationary elements) or moving (elements smoothly translating in random directions at 10 deg s⁻¹). A target was always present, and on each trial subjects responded twice: firstly to indicate that they had found this target, at which point all elements were masked and the reaction time recorded; secondly to identify the target's location. Stimuli were varied across blocks to manipulate search efficiency, as reflected by the slope of the static search functions. For very efficient and very inefficient search, neither reaction times nor performance differed between the static and moving conditions. In the middle range of efficiency, however, motion increased reaction times and decreased performance. We suggest that a ceiling effect obtains for highly efficient search, and this accounts for the absence of any difference in performance and reaction times between the static and moving conditions. Why a difference between static and motion conditions is restricted to an intermediate range of search efficiency remains unclear, but a simple strategy change seems unlikely. These data challenge current models of visual search.

◆ **Suboptimal selection of initial saccade in a visual search task**

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How does the visuomotor system plan saccades in a visual search economic task? Subjects ($N = 8$) saw two visual tokens in the periphery and were instructed to make a saccade. During the saccade, one of the two tokens would change and the subjects then judged how the token had changed. Subjects received rewards for correct responses. Prior to the main experiment, we mapped subjects' visual sensitivity to token change at different eccentricities. We run two series of experiments in which either the spacing between the tokens or their sizes was varied. When the tokens were near to each other, or their size was large, subjects could reliably identify the token change from a fixation point midway between the tokens. If the tokens were far apart or small, then subjects would perform better by using a stochastic strategy consisting on saccading to one the tokens. We found that subjects were suboptimal in both experiments. Most subjects had a constant strategy and did not take into account the visibility of the tokens when planning their saccades. They earned, on average, half the maximum expected gain. To conclude, even in simple displays with only two tokens, and after training, subjects do not plan saccades that maximize expected gain.

◆ **Spot the ball: The extent of the functional visual field when searching natural scenes**

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In visual search with eye movements, the size of the functional visual field—within which a target may be detected—is smaller than when the eyes are stationary (Motter and Simoni, 2008 *Vision Research* **48** 2382–2393). How, if at all, does the extent of the functional visual field change in search over a variety of natural scenes? To address this question, observers' gaze was monitored with an infrared video eye tracker (250 Hz) while they searched natural images for a randomly

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located, neutral grey sphere (Munsell N7). Where a target was correctly detected, observers' fixation fell within approximately 3° of the target, when averaged over scenes, giving a lower limit on the extent of the functional visual field. Despite the agreement between observers in this lower limit, there were notable differences between their detection abilities, as measured by d' from signal-detection theory. Idiosyncratic fixation patterns across observers suggested that these differences may be due to variation in individual search strategies. For all observers, the size of the functional visual field altered with the scene. This may be a consequence of natural structures in the scenes acting as potential distractors, analogous to crowding effects in target-distractor search tasks.

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◆ **Compensatory saccadic training selectively improves natural exploratory activities in hemianopia**

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Suprachiasmatic lesions of the visual pathways can cause homonymous hemianopia with common visual spatial disorders. Patients complain of declined daily exploratory activities, mobility and visual search, missing input on the blind side. Using random patient assignment and a control group, we asked if exploratory saccadic training (EST) would selectively improve patients' eye-movement behaviour on the blind side and performance on natural exploratory tasks. Two groups of fifteen hemianopic patients accomplished for six weeks either EST (a visual search task) or a control training task not requiring eye movements, but stimulating visual fields by flicker. Response times (RT) during natural search, fixations while scanning natural scenes, fixation stability, visual fields, and quality-of-life scores were collected before, after, and six weeks post-training. Unlike in the control group, EST improved natural-search RT on the blind side. While scanning natural scenes, solely with EST, more fixations occurred toward the blind side. EST reduced fixation stability, increasing fixation asymmetry toward the blind side. Visual fields remained unchanged in both groups. EST patients reported improvements in the social domain. In patients with hemianopic orientation disorder, compensatory saccadic training selectively improves exploratory eye movements, natural search, and scanning on the blind side, and thus subjectively facilitating activities of daily life.

◆ **Assessing the interaction of bottom – up and top – down factors on the eye-movements in visual search for a human target**

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In most visual search experiments, only abstract shapes are displayed and top–down processing is engaged solely by specifying target features. Here, we present a search experiment in which participants were faced with an actual, more realistic task: finding an enemy soldier displayed together with a visually salient distractor and a second distractor (a possible hiding location) with semantic relevance for the search task. During the experiment the salience and eccentricity of the target and the visual distractor were varied. Eye-movements were recorded and used to evaluate the effects of salience and eccentricity of target and distractors on search performance. The results of the experiment show that the distractor can indeed distract from the search task, but does not completely override the task demands. Furthermore, the distracting effect depends on the distractor saliency with the highest saliency surprisingly not yielding the most distraction. The semantically relevant distractor also reduces search performance, but its effect is different in nature, indicating a difference in the perception and processing of this object. Another important finding is that semantically relevant objects are used to guide the eyes in order to improve search performance.

◆ **Are there differences in search strategies and eye movement behaviour in 2-D vs 3-D environments?**

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Comparing traditional 2-D with emerging 3-D visualizations often yielded inconsistent performance results caused by confounding factors such as task demands and details of interface design (Smallman et al 2001). We suggest that the application of eye tracking as a psychophysiological measurement can help to clarify the ambiguity of pure performance data. In our study, we analyzed performance and eye movement characteristics during visual search in a 2-D and 3-D

presentation of a car engine component (engineering drawing vs CAD model). We found only marginal differences between both types of presentation in performance but fixation durations and saccade amplitudes differed significantly. A closer inspection of fixations in the 3-D condition revealed a stronger increase of task-relevant fixations (ie fixations in the target region) over time. Moreover, in the 3-D condition, we made a distinction between fixations with or without object manipulation. Performance values differed accordingly, with better results if manipulation was applied. Our results demonstrate advantages of 3-D visualization, but only if the design allows an optimal and flexible amount of interaction. Based on our results, we conclude that eye tracking can provide the required data to further improve the presentation of 3-D information.

◆ **The effect of different artificial central scotomata on eye-movement patterns**

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Central loss of vision, as found in age-related macular degeneration (AMD), is one of the leading causes of blindness. To experimentally study visual capabilities and eye-movement patterns in relation to particular properties of the defect is often difficult or impossible in the patient population. We have therefore used healthy observers with simulated defects (central scotomata), which allows for a better control of the underlying variables. Here we introduced four types of artificial gaze-contingent scotomata (relative, absolute, distorted with a static distortion, and warped with dynamic visual inputs), resembling particular forms of AMD. We compared behavioral and eye-movement measures for different types and sizes (0, 2, 4, 8 deg) of artificial scotomata for a 3-D shape-from-texture identification task. As expected, the number of fixations, dwell time, response time, and identification errors increased as a function of scotoma size for absolute, distorted, and warped scotomata. The distorted and warped scotomata were more disruptive than the other types (relative and absolute), as shown by larger changes of fixation positions. Observers developed a fixation strategy for large scotomata that allowed them to examine the stimulus features from a more central position along the X-axis.

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◆ **Attention operates on non-retinotopic feature maps in visual search**

M H Herzog, M Boi, H Ogmen¶, J Krummenacher§ (Laboratory of Psychophysics—Brain and Mind Institute, Ecole Polytechnique Fédérale de Lausanne, Switzerland; ¶ Center for Neuro-Engineering and Cognitive Science, University of Houston, USA; § Department of Psychology, University of Fribourg, Switzerland; e-mail: michael.herzog@epfl.ch)

At the heart of feature integration theory is a master map which operates on dimension-based feature maps. It is assumed that these feature maps are organized retinotopically. If in conjunction search, for example, a horizontal green line has to be searched for, the master map ‘looks’ at the retinotopic position (x,y) in both the color and the orientation maps whether they contain a ‘green’ and a ‘horizontal’ entry, respectively. Here, we show evidence that attention operates on non-retinotopically organized feature maps. We presented a Ternus–Pikler display where three squares shifted horizontally back and forth by one inter-square distance. This created a periodic motion where two squares always overlapped in successive frames. Each square contained a different conjunction search display and the observers were asked to identify a conjunction target in the central square. Theories assuming retinotopically organized feature maps predict poor performance because of the spatial overlap of the different search displays in successive frames. However, we found a remarkably good performance. Moreover, observers clearly perceived the search display in the central square because, as we argue, perception and attention are based on non-retinotopic feature maps—contrary to most theories of visual search.

COMPUTER, MACHINE, AND ROBOTIC VISION

◆ **Eye movements on blended natural videos**

L Pomarjanschki ¶, M Dorr¶, E Vig¶, E Barth¶ (Graduate School for Computing in Medicine and Life Sciences [¶] Institute for Neuro- and Bioinformatics), University of Lübeck, Germany; e-mail: laura@inb.uni-luebeck.de)

Our work explores the impact that superposition of multiple videos has on eye movements. Thirty-eight videos were created by blending either two or three natural movies, randomly picked from a set of fourteen natural movies (HDTV resolution, 20 s duration). The blending was performed on an anisotropic spatiotemporal Laplacian pyramid with 5 spatial and 5 temporal levels in order to equalize the contribution of each movie to each frequency band. Eye movement data was recorded from ten subjects free-viewing these movies. Using this data set, we predicted eye movements based on the geometrical invariants H, S, and K, which denote the number of locally used degrees of freedom in a movie; this method has been used successfully on single movies.

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We compared the prediction performance of (i) the invariants computed on the blended movies, and (ii) the average of invariants of the individual movies. For invariants computed on the blended movies, we achieved ROCs from 0.71 (H) to 0.75 (K), which are significantly better than the ROCs of 0.66 to 0.70 based on the average of the individual videos' invariants. This indicates that low-level structure introduced by the blending plays an important role in gaze guidance on blended movies.

◆ **A gaze-contingent display for gaze guidance**

M Dorr, E Barth (Institute for Neuro- and Bioinformatics, University of Lübeck, Germany; e-mail: dorr@inb.uni-luebeck.de)

We present a gaze-contingent display that spatio-temporally filters a movie in real time. For each pixel, filter parameters can be specified in retinal coordinates. The display is based on an anisotropic spatio-temporal Laplacian pyramid that decomposes the video in its spatio-temporal frequency bands; these frequency bands can then be weighted locally in the pyramid synthesis step. Because of the high computational cost of the required upsampling of all pyramid levels to full spatio-temporal resolution in each frame, we implemented our algorithm on graphics hardware using the Cg language. We achieve real-time performance (> 30 frames s^{-1}) on HDTV videos (1280×720 pixels). Since most operations need to be performed at the video frame rate only and the latency-critical synthesis takes only 2 ms for a pyramid with 5 spatial and 5 temporal levels, our system is suitable for saccade-contingent experiments. We use our gaze-contingent display to selectively suppress and enhance spatio-temporal content as a function of current gaze and thereby change the saliency distribution of a movie in real time (see <http://www.gazecom.eu>).

◆ **A machine learning framework for gaze guidance**

E Vig, M Dorr, K R Gegenfurtner¶, E Barth (Institute for Neuro- and Bioinformatics, University of Lübeck, Germany; ¶ Abteilung für Allgemeine Psychologie, Justus-Liebig-Universität Giessen, Germany; e-mail: vig@inb.uni-luebeck.de)

What constitutes the difference between fixated and non-fixated movie patches? How can we change a patch to make it more or less salient? Here, we present a novel computational model of low-level saliency with dual emphasis: the same machine learning framework is used (i) for predicting saccade targets in natural dynamic scenes, and (ii) for learning how to alter the saliency level of these targets. We use a large data set of eye movements on high-resolution videos of natural scenes. The 40000 detected saccades are used to label movie patches as attended and non-attended. The proposed saliency measure, spectral energy, is computed in the neighborhood of each location on each scale of an anisotropic spatiotemporal Laplacian pyramid. On this simple low-dimensional representation of a patch (only one value, the spectral energy, per scale) we train a support vector machine, which outperforms state-of-the-art saliency predictors, reaching an ROC score of 0.8. Furthermore, we use this classifier to derive transformations in the energy profiles that alter the saliency distribution of the scene.

◆ **A computational model of visual search saliency for road signs diagnostic**

L Simon, J-P Tarel, R Brémond, H Panjo (LEPSIS, Université Paris Est, LEPSIS, INRETS-LCPC, France; e-mail: ludovic.simon@lcpc.fr)

Driving involves visual exploration of the road environment and one important driving subtask is to look for road signs. We propose a new computational model of visual search saliency in natural scenes, as current ones are limited to laboratory situations. Relying on statistical learning algorithms, our algorithm captures the priors a driver learns on road signs appearance. It can also be applied to other kind of objects. The proposed algorithm is designed to develop a diagnostic system for the road signs saliency allowing to decide if drivers notice them well enough. We performed a psycho-visual experiment to assess our model, in a context close to driving, with a remote eye tracker. Subjects were asked to pretend they were drivers of the car from which the images were taken. In the first phase of the experiment, the subjects were asked to count for the 'no entry' signs. In the second phase, they had to rate the saliency of each 'no entry' sign. The statistical analysis showed that the proposed model is correlated to human behaviour using objective (detection rates and fixation's durations) and subjective (scoring) indicators of the visual saliency of road signs.

◆ **Drosophila melanogaster exhibit perceptual generalization for the shapes of a circle and a cross**

J-C Chen, S H-L Chien, W-Y Lin¶ (Graduate Institute of Neural & Cognitive Sciences [¶ Graduate Institute of Integrated Medicine], China Medical University, Taichung, Taiwan; e-mail: sarinachien@mail.cmu.edu.tw)

Chien et al (*ACPV 2008*) reported that fruit flies could learn to discriminate between a circle and a cross. Here we further explored whether flies exhibit a form of perceptual generalization [Hebb, 1949 *The Organization of Behavior* (New York: Wiley)]. The stimuli were $2 \text{ cm} \times 2 \text{ cm}$ printed paper and were back illuminated by LED flashlights. Using a T-maze like apparatus

(Tully and Quinn, 1985 *Journal of Comparative Physiology A* **157** 263–277), we first trained flies to discriminate between a circle and a cross sequentially with one being associated with heat (aversive conditioning). In the test phase, flies were presented with the two stimuli located on the opposite arms. The rationale was that if the flies did learn which stimulus was unsafe (ie the heated one), we expected to see significantly fewer flies would stay in the unsafe arm than in the safe arm. Our results (>1500) revealed that, when trained with a cross and a circle made of solid lines, flies showed statistically significant learning behavior for the same pair of shapes made of dots (and vice versa). This finding supports the notion that flies can learn to generalize simple shapes. Additional control experiments also revealed that this is not due to a lack of discriminability or unequal spontaneous preference between the shapes.

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- ◆ **Attention and action selection in a robot controlled by principles of vertebrate neuromodulation**
J L Krichmar (Cognitive Sciences, University of California, Irvine, USA;
e-mail: jkrichma@uci.edu)

Neuromodulatory systems alter neuronal responses such that an organism can respond quickly and accurately to environmental changes. We present a detailed neural model of the dopaminergic and serotonergic neuromodulatory systems to test the hypothesis that phasic neuromodulation can drive attention and select actions (Krichmar, 2008 *Adaptive Behavior* **16** 388–399). The neural simulation, which controls a robot's behavior, consisted of a visuomotor area with neurons that responded preferentially to different colors and drove action areas, a dopaminergic neural area (VTA), a serotonergic neural area (Raphe), and behavior areas. Based on empirical and theoretical findings, neuromodulation amplified sensory synaptic projections relative to recurrent or associational projections in postsynaptic neurons in the simulated network. The robot, which had active vision and collision sensing, explored a room that had an interactive floor. Panels on the floor displayed different colors and could communicate the 'value' of a panel to the robot. Green panels had an arbitrary value of good, red panels had a value of bad, and all other colors (six in all) were neutral. The robot learned to associate green with orienting behavior, and red with avoidance behavior. Green stimuli caused a phasic response in the VTA neurons resulting in an amplification of the green visuomotor area, a dampening of distracter colors, and a strong increase in orienting activity. Red stimuli caused a phasic response in the Raphe neurons that amplified red visuomotor and avoidance behavior, while suppressing neural activity in other visuomotor, neuromodulatory, and behavior areas. An intact neuromodulatory system was necessary for correct behavioral responses and lesions of neuromodulatory responses significantly lowered the signal to noise ratio in the visuomotor area during behavioral responses. These experiments suggest a physiological mechanism of how neuromodulatory systems influence attention and decision-making.

- ◆ **Measurement of facial scarring in children with cleft lip/cleft lip and palate: a preliminary study**
D R Simmons, A Bell¶, A Bowman§, D Brown\$, R Lo#, K Millar‡, J-P Siebert#, M Xiao##, A Ayoub¶ (Department of Psychology [¶ Glasgow Dental School; § Department of Statistics; # Department of Computing Science; ‡ Section of Psychological Medicine], University of Glasgow, UK; e-mail: david@psy.gla.ac.uk)

Cleft lip with or without cleft palate (CLP/CL) affects about 1/650 live births in the UK. Surgical correction in infancy usually leaves a distinctive scar on the upper lip. We have attempted to measure this scarring in 10-year-old children, and compare it with other clinical measures. Digital images of the faces of 51 CLP and 44 CL children were calibrated using standard techniques of digital colorimetry and transformed into CIELAB space. Scar regions on the upper lip were located by searching for regions of high entropy in the (red–green) sub-image. This method was successful in locating a scar in about 80% of cases. The scar region was then characterized in terms of its entropy difference, colour difference and size with respect to surrounding regions of the upper lip. Preliminary analysis indicates that expert clinicians' ratings of scar severity were related to their redness. There was also a small but significant correlation between parents' assessments of their child's 'total difficulties' and the scar luminance contrast. These results and other observations suggest that the severity of facial scarring is not a straightforward correlate of colour but depends heavily on the context in which the judgments are made.

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- ◆ **Attentive mobile robot visual maps via bubble memory**
S Cayci, O Er Kent, H I Bozma (Bogazici University Electrical and Electronics Engineering, Intelligent Systems Laboratory, Turkey; e-mail: semih.cayci@boun.edu.tr)
- Perceiving robots can perform efficiently by allocating limited resources to interesting parts of a scene. Fixating on interesting points is achieved by controlling the saccadic camera movements.

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Attentional sequence is a sequence of features extracted from fixated regions during attentive processing. A model—bubble memory—was previously proposed for encoding this spatiotemporal data based on deformation of a spherical three-dimensional surface (Soyer et al, 2006 *Autonomous Robots* **20** 61–80). Bubble surface can be deformed according to the feature values observed at the fixation points. This paper develops bubble-based visual map building for an attentive mobile robot as it is navigating. At each viewpoint, the robot saccades around the scene and deforms a set of bubbles based on its response to a variety of edge, colour and corner filters. The bubbles altogether constitute the visual spatiotemporal map as seen from that viewpoint. As the robot navigates to another viewpoint, the bubble set is deformed according to the new sequence formed there. It does not need to store the newly formed bubble set or search in its memory unless major scene changes have occurred. Experiments reveal that viewpoints having similar visual scenes have bubble sets which are also similar.

COMPUTATIONAL MODELLING

◆ Analysis of optical flow at object occlusions

S Ringbauer, F Raudies, H Neumann (Institute of Neural Information Processing, University of Ulm, Germany; e-mail: stefan.ringbauer@uni-ulm.de)

In navigation tasks discrimination of static from moving obstacles is critical for collision avoidance. At obstacle boundaries which attract attention (Rothkopf and Ballard, 2009 *Visual Neuroscience* **26**) observer and obstacle movements produce salient flow changes. It remains to be seen whether independent object motions can be distinguished. A computational model with stages of cortical motion processing is proposed. Changes in optical flow are measured in terms of speed and direction differences over space along the local flow direction, leading to representations of accelerations/decelerations and rotations in a local gauge coordinate system. Such oriented gradient patterns (Tsotsos et al, 2005 *Computer Vision and Image Understanding* **100**) are registered by mechanisms similar to area MSTd pattern cells. Translational observer movement in a scene with stationary objects leads to radial motion with depth dependent speeds. At depth discontinuities of occluding objects only local accelerations/decelerations occur. If an independently moving object (IMO) is present flow is superimposed upon the observer induced flow. With very few exceptions this causes rotational flow components at the IMOs boundaries which is detected in the gradient pattern. Consequently, local direction changes in optical flow induced by translatory observer movement indicate the presence of IMOs and their boundaries, respectively.

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◆ A hierarchical computational model of statistical learning of two-dimensional visual shapes

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Understanding how the primate brain recognizes a large number of object classes entails a deeper understanding of the functioning and the selectivity properties of different visual areas in the ventral pathway. Here we focus on the underlying computational principle of cortical shape selectivity. We propose a computational approach where selectivity of the units to two-dimensional visual shapes emerges as a result of statistical learning at multiple hierarchical stages. Unlike the neural network approaches, the connections between units from consecutive levels are highly sparse and specifically designed to code the spatial relations among the constituent shape parts. Applied to a large collection of natural images, the units in the model become selective to contour fragments at multiple levels of specificity and complexity. The learned tuning properties of units in the first four layers closely resemble the ones in the cortical areas V1–V4 (Pasupathy and Connor, 2002 *Nature Neuroscience*; Anzai et al, 2007 *Nature Neuroscience*), whereas the units in the higher layers are selective to increasingly more complex and class specific contours. This could help to better understand and predict the complex tunings of IT neurons.

◆ An accommodation-dependent human eye model with the constant volume and refractive index

E K Kang, C K Hwangbo, S C Park¶ (Department of Physics, Inha University, South Korea; §Department of Physics, Dankook University, South Korea; e-mail: mogoai@daum.net)

In this study, we propose a human eye model using an approximation of the constant volume and refractive index in the crystalline lens during accommodation. The human eye model based on the previous models of relaxed emmetropia (Gullstrand, 1909; Navarro et al, 1985) consists of four centered surfaces and the crystalline lens shape at a different accommodation level is assumed to be a simple conic function. The human lens parameters, such as curvatures and thickness, are calculated during accommodation and the variation of asphericity is adjusted to the constant volume of relaxed human lens. The result shows that the anterior and posterior radii of curvature as well as the equatorial diameter decrease during accommodation while the lens thickness

increases, which is in agreement with the Helmholtz accommodation theory and the experimental data published in the literature. It suggests that the proposed human eye model with a simple approximation can be used for description of the changing geometry during accommodation.

◆ **Principal component analysis of fourier transforms discriminates visual art from other image categories**

M Koch, J Denzler, C Redies[¶] (Department of Computer Science, Friedrich Schiller University of Jena, Germany; [¶]Institute of Anatomy, University of Jena School of Medicine, Germany; e-mail: redies@mti.uni-jena.de)

On average, natural scenes show a unique property in the Fourier domain—a roughly $1/f^2$ power spectrum, to which processing in the human visual system is optimally adapted. Recent studies reported similar properties in visual art of different styles and epochs. Here, we compared various datasets of photographs (natural scenes, objects, faces) and man-made images (art, cartoons, comics, scientific illustrations). Each dataset contained at least 150 images (1800 images in total). Results showed that, like art and natural scenes, cartoons and comics possess roughly $1/f^2$ power spectra. Principal component analysis of the 2-D power spectra revealed statistical differences between the image categories that were verified pairwise by significance testing. The resulting frequency-domain eigenspace achieved a good separation of the diverse categories. Principal component analysis carried out separately for each category showed that the first components of the art categories (graphic art, portraits and paintings) were similar, despite large differences in subject matters and artistic techniques. The power spectra of art images can be fitted well to a model that assumes $1/f^2$ characteristics and isotropy. In conclusion, art images display properties in the Fourier domain that allow to distinguish them from other image categories.

◆ **Do dynamic models of accommodation/vergence relationship apply for hyperstereoscopic stimuli?**

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Dynamic models have been suggested to describe the interactive coupling of vergence and accommodation responses (Hung, 1992 *Ophthalmology and Physiological Optics* **12** 319–326; Schor, 1992 *Optometry and Vision Science* **69** 258–269; 1999 *Ophthalmic and Physiological Optics* **19** 134–150). Hyperstereopsis refers to viewing conditions based on an artificially increased inter-pupillary distance. This optical configuration results in increasing the binocular disparities and altering the accommodation/vergence relationship. An experiment was conducted to test whether those models would apply for oculomotor adaptation induced by such optical conditions. A Helmholtz telestereoscope was used to generate such binocular stimuli. Horizontal disparities were 3 times higher than in natural viewing conditions when alternatively reading a text at 0.4 and 4.5 m for 10 minutes. Horizontal phoria and AC/A ratio were both increased after exposure. The trend of the oculomotor alterations was in agreement with the models which predict the bilateral impact of blur and disparity processing in natural conditions. Those dynamic models will be further questioned to determine how far each of their components can quantitatively account for adaptation when facing changes in stereoscopic conditions.

◆ **Central performance drop in saccadic latencies**

M Wischniewski, H Koesling[¶], L Kehrer, H Ritter[¶] (Neuro-Cognitive Psychology, Faculty of Psychology and Sports Science [[¶]Neuroinformatics Group, Faculty of Technology], Bielefeld University, Germany; e-mail: marco.wischniewski@cit-ec.uni-bielefeld.de)

Processing fine visual detail normally works best in the human fovea. Kehrer (1989 *Spatial Vision* **4** 45–62) and others, however, demonstrated that specific contrast discrimination tasks are more accurately performed peripherally than foveally. This effect, referred to as central performance drop (CPD), was found in a detection task. If the CPD is also present in an eye-movement task, latencies of saccades towards peripheral contrasts should be shorter than for saccades towards near-foveal contrasts. We measured saccadic latencies in an orientation discrimination task where subjects had to detect spatially confined orientation contrasts in otherwise uniformly oriented line-segment patterns. In addition to contrast eccentricities we also varied the spatial frequency of the line segments. Saccadic latencies show a significant CPD and, furthermore, the shape of the CPD is modulated by the stimulus' spatial frequency. Eye movements towards orientation contrasts are thus significantly faster for peripheral rather than for near-foveal targets. Using a genetic algorithm for parameter optimisation, a two-stage inhomogeneous retinal filter model (Gabor orientation detection plus Difference-of-Gaussians contrast amplification) successfully reproduced the CPD effects. Findings demonstrate that visual saliency affects detection as well as eye-movement performance and underline the need to take into account low-level image features in saccade modelling.

Tuesday

◆ **Modeling neurophysiological and psychophysical effects of attention via dynamic modulation of receptive fields**

O Baruch, Y Yeshurun (Department of Psychology, University of Haifa, Israel; e-mail: oritb@research.haifa.ac.il)

The goal of this study is to develop and test a computational model of spatial attention. The model is based on neurophysiological studies demonstrating attentional modulation of neuronal response in the visual cortex. Some of these studies suggested that attention shifts the centers of neighboring receptive fields towards the attended location. Others have found a contraction of the receptive fields' spatial extent. We implement both phenomena and test their separate and combined ability to predict various attentional effects found by both neurophysiological and psychophysical studies. The model includes two hierarchical neuronal layers and it presents attentional influences at the single cell as well as at the population level. In particular, the model successfully simulates attentional influences on gain modulation; modulation of neuronal responses to multiple stimuli within the receptive field, enhancement of contrast sensitivity; effects on spatial and temporal resolution; prolongation of temporal integration; prior onset; and the spatial suppression surrounding the focus of attention. This model of attentional effects is the first to link physiological measurements at the unit level with such a diverse range of psychophysical findings, specifically with findings related to both the spatial and temporal domains of perception.

◆ **How do object reference frames and motion vector decompositions emerge from multiple moving targets?**

J Leveille, S Grossberg, M Versace (Cognitive and Neural Systems, Center for Adaptive Systems, and Center of Excellence for Learning in Education, Science, and Technology, Boston University, USA; e-mail: jasminl@cns.bu.edu)

Various motion percepts have been shown to obey a rule of vector decomposition, where global motion appears to be subtracted from the true motion path of localized stimulus components (Johansson, 1950 *Configurations in Event Perceptions: An Experimental Study* (Uppsala: Almqvist and Wiksells). This results in striking percepts wherein objects and their parts are seen as moving relative to a common reference frame. While vector decomposition has been amply confirmed in a variety of experiments, no model to date explains how it may occur in neural circuits. The current model shows how vector decomposition results from V1/V2/MT interactions postulated in the motion stream of the 3-D Formotion model (Grossberg, 1991 *Perception & Psychophysics* **49** 117–141; Francis and Grossberg, 1996 *Perception* **25** 543–567; Baloch and Grossberg, 1997, *Vision Research* **37** 3037–3059; Grossberg et al, 2001 *Vision Research* **41** 2521–2553; Berzhanskaya et al, 2004 *Journal of Vision* **4**(8):573, 573a). In order to assign ambiguous motions to their correct depths, the model predicts how motion signals at a nearer depth may be subtracted from corresponding signals at a farther depth. In response to displays wherein vector decomposition is possible, this results in a shift in motion direction. This mechanism has enabled us to simulate classical Duncker (1929 *Psychologische Forschung* **12** 180–259) and Johansson (1950) percepts. These simulations clarify the interplay of mechanisms of depth and motion perception in the formation of a frame of reference.

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◆ **Physiologically plausible model of a novelty filter that simulates orientation-contingent colour aftereffects**

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While the proposed earlier (Maximov and Maximov, 1997 *Perception* **26** Supplement, 19) linear computational model of a novelty filter demonstrated fundamental possibility of the McCollough-effect in the network with modifiable synapses, it was physiologically implausible. Unlike the Hebbian synapses whose plasticity was controlled by membrane potentials of two neurons immediately forming a synaptic contact, there was a third neuron in that model, involved in the control of modification of the synaptic weight. Here we suggest a new neural model of the novelty filter that consists of three isomorphic neural layers of analog neurons. Input neurons act as temporal differentiators to eliminate constant component of the signal. Each neuron of the associative layer is synaptically connected to a restricted set of nearby neurons of the input layer. The synaptic weights are changed according to the Hebbian learning rule. Each of the output neurons calculates the difference between excitation levels of input cell and corresponding associative neuron. The output cell is in turn connected with the latter by means of additional feedback synapse permitting control signal to propagate to modifiable synapses. The results of simulation show that this scheme of novelty filter presents the same phenomena as our initial novelty filter does.

- ◆ **Invariant recognition of goal-directed hand actions: a physiologically plausible neural model**
F Fleischer, A Casile, M A Giese (Department for Cognitive Neurology, Hertie Institute for Clinical Brain Research and Center for Integrative Neuroscience, Tübingen, Germany; e-mail: falk.fleischer@medizin.uni-tuebingen.de)

The recognition of transitive, goal-directed actions requires highly selective processing of shape details of effector and goal object, and high robustness with respect to image transformations at the same time. The neural mechanisms required for solving this challenging recognition task remain largely unknown. We propose a neurophysiologically-inspired model for the recognition of transitive grasping actions, which combines high selectivity for different grips with strong position invariance. The model is based on well-established physiologically plausible simple neural mechanisms. Invariance is accomplished by combining nonlinear pooling (by maximum operations) and a specific neural representation of the relative position of object and effector based on a gain-field like mechanism. The proposed architecture accomplishes accurate recognition of different grip types on real video data and reproduces correctly several properties of action-selective neurons in occipital, parietal and premotor areas. In addition, the model shows that the accurate recognition of goal-directed actions can be accomplished without an explicit reconstruction of the 3-D structure of effectors and objects, as assumed in many technical systems for the recognitions of hand actions. [Supported by DFG (SFB 550), EC (FP6 project COBOL), and the Hermann und Lilly Schilling Foundation.]

- ◆ **White effect without physical edges**
M Hudák, J Geier (Stereo Vision Ltd, Budapest, Hungary; e-mail: hudakmariann@gmail.com)

We show a new variant of White's illusion: the pattern comprises small randomly organised black dots replacing black stripes, on a grey background, and small randomly organised white dots replacing white stripes. The area of the grey targets in the original White's illusion are left empty, so that it has the same luminance as the grey background of the whole pattern. Physically, the whole pattern is a homogenous grey except for the dots. White's effect, however, is still visible in this case: those gaps surrounded by white dots seem lighter than those surrounded by black dots. Nonetheless, the figure contains no junctions and no physical edges. This phenomenon is in contrast with theories based on junctions. It also challenges the scission theory of White's effect, since no transparent surfaces are perceived. It is also difficult to explain the illusion in terms of grouping principles in the absence of physical edges and stripes. Bull's eye illusion and circular White effect also work when composed of dots. Geier's diffusion-based computer simulation can reproduce this new (and all other known variants of White's) effect in accordance with human perception, without including any secondary illusory effect, grouping, or segmentation.

- ◆ **Learning of motion and form patterns from head and body movements for the analysis of human visual communication**
U Weidenbacher, H Neumann (Neural Information Processing, University of Ulm, Germany; e-mail: ulrich.weidenbacher@uni-ulm.de)

Humans are capable of judging the voluntary movements of others on initiating communication. Such movements are characterized by head or body turning towards the target of initial contact. Evidence suggests that neurons in superior temporal sulcus (STS) seem to process such information (Perrett et al, 1985 *Behavioural Brain Research* **16**). How information from different processing pathways contributes to such STS responses is still open to debate. We used a biologically inspired model proposed by Giese and Poggio (2003 *Nature Reviews Neuroscience* **4**) that simulates both form and motion pathways. In the model central ventral pathway prototypical views of head and body posture (snapshots) as well as their temporal appearances were learned unsupervised in a two-layer network. In the model dorsal pathway prototypical velocity patterns are generated by local motion detectors. These learned patterns are combined into typical motion patterns appearing from head and body movements on establishing visual contact. Finally, the activity from both pathways was integrated to extract a combined signal from motion and form features. We demonstrate a Hebbian learning scheme capable of learning form and motion features used in the detection of specific behaviourally-relevant motion patterns. We show that information from both pathways is important for the extraction of signals that encode head or body movements.

[Supported by DFG Collaborative Research Centre SFB/TRR 62.]

Tuesday

DECISION-MAKING AND REWARD◆ **Probabilistic extrapolation of complex curves**

T G Tanner (Department Human Perception, Cognition and Action, Max Planck Institute for Biological Cybernetics, Tübingen, Germany; e-mail: tanner@tuebingen.mpg.de)

I investigate how humans solve the underconstrained problem of spatial extrapolation of complex 2-D curves. Contour continuation is typically modeled using local variational principles such as minimizing total curvature or variation of curvature and have only been applied to a very limited set of curves classes. Singh and Fulvio (2006) showed that only a probabilistic model of these constraints can explain the continuation of arcs of Euler spirals. I investigate whether this model generalizes to more complex curves such as polynomials or regular curves, how much higher-order information is used, and how the extrapolation is influenced by the experimental design. Subjects report either the position of a single curve dot behind a semi-circular occluder or draw the distribution of possible extrapolants. Results show that subjects report multiple extrapolants for more complex curves if they are given the opportunity (by drawing multimodal distributions or by probability matching). I model the results with Bayesian model averaging, and show that this explains the data better than a static model. This suggests that observers do not use a fixed extrapolation scheme but can also adapt to the context, taking into account the complexity of the visible portion of the curve.

◆ **Explicit estimation of visual uncertainty: a new motion extrapolation paradigm**

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Previously, we demonstrated that observers have explicit access to an estimate of visual uncertainty during a motion extrapolation task (Graf et al, 2005 *Vision Research* **45** 3050–3059). Surprisingly, observers appeared to integrate information over an extended motion path to derive this estimate. We explored these issues again using a new extrapolation paradigm. Observers tracked a dot moving on a random walk from a central start position to its disappearance behind an annular occluder. Observers then set the position and width of an arc segment (capture region) on the outer edge of the occluder. Observers received points if the dot emerged within the capture region (wider regions scored fewer points). Observers scaled arc length appropriately for motion variability and occluder width. In a second experiment, we divided the circular dot motion region into eight annular segments and assigned motion variability as either high or low in each segment. From the data, we derived a weighted linear model specifying the contribution of motion in the first four and last four segments to the arc length setting. We confirmed that observers used a large extent of the motion path to estimate visual uncertainty but that more recent data had a significantly larger contribution.

◆ **Motivational valence improves visual detection performance**

M Rothkirch, A Gómez-Carrillo de Castro, P Sterzer (Department of Psychiatry, Charité, Berlin, Germany; e-mail: philipp.sterzer@charite.de)

Human behaviour is guided by motivational factors often tied to reward and punishment. Adaptive behaviour therefore necessitates the selection of motivationally relevant sensory information. Accordingly, recent studies have shown that visual perception can be improved by motivational incentives. In these studies, the motivational significance (valence) of upcoming target stimuli was indicated by preceding cue stimuli. Here, we asked whether visual processing is also enhanced when only the target itself contains valence information. In a psychophysical experiment, human subjects performed a 2-alternative forced choice task where they had to detect a briefly presented low-contrast Gabor patch. Two possible orientations of the Gabor (45° or 135°) were associated with high (0.50€) or low (0.05€) valence, respectively. That is, subjects could on each trial win the amount associated with each respective orientation by correctly detecting the target, but also lose the same amount if they missed it. Performance level was held constant by adaptation of the target contrasts using separate staircase procedures for each Gabor orientation. Results show that subjects reached lower contrast levels for high valence stimuli. This supports the notion that early visual cortex shows plasticity in favour of a better detection of motivationally relevant stimuli.

◆ **Human intrinsic visuomotor rewards in obstacle avoidance**

C A Rothkopf, D H Ballard¶ (Frankfurt Institute for Advanced Studies, Germany; ¶ Department of Computer Science, University of Texas at Austin, USA; e-mail: dana@cs.utexas.edu)

Neurophysiological and psychophysical studies in primates and humans have shown the pervasive role of reward in learning of visuomotor activities. Reinforcement learning algorithms have been formulated that characterize the neuronal signals of dopaminergic neurons in response to the

occurrences of stimuli associated with rewards and the delivery of the rewards across learning. Common to all these experiments is that the reward structure of the task is explicitly controlled by the experimental setup. But the value functions underlying fixations or control of walking direction are not known a priori in visually guided activities in natural behavior. We present a new algorithm, which is able to infer these value functions. The algorithm takes advantage of the inherent structure of the task by compactly representing the value functions with a small number of basis functions. The algorithm was applied to data collected from human subjects navigating in a virtual environment while avoiding obstacles. The value functions underlying these tasks are recovered for each participant and the validity of the algorithm is verified by evaluating the RMS-error between the actual trajectories and simulated ones utilizing the extracted parameters. Importantly, these rewards correlated with the proportions of fixations on the corresponding object classes ($\rho = 0.72$).

TEXTURE SEGMENTATION

◆ **Texture segmentation: Sampling units on the saliency map increasing with eccentricity?**

U Schade, C Meinecke (Institut für Psychologie, Universität Erlangen-Nürnberg, Germany; e-mail: ursula.schade@psy.phil.uni-erlangen.de)

In the context of texture segmentation we can describe target detection as detection of a texture irregularity. It has been shown that a task-irrelevant irregularity in the mask ('patch') impairs the detection of the relevant target in the stimulus ('target'). The impact of the 'patch' decreases with increasing spatial distance between 'target' and 'patch' (Schade and Meinecke, under review). In this study we ask whether this distance effect can be modulated by the retinal eccentricity of the 'target'. We assume that the size of the sampling units on the saliency map (Itti and Koch, 2001 *Nature Reviews Neuroscience* 2 194–203) enlarges with eccentricity. The influence of the 'patch' should be limited to a critical distance around the 'target' position. The critical distance itself should vary as a function of eccentricity. Our data confirm this assumption: The impairing effect of the 'patch' was limited to a smaller distance around central 'targets' as compared to peripheral 'targets'. Generally, the critical distance increased with the eccentricity of the 'target'. The data support our assumption that the size of the sampling units on the saliency map increases as a function of eccentricity.

◆ **Texture segmentation: does M-scaling explain the N2p eccentricity effect?**

S Schaffer, C Meinecke (Institute of Psychology, University of Erlangen-Nürnberg, Germany; e-mail: Susann.Schaffer@psy.phil.uni-erlangen.de)

For target detection in texture segmentation tasks, the fit between the structures of the stimulus (eg spatial frequency) and those of the visual system (eg sensitivity to high spatial frequencies in the fovea) is crucial. Thus, detection performance is better either for foveal targets or for peripheral targets, depending on where the fit is optimal. It is assumed that different processes in periphery versus fovea account for detection asymmetries as a function of retinal eccentricity. Eccentricity effects in texture segmentation tasks can also be observed in event-related potentials (ERP). In target-present trials, foveal targets elicit a larger N2p than peripheral targets do. In our study, we investigate whether this N2p eccentricity effect can be explained by quantitative differences between peripheral areas and the fovea, eg cortical magnification. In Experiment 1, all texture elements were size-scaled according to the cortical magnification factor from the equation of Rovamo and Virsu [1979 *Experimental Brain Research* 37(3) 495–510], whereas in Experiment 2 only the target patch was scaled. Our results indicate that cortical magnification alone cannot sufficiently explain the N2p eccentricity effect.

◆ **Bistable depth ordering in motion transparency**

S Wardle, D Alais, J Cass (School of Psychology, The University of Sydney, Australia; e-mail: swardle@psych.usyd.edu.au)

Depth and form cues contribute to the segmentation of transparent motion signals. We generated transparent motion stimuli that were bistable in depth and examined whether spatial frequency systematically biased the relative depth ordering of the component patterns. Transparent motion movies consisted of two superimposed spatially narrowband filtered noise patterns translating in opposite directions at 3.125 deg s^{-1} . The spatial frequency of each component pattern was centred on 0.4, 0.8, 1.6, 3.2, or 6.4 cycles deg^{-1} with a bandwidth of one octave. Each pair of component patterns was individually matched for perceived contrast using thresholds estimated from two interleaved adaptive QUEST staircases. Subjects tracked the relative depth ordering of the two component patterns in each movie over several trials. Overall, there was a bias to perceive the higher spatial frequency pattern as behind the lower spatial frequency pattern. The results will be discussed in relation to natural images and contrasted with a similar observation in transparent plaid stimuli [Moreno-Bote et al, 2008 *Journal of Vision* 8(7):20, 1–13].

Tuesday

- ◆ **Seeing texture edges without segmentation, by contextual modulations within the texture region**
V Robol, C Casco (Department of General Psychology, University of Padua, Italy;
e-mail: valentina.robol@unipd.it)

Confirming our previous findings [Giora and Casco, 2007 *Vision Research* 47(7) 879–886], we show that contextual influences between local collinear elements in a large texture region, either congruent or non-congruent with the texture boundary, modulate texture segmentation based on orientation contrast by edge-based mechanisms [Malik and Perona, 1990 *Journal of the Optical Society of America A* 7(5) 923–932]. These two contextual effects have different temporal dynamics, occurring at durations shorter than 40 ms and longer than 80 ms. The major finding is that when orientation discrimination based on orientation contrast is at chance level, congruent contextual influences allow edge discrimination to reach an above chance level at short durations, while non-congruent contextual influences allow edge discrimination to reach an above chance level at long durations. Furthermore, the two facilitatory contextual influences occur provided that elements are collinear, iso-oriented and have the same contrast polarity—at both low and high spatial frequencies when elements are congruent and only at high spatial frequency when they are non-congruent. We have demonstrated that the role of contextual influences between 1st order channels iso-oriented, collinear and having the same contrast polarity goes beyond a facilitation of segmentation by edge-based mechanism, allowing texture edges to be seen when orientation discrimination at the edge fails.

- ◆ **Segmentation of instant isoluminant chromatic textures**
S Fomins, L Zarina (Department of Optometry and Vision Science, University of Latvia,
Riga, Latvia; e-mail: sergejs.fomins@gmail.com)

Temporal stimuli were used to obtain reaction times to texture stimuli of different design (Fomins et al, 2008 *Perception* 37 Supplement, 80). Previously obtained data in a masking study is in good agreement with data by Rousselet et al (2002 *Nature Neuroscience* 5 629–630). To determine the functioning of the horizontal networks we applied the same method for the opponent and non-opponent isoluminant chromatic stimuli. The isoluminance values were obtained by flicker photometry. Our results show a decrease in reaction times and perception of chromatic textures in comparison to those derived with luminance stimuli. As expected, blue–yellow stimuli are processed more slowly than red–green stimuli. The stimulus design affects the segmentation of stimuli varying in colour.

GROUPING

- ◆ **Motion-induced blindness and perceptual grouping: the role of grouping cues reconsidered**
D V Devyatko (Department of Psychology, Lomonosov Moscow State University, Russia;
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Salient target dots fluctuate in awareness due to the motion-induced blindness (MIB) when they are superimposed on a moving mask (Bonneh et al., 2001). It was shown that dots tend to disappear and reappear simultaneously when they are connected by a line or have a common region (Mitroff and Scholl, 2005). We investigated whether a common mask itself could be a perceptual grouping cue and lead to an increased amount of simultaneous disappearances and reappearances of two target dots as compared to two separate masks. To test this possibility, we measured dots transitions when they were perceptually grouped by the mask (one mask vs two separate masks) and/or connected by the line. We found that amount of simultaneous disappearances/reappearances was indeed greater in the common mask condition than in the two masks condition ($t_{14} = 4.624$, $p = 0.000$; $t_{14} = 3.598$, $p = 0.003$ correspondingly). General amount of disappearances was also greater in the common mask condition. However, there was no significant difference in amount of simultaneous switches of two dots connected by the line. The latter result contradicts previous findings and calls into question the idea that a connecting line makes target dots a perceptual unit. [Supported by RFBR, #08-06-00171-a.]

- ◆ **The estimation of quantitative ranges of invariance in visual perception**
V N Chikhman¶, Y E Shelepin¶, O A Vakhrameeva¶, S V Pronin¶, N Foreman§, P Passmore##
(Information Technology [¶ also Visual Physiology], Pavlov Institute of Physiology,
St Petersburg, Russia; § Department of Psychology [## Department of Computer Science],
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To determine the quantitative ranges of invariance in the visual perception of objects viewed at different distances and different viewing angles, we have provided a set of psychophysical measurements of recognition thresholds of incomplete line drawings (Gollin-test) with different sizes and rotations. New experimental data are presented, relating invariance to image size transformation and image rotation. We demonstrated that there is a wide range of angular sizes (from 1.0 up to 50 deg) across which the threshold of recognition of incomplete images does not

depend on object size. However, there was found to be a narrow range of small stimulus sizes (0.19–1.0 deg) within which there was found to be a dependence of performance on object size. In additional experiments with naive participants, we extended our earlier investigations (Chikhman et al, 2008 *Perception* 37 Supplement, 119) by making more exact threshold measurements for the recognition of 3-D objects when viewed as incomplete 2-D images, varying the perspective of 3-D objects during testing. The possible algorithms for template formation for 3-D objects in the human visual system are discussed and modeled, taking into account the invariance mechanism.

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◆ **How global and local visual processings are affected by the priming of affective concepts**

R Bianchi, E Laurent (Department of Psychology and Laboratoire de Psychologie, ENACT-MCA, University of Franche-Comté, Besançon, France; e-mail: eric.laurent@univ-fcomte.fr)

Level-of-focus of visual perception is influenced by affective processes. The affect of joy is associated to a global processing whereas the affect of sadness is correlated to a local processing. Thus, joy would increase a focusing on the whole while sadness would elicit a focusing on the parts. However, recent findings tend to show an unexpected inversion of these results when a mere affective concept—instead of an affective state—is induced. In this experiment, depending on the condition, participants were either primed with joyful, neutral or sad concepts through a sentence unscrambling task. Then, they had to indicate whether a target figure was more similar to a first item matching its global shape or to a second item matching its local components. Results showed that following joy priming, participants processed figures on more local properties as compared to what was observed following sadness priming. Our results confirm that affective concept processing can change subsequent visual perception sensitivity to global and local aspect of stimulation and highlight the need to distinguish between affective state or feeling on the one hand, and affective concept or abstract information on the other hand, each process leading to different consequences for visual perception.

◆ **Visual search of the second-order targets with uncertainty**

D V Yavna, V V Babenko, A A Soloviev (Department of Psychology, Southern Federal University, Rostov, Russia; e-mail: yavna@philos.rsu.ru)

Recently second-order visual mechanisms have been extensively studied. However, it remains unclear whether they are a fixed set of filters with different tuning or whether they are formed by top-down mechanisms that depend on the task. To explore this issue, we used a visual search task in two experimental conditions: the second-order target was either known a priori or unknown to the observer. In the course of the first experiment we used as a target a pre-defined patch of texture with the modulated contrast. Distractors were similar textures without modulation. There were 6 targets in the course of the second experiment. They differed by the carrier (patches or noise) and the envelope (positive or negative concentric Gabor, vertical or horizontal sinusoid) and they were randomly alternated. At the same time the distractors had the same carrier and did not have the envelope. Visual search time did not depend on the number of distractors in both conditions, ie even when the second-order target was not known in advance, the search was parallel. In this case the second-order detectors could not be modulated by top-down mechanisms before the search. The result suggests that the second-order mechanisms represent a fixed set of filters.

Wednesday

WEDNESDAY

TALK SESSION A

MOTION MECHANISMS AND OPTIC FLOW

◆ **Visual perception of social interaction: gender effects on oscillatory gamma MEG response**

M A Pavlova, M Guerreschi¶, W Lutzenberger§, I Krägeloh-Mann (Children's Hospital, University of Tübingen, Germany; ¶ Department of General Psychology, University of Padua, Italy; § MEG-Center, University of Tübingen, Germany; e-mail: marina.pavlova@uni-tuebingen.de)

The ability of humans to predict and explain other people's actions is of immense value for adaptive behaviour and non-verbal communication. Gender differences are often evident in the visual processing of social signals, but the underlying neurobiological basis for these differences is unclear. Combining visual psychophysics with magnetoencephalography (MEG), we assessed gender disparities in the induced oscillatory neuromagnetic response to visual social interaction depicted by motion. A robust difference in the induced gamma response was found between females and males over the left prefrontal cortex, a region implicated in perceptual decision making. The induced gamma MEG response peaked much earlier in females than in males. Contrary to popular wisdom, the outcome of this study indicates that gender effects are not evident in the network engaged in visual social perception, but in the regions engaged in perceptual decision making. We assume that differences in brain processing may not only elicit but also prevent behavioural differences, for example, impulsive perceptual decisions, if they are maladaptive.

◆ **Shape-driven motion perception: human performance is optimally efficient**

Q Zaidi, E Cohen¶, A Jain (Graduate Program in Vision Science, College of Optometry, State University of New York, USA; ¶ Department of Psychology, Vanderbilt University, Nashville, USA; e-mail: qz@sunyopt.edu)

To understand the interactions between form and motion processing involved in object motion perception, we investigated how extracted shape properties can drive perceived motion. In a new paradigm, identical dots were moved in and out along spokes radiating from a center, in a manner consistent with the rotation of shapes distorting dynamically with random noise. Rotation-direction discrimination as a function of the magnitude of non-rigidity, ruled out motion-perception models based on combining the shortest/slowest local motions, but was consistent with the use of global position-invariant rotation filters. Stimuli with alternating rigid and non-rigid segments showed that rotation filters must include either lateral facilitation or regional computations. In addition, observers could discriminate rotation directions in the presence of extremely non-rigid symmetric distortions at speeds up to 11 Hz. In these stimuli, only the symmetric axis maintained continuous motion, and thus perception could not be explained by rotation filters. An optimal Bayesian observer was constructed to infer rotation direction by Procrustes shape analysis. Human rotation discrimination for arbitrary non-rigidities matched the shape-based optimal observer's performance, and well exceeded it for symmetric non-rigid shapes. Human observers are thus optimally efficient at perceiving object motion by matching non-rigid shapes and extracting informative shape properties.

◆ **Interactions between global form and motion in high-density VEPs**

J Wattam-Bell, S Merwin, M Oxley, V Palzes, D Birtles (Department of Developmental Science, University College London, UK; e-mail: j.wattam-bell@ucl.ac.uk)

We have recently shown that steady-state VEPs to global form and motion have distinct scalp topographies, implying distinct neural generators. Moreover, with superimposed form and motion stimuli, there is no evidence of between-modality masking of psychophysical coherence thresholds. These findings indicate relatively independent processing of global form and motion. Here, we examine whether form and motion VEPs can be recorded simultaneously in adults, using superimposed stimuli alternating at different, non-harmonic frequencies (2.0 and 2.5 Hz). Simultaneous recording would reduce overall testing time (invaluable for infant studies), and also reveal any non-linear interactions between the stimuli, as responses at the sum and/or difference of the alternation frequencies. In the event, superimposing the stimuli severely attenuated the responses to both form and motion, with little evidence of interaction. Local and global responses were equally affected. Explicit instructions to attend to just form or motion significantly increased the response to the attended stimulus, but amplitudes were still only half those for the same stimulus presented separately. The results suggest that the form and motion stimuli mask each other at an early stage, prior to global processing, which seems to contradict the psychophysical findings. Experiments combining psychophysics and VERP recording should help resolve this.

- ◆ **The vector sum of motion strengths describes the perceived motion direction of first-order plaids**
G Sperling, D T Liu (Department of Cognitive Sciences, University of California, Irvine, USA; e-mail: sperling@uci.edu)

A plaid motion stimulus consists of two superimposed sinewave gratings moving linearly in independent directions. Every plaid has a rigid interpretation as a translating single frame. In Type II plaids, the rigid direction lies outside the angle between the component directions. Fast-moving Type II plaids seldom appear to move in the rigid direction, they move in a direction between the two component directions. To simplify the problem of determining the visual system's algorithm for computed perceived plaid direction, we studied Type II plaids with spatial frequencies of 1 cycle deg⁻¹ and temporal frequencies so high (10 and 20 Hz) that the third-order motion system ('feature tracking') was excluded. When plaid component contrasts were varied from 1–32%, perceived direction depended only on the components' contrast ratio, independent of overall contrast. From these data, we derived a motion vector-strength to characterize a moving sinewave grating of a particular contrast and temporal frequency. To accurately predict the perceived direction of a new motion plaid, simply sum the previously derived motion vector-strengths of the components. However, as the temporal frequency of components is decreased (thereby admitting third-order motion processing), the perceived direction of plaids increasingly deviates towards the rigid direction.

- ◆ **Human visual area V6 is selectively responsive to egomotion-compatible optic flow**
A T Smith, V Cardin (Department of Psychology, Royal Holloway, University of London, UK; e-mail: a.t.smith@rhul.ac.uk)

The analysis of visual cues to self-motion (egomotion) is primarily associated with cortical areas MST, VIP, and (recently) CSv. Various other areas, including visual areas V6 and V6A, and vestibular areas PIVC, 2v, and 3aNv are also potentially suited to processing egomotion, but it is not known whether they are actually involved. We have explored which of these areas is sensitive to visual cues to egomotion. In a 3 T fMRI experiment, we presented participants with two types of random dot kinematograms that either did or did not simulate egomotion. The stimuli were based on those used by Wall and Smith (2008 *Current Biology* **18** 191) to demonstrate egomotion sensitivity in MST, VIP and CSv. Responses to a single, egomotion-compatible flow stimulus were compared with responses to an array of flow patches that is not egomotion-compatible. Visual area V6 and vestibular areas PIVC and 2v were all differentially responsive to egomotion-compatible visual stimuli, suggesting that they may be involved in encoding egomotion. The use of such stimuli provides a simple localiser for fMRI studies of human V6, which previously required wide-field retinotopic mapping to identify it, and of PIVC and 2v, which previously required galvanic or caloric stimulation.

- ◆ **Support for a spatiotemporal association field account of multiple object tracking**
T S Horowitz[¶], M A Cohen[¶] (Department of Ophthalmology, Harvard Medical School, Boston, USA; [¶] Surgery, Brigham and Women's Hospital, Boston, USA; e-mail: toddh@search.bwh.harvard.edu)

Humans can track 4–5 independently moving objects. How does the visual system accomplish this? We propose that observers attend to trajectories, which we think of as spatiotemporal contours. The association field hypothesis, which proposes that propagation of associations between local neural units facilitates completion of contours in space [Field et al, 1993 *Vision Research* **33**(2) 173–193]. Extending this logic into the temporal domain, we suggest that tracked objects generate association fields propagating forward in time. These fields should be stronger for objects whose orientations are collinear with their trajectories. Stronger association fields should produce more precise information about trajectories. Observers tracked 2 or 3 of 10 ovals. The angle (τ) between the major axis of each oval and its trajectory was varied (within displays) between 0° and 90°. After 5 s of motion, ovals were replaced with disks. Observers adjusted a probe arrow on a single target to match that target's trajectory. We computed the standard deviation (σ) of a gaussian fit to trajectory error distributions. We predicted that σ would be smallest when $\tau = 0^\circ$, reflecting a stronger association field. This prediction was confirmed in three experiments. These results support the notion of spatiotemporal association fields in tracking.

- ◆ **Unifying mechanisms of motion integration and segregation in area MT: a neural model**
C Beck, H Neumann (Institute of Neural Information Processing, University of Ulm, Germany; e-mail: cornelia.beck@uni-ulm.de)

In many neurophysiological experiments, area MT has been investigated to clarify how it achieves pattern motion computation. However, results are contradictory, indicating two different strategies of pooling input from V1 (integrationist concept) or selectively relying on localized features of V1 (selectionist concept) [Pack and Born, 2008 *The Senses: A Comprehensive Reference* (Oxford:

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Academic Press)]. Furthermore, interactions of form and motion pathway modulate the motion activity around occlusions as demonstrated in the barberpole illusion (Pack et al, 2004 *Journal of Neuroscience* **24**). We propose a neural model for the computation of pattern motion in MT by combining integrationist and selectionist strategies based on two cell populations in V1 measuring 1-D normal flow and 2-D motion at localized feature locations (Pack et al, 2003 *Neuron* **39**). Ambiguous motions along elongated boundaries are disambiguated over time through MT–MSTl modulatory interactions, solving the aperture problem in MT. Modulation of MT responses via model area V2 representing local form at occlusions reduces extrinsic feature motion in the integration mechanism. Our model replicates the motion perception of complex visual stimuli like the barberpole and chopstick illusions [Anstis, 1990 *AI and the Eye* (London: John Wiley)]. It gives a possible explanation how integration and input selection can be unified in MT and combined with modulatory interactions of the form pathway.
[Supported by EU-project 215866-SEARISE.]

- ◆ **Contrast reveals all: A new model of image-velocity estimation using MT neurons**
J A Perrone, R J Krauzlis¶ (Department of Psychology, The University of Waikato, New Zealand; ¶ Systems Neurobiology Laboratory, The Salk Institute for Biological Studies, San Diego, California, USA; e-mail: jpnz@waikato.ac.nz)

Low contrast gratings can appear to move both slower and faster than high contrast gratings, depending on their temporal frequency [Thompson et al, 2006 *Vision Research* **46**(6/7) 782–786]. Currently, no image-based, velocity estimation model can explain this finding. We have developed a new model that is able to replicate this speed-contrast effect. The model uses the inputs from a small set of MT pattern neurons to determine the velocity of moving features in 2-D image sequences (Perrone and Krauzlis, 2009, Vision Science Society). The pattern neurons are simulated using a previously developed model of MT neurons based on realistic V1 neuron inputs (Perrone, 2004 *Vision Research* **44** 1733–1755; Perrone and Krauzlis, 2008 *Journal of Vision* **8**(9):1 1–14). Our velocity code uses inhibition between MT units of different spatial scales and this proposed mechanism is supported by data from Pack et al (2005 *Journal of Neurophysiology* **93**(3) 1809–1815) showing center–surround contrast effects in MT neurons. The velocity estimates are based on a weighted vector average calculation performed on the outputs of the inhibited MT neurons. Contrast alters the speed tuning curves of our MT input units consistent with MT data (Krekelberg et al., 2006 *Journal of Neuroscience* **26**(35) 8988–8998) and it is these tuning curve changes that generate the Thompson et al's speed-contrast effect in the model.

TALK SESSION B

3-D PERCEPTION AND SPATIAL VISION

- ◆ **Veridical binocular perception of 3-D shape**
Z Pizlo, Y Li, T Sawada, R M Steinman (Department of Psychological Sciences, Purdue University, West Lafayette, USA; e-mail: pizlo@psych.purdue.edu)

Binocular disparity provides a potentially useful metric depth cue but its utility is uncertain because the eyes' separation is small relative to the distances of most objects 'out there'. Disparity only allows the reliable estimation of the order of points in depth. This capacity, which affords 'stereoacuity', cannot reconstruct the environment's metric structure. Can disparity serve some other function? We found that stereoacuity's ordinal information provides a highly reliable 3-D shape cue. This result contradicts all prior studies, where using simple shapes and limited viewing conditions, turned studies of shape into studies of depth. Once shape is studied properly, disparity's utility becomes obvious. We will show how our monocular 3-D shape recovery model (ECVP 2008) can use disparity to provide highly accurate binocular 3-D shape recovery. In our monocular model, a single 2-D image determined the 3-D symmetric shape up to one unknown parameter, its aspect ratio, and when the aspect ratio changed, the depth order of its visible shape features also changed. But, when stereoacuity is added to provide this order, the 3-D shape recovered is extremely accurate (veridical). The veridicality of our binocular 3-D shape model, evaluated by its aspect ratios, is at least as good as our human subjects'.

- ◆ **Global vertical disparity influences stereo correspondence**
G P Phillipson, J C A Read¶ (Institute for Adaptive and Neural Computation, School of Informatics, University of Edinburgh, UK; ¶ Institute of Neuroscience, Newcastle University, UK; e-mail: s0568415@sms.ed.ac.uk)

Stereovision requires the brain to find matches between image features in two retinas. The correct match lies on an epipolar line determined by the orientation of both eyes. Thus, information about epipolar geometry could potentially simplify stereo correspondence by indicating where matches are likely to be found. We investigated this by asking subjects to detect a disparity-defined

disc presented at 10 deg eccentricity in a random quadrant. Task difficulty was altered by decreasing the interocular correlation, making stereo correspondence harder due to the increasing number of dots with no match in the other eye. We find that adding on-screen vertical disparities which simulate infinite viewing distance can actually increase task performance. Thus, human stereo correspondence may concentrate its search near the epipolar lines appropriate to infinity, even when this is inconsistent with the oculomotor system. However, an inconsistent vertical disparity field, where the periphery (> 20 deg) indicates the correct 30 cm viewing distance while the region < 20 deg indicates infinite viewing distance, has an even more detrimental effect. Thus, the brain may not simply search a fixed zone on the retina, but may adjust its search according to the epipolar geometry indicated by the global vertical disparity field.

- ◆ **Alternation frequency thresholds for stereopsis reveal different types of stereoscopic difficulties**
S I Rychkova, J Ninio¶ (Eye Microsurgery Clinic, Irkutsk, Russia; ¶ Laboratoire de Physique Statistique, Ecole Normale Supérieure, Paris, France; e-mail: rych.sv@mail.ru)

When stereoscopic images are presented alternately to the two eyes, stereopsis occurs at at least 3 Hz full cycle frequencies (eg, Ludwig et al, 2007 *Perception & Psychophysics* **69** 92–102). We studied the transition to stereopsis with twelve subjects, using 21 different stereograms presented on a synoptophore. For all stimuli, the subject-averaged minimal frequency F for stereopsis with stable fusion was 0.7 Hz higher than the minimal frequency for depth with apparent motion in the images. The lowest F values (4.2 to 4.6 Hz) were observed with stimuli involving 2 to 4 simple disjoint elements (circles, arcs, rectangles). Higher F values were needed for stimuli containing slanted elements (1 to 2 Hz increment), curved surfaces (2 to 4 Hz increment), overlapping elements at two different depths (1 to 1.5 Hz increment) or camouflaged overlapping surfaces (> 4 Hz). A textured cylindrical surface thus appeared easier to interpret (7.5 Hz) than a pair of slanted segments separated in depth but forming a cross in projection (8.5 Hz). Training effects were minimal, and F usually increased as disparities were reduced. The hierarchy of difficulties thus revealed may shed light on various problems that the brain needs to solve during stereoscopic interpretation.

- ◆ **Depth information does not speed up a texture segmentation task unless the required reaction time is longer than about 1 s: implications for the relative roles of striate and extra-striate cortices in input driven attentional guidance**

L Zhaoping, N Guyader¶, A Lewis§ (Department of Computer Science, University College London, UK; ¶ Image and Signal, Grenoble Image Parole Signal Automatique Lab, France; § Goldman Sachs International; e-mail: z.li@ucl.ac.uk)

We consider segmentation of two neighboring textures of uniformly, but differently, oriented oblique bars. The reaction time (RT) for this task becomes much longer when an irrelevant texture, comprising spatially alternating horizontal and vertical bars, is superposed on the same grid. This is a predicted signature (Zhaoping and May, 2007 *PLoS Computational Biology* **3** e62) of the bottom-up saliency mechanisms in primary visual cortex (V1). Putting the task-irrelevant texture behind the relevant texture in depth reduces interference substantially, suggesting depth cues might also contribute to attentional guidance. Since depth separation is caused by a horizontal shift between the two textures in one or both monocular images in a dichoptic display, an important question is whether a flat 2-D stimulus lacking depth cues, made by presenting the modified monocular images identically to both eyes, reduces interference or RT as effectively. We found that interference is reduced as effectively, unless the 2-D stimulus requires an RT (of subjects' report for the task) longer than about 1 s. Since physiological data suggest that extra-striate cortical areas, but not V1, are significantly involved in depth and surface perception, our observations imply that V1 dominates in input-driven attentional guidance initially after stimulus onset, and extra-striate cortices contribute only later.

- ◆ **Stereoscopic depth magnitudes at greater distances in an old steam railway tunnel**

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Unlike disparity thresholds, depth magnitudes (which require scaling for distance), have been little measured beyond a few metres. The present studies used remote bluetooth-controlled LED targets presented in a disused steam railway tunnel at Helensburgh, NSW, with distances of 20 m and 40 m to the nearest target and disparities up to 4.5 min of arc between targets. Conditions were either completely dark or lighted to provide perspective cues up to the nearest LED. Observers estimated depth in metres. Even in the dark, depth was scaled by disparity and

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superior to monocular depth. With perspective scaling available, monocular depth did not improve but stereo depth increased strongly for most observers and was considerably greater at 40 m than at 20 m. Even the greatest depths reported were strongly attenuated from geometric prediction to about half predicted value at 20 m (similar to Allison et al, 2009) at 9 m). At 40 m the greatest depths reported were about 4 m for predicted depths of about 30 m. Clearly disparity influences perceived depth magnitude and perspective acts as a scaling cue at distances greater than 20 m. Depth compression cannot be attributed to perceived distance in either the light (reasonably accurate) or the dark.

◆ **Binocular disparities, motion parallax and geometric perspective in Patrick Hughes's 'Reverspectives'**

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Patrick Hughes's 'Reverspective' artwork, in which the perceived depth of the truncated pyramids is opposite in direction to their physical structure, have been of significant interest for vision scientists. Not only is the depth reversed in 'Reverspective' pictures but also the depth-reversed 3-D structure appears to rotate with the observer during side-to-side head movements. Papathomas [2007 *Spatial Vision* **21**(1/2) 79–95] argued that 'top-down' processes play an important role in the effect and he attributed the illusory rotatory motion to a "discrepancy between the expected and actual retinal optic flows". The aim of the present experiments was to determine the role of disparities, parallax and the different components of perspective information—linear-, size-, and edge-perspective—in creating the effect, using a series of reverspective models in which both the slant of the pyramid sides and the texture covering the surfaces were manipulated. The strength of the different cues under monocular and binocular viewing was derived from the distance at which the illusory effect broke down. Linear-perspective and edge-perspective effects were found to be more important than size-perspective. We also show that there is no need to invoke 'top-down' processes to explain the effect if the nature and limitations of motion parallax information are understood correctly.

◆ **Inferred motion perception of light sources in three-dimensional scenes is color-blind**

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An impressive function of the visual system is to estimate surface properties from retinal images that confound object properties with the light field's spatially varying chromaticity and luminance. Estimating the light field and object geometry constrains surface property estimates, and previous work indicates that light field parameters are estimated (eg, Gerhard and Maloney, 2008 *Vision Sciences*). Can the visual system also track temporal changes in the light field? If so, what information is used? For example, standard motion perception is driven by luminance while color is uninformative. We evaluate whether the same is true of inferred light source motion. Observers viewed three-dimensional surfaces illuminated by an out-of-view moving punctate source and a diffuse source. On half the trials, the punctate and diffuse sources had different chromaticities, thereby providing more information about motion direction. Of seven observers, all reported motion direction above chance (31%–77% correct). Only the observer with the poorest performance benefited significantly from the added color information. We explored the impact of other dynamic and static image properties using a generalized linear model. We conclude that observers rely on several scene statistics to monitor temporal changes in the light field's intensity distribution, but color does not play a major role.

◆ **The image-based acuity model: A general model for image recognition**

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Watson and Ahumada (2008, <http://journalofvision.org/8/4/17/>) proposed an image-based model for predicting acuity from optical aberrations. In this model a 'neural' image is computed from the optics and a neural contrast sensitivity function. In the ideal observer version of the model, the neural images for all letters of a given size serve as templates. When a target is presented, white 'internal' noise is added to its neural image, and the response of the observer is the nearest template. The performance of this model is only a function of the noise level and the matrix of cross-correlations among the neural images. The noise level we estimated from the observers in Cheng et al (2004, <http://journalofvision.org/4/11/1/>) ranged from 0.5×10^4 to 10^5 deg^{-2} , consistent with the noise level of the Modelfest observers (2005, <http://journalofvision.org/5/9/6/>). Watson and Ahumada (2008) presented simple acuity metrics that assumed no correlation among templates. Here we derived and tested metrics that include the cross-correlations among templates. Predictions were computed for blurred and unblurred tumbling E images and Sloan letters. The new metrics

give improved predictions, but simulations are so fast that approximations may not be needed. This acuity model is a generalization of the Spatial Standard Observer model for image detection and discrimination, providing with arbitrary templates a general model for image recognition.

SYMPOSIUM

POPULATION ENCODING FOR HIGH-DIMENSIONAL VISUAL REPRESENTATIONS

◆ **Decoding conscious and unconscious visual representations from patterns of human brain activity**

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It has recently emerged that the sensitivity of fMRI can be dramatically increased if the full information present in large ensembles of voxels is appropriately taken into account. For example, supervised learning can be used to train a pattern classifier to distinguish between several orientation stimuli viewed by a subject based on the characteristic distributed brain responses they evoke in visual cortex. This holds even though the relevant features are represented at a finer spatial scale than the nominal resolution of single voxels. Here several studies will be presented that apply such supervised learning to the study of conscious and unconscious visual processing in humans. In one study the information about a stimulus that is available to a subject for a perceptual decision is compared to the information that can be decoded from early visual areas. This reveals that V1 has information about stimulus features even when they are rendered completely invisible due to masking, suggesting that V1 can have information about visual stimuli that is not available for conscious access. A second study demonstrates that pattern classification can be used to accurately predict on a second-by-second basis participants' conscious perception while it undergoes many spontaneous changes during binocular rivalry. Importantly, this reveals that the source of predictive information differs between visual areas, being more eye-based in V1 and more percept-based in V3. A third study demonstrates that a subject's behavioural choices can be predicted from different brain regions depending on whether a stimulus is either clearly visible or almost invisible, thus suggesting that the brain adopts different modes of decision making under high and low visibility conditions. Taken together this provides valuable information about the nature of perceptual coding in visual cortex and how such encoding is affected by changes in awareness.

◆ **Visual image reconstruction from human brain activity: A modular decoding approach**

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Perceptual experience consists of an enormous number of possible states. Previous fMRI studies have predicted a perceptual state by classifying brain activity into pre-specified categories. Constraint-free visual image reconstruction is more challenging, as it is impractical to specify brain activity for all possible images. Here, we present a modular decoding approach in which a visual image was assumed to consist of multiscale local image bases (modules). The contrasts of the local image bases were independently decoded from fMRI activity, and then combined to create a reconstructed image. We show that arbitrary binary-contrast images were accurately reconstructed by the decoding model trained with fMRI activity patterns only for several hundred random images. Reconstruction was also used to identify the presented image among millions of candidates. The results suggest that our approach provides an effective means to read out complex perceptual states from brain activity.

◆ **Representation of object category structure by the neuronal population of inferior temporal cortex**

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Our mental representation of categories has a hierarchical organization and facilitates rapid and effortless categorization of visual objects. I studied the neural underpinning of this representation by recording responses of 674 neurons in inferior temporal cortex (IT) of two macaque monkeys. During the recordings, the monkeys passively viewed several presentations of more than 1000 natural and artificial object images. I used unsupervised clustering methods to investigate the grouping of the images according to the similarity of the responses they elicited in the population of IT neurons. The results revealed a hierarchical representation that approximates our intuitive category structure. Animate and inanimate objects created distinguishable clusters. Within the animate cluster, bodies, hands and faces created separate clusters. Each of these was further divided into subordinate categories. The representation of this categorical structure was distributed across the neural population and was highly preserved even when category-selective cells were excluded from the population. This distributed representation allows easy and fast retrieval

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of image categories because the response patterns were linearly separable for different categories. Finally, the categorical representation seems to be specific to IT; simulation of LGN and V1 responses failed to replicate the hierarchical structure. The experimental results suggest that IT population represents the hierarchy of natural categories through selective development of tunings for complex visual attributes that define these categories.

◆ **Fast and robust decoding of visual information from intracranial field potentials in the human visual cortex**

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The remarkable pattern recognition abilities of humans and other primates surpass the most sophisticated computational algorithms available today. The difficulty of the recognition problem stems from the need to achieve high selectivity in a fraction of a second while maintaining robustness to object transformations. We quantified, at high temporal resolution, the amount of information conveyed about objects and their transformations by intracranial field potentials from 1494 electrodes in eighteen human subjects. Subjects were presented with images containing one or more objects or with movies. Using a statistical classifier, we could accurately decode object category information in single trials as early as 100 ms after stimulus onset. Decoding performance was robust to changes in rotation, scale and clutter. Furthermore, visual information could also be decoded under dynamic viewing conditions and in the presence of background clutter. The results revealed that physiological activity in the human temporal lobe can account for some of the key properties of visual recognition, and they provide strong constraints for computational models of human vision.

◆ **Characterizing categorical and continuous visual-object codes in man, monkey, and computational models with representational similarity analysis**

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In man and monkey, inferior temporal (IT) cortex contains visual object representations at the interface between perception and cognition. Although IT has been intensively studied in both species, IT representations of the same objects have never been compared between the species and IT's computational mechanism and role in categorization are not well understood. Here we presented monkeys and humans with the same images of real-world objects and measured the IT response pattern elicited by each image. In order to relate the representations between the species and to computational models, we use representational similarity analysis (RSA). RSA characterizes a neuronal population code by means of a representational dissimilarity matrix. For each pair of experimental conditions (eg each pair of stimuli), the representational dissimilarity matrix contains an entry reflecting the dissimilarity of the activity patterns associated with the two conditions. We find that IT response patterns form category clusters, which match between the species. The clusters correspond to animate and inanimate objects; within the animate objects, faces and bodies form subclusters. Within each category, IT distinguishes individual exemplars and the within-category exemplar similarities also match between monkey and human. In the human, categoricity appears to arise early on along the ventral stream, at the level of the lateral occipital complex. A range of computational models we tested did not account for the categorical nature of the object representations in IT, while human behavioral similarity judgments showed even greater categoricity than IT and a similar yet distinct categorical structure, in which the human/nonhuman distinction was more prominent than in IT. Our findings suggest that primate IT across species may host a common code, which combines a categorical and a continuous representation of objects. At the methodological level, RSA allows us to bridge fundamental divides of our science so as to relate human to monkey, cell-recordings to fMRI, and brain-activity data to behavioral measures and computational theory in an information-rich, quantitative framework that is well-motivated by cognitive theory.

TALK SESSION C

SCENE PERCEPTION

◆ **The perception of sunsets**

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Sunsets appear beautiful, but little is known about the underlying visual processing. Near sunset, the sky near the sun is red due to Mie scattering, while the solar disk is less intense and redder due to Rayleigh scattering. We simulated various atmospheric conditions, projecting a landscape with a large extent of sky, and a spotlight to simulate a solar disk. Sixteen sky colours were

presented, of which two corresponded to noon and sunset skies. They were matched for luminance and saturation. Other, unnatural, colours were used as foils. Two solar elevations were used: 2.7 and 9.2 deg above horizon. A mobile eye tracker recorded fixation. Subjects rated scene pleasantness, and the subjective size of the sun. The results suggest that aesthetic quality is determined by the elevation of the sun, rather than the chromatic or intensity parameters of the scene—thus, the redness of the sky or the sun are not predictors of aesthetic quality. Fixations avoid the solar disk, but the extent of avoidance does not vary with elevation. The findings suggest that aesthetic quality may be related to a dynamic interaction between the opposing demands of salience and repulsion from strong sources of light.

◆ **Limits on the non-selective processing of scenes**

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Aspects of the gist, global structure, and statistical regularities of scenes can be reported under conditions that permit attentional selection of few if any objects in the scene. What are the limits on this non-selective processing? During natural viewing, do we simultaneously extract, for example, the presence of animals, the mean orientation, and the 'openness' of a scene or must we select a specific non-selective property? We compared conditions where observers were cued to global image properties either before or after stimulus presentation. Observers' post-cued performance was well beyond what could be achieved if that processing ability had to be set to one attribute at a time. However, performance was below what would be predicted if observers computed all non-selective properties without cost. In a second set of experiments, observers monitored RSVP streams of scenes. In a block of trials, three targets were used (eg person, vehicle, beach). On each trial, observers searched for one target category (eg beach). Errors were elevated when the target for the trial occurred in an image that also contained another target type (car on beach) Apparently, the car sometimes blocked encoding of the beach. Non-selective processing of semantic information cannot encode all available signals.

◆ **Distance and alignment effects in survey knowledge of a highly familiar city**

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In this experiment we examined alignment and distance effects in human memory for a highly familiar environmental space. Twenty-seven participants who lived on average seven years in Tübingen saw a photorealistic virtual model of the city centre of Tübingen (Virtual Tübingen) through a head-mounted display. They were teleported to five different places in Virtual Tübingen and asked to point towards well-known target locations. This procedure was repeated 36 times for each of the target locations in 12 different body orientations. Participants pointed much more accurately when oriented northwards regardless of target. There were no significant correlations between straight line distance to the pointing target and pointing speed or accuracy. These results are consistent with the assumption that all locations were represented within one oriented coordinate system. Even though this is predicted by reference direction theory, it is unclear why, first, almost all participants have the same reference direction, and second, why this direction is north. We discuss our results with respect to well-known theories of spatial memory and speculate that the bias for a north orientation is because participants rely on the memory of a map of Tübingen for their response.

◆ **Less is more: smaller images appear richer in detail**

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The present study systematically examines the cursory experience that the perceived detailedness of an image depends on its size, even when physical detailedness is identical. Subjects performed a two-interval forced choice task on a pair of images, deciding which of the two images was richer in detail. We assessed both natural images and random patterns. One of the images in each pair was one third of the linear size of the other, but otherwise identical. Physical detailedness was defined as the product of upper spatial cutoff frequency and linear image size in pixels, and adjusted via a low-pass wavelet filter. Depending on the type of image, subjects experienced subjective equality when the physical detailedness of the larger image was 0.13–0.24 log units higher than that of the smaller image. This suggests that smaller images appear more detailed when physical detailedness is equal. The effect was robust across most subjects, not specific to certain images, but larger for those images that were more detailed in the first place. It is not readily explained by differences in contrast sensitivity, but may rather have its origin in visuo-cognitive strategies of image evaluation.

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◆ **Change in appearance of textures with randomisation of Fourier phase**

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It is known that humans can discriminate visual textures on the basis of differences in statistics higher than the second order. However, these results have been obtained using artificial textures made up of geometric elements, and the effects of manipulating higher order statistics in textures with a more natural appearance have not been examined quantitatively. We therefore investigate the effect of gradual phase randomisation on the ability of observers to discriminate synthetic textures with a naturalistic appearance. We keep the first and second order statistics of textures constant as phase is randomised, so that any perceived changes are due only to changes in third and higher order statistics. A difference scaling method is used to derive perceptual scales for each observer, and this shows a monotonic effect of the degree of randomisation on appearance. The greatest change is perceived between 20% and 60% randomisation, with little change in appearance above and below this range. We propose a biologically plausible model based on a local measurement derived using phase congruence information to account for the observed effects of phase randomisation on discrimination of texture pairs. We show that the same behaviour can be achieved in both perceptual and feature spaces, which can be related by a linear relationship within a log-log space.

◆ **Texture representations in human scene-responsive cortex**

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Humans can recognize visual scenes in a single glance, but what neuronal representations mediate this remarkable ability? Computational modeling suggests that scenes are processed as if they were textures so that textural statistics can be used for scene recognition. Here, we used fMRI to test whether or not human scene-responsive cortex maintains such textural scene representations. To be effective, these textural representations should be stable over changes in viewpoint. In a repetition-priming experiment, we identified brain regions that maintain texture representations across changes in scale and orientation. With a conventional localizer sequence, we identified three well-established scene-responsive brain regions: the parahippocampal place area (PPA), retrosplenial cortex (RSC), and the transverse occipital sulcus (TOS). Our results show that these scene-responsive brain regions all maintain texture representations across changes in scale and orientation. These results strongly support the notion that human cortical scene processing is based on textural representations.

◆ **Context shapes neural activity even in non-stimulated early visual areas**

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The shaping of perception by context is ubiquitous in our daily vision. In the case of apparent motion, for example, a context of two squares (a certain fixed distance apart) flashing in succession creates the illusion of a single square moving from one position to the other. We have shown, moreover, that V1 is activated on the path of such apparent motion (Muckli et al 2005). In the present work we investigate whether a surrounding context of different natural visual scenes leads to discriminable patterns of neural activity in non-stimulated early visual areas. Using fMRI and multivariate pattern analysis, we show that the cortical representation of a non-stimulated quarter-field carries information that can discriminate between different natural visual scenes presented to observers. According to predictive coding models of cortical function (eg Rao and Ballard, 1999), feedback from higher visual areas could provide this discriminative information.

◆ **Vision senses number directly**

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We have recently shown that numerosity is strongly susceptible to adaptation, suggesting that it is a primary sensory attribute (Burr and Ross, 2008 *Current Biology* **18** 425–428). Others (eg Durgin, 2008 *Current Biology* **18** R855–R858) have claimed that number is not sensed directly, but indirectly from ‘texture density’. Using the Method of Single Stimuli we asked observers to judge separately the numerosity and density of displays in which number, density and area were varied, keeping one of these parameters constant. Numerosity judgments were as precise as density in all conditions, including intermingled conditions, where numerosity varied unpredictably

with density. Numerosity judgments with constant density were statistically more precise than those for constant area, unlikely if numerosity judgments depended on density. And numerosity judgments with constant numerosity showed no tendency to follow density (although there was a slight tendency for density judgments to follow numerosity). In a separate experiment we show that apparent numerosity decreases with luminance, by about 8% per log-unit, while density of random square patterns is totally independent of luminance. We conclude that numerosity is a primary sensory quality like shape or colour, enabling rough estimates of number to be made directly, without the intervention of counting or other cognitive mechanisms.

◆ **Perceptual rivalry in tri-stable stimuli**

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When the visual system is confronted with multiple equally probable interpretations of a scene, perception typically switches between these alternatives. The timing of these alternations is widely considered to be spontaneous and unpredictable. Under laboratory conditions, such perceptual rivalry is often studied by presenting stimuli that allow exactly two possible perceptual interpretations: 'bi-stable' figures. In this situation, the probability of one percept to occur and the probability to remain in the alternative state are inversely related. Hence the probability of a state to occur and its dominance duration cannot be disentangled. Previous studies have overcome this issue by using discontinuous presentation paradigms. Here we suggest an alternative approach that allows presentation to remain uninterrupted: tri-stable figures. Variations of moving plaid stimuli and of overlapping coloured gratings yielded three distinct movement or colour percepts, respectively. We found that the dominance duration of the current percept depended on the preceding perceptual state. Furthermore, the following perceptual state was predicted by the current dominance duration. Our results suggest a lasting effect of preceding perceptual states on subsequent perception. This provides further evidence against a purely stochastic, memory-free account of rivalry, generalizing earlier findings to continuous stimulus presentation.

◆ **Visual perception of peripersonal space depends on motor representation: Evidence from psychophysical and brain imaging studies**

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Target selection for action depends not only on the egocentric location of visual stimuli estimated from optical and oculomotor variables but also on the estimation of current action possibilities. It follows that the perception of the boundary of peripersonal space depends on motor representation. A behavioural study showed that motor adaptation to a biased visual feedback (+3 cm) produced a decrease of movement amplitude with a concomitant shift of the perception of the boundary of peripersonal space. A regression analysis showed that the gradual increase of reaction times with target distance was evident both in the perceptual and the motor task. This is in agreement with Fitt's law. Furthermore, maximum reaction times were registered at the boundary of reachable space and decreased abruptly for targets judged farther than this distance, suggesting different cognitive processes for near and far targets. A relationship between perception and action in reachability judgment has been also shown in an fMRI study. Data revealed that perceptually determining what is reachable activated a frontoparietal brain network including the cerebellum. In particular, the activation of the cerebellum depended on target location and correlated with reaction times. Overall, the results indicate that motor representation contains information about the dynamic behaviour of the body in relation to the environment and can interact with the visual system to specify the boundary of peripersonal space.

VIELBERTH LECTURE

◆ **The extraction of 3-D shape: a story of gradients, neurons, and images**

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Human and nonhuman primates can recover the third dimension of shape, depth structure, from four cues: shading, texture, motion and disparity. We begin to understand how this is achieved by the primate visual system. Three cues, texture, motion, and disparity are treated in relatively similar ways. In macaque three parietal regions, CIP, anterior LIP, and AIP house neurons selective for first or second order gradients of texture, speed, or disparity. In humans four parietal regions are involved, the anterior two of which might be homologous of the two anterior IPS regions in monkey. The main species difference is a weaker sensitivity for the motion cue in macaque compared to human. In the macaque ventral visual pathway fewer regions are involved: MT/V5 and FST for motion, TEs for disparity, and TEO for texture.

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In humans similarly only few regions, located in or below the hMT/V5+ complex, are involved. These ventral regions also house gradients selective neurons. The shading cue appears to be processed only in the ventral pathway: in TEO and posterior TE in the monkey, and in a corresponding region in caudal ITG in humans. The neuronal mechanism is still unclear and might include more than just the extraction of luminance gradients. All regions involved in processing depth structure also process 2-D shape, and hence can provide a complete description of 3-D shape.

POSTER SESSION

PERCEPTION AND ACTION

◆ **The influence of the current situation on the recall of survey knowledge: the case of location and body orientation**

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Theories of situated and embodied cognition have been gaining more and more attention recently. We examined the influence of the current situation (ie, location and orientation) on accessing spatial memory of locations within one's city of residence. Tübingen residents produced a simple map of the city centre, by arranging small badges representing well-known locations on a sheet of paper. Participants produced the maps at different locations relative to the city centre (north of, east of, etc) and in different body orientations (facing north, east, etc). We analyzed the orientation of these maps (north up, east up, etc). We found an influence of location and body orientation on the orientation of the maps. Participants produced maps in the orientation they were facing more often than expected by chance (eg, produced an east up map when facing east). Participants also oriented the maps according to their viewpoint more often than expected by chance (eg, produced a west up map when located east of the city centre). These results indicate that participants do not just access spatial long-term memory of their city of residence, but that they adjust it according to their current situation.

◆ **Shape, lightness, and affordances**

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In Simon tasks, performance is better when the position of an object's handle corresponds to the position of the response (AE, affordance effect). However when participants are asked to discriminate the colour of an object (eg green vs red), the AE is not found. It appears as if surface colour is a feature that can be processed independently from shape. In this study we tested the AE in conditions in which surface colour cannot be easily disjoined from shape. We used a lightness illusion devised by Anderson and Winawer (2005 *Nature* **434** 79–83) as a tool to entangle surface colour with shape. A Simon task was implemented in which participants were required to discriminate the lightness (light grey vs dark grey) of familiar object silhouettes with handles oriented right or left by pressing one of two right/left response keys. Stimulus location was also evaluated by presenting the objects at two different depths. Results show a significant AE with a larger effect in the first blocks of trials. The AE is also affected by stimulus distance in our setup. Our findings suggest (a) that lightness is tightly entangled with surface-shape perception, and (b) that the robustness of the AE is modulated by learning.

◆ **The effect of spatial distractors on visuomotor responses depends on their detection: evidence for no dissociation between perception and action**

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The dominant model of dissociation between perception and action has recently been challenged by studies assessing both perceptual and motor responses on each trial. In this context, the present study was designed to test whether the effect of spatial distractors on visuomotor responses depends on their detection. Eight participants performed a pointing task to a target presented at 10° distance and 45° eccentricity to the left or right of the fixation point. In 75% of the trials, a 10 ms near-threshold distractor appeared 80 ms before the target unilaterally or bilaterally at 30° eccentricity with respect to the target. On each trial, participants judged the presence/absence of the distractor for both sides. Compared to the baseline (Correct Rejections, ie distractor absent and not detected), results showed shorter latencies ($p < 0.01$) and trajectory deviations toward

the perceived distractor ($p < 0.05$) only for hits (distractor present and perceived) for both type of presentation (unilateral and bilateral). In conclusion, the distractor must be both present and perceived to affect the motor responses. These results are in line with previous data which suggest that the two streams within the visual system, instead of being independent, may use the same visual input with different decisional indices.

◆ **Saccadic latency and predictability of stimulus location influence the effect of the Müller-Lyer illusion on saccades**

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Effects of visual illusions on saccadic eye movements have been found to be highly variable. In this study we try to find out whether experimental differences such as predictability of saccade direction, stimulus duration and saccadic latency can explain part of this variability. Subjects are asked to make a saccade from one end of a Müller-Lyer figure to the other end. By changing the predictability of the location of the stimulus, we show that the illusion has a moderate effect on saccades (16%) when the stimulus is at a highly predictable location. This amount increases when the stimulus location becomes more unpredictable (up to 23%). No difference in illusion effect is found between long and short stimulus durations. Additionally, the illusion effect was calculated for different saccadic latencies. For very short latencies a maximum illusion effect of about 30% is found, which decreases by 6% with every 100 ms latency increase. We conclude that predictability of the stimulus location and saccadic latency influence the effect of the Müller-Lyer illusion on saccades.

◆ **Vertical and horizontal eye and head movements during locomotion and simultaneous stimulus pursuit**

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The ability to keep stable fixation is important for some visual tasks. Locomotion causes translational head movements (HM; bob, heave), which need to be compensated to achieve stable fixation, either by rotational HM (pitch, yaw) or eye movements (EM) or both. Here we examined these HM and EM compensations in the case of simultaneous stimulus pursuit. Participants moved on a treadmill, fixating a stationary or oscillating spot, while EM were recorded with an eye tracker and HM with a motion capture system. We examined discrepancies between eye and stimulus position, and compensation by EM and rotational HM. For vertical and horizontal pursuit movements, vertical and horizontal EM compensated only partially, and rotational HM contributed only sporadically, and more for walking. Correlations between stimulus motion and EM were highest for standing and lowest for running. For all stimulus conditions, the amount and the variability of fixation deviations increased from standing to walking and running. The results show that EM can be used simultaneously to compensate reflexively (VOR) for movement distortions and to actively pursue a moving stimulus while walking or running. Accuracy of stimulus fixation is more detrimentally affected by running.

◆ **Sensorimotor adaptation to a biased feedback modifies the visual perception of peripersonal space**

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Target selection for action depends not only on the egocentric location of objects estimated from optical and ocularmotor variables but also on the assessment of current action possibilities. In the present study, we investigated the effect of a transient visuomotor adaptation to a +3 cm shift of the end-point visual feedback on the subsequent perceptual estimates of what is reachable. In the control group (no biased feedback), motor performances were accurate and the perceived boundary of what is reachable slightly overestimated action capabilities. Adaptation to the biased feedback (experimental group) resulted in a decrease of movement amplitude (−3.7 cm) with a concomitant shift of where the boundary of what is reachable was perceived (−3.5 cm). Regression analysis showed that reaction time increased gradually in the perceptual and the motor task with target distance, thus in agreement with Fitt's law. Maximum reaction time occurred at a distance corresponding to the boundary of reachable space and decreased abruptly for targets located farther than this distance, suggesting different visual processes for near and far targets. These data suggest that perceiving visually what is reachable depends on motor representations and is thus affected by sensorimotor adaptation. We discuss the possibility that motor representation contains information about the dynamic behaviour of the body in relation to the environment and can interact with the visual system to specify the boundary of peripersonal space.

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◆ **Prior observation or production of a motor action improves the perception of biological motion: Evidence for a gender effect**

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This study aimed at testing the effect of prior visual observation of a human motor performance on the perception of biological motion. Participants were exposed to a video sequence showing either a running man (visual priming) or a moving car (neutral priming) before being required to judge the direction of a point-light display of a runner embedded in a high density dynamical mask. Results showed that perceptual correct judgments improved and response time increased in the visual priming condition compared to the neutral priming condition in which judgments were at random. Because this effect was observed for males only, we performed a second experiment with the aim of evaluating the role of gender congruency in the visual priming condition. Six groups of participants composed of either males or females performed a point-light display discrimination task after having received neutral, visual-male or visual-female priming information. Results showed that point light display judgments improved in the visual priming conditions with a concomitant increase of response time, but this effect was dependent on the gender congruency between the observer and the priming information. Finally, we showed that producing oneself a motor activity similar to the one observed in the video sequence improved participants' performance to the same extent when judging the point light display, without any gender difference. Overall these findings argue in favour of common representational medium for the perception and production of motor action and show that the perception of biological motion can be improved by both actual motor activity and action-related visual information. However, visual priming effect were found to be broadly dependent on matching gender of the prime with that of the observer, suggesting a gender specificity of stored motor repertoire in human.

◆ **Dual egocenter hypothesis on angular errors in manual pointing**

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We examined the dual egocenter hypothesis that a target is pointed to as if its direction were judged from a kinesthetic (visual) egocenter in visually-directed (kinesthetically-directed) pointing, in which a visually (kinesthetically) memorized target is pointed, immediately after the direction is judged from a visual (kinesthetic) egocenter. Fifteen observers showed that angular differences between directions from the visual egocenter and those from the kinesthetic egocenter in the visually-directed pointing increased linearly as a function of those between directions from the kinesthetic egocenter and those from the visual egocenter in the kinesthetically-directed pointing, with unity slope and nearly zero intercept. The result supported the hypothesis that directions represented in visual space are transferred to kinesthetic space in visually-directed pointing and those represented in kinesthetic space are transferred to visual space in kinesthetically-directed pointing.

◆ **Observer's control of the moving stimulus increases the flash-lag effect**

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The flash-lag effect (FLE) consists in perceiving a briefly presented stationary stimulus to lag behind an aligned moving stimulus. In a first experiment (Scocchia and Baud-Bovy, 2005 *Perception* 34 Supplement, 245), we found that the FLE was larger when participants controlled the moving stimulus by means of a robotic arm (visuo-motor condition), compared to a computer-controlled condition (visual condition). Here, we addressed the possibility that the observed modulation of the FLE was due to attentional rather than to motor factors in a second experiment, which comprised four conditions: two conditions replicated the first experiment whereas in the other two conditions participants were required, respectively, (i) to perform the same task as in the visuo-motor condition, but their movement no longer produced the moving stimulus movement, which was computer-controlled, and (ii) to click the mouse as soon as they detected a change in shape of the moving stimulus. The results show that the increase in FLE magnitude observed when participants exert an active control on the position of visual stimuli can be ascribed to a specific visuo-motor interaction, rather than to possible attentional effects, namely, of (i) double-task factors, and (ii) spatial attention.

◆ **Stimulus compliance influences the force of the exploratory movement**

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We investigated the effect of stimulus and task properties on the control of exploratory movements in active touch. In Experiment 1 we varied the compliance of silicon rubber stimuli with deformable surfaces. Participants freely explored pairs of lowly compliant stimuli (harder condition) or of highly compliant stimuli (softer condition) with a bare finger, and were asked to select the softer one. Pairs from the two conditions were presented either block-wise, or in randomized order (blocked vs randomized session). In the blocked session, exploratory force was always higher for the harder than for the softer stimuli (long-term adjustment). In randomized sessions force was only higher for the harder stimuli that were explored as second within a trial and it did not differ between softness conditions for the firstly explored stimuli, indicating even short-term movement adjustment. In Experiment 2 we, additionally, varied task difficulty by using a large vs a small compliance difference between the two stimuli of each pair. Participants applied higher forces in order to discriminate difficult pairs, probably in order to improve their perception. This effect was observed in blocked, but not in randomized sessions, indicating that strategic adaptations to task difficulty are slower than those to stimulus properties.

SPATIAL VISION

◆ **The role of integrated head and body orientation on the allocation of spatial attention**

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A key requirement for reciprocal social interaction is the computation of the direction in which others are attending. To this end, humans rely on a multiplicity of social cues. An unanswered question is how exactly we decode the interrelation between different human body parts across orientations on the direction of attention. Previously, two models of the inter-cue relationships have been proposed: (a) a normal congruity effect of the eye-head relationship, with shorter RTs when both cues are oriented congruently (Langton and Bruce, 1999 *Visual Cognition* 6 541–567; Driver et al, 1999 *Visual Cognition* 6 509–540) and (b), a reverse congruity effect of the eye-body relationship, in which incongruently oriented body parts suggest an action component involved in the human pose (Hietanen, 1999 *Psychological Research* 66 174–179; Seyama and Nagayama, 2005 *Visual Cognition* 12 103–116). The present study aimed to clarify the role of body orientation in the computation of direction-of-attention. We first provide further evidence that the visual mechanisms involved in social attentional orienting integrate body and head orientation. Next, we show that an action component, resulting from a reverse congruity effect of the head–body relationship, affects the perceived attention direction. The results are discussed in terms of current models of inter-cue relationships and models describing the computation of direction-of-attention.

◆ **Senescent changes in photopic spatial summation in the peripheral retina**

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The size of the area over which there is complete spatial summation is inversely related to ganglion cell density at the corresponding retinal eccentricity. Here we address the question of how age-related losses in photoreceptor and ganglion cell density affect spatial summation. Contrast detection thresholds were measured in a group of younger (average age 21 years) and older (average age 73 years) subjects for stimuli presented at 6 deg in the nasal retina. The stimulus was a 4 cycles deg⁻¹ vertical Gabor patch with stimulus area varying from 0.13 to 12.56 deg². A Maxwellian-view optical system with an artificial pupil was used to maintain constant retinal illuminance (~76 Troland) across subjects. Data were fitted with a bilinear function (slopes of 0.5 and 0) using a least-squares criterion when log thresholds were plotted as a function of log stimulus area. The inflection point of the fitted lines defines the area of complete spatial summation. Older subjects show a statistically significant enlargement of summation area and an elevation of contrast detection thresholds compared to younger subjects. Increases in the summation area may be due to neural remodeling of cortical cells resulting in senescent modification of spatiotemporal channels following age-related losses in ganglion cells. [Supported by a National Institute on Aging grant AG04058].

◆ **Visual acuity in x , y , and z**

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The more a stimulus is presented in the visual eccentricity, the smaller the probability to recognize it due to decreasing visual acuity. The decline of acuity has been quantified for the horizontal

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dimension (x -axis), and for the vertical dimension (y -axis). For depth, that is for the z -axis, however, the decline is still unknown and might be traced back to performance assessment problems. We developed a set-up that allows assessment of performance at various distances in depth. With this set-up we measured letter recognition performance at 3° , 6° , and 9° of eccentricity in all three dimensions: left of fixation (x -direction), above fixation (y -direction), and behind fixation (z -direction). The data replicated the already known effects of eccentricity and of the inferiority of vertical relative to horizontal acuity. Additionally, the worst performances were observed for the z -direction. This inferiority was even stronger for binocular relative to monocular viewing, which can be traced back to double images evolving in binocular vision. As expected, further results show that performances for virtual depth are much better than in real depth. Implications for stereoscopic viewing as well as for models of visual perception are discussed.

◆ **The effect of prior information about symmetry axis on symmetry detection**

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In a symmetric display, each part of the stimulus is a reflection of another part about an axis. We investigated how the prior information about symmetry axis affects symmetry detection. The target stimuli were random dot displays structured to be symmetric about a randomly-chosen axis that was either vertical, horizontal, or one of the two diagonals. In each trial, either the target or a non-symmetric pattern was superimposed on random-dot mask. The observers' task was to determine whether the target was presented. The stimuli were viewed through eight apertures (1 deg diameter) evenly distributed around a 6 deg diameter circle. The information about the axis was manipulated by (i) cuing of axis orientation before the trial, and (ii) salience: whether the apertures were on- or off-axis. The percentage of correctly detecting symmetry was measured at different target and mask densities. The slope of the psychometric functions was about constant regardless axis manipulation, suggesting that the slope was set by a neural processing property rather being a function of uncertainty level. When the axes were visible and/or cued, the target threshold decreased 10-fold. The target threshold vs mask density function was flat at low mask density and increased with a slope of one beyond a critical density. Thus, knowledge of the axis location increases sensitivity to symmetry without affecting the level of uncertainty about the axis.

◆ **Effects of orientation contrast and spatial frequency on metacontrast masking**

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In the classic metacontrast paradigm a small disk is presented briefly (eg 30 ms) followed after some critical temporal interval by a surrounding annulus. At stimulus onset asynchronies (SOAs) roughly around 50 ms the disk's visibility is strongly reduced. The spatiotemporal properties of masking were manipulated using a Gabor patch as target and an annulus with a sinusoidal grating and a Gaussian envelope as mask. We varied spatial frequency, orientation contrast and SOA between target and mask, and recorded subjective visibility ratings, individually normalized by means of ratings for target- and mask-only trials. We fitted a descriptive masking function to the data and analyzed the strength of masking as well as the SOA where masking was optimal (SOA_{max}). We found that the strength of masking is negatively correlated with spatial frequency, as well as orientation contrast. Furthermore, we found a linear relationship between SOA_{max} and orientation contrast. The effect of spatial frequency on masking strength is well explained by different contributions of sustained and transient visual channels to masking. The effect of orientation contrast on masking strength and SOA_{max} may be explained by the propagation of inhibitory signals along orientation columns in early visual areas.

◆ **The FrACT goes hyperacute: Automatic measurement of vernier acuity**

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One of the key determinants of spatial vision—visual resolution—is easily measured by the Freiburg Visual Acuity and Contrast Test (FrACT). The subjective 'easiness' of the test is particularly due to the intuitive task design, a self-paced trial progress, and the low number of total trials, allowing robust threshold estimates after only 24 subject responses. Here, we set to investigate whether visual hyperacuity (vernier acuity) can be measured with similar procedures on a comparable high level of threshold reproducibility. Because humans can detect the relative offset in a pair of abutting lines to very small degrees, tests of vernier acuity usually demand high-resolution display devices or large observer distances. The optotypes presented here utilize anti-aliased, Gaussian luminance profiles, granting feasible observer distances and the use of

off-the-shelf computer displays and equipment. To build a representative dataset, we compared monocular and binocular normal (Landolt) acuity with monocular and binocular hyperacuity in 60 healthy eyes of thirty young subjects. The results confirm a linear relationship between acuity and hyperacuity and verify typical binocular summation ratios reported earlier for similar tasks. Relations between vernier acuity and optical quality of the subjects' eyes are discussed.

- ◆ **The disparity and contrast sensitivity function compared: new insights from barn owl vision**
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The spatial resolution of stereovision is a key determinant of shape perception. By presenting binocular pairs of random-dot patterns, wherein binocular disparity is a periodically modulated function of position, the spatial resolution of shape-from-stereo can be measured. Such corrugated random-dot stereograms (RDSs) produce gratings-in-depth, thereby providing a technique of relating shape sensitivity to corrugation frequencies. This relationship is known only from human psychophysics where it is used to define the disparity-contrast sensitivity function (DSF). The human DSF is characteristically inverted U-shaped. Thus, stereo resolution is the highest at an intermediate frequency, reflecting bandwidth limited properties of stereo acuity. Here, we present a series of RDS-based psychophysical experiments determining the DSFs in two barn owls and two humans. The tested bandwidths spanned 3–4 octaves. Compared to the human DSF, the owls' maximal sensitivity was shifted towards the low spatial frequency end (owl: 0.09–0.17 cycle deg⁻¹; man: 0.35–0.57 cycle deg⁻¹). In contrast to our human observers, the owls showed a relative insensitivity to horizontally, rather than vertically, oriented corrugations at low frequencies. In conclusion, the computational strategies adopted for shape-from-stereo in owls and humans are closely similar in the sense that both bandwidth-limitation and corrugation-orientation selective mechanisms play a critical role.

- ◆ **Texture segmentation: top-down influences on the detection of pop-out targets?**
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Texture segmentation is generally attributed to bottom-up mechanisms of stimulus processing. We tested if performance in a classical texture segmentation task could be mediated by top-down factors. Textures comprised elements of varying orientation and/or luminance. In addition to the task-relevant target patch, stimuli contained task-irrelevant texture edges in either the same feature dimension as the target or in a different one. In Experiment 1 conditions were presented in blocks, so that subjects knew which would be the target-defining dimension in the next trial. By means of a top-down weighting mechanism subjects should be able to increase their performance in conditions in which target and irrelevant edges were defined in different dimensions. Consistent with this prediction results demonstrated that texture edges had less detrimental effects on performance if they were not in the same dimension as the target. In Experiment 2 stimuli were presented in randomized order to prevent any top-down weighting of feature dimensions. However, the pattern of results was comparable to that of Experiment 1, indicating that observed differences in performance between conditions cannot be attributed to top-down influences.

- ◆ **Two contextual pairs of spots in the illusion of extent**
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In the interpolated Brentano figure, the imaginary wings were formed of two pairs of contextual spots. The positions of the wing spots in the first pair were fixed at the same distance from the stimulus terminator spots. The positions of the spots in the second pair varied and were distributed evenly around an appropriate first-pair-spot with the same distance, within an imaginary radius. The radius tilt angle was considered as an independent variable in the measurements of the strength of the illusion of extent. The experimental data suggested additive distracting effects caused by the two pairs of the contextual spots when they were present on the same terminator side and formed particular patterns. The minimum strength showed subtraction of the effects when the two pairs of the contextual spots appeared on the opposite sides of the stimulus terminator spots. The concept of centroid biases (Morgan et al, 1990 *Vision Research* **30** 1793–1810) has been employed for quantitative modeling of the experimental data obtained.

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◆ **Modulation of the redundant signal effect by target eccentricity**

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The present study examines whether interhemispheric neural summation is affected by the eccentricity of visual stimuli in the visual field. We used a redundant signal effect (RSE) paradigm, with visual stimuli (red or blue) presented at different eccentricities to one or both hemifields in normal participants. Subjects responded more quickly to bilateral stimuli than to unilateral ones (ie RSE). Confirming previous findings, a RSE explainable by neural coactivation occurred only with red stimuli, visible to the superior colliculus (SC), whereas blue stimuli, invisible to the SC, yielded a probabilistic RSE. Critically the RSE was explained by neural coactivation only when red stimuli were presented in the periphery of the visual field; instead, centrally located stimuli always yielded a RSE of the probabilistic type, regardless of stimulus colour. Our results provide novel evidence that interhemispheric neural summation, which likely involves the SC, critically depends on the spatial localization of the targets within the visual field.

◆ **Effects of ISI on tailgate blindness**

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Masking makes it difficult to attend to a target without also attending to its mask. However, by presenting the target at multiple locations (each masked) in an apparent motion sequence (Cavanagh et al, 2008 *Journal of Vision*), observers are able to attentively track the repeating target and avoid the masks that precede and follow it at each location. Surprisingly, once the target is isolated, it is clear that it has not been degraded nor integrated with a persisting mask, instead, it has vanished—the location in the moving sequence where the target should be present appears empty. Most likely, the masks suppress the onset and offset transients of the target, rendering an otherwise suprathreshold stimulus invisible (cf Motoyoshi, 2008 *Vision Sciences*). Here we compare the contribution of the onset and the offset transients to this loss of visibility for the moving target. When an ISI was inserted between the preceding mask and the target, visibility and performance rose quickly. Placing the ISI between the target letter and the trailing mask, however, produced little advantage. These results suggest that target visibility requires a strong onset transient: when the target follows a preceding mask too closely, its onset transient is lost and the target fails to reach awareness.

◆ **Perceptual prevalence of the fine structure of natural images revealed using visual chimeras**
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The relative perceptual importance of first-order fine spatial structure and second-order large-scale variations of local contrast in natural images can be shown by means of stimuli with conflicting information from fine structure and local contrast. In correspondence with auditory chimeras (Smith et al, 2002 *Nature* 416 87), a visual chimera is a synthetic image which has the fine spatial structure (FM carrier) of one image and the local contrast (envelope) of another image in each spatial frequency band. To synthesize it, a pair of images was used as input of a bank of isotropic filters, the output of each filter was factored into envelope and carrier, and then they were multiplicatively mixed for each spatial-frequency band. To compute image envelope and carrier in each band we used the Riesz transform (an isotropic generalization of the Hilbert transform for multidimensional signals) and the associated monogenic signal (the vector-valued function counterpart of the analytic signal). Both in single-band and in multi-band visual chimeras of natural images, our results show that the image identified by the observers in a visual chimera came from the FM carrier irrespective of centre spatial frequencies, bandwidths, and number of spatial-frequency bands used for synthesis, thus the information present in the FM carrier completely dominates over the information present in the envelope. This perceptual prevalence of the fine structure of images is surprising if one considers the existence of a special second-order vision exclusively devoted to the processing of the spatiotemporal envelope of visual stimuli.

◆ **Attraction of empty spaces: an experiment on attention process**

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It seems that the presence of distractors and their features are important in attention process. To test this hypothesis we verified the influence of number, distance and shape of distractors on negative priming. Ten subjects participated in a 3-step computerized experiment, in which the

reaction-times of 1 vs 2 distractors trials, near vs far distractor trials, and same vs different distractor trials, were analyzed. The 'negative priming effect' was significantly less in two distractors than one distractor trials. (+35 vs +11 ms) Surprisingly we detected facilitated responding to blank space(s) in controls, with significantly more facilitation in 2 distractor trials (-22 vs -62 ms). In addition, the presence of target in the location of previous target or distractor(s) both elongated the reaction-time. The shape and distance of distractors did not affect the suppression. We conclude that any filled space becomes suppressed, and empty spaces attract the attention. The increase in the number of distractors reduces the effect of negative priming, meaning that the suppression of distractors is divided. This is also true about the division of attention between empty spaces in control trials. Ineffectiveness of the distractors features on suppression implies again that the presence of distractors is more important than their characteristics.

◆ **Perceptual biases in judging the separation between objects**

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One of the primary goals of early visual analysis is to accurately encode the distance between objects in visual space. In this study, observers were asked to estimate the separation between luminance-defined and contrast-defined patches—a spatial interval task. Seven different stimulus sizes, presented at a range of separations, were randomly interleaved within a method of constant stimuli. From the resulting data we calculated the physical separation required for each size to be perceived as equal to the mean of the set. For luminance-defined patches, large stimulus sizes required a much greater separation in order to equate perceived separation with small stimulus sizes. This relationship was linear and unrelated to the perceived position of stimulus edges. On the other hand, the perceived separation between contrast-defined targets was unaffected by stimulus size. Instead, for a fixed stimulus size, perceived separation was reliably modulated by systematically changing the spatial frequency of the background. These results demonstrate that the spatial scale of visual analysis has a marked influence on the way we encode relative position. Moreover, these perceptual distortions of space may underpin motion misperceptions, such as the Brown illusion, where the perceived speed of an object is influenced by its size.

◆ **Cross- vs within-channel masking in contrast discrimination**

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Cross-surround (orthogonal to target orientation) facilitation is a robust phenomenon, minimally affected by contrast of surround stimuli; iso-surround (identical to target orientation) facilitation is a fragile effect and is easily disturbed by the surround contrast (Yu et al, 2002 *Journal of Vision* 2 243–255). Cross- and iso-oriented surround stimuli are thought to affect sensitivity to the target stimulus by cross- and within-channel masking, respectively. Flanking Gabor stimuli arranged in a 'chain' (stimuli arranged laterally in a row) have been used in contrast sensitivity experiments. However, the role of iso- and cross-oriented flanker contrast in contrast discrimination (CD) is not well understood. The present study examined the effect of flanker contrast (30% and 70%) on CD in cross- and iso-oriented chain flanker conditions. CD thresholds were measured in each of four conditions (cross-30, cross-70, iso-30 and iso-70) in ten normally-sighted adults using a temporal two-alternative forced-choice adaptive staircase procedure. We found that CD is not affected by contrast of cross-oriented flankers. However, for iso-oriented flankers, low contrast (iso-30) was found to facilitate CD compared to high contrast flankers. Our results are consistent with previous work on surround modulation, suggesting that cross- and within-channel masking are processed similarly in chain flankers as well as surround masking stimuli in CD.

◆ **Age-related differences in temporal processing**

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Visual backward masking paradigm, as determined with the shine-through effect, is a very sensitive tool to detect age related differences in visual temporal processing. We presented a vernier offset to the left or right followed by a grating mask which impedes vernier offset discrimination. Because of the use of such a vernier acuity task, visual deficits are unlikely caused by optical deficiencies. In the first experiment, we found strongly deteriorated masking performance of

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elderly from 60 years on and teenagers basically from 7 to 13 years compared to controls aged between 18 and 32 years. In a second experiment, we varied the spatial and temporal layout of the mask, for example, by inserting a small gap in the grating mask. With these manipulations, processing deficits in elderly turned out to be very different from the teenagers' ones. Teenagers were sensitive to the gaps (and other manipulations) whereas elderly were not—possibly because elderly low-pass filter visual information, such as the gaps, related to a loss of retinal and other neurons.

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◆ **Pattern types influence creation of colour based Boolean maps**

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The Boolean map theory proposes that visual search requires sequential creation of spatial representations—Boolean maps (Huang and Pashler, 2007 *Psychological Review* **114** 599–631). Subjects viewed couples of targets, made of randomly scattered red, green, yellow, and blue squares (four in each colour) forming a square pattern. Half of the time targets in couples were different, replicating the original conditions: (ABBA) A-coloured square changed to colour B, B-coloured square to colour A; (ABCD) A-coloured square changed to colour B, C-coloured square to colour D. However, original results were not replicated suggesting that some visual information is available before the maps creation, influencing the formation sequence. We modified the ABBA condition keeping the type of change: (AAAA) the targets consisted of eight A-coloured squares, or; (AAAB) of two A-coloured squares; and the rest were B-, C-, and D-coloured. The subjects displayed higher RTs responding to the two additional conditions, in relation to the original conditions, but there was no difference between the two conditions. Dependence of reaction time on types of colour patterns used, even when the amount of change and the number of colour patterns affected were equal, showed that some information was accessible before maps were created.

◆ **Distinguishing lateral interaction from uncertainty reduction in collinear flanker facilitation of contrast discrimination**

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To clarify the role of lateral interaction and uncertainty reduction in collinear flanker facilitation of contrast discrimination, we investigated the effect of flankers and spatial cueing on the contrast discrimination threshold. Five observers participated in this study. The task of observers was to detect a 1.3 cycles deg⁻¹ vertical Gabor target superimposed on one of the Gabor pedestals presented at 3 deg to the left and right of the fixation point. We measured the target-threshold vs pedestal-contrast (TvC) functions in four (2 × 2) conditions: with or without the presence of collinear flankers and with or without a spatial cue indicating the location of the target prior to presentation of the target. The presence of the flankers decreased the target threshold at low pedestal contrasts but increased the threshold at high pedestal contrasts, while the presence of spatial cues decreased the target threshold at all pedestal contrasts regardless of the flanker condition. The flanker effect was similar in cued and non-cued conditions, suggesting that the flanker effect was similar regardless the uncertainty level. The TvC functions fit well with a divisive inhibition model in which the presence of collinear flankers increases both the excitatory and inhibitory terms of a divisive inhibition response function, while cueing only increases the excitatory term.

◆ **Detection of second-order Gabor patterns of different lengths, widths and spatial frequencies**

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Contrast thresholds of vertical second-order Gabor patterns with spatial frequency (SF) of 1.45, 2.9, and 5.8 cycles deg⁻¹ were measured as a function of their width and length, using 2AFC method. To evaluate the spatial summation properties of underlying mechanisms, second-order threshold contrast energy (TCE) was calculated for all stimulus sizes used and the place of the minimal second-order TCE along the length and the width was determined. It was found that the length corresponding to the minimal second-order TCE is slightly greater than the width corresponding to minimal second-order TCE. The decrease of the SF from 5.8 to 2.9 cycles deg⁻¹ shifted the place of the minimal second-order TCE to approximately two times greater values of both stimulus length and width. However, further SF decrease from 2.9 to 1.45 cycles deg⁻¹ shifted the minimum of the second-order TCE along the length and the width by a factor less than 2 or even did not shift the minimum at all. The results are in accordance with a model in

which the underlying mechanism is an array of slightly elongated receptive fields and of a size that is inversely proportional to the preferable SF within some limits.
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◆ **Global pooling in shape perception**

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Humans are remarkably sensitive in detecting minute deviations from circularity, an ability dependent upon mechanisms summing information along entire contours. The aim of this study was to determine if global summation is specific to circles or a more universal feature of shape processing. Contour discrimination was measured for radial frequency patterns, defined by their number of lobes (frequency) and the 'sharpness' of each lobe (amplitude). Thresholds were determined for shapes of 3 and 5 lobes, each with amplitudes ranging between 0 (ie discrimination against a circle) and $20\times$ detection thresholds (eg discriminating five-sided star-shapes). The ability to integrate information along contours was measured by applying deformations to various fractions of the contours. Discrimination thresholds remain in the hyperacuity range for amplitudes up to $2.5\times$, but increase for higher amplitudes. Comparing performance when deformation is applied to contour fractions shows significant global pooling. There are no systematic differences in the amount of global pooling across the range of shapes tested. Global pooling, therefore, is not restricted to circles but also evident for non-circular contours. Similarities with respect to the nature and extent of global processing suggest that analogous channels might process various contour shapes.

◆ **Are observers robust when localizing simple 'uncontaminated' dot clusters?**

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When localizing composite dot clusters, observers assign less weight to dots in a smaller sub-cluster to the extent that they can segment it laterally from the larger, main cluster (Juni and Singh, OPAM2006). This segmentation-based robustness can occur even when the smaller sub-cluster lies entirely within the larger cluster (Juni et al, VSS2008). Here we test whether the visual system down-weights eccentric dots when localizing simple clusters lacking segmentation cues (no contaminating dots added). Stimuli: Isotropic clusters containing 100 dots were drawn either from a bivariate Gaussian ($SD = 0.893^\circ$) or from a comparably scaled t -distribution. In a 2AFC task, observers indicated whether the cluster's center was to the right or left of a reference. Analysis: We used a generalized linear model to estimate the influence of the dots on observers' PSE as a function of their binned horizontal location. This influence was compared against the prediction of a simple center-of-gravity model. Results: For both distributions, only a minority of observers exhibited an influence of the most eccentric dots that was less than the COG model. Conclusion: Most observers do not exhibit robustness in the absence of segmentation cues; however such 'statistician's robustness' is not impossible as evidenced by some observers.

◆ **Perception of numerosity at the time of saccades**

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Recent findings suggest that numerosity is a basic perceptual attribute of visual displays, depending on spatially selective adaptive mechanisms. Here we ask whether perceived numerosity is affected by saccades, which cause transient changes of spatial tuning in many visual areas. Subjects compared the numerosity of two random-dot patterns presented sequentially ($ISI = 1.5$ s): a reference stimulus with numerosity 30 and a test stimulus with variable numerosity. Both were flashed briefly (10 ms), the test at the onset of a 20° rightwards saccade. They were presented at various positions relative to the saccade trajectory. When the test was presented just before or during the saccade, its numerosity was systematically underestimated. The dynamics of the effect was sharp and reproducible across subjects, very similar to the dynamics of localization errors caused by saccades. The perisaccadic reduction of numerosity could not be explained by a mere reduction of visibility for perisaccadic stimuli. Saccades also caused more subtle changes in perceived numerosity lasting over hundreds of milliseconds. After saccade landing, numerosity was overestimated by about 50%, returning to veridicality at about 600 ms post saccade. These findings suggest that saccades affect the representation of numerosity, possibly by triggering the

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remapping of visual representations in a network of frontoparietal areas known to be involved in the processing of space, time and numerosity.

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◆ **An Oppel-Kundt figure with various patterns in the filled intervals**

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In the modified Oppel-Kundt figure formed of spots, the empty test interval was flanked by two filled referential intervals. The error value of the length matching between the test and references was measured as a function of the number of the filling spots in random presentations of the stimuli with different spot number. In different experiments, the order of the filling varied: (a) the spot sequences started in the centers of the referential intervals and drifted toward their ends; (b) they started at both ends and drifted toward the centers; (c) the sequences started at the middle or lateral ends and drifted outwards toward the opposite sides. Complete filling comprised 12 evenly distributed spots. According to the experimental curves, the spots at the ends of the referential intervals contributed to the illusion more effectively than those in the centers, independently on the filling order. The effectiveness of the spots at the middle and lateral locations of the referential intervals was about the same. The data obtained are consistent with the model of information integration (Erdfelder et al, 1994 *Zeitschrift für Psychologie mit Zeitschrift für Angewandte Psychologie* **202** 133–160).

◆ **Camouflaged symmetry**

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A technique to visually camouflage plane symmetry groups in 2-D natural textures is introduced. Two experiments tested discriminability of symmetry groups $p1$ (translation), $p2$ (rotation), pm (reflection), and pg (glide reflection) in 4-oddity and 5AFC designs, using different or same textures per set of stimulus pictures, respectively. Detection of $p1$ was enhanced by pm distractors, and impaired by those of pg , in 4-oddity. $p2$ proved discriminable against $p1$, pg did not, in 5AFC. Findings are interpreted as qualifying broad claims about symmetry as organizational principle of vision. Analysis of task demands and visual search strategies suggests that discrimination of symmetry groups and operations requires scrutinizing sufficiently large ‘regions of integration’ for critical features (Dakin and Herbert, 1998 *Proceedings of the Royal Society of London Series B: Biological Science* **265** 659–664), and as such is a late achievement in visual processing.

FACE PERCEPTION

◆ **Investigating the automaticity of gaze cueing: A saccade curvature analysis**

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In four experiments, we investigated the automaticity of attentional shifts produced by either gaze cues, arrow-cues, or peripheral distractor onsets by comparing their effects on the trajectories of saccades made in the orthogonal direction. In Experiment 1, a gaze-cue, an arrow, or a peripheral distractor appeared simultaneously with the target. Saccades were found to deviate towards the direction indicated by the centrally presented gaze and arrow cues, but deviated away from peripheral distractors. In Experiment 2, the cues appeared 300 ms before the target and saccade trajectories deviated away from the direction specified by both types of central cues and peripheral distractors, but deviations were greater for the peripheral distractors. Experiment 3 showed similar trajectory deviations for photos of faces rather than line drawings and strong effects of gaze direction on saccadic response times. Experiment 4 demonstrated that the strong deviation away for the peripheral distractor was independent of its salience. Our results suggest that arrow and gaze cues can shift someone’s attention, but that this shift might not be as automatic as those induced by peripheral distractor onsets.

◆ **Perception and gaze behaviour: How do we look at faces?**

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Face perception and visual attention play an important role in the judgement of social characteristics. The analysis of gaze behaviour by an eye tracker provides information on how we are looking at faces. The objective of the present study was to determine what we are exactly looking at when estimating the age of a face and whether some features are more influential than others. The eye movements of women exposed to faces demonstrating different signs of aging were tracked.

Twenty-two women from a narrow age cohort were exposed twice to female facial pictures: a first time without any instruction, and a second time with the instruction to estimate the age of the faces shown. Images of the faces showing different signs of aging were from women of three age groups: young (30–39), middle (40–49) and old (50–59). We observed a common behaviour in the group of viewers exposed to female faces whatever the instructions. When subjects were instructed to rate the age of a face, their eyes remained fixated within an area which covers the eyes, the nose and the middle upper part of the mouth. More than 75.5% of all fixations fall within this area, whereas when subjects were instructed to just look at the faces, this area demanded only 64.7% of all fixations. Our results suggest that we mainly look at internal features when estimating the age of a face and we strongly focus on the eyes.

- ◆ **Face recognition and eye movements: landing on the nose is not always necessary**
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Eye movement recordings obtained during prolonged passive viewing of a face usually reveal a concentration of fixation points on informative facial elements—eyes, eyebrows, nose, mouth—the overall eyetrace pattern resembling the test image. However, such patterns have little in common with the process of face recognition. In a recent paper, Hsiao and Cottrell asked “How many fixations do we really need to recognize a face, and where are they located?” (2008 *Psychological Science* 19 998–1006). Their experimental data provide evidence that two fixations suffice and that the first landing position is always on the nose. We verified the validity of these conclusions in other experimental conditions. In particular, the face inspection strategy was modified by varying the initial position of the fixation cross, image size, and face orientation. Eye movements were recorded in twenty subjects. It was confirmed that in most cases 1–2 fixations were indeed sufficient for face recognition. However, the gaze landing positions depended on the experimental condition and demonstrated significant inter-individual variability. The crucial landing points could be situated on the forehead, eyes, mouth, and not always on the nose. These results suggest that the face recognition algorithm is not ‘linked to the nose’.

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- ◆ **The fMRI correlates of multi-face adaptation**
K Nagy, M Zimmer, M W Greenlee¶, G Kovács (Department of Cognitive Sciences, Budapest University of Technology and Economics, Hungary; ¶Psychologie Institut, Universität Regensburg, Germany; e-mail: spenot2@freemail.hu)

Adaptation to a given face leads to face aftereffects. Currently this topic attracts a lot of attention because it clearly shows that adaptation occurs even at the higher stages of visual cortical processing. However, during our every-day life faces are not appearing in isolation, rather they are usually surrounded by other stimuli. Here we used psychophysical and fMRI adaptation methods to test if we adapt to the gender properties of a multiple face stimulus. As adaptors we used stimuli composed of eight different individual faces, positioned peripherally in a ring around fixation spot. We found, that gender discrimination of a subsequent centrally presented target face is significantly biased as a result of long-term (4 s) adaptation to either male or female stimulus composites. Similarly to our previous results (Kovács et al, 2008) we observed the largest fMRI signal adaptation in the right fusiform and in the right occipital face areas. Our results suggest that humans extract the statistical features of a multiple composite stimulus and this process occurs at the level of occipito-temporal face processing.

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- ◆ **Identity aftereffects for familiar faces depend on training and residual information in the test image**
G MacKenzie, R Jenkins, A M Burton (Department of Psychology, University of Glasgow, UK; e-mail: g.mackenzie@psy.gla.ac.uk)

Adaptation has become a popular tool for investigating face perception, and face identity aftereffects may provide support for norm-based coding in ‘face space’. Previous identity aftereffect studies have used computer generated faces, for which participants learn names in a training phase. But if the adaptation technique probes an observer’s face space, it should work without training if familiar faces are used. We tested this hypothesis in five experiments, following the method of Jiang et al (2007 *Vision Research* 47 525–531). We found no significant identity aftereffects using familiar faces without training (Experiment 1). However, a reliable effect was observed when we reinstated the training and test procedures of Jiang et al. Follow-up studies showed that the effect depends on training on the stimulus set (Experiment 3), and residual identity information in the test images (Experiment 4); these factors were necessary for reliable

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identity aftereffects to be observed. Finally, we replaced our faces with inverted contrast-negative faces and found reliable 'identity' aftereffects using these unidentifiable stimuli (Experiment 5). We conclude that standard face adaptation procedures tell us very little about face space, and much more about the ability of experimental subjects to learn arbitrary stimulus sets.

◆ **Sex categorization is influenced by facial information about identity**

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According to Bruce and Young's (1986 *British Journal of Psychology* 77 305–327) classic model of face recognition, sex-related information about a face is accessed independently of information about identity. Therefore familiarity with a face should not influence sex categorization. This issue of independence has remained controversial as it has been supported in some studies and questioned in others. Here we used faces that were presented in two conditions: sex-unchanged and sex-changed. Participants were very familiar with some of the identities. For all participants, the unchanged familiar faces presented congruent identity and sex information while the sex-changed familiar faces presented incongruent identity and sex information. Participants performed a sex categorization task on all familiar and unfamiliar faces presented in the unchanged and sex-changed condition. They were asked to ignore identity and base their responses solely on the sex appearance of the faces. Our results show that participants were slower and less correct for sex-changed than for unchanged familiar faces while those differences did not appear for unfamiliar faces. These results indicate that sex and identity are not independent as participants could not ignore identity information while doing a sex categorization task.

◆ **Encoding of object and face categories by simultaneously recorded local field potentials and single cell activity in the inferior temporal cortex of the macaque monkey**

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We investigate to which extent signals recorded from the inferior temporal (IT) cortex of two macaque monkeys can discriminate between (i) faces vs objects, and (ii) monkey vs human faces. During a fixation task, we simultaneously recorded the local field potential (LFP) and spiking activity of single cells at 202 different sites. On each site we computed (i) visual-evoked potentials (VEP), (ii) single-trial-based instantaneous power and phase for different frequency bands, and (iii) spiking activity of single neurons. Considering the VEPs, specifically the P100 deflection, we found that its onset latency occurred earlier for faces than for objects ($p < 0.01$) and for monkey than for human faces ($p < 0.05$). In contrast, the P100 amplitude did not systematically differentiate between these categories. In the frequency domain, we found that the amount of phase-locking (across trials in single electrodes) of the theta-band around the P100 discriminated between faces/objects and humans/monkeys. Finally, we found that differences in the amount of phase-locking of the gamma-band around P100 between faces/objects were significantly correlated with faces/objects selectivity of single neurons at those locations. Our findings provide novel insights into the neural mechanisms of object and face recognition.

◆ **Are we all prosopagnosics for other race faces?**

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Congenital prosopagnosia, the lifelong inability to recognize faces, and the other race effect (ORE), worse recognition of other race faces compared to own race faces, are two prominent topics in face recognition. Here, we report on a direct experimental comparison of the two phenomena. Previous studies demonstrated that prosopagnosics rely more on featural rather than on holistic facial information. We aimed to control the amount of featural information by different presentation times (PTs) allowing different numbers of saccades. A group of German prosopagnosics, a German control group, and a group of Chinese non-prosopagnosics were shown European faces for short PTs. In the following recognition test we presented targets and distractors under unlimited viewing. For all learning PTs, prosopagnosics performed worse than German controls. In general, Chinese performed worse than German controls but not significantly different from prosopagnosics. Only for the shortest, still pre-saccadic PT, were there no performance differences for Chinese subjects and German controls. Our results demonstrate performance parallels between prosopagnosia and the ORE but also indicate a different time-course in the processing of facial information. The everyday recognition performance impairment of both phenomena might be similar, but their functional background is different.

◆ **Early correlates of face visibility**

M Zimmer, G Kovács¶ (Department of Cognitive Sciences, Budapest University of Technology and Economics, Hungary; ¶ Institute of Psychology, Universität Regensburg, Germany; e-mail: gkovacs@cogsci.bme.hu)

The perception of a briefly presented stimulus is strongly impaired when it is followed by another stimulus, a phenomenon called backward masking (BWM). Here we used event-related potential (ERP) recordings to investigate how neural processing of facial expressions is affected by BWM. To control the visibility of the stimulus we presented different masks (upright face, inverted face, and a noise image) after various stimulus onset asynchronies (SOA). Behavioural data suggest that expression discrimination is affected by BWM and detection of fearful faces is an easier task for humans compared to neutral ones. Since behavioural BWM effects were observed only in the case of neutral faces, in our electrophysiological analyses we concentrated only on these. In the upright face mask condition, similarly to earlier studies (Pegna et al, 2008; Genetti et al, 2009), we found that decreasing the SOA to a value where expression detection was hardly possible reduced the amplitude of face-specific positive (P2) and negative (N2) differential ERP components, peaking around 200 ms and 240 ms after stimulus onset, respectively. Inverted face and noise masks evoked smaller BWM effects and in the later case the amplitude of this differential ERP component was also reduced at the shortest SOA. However, in contrast with previous results, we observed BWM effects on the face-related P100 and N170 components of the ERPs as well. Surprisingly, behavioural masking effect showed significant correlation not only to the amplitude of the P2 component, but also to the amplitude of N170. Our results suggest that the face visibility affects already the early face specific N170 component of the ERP.

◆ **Gender-partitioning of face space and family resemblance**

H J Griffin, A Johnston (Department of Psychology, University College London, UK; e-mail: harry.griffin@ucl.ac.uk)

Psychophysical and neurophysiological evidence suggests that faces are represented in a mean-centred multi-dimensional face space. However, the organization of face space is poorly understood. We assessed whether face space can be partitioned by investigating the perceptual consequences of translating vectors describing male faces relative to the male mean to the female mean and vice versa. We used a markerless morph-vectorisation technique, based on the multi-channel gradient model, to provide vectors describing deviation of shape and texture from an average face. Vectors for male and female faces were subject to separate Principal Components Analysis (PCA). Cross-gender face and antiface pairs were created by mapping mean-relative vectors between male and female PCA spaces. Twenty-four subjects were presented with an original and a synthesized cross-gender partner alongside a distractor pair, which were unrelated. Subjects were asked to indicate which of the pairs were siblings. In a separate experiment we compared anti-face partners and random pairings. Related cross gender pairs were perceptually more similar than random distractor pairs, which were more similar than face-antiface pairs. Face inversion significantly reduced accuracy. The similarity of synthesised siblings indicates that face space can be dynamically partitioned, allowing the extraction of 'family resemblances' in disparate groups of faces.

◆ **Perceptual learning for multiple face orientations**

C A Gomes, M Mendes¶, P Figueiredo§ (School of Psychological Sciences, University of Manchester, UK; ¶ Psychology Department, Centro de Investigação em Psicologia da Universidade de Lisboa, Portugal; § Physics Department, Instituto Superior Técnico, Lisboa, Portugal; e-mail: Carlosalexandre.Gomes@postgrad.manchester.ac.uk)

The well-established face inversion effect refers to a declination of performance for inverted compared to upright faces. However, perceptual learning for faces presented in non-upright orientations has not been systematically investigated. We conducted two experiments in which we investigated perceptual learning for multiple face orientations over short periods of time (Experiment 1) and for a single orientation over long-term training (Experiment 2). In Experiment 1, participants performed a same-different discrimination task (DT) on pairs of faces presented in orientations ranging between 0 and 300°. A quadratic effect was observed across orientations for both reaction times and error rates, indicating a deterioration of performance away from 0° and towards 180°. Moreover, we found that error rates as well as reaction times significantly decreased across blocks of trials, indicating a learning effect. In Experiment 2, participants carried out the DT over the course of four consecutive days (4 sessions) on faces with a single orientation (120°). Here, we observed a main effect of session, indicating that participants became significantly faster and more accurate with training. Finally, when tested with a different orientation (240°) at the end of the last session, participants showed a similar performance compared with the trained orientation (120°), suggesting that transfer of learning across orientations took place.

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◆ **Face selectivity is parameter-dependent in FFA**

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To clarify neural mechanisms underlying face processing, we independently measured responses to six stimulus parameters in fusiform face area (FFA) and control areas (PPA and V1) using otherwise-equivalent fMRI procedures and shared face stimuli. The parameters were contrast level, contrast polarity, rotation in plane, rotation in depth, size, and position. For five of the six parameters, FFA responses were highly correlated with V1 responses. These FFA responses apparently reflected activity occurring in lower cortical areas, unspecialized for face processing. However for contrast polarity, FFA responses were unique. Responses decreased when the contrast polarity of faces was reversed in FFA, but not in V1. This supports a specific role for FFA in face recognition. Equivalent responses ('invariance') to a lower-level feature simplify face/object computations. However only one parameter produced invariant responses in FFA. Remaining parameters were quite influential in FFA: non-optimal values actually reversed category preference, from faces to unfamiliar objects.

◆ **Morphing morphing faces**

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We have made cyclic morphing animations using two different faces. The morphing animations gradually evolved from one face to the other, and vice versa. When free viewing, the perceived changes were not very large, but the changes could easily be observed. Observers were asked to fixate on a dot that was projected on the morphing faces. The dot clearly affected the appearance of the morphing faces. When the dot made small movements (eg, a circular trajectory between the eyes), the morphing was hardly perceived. However, when the dot was suddenly projected stationary on the morphing faces (again between the eyes), the perceived morphing increased dramatically; relatively small differences between the two faces appeared to be blown up to much larger proportions. This perceptual enhancement of facial differences included various characteristics such as the shape of the eyes, the position of the eye brows, and the colour of the skin. We discuss the observed differences and relate them to the attentional modulation of transient signals and to phenomena like saccadic suppression, peripheral fading, and the representational momentum.

◆ **The interactive effects of facial distinctiveness and semantic one on facial encoding**

N Takahashi, H Yamada (Department of Psychology, Nihon University, Japan; e-mail: nonname34@live.jp)

It has been known that unfamiliar faces which are perceived as distinctive or unusual are more accurately recognized. However, the distinctiveness of another person's semantic information such as his or her surname might be the other factor which affects the encoding of the person's face. Nevertheless, how these factors, the facial distinctiveness and the semantic one interact with each other on the perceptual encoding of faces seems to have not systematically been investigated yet. We hypothesized that the congruency of two kinds of distinctiveness would facilitate or inhibit the perceptual encoding of faces. In the first block of the experiment participants were shown four types of face-surname pairs (high or low distinctive faces with high or low distinctive surnames) and asked to rate the degree of congruency between the distinctiveness of face and the one of the paired surname. The second block of the cued recall task run 5 minutes after the first. The results showed that participant performance on the recall task was higher in the low distinctive face with low distinctive surname than in the other pairs, suggesting that how the visual encoding of face might be affected by semantic information of the person should be investigated further.

◆ **Self-face recognition: now it looks like me, now it doesn't**

F M Felisberti (Psychology Unit – FASS, Kingston University, UK; e-mail: f.felisberti@kingston.ac.uk)

Little is known about self-face recognition and most studies morphed two faces to investigate self-awareness. Here, self-face recognition was investigated using a 2AFC task in which the size of central (eyes, nose, and mouth) and peripheral (chin and face width) features was digitally manipulated. Participants ($N = 31$) were asked to choose which of two images (original vs chimeric) was the true photograph of their face. When the size of eyes, mouth, and nose was simultaneously increased or decreased by half, self-recognition was faster and more accurate (> 93%) than when each feature was changed individually. Participants recognised their eye

size accurately, but judged their mouths and noses as being smaller than they actually were. Surprisingly, performance was at chance level when changes were made to chins and face widths. Afterwards, participants were asked to choose which of the two images they liked most. Results were similar to the first part of the experiment; participants not only judged their mouths and noses as being slightly smaller but also preferred them to be smaller. The results revealed strong variations in performance to local changes in self-face features, both in terms of accuracy and speed. Recognition thresholds and gender differences will be discussed.

- ◆ **Familiar faces generate greater skin conductance responses than famous or unfamiliar faces**
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Ellis and Young (1990 *British Journal of Psychiatry* **157** 239–248), Hirstein and Ramachandran [1997 *Proceedings of the Royal Society, London, Series B* **264**(1380) 437–444], and Breen Caine and Coltheart [2000 *Cognitive Neuropsychology* **17**(1/2/3), 55–71] have explained Capgras syndrome, where familiar people are perceived as impostors, as a loss of the affective response to the familiar person. Faces of unfamiliar, famous, and familiar (a picture provide by the participant) people were presented to student participants while skin conductance was measured. The skin conductance response to the familiar face, was significantly larger than to the unfamiliar face which did not differ significantly from the responses to the famous faces. These results accord with the earlier studies quoted above. In a second experiment participants cut up a printed version of their familiar face, as well as an unfamiliar face while skin conductance was measured. There was a significantly larger response to the cutting of the familiar face compared to the unfamiliar face particularly if it had been highly positively rated. These data support the idea that familiar faces generate affective responses in most people, that can be measured by skin conductance.

- ◆ **Abnormal facial outward appearances and their impact on facial attractiveness and attribution of personality**
C C Carbon, R Jagsch¶ (Department of General Psychology and Methodology, University of Bamberg, Germany; ¶ Faculty of Psychology, University of Vienna, Austria; e-mail: ccc@experimental-psychology.com)

Current research in the field of facial aesthetics mainly focuses on beauty, and attractive and sexy faces. Meanwhile, abnormal facial outward appearances, induced for instance by dysgnathic conditions, are excluded despite tremendous effects on social life, attribution of personality, and attractiveness of humans affected by such conditions. In Study 1, twenty naive participants had to evaluate forty dysgnathic persons (eighteen retrognathic: 'overbite', 22 prognathic: 'underbite') photos by means of attractiveness, age and the big five personality traits. The stimulus database contained frontal and profile images taken on two different occasions: before and after having had an orthognathic surgery. Data showed strong negative effects of dysgnathic images on attractiveness, extraversion, social agreeableness, emotional stability, and openness, and were rated as much older than expected. In Study 2, alternative twenty participants received first comprehensive information on the medical condition of dysgnathia. Then, they had to carry out the same task as in Study 1. Data replicated the general pattern, although effects were much weaker for the personality traits. For attractiveness, medical knowledge even strengthened the malus of dysgnathia. Both studies broaden the perspective of facial attractiveness research towards a wider range of aesthetic evaluations, personality attributions and clinical research.

- ◆ **The inhibitory effect of retrieval on face recognition**
M Matsukawa, N Suto¶ (Graduate School of Humanity and Social Sciences [¶ Department of Psychology, Faculty of Letters], Chiba University, Japan; e-mail: niwaka.surf.rider@gmail.com)

The aim of this study was to investigate the effect of prior inserted task in the recognition of a learned face. Participants inspected face stimuli and were given two successive recognition tests. In the first test (inserted task), participants were asked to judge whether the half of studied stimuli (probe targets) were learned or not. In the second test (final recognition task) conducted immediately after the inserted task, participants recognized all of the target stimuli and equal numbers of distractors one at a time. There were two conditions (Part, Whole) in the inserted task. In the Part-condition, the left eye and its nearby area of target stimuli was presented, and veridical stimuli were presented in the Whole-condition. Results showed that, in the final recognition task, hit rate of the non-probe targets deteriorated more than for probe targets and that Whole-condition had a lower hit rate than Part-condition. These results mean that non-probe targets were inhibited by retrieving probe targets. It is suggested that the strength of inhibition depended on the facial configuration.

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◆ **Recognition of briefly presented familiar and unfamiliar faces**

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Early processing stages in the perception of familiar and unfamiliar faces were studied in four experiments by varying the type of available facial information in a four alternative forced choice recognition task. Both reaction time and recognition accuracy served as dependent measures. The observed data revealed an asymmetry in processing familiar and unfamiliar faces. A markedly weak inversion effect and strong blurring effect suggest a limited usage of spatial relations within early processing stages of unfamiliar faces. Recognition performance for whole familiar faces did not deteriorate due to blurring or the presentation of isolated internal features, suggesting a low level of representation for featural properties of familiar faces. Based on the data we propose that recognition of familiar faces relies much more on spatial relations among features, particularly internal features, than on featural characteristics. In contrast, recognition of unfamiliar faces resorts mainly to featural information.

◆ **Evaluating the possible effect of gender-related words on face gender decision task**

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It has been shown that exposure to a previous stimulus can affect recognition of the next one. When the first and second stimuli belong to the same category, this facilitative effect is called categorical priming. We wanted to investigate whether face gender recognition is affected by previous exposure to a gender-related stimulus, eg words. To test this we designed a face gender recognition task and used two word categories (people vs objects' name). In Experiment 1 we used visible word primes, each prime (a female's, male's, or an object's name) was followed by a photograph of a face, the subject having to indicate face gender by a key press. In Experiment 2, to evaluate the unconscious effect of primes we tried to make the primes invisible by using a sandwich masking paradigm. Analysis of accuracy and reaction times revealed no significant effect of gender-related words on face gender categorization in both experiments. One conclusion might be that face gender categorization is not affected by semantic data of other stimulus type such as words.

PERCEPTION OF EMOTIONAL EXPRESSION

◆ **Sensual expressions on faces**

A W Hendriks, R Engels, M Roek (Behavioural Science Institute, Radboud University Nijmegen, The Netherlands; e-mail: aw.hendriks@bsi.ru.nl)

We explored the possibility that an emotional facial expression exists specifically for signalling sexual interest. We selected photographs of twenty-eight fashion models (male and female) with large portfolios (range 81 – 1593), choosing only face photographs in which the model was looking into the camera. Twelve face photographs were selected of each of the models, one with a neutral facial expression, one with a happy expression, one which we thought bore a more or less sensual expression and nine randomly chosen ones. The randomly selected photographs were usually attractive and often sensual-looking as well. The photographs were presented to young adults ($N = 488$) via a website, all within each set shown simultaneously in random positions in a 3×4 array. The participant's task was to choose from each set the photograph that bore the most sensual expression. The photographs most often chosen as the most sensual one were analysed using a facial-expression coding system. The results showed that the sensual emotional expression had specific characteristics that differed systematically from universal facial expressions, and that it also differed for male and female faces. These findings will be discussed in the light of a possible biological basis for sensual expressions.

◆ **Emotional enhancement in retinotopic visual cortex**

A Gómez-Carrillo de Castro, M Rothkirch, C Kaul[¶], P Sterzer (Visual Lab, Charité, Klinik für Psychiatrie und Psychotherapie, Berlin, Germany; [¶] Wellcome Institute for Neuroimaging, University College London, UK; e-mail: ana.gomez@charite.de)

Sensory processing in visual cortex is known to be enhanced by emotional stimuli. However, little is known about processing of emotional stimuli in early retinotopic cortex. If preferential processing is to guide appropriate behaviour, emotional enhancement in visual cortex should be retinotopically specific. We used a combined blocked and event-related fMRI paradigm where emotion and spatial attention were modulated independently to assess their influences on early visual processing in retinotopic cortex. Subjects performed a gender identification task for pairs of faces and scrambled face images presented simultaneously in the four visual quadrants. Prior to

each block, subjects were cued to attend to one diagonal pair of possible stimulus locations. Trials in a randomized order within blocks consisted of the following image combinations: attended fearful face and unattended neutral face, attended neutral face and unattended fearful face, attended neutral face, and unattended neutral face. Ten healthy volunteers underwent whole-brain fMRI with online-eyetracking and retinotopic mapping. Processing of face stimuli in early visual cortex was strongly modulated by attention and, to a lesser extent, also by emotional expression. These results suggest that both attention and emotion enhance processing of visual stimuli in retinotopic visual cortex.

◆ **When angry faces are just cross(es)**

C Coelho, S Cloete, G Wallis (School of Human Movement Studies, University of Queensland, Brisbane, Australia; e-mail: gwallis@hms.uq.edu.au)

Human faces are a class of stimuli for which specialised visual recognition mechanisms have been claimed to exist. One aspect of this perceived 'specialness' is the idea that threatening facial expressions may be processed by dedicated visual pathways. Evidence for this proposal comes largely from visual search tasks which have established that faces bearing threatening expressions are detected more rapidly than faces bearing positive or neutral expressions, a result widely referred to as the 'face in the crowd' effect. One open criticism of this effect is that it may be due to low-level visual artifacts, rather than biological preparedness. We report experiments aimed at investigating this possibility. The first study replicated the basic face-in-the-crowd threat advantage but also measured a comparable (though larger) effect using stimuli comprised only of obliquely oriented lines. Similar results were achieved with these stimuli rotated, which had the effect of removing any remnant of facial appearance. The results provide compelling evidence that low-level features underlie the face-in-the-crowd effect for caricature faces. As such, they serve to undermine theories which propose that the detection of threatening facial expressions is mediated by separate, dedicated processing channels.

◆ **Going beyond universal expressions: investigating the visual perception of dynamic facial expressions**

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Investigations of facial expressions have focused almost exclusively on the six so-called universal expressions. During everyday interaction, however, a much larger set of facial expressions is used for communication. To examine this mostly unexplored space, we developed a large video database for emotional and conversational expressions: native German participants performed 58 expressions based on pre-defined context scenarios. Three experiments were performed to investigate the validity of the scenarios and the recognizability of the expressions. In Experiment 1, ten participants were asked to freely name the facial expressions that would be elicited given the scenarios. The scenarios were effective: 82% of the answers matched the intended expressions. In Experiment 2, ten participants had to identify 55 expression videos of ten actors, presented successively. We found that 20 expressions could be identified reliably without any context. Finally, in Experiment 3, twenty participants had to group the 55 expression videos based on similarity while allowing for repeated comparisons. Out of the 55 expressions, 45 formed a consistent group, respectively, showing that visual comparison facilitates the recognition of conversational expressions. Interestingly, none of the experiments found any advantage for the universal expressions, demonstrating the robustness with which we interpret conversational facial expressions.

BIOLOGICAL MOTION

◆ **Perceiving biological motion from isoluminant displays: Motion is not required**

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A recent study reported that humans did not perceive biological motion (BM) from S cone-opponent (blue–yellow) isoluminant displays (Garcia and Grossman, 2008 *Vision Research* **48** 1144–1149). BM was presented peripherally, and was embedded in isoluminant noise dots. However, it is known that BM suffers very strongly from masking in the visual periphery even in luminance displays (Ikeda et al, 2005 *Vision Research* **45** 1935–1943). Unfortunately, Garcia and Grossman did not test whether masking explains their results, and so concluded erroneously that motion is necessary to perceive BM. Here we reproduce these results and show that the recognition of still frames suffers as much as BM, so that masking probably explains the effect. In further experiments we used luminance noise, for it is known that this masks residual luminance information, but does not mask form. We found that BM is easily recognised, both in L/M (red–green) and the S cone-opponent isoluminant stimuli. We conclude that motion may be helpful but is not necessary for perceiving biological motion.

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- ◆ **Temporal aspect of biomechanical constraint on visual recognition of human body motion**
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Visual recognition of natural body postures is more efficient than biomechanically impossible postures (Reed et al, 2003 *Psychological Science* 16 302–308). View dependency was more explicit with impossible postures or movements than with possible ones (Kitazaki and Inoue, 2004 *Journal of Vision* 4 233a). Thus, biomechanical constraints are utilized for perception of human body. We focused on the temporal aspect of biomechanical constraints. Point-light biological motions (20 actual body movements) were made using a motion-capture device. While each action took 3.2–6.8 s, only 1.0 s motion at the midpoint of the action was extracted as a stimulus. Two stimuli were sequentially presented, and subjects were asked to judge whether they were identical as quickly and accurately as possible. Independent variables were temporal sequence (forward or backward presentation of each motion), orientation (upright or inverted body), and view difference (0, 45, 90, 135, and 180 deg). We found that the sequential matching across views was more accurate with forward than backward (reverse) presentations, and better with upright than inverted bodies. The backward presentation increased view dependency of the performance. These results suggest that the human visual system utilizes not only spatial but also temporal aspects of biomechanical constraints to recognize human body motions.

- ◆ **Visual sensitivity to manipulations of human kinematics in point-light characters**
 W Stadler, J Parkinson, A Springer, W Prinz (Department of Psychology, Max Planck Institute for Cognitive and Brain Sciences, Tübingen, Germany; e-mail: stadler@cbs.mpg.de)
 The present study was designed to assess the visual sensitivity of human participants to details of human kinematics. In two rating experiments, motion-capture recordings of different human actions were presented. Each of the 13 different actions was shown in 7 versions, including an original recording and 6 manipulated versions which were stepwise reductions of typical human kinematics. All stimuli were shown in point-light animations which lasted between 2–8 s. Original and manipulated versions of all actions were randomly intermixed during presentation. Participants were instructed to detect artificially generated movements. After watching a particular animation, they were asked to indicate whether they had seen an original recording of a human or an artificially generated version. Results revealed a surprising resistance towards the reduction of variations in velocity and trajectory within action segments. However, the ratings highly differed between the actions and were also influenced by prior information which was varied in two experiments. Factors that influenced the ratings will be discussed.

- ◆ **Temporal sampling in the perception of biological motion**
 B Aragão, C Mendonça, L Fontes, J A Santos (Department of Psychology, University of Minho, Portugal; e-mail: brunoaragao@sapo.pt)
 Studies on visual perception pointed to a much larger temporal summation for biological motion than for simple translational patterns. Typically, an observer needs around 2000 ms to perceive a biological stimulus while for a simple translation 600 ms are usually more than enough. Moreover, biological motion perception seems to be dependent on velocity and on the number of cycles (cf. Neri et al 1998). Biological motion is quite complex, with translational and rotational motion components. However, most experiments on biological motion perception have been done with quite low temporal samplings (ie, frame rates), between 30 and 60 Hz. Therefore, the larger temporal summation might be just a consequence of an insufficient temporal sampling of the stimuli, as used in most experiments, rather than an indicator of a perceptual impairment per se. The present study aimed to investigate the influence of temporal sampling in the perception of biological motion. A task of direction discrimination was used. Perceptual thresholds and reaction times were analyzed as a function of the temporal sampling (30 to 116 frame rate) of point-light walkers stimuli. Further studies will correlate the psychophysical data with cortical activity, using fMRI techniques.

◆ **On the mechanism of a movement direction in biological motion perception as inferred from the backscroll illusion**

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It has been reported that biological motion perception is produced by form and motion information, but it is still controversial which information is more predominant. To investigate the mechanism that produces signals of gait direction of biological motion perception, we measured direction responses in the backscroll illusion induced by point-light biological motion perception. We varied the size (0.71 to 5.68 degree square) and location (center, upper, or lower area) of a 0.3 cycle deg^{-1} -sinusoidal grating flicker pattern as a background to the point light biological motion stimulus (the human gait moving at a speed of 2.62 deg s^{-1}), and six observers reported their impression of the background gratings (leftward or rightward motion or flickering). The percentage of the backscroll illusion inferred from the responses of the direction impression as a function of the size of the background depended on the location of the background. This indicates that local motion or mid-level optical flow information of the gait is predominant to determine the motion direction in biological motion perception. Acknowledgements.

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◆ **Interference between object processing and biological motion recognition**

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The perception of biological motion is a very robust phenomenon which might be mediated by complex motion or by dynamic body form analysis. If form is the important information, we would assume interference between object recognition and the perception of pointlight walkers. We used a walker stimulus in which the point lights were replaced by complex objects (Hunt and Halper, 2008 *Journal of Vision* 8(9):12, 1–5) to investigate whether task-irrelevant object processing can influence the perception of biological motion. We created different walkers by replacing the standard dots by pictures of objects or non-objects. Objects were from different categories, for example vegetables, tools, cars, animals and pictographs. Non-objects were shapes, which matched the form of the objects but were either inverted, scrambled, or contained a random gray level pattern. In two experiments subjects were asked to decide if the stimulus walked forward or backward. In the first experiment we measured reaction times and in the second experiment we investigated discrimination in noise. The results show that objects deteriorate the recognition of biological motion to a larger extent than non-objects do. We conclude that object recognition interferes with the processing of biological motion.

◆ **Effects of sexual dimorphism on perceived attractiveness from biological motion**

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Attractiveness is a trait with high social and biological relevance, as a cue to guide mate choice. To date, attractiveness has been studied mainly with face stimuli. A robust finding is that attractiveness and femininity go together in women's faces: women with feminine faces are consistently rated as more attractive, both by male and female raters. This finding is frequently explained on the basis that femininity within the female face is an indicator of sex hormone levels, and ultimately of reproductive value. However, the face is only one source of potential fitness-related information. Body motion can also convey a variety of socially-relevant information, such as age and sex. Here we investigated the role of sexual dimorphism on attractiveness from body motion. Participants were asked to rate the attractiveness of walkers using a 7-point Likert scale. Unlike faces, highly feminine gaits were perceived as less attractive than more neutral ones. These results suggest that body motion and facial features may signal different aspects of an individual's biological condition, possibly reflecting different selection pressures.

◆ **Specific influences of self-motion on the detection of biological motion**

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The perception and execution of motor actions are tightly interlinked, and numerous experiments suggest the existence of common sensorimotor representations. However, the exact nature of such representations remains largely unknown. Using a special VR setup we tested the influence of body motion on the perception of online-generated biological motion in signal-detection tasks.

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Observers had to detect whether a moving point-light arm is present in the scrambled noise-mask or not. The arm was presented with different time delays (40–560 ms) (Experiment 1), or spatially coherent or incoherent with their own movement, presenting the ipsilateral or the opposite arm (Experiment 2), or rotating the visual stimulus in the image plane by different amounts (Experiment 3). Performance was quantified by noise-tolerance values computed from d' measurements. A significant facilitatory influence of the own movement on the detection task was observed only if the visual stimulus was temporally and spatially coherent with the executed movement. Recognition performance significantly deteriorated with increasing temporal ($F_{1,16} = 19.46$, $p < 0.001$) and spatial mismatch (Experiment 2: $F_{1,16} = 12.82$, $p = 0.002$; Experiment 3: $F_{1,6} = 9.494$, $p = 0.020$). This modulation of vision by motor execution cannot be explained by simple cues, like rhythm detection. Rather, the results support an interaction between motor representations and biological-motion vision in terms of dynamic feedback signals that act on visual representations in a retinal frame of reference.

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- ◆ **The role of the parieto-premotor network in the processing of auditory-visual biological motion**
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Our aim was to identify the cortical network involved in the integration of auditory and visual biological motion signals. We first determined the cortical regions of auditory and visual co-activation (Experiment 1); the conjunction analysis based on unimodal brain activations identified four regions consistent with an extended mirror-neurone system (MNS): middle temporal, inferior parietal lobule (IPL), ventral premotor cortex (vPM), and the cerebellum. The brain activations arising from bimodal motion stimuli (Experiment 2) were then analysed within these regions of sensory convergence. Auditory footsteps were presented concurrently with either an intact visual point-light-walker (biological motion) or a scrambled point-light-walker; auditory and visual motion could either be congruent, ie same motion direction (both receding), or incongruent. Our main finding is that motion incongruency affects the activity in the parieto-premotor MNS (IPL and vPM) only if the visual point-light-walker is intact. This is consistent with the idea that the MNS encodes movement patterns by neural simulation. Our results extend our current knowledge by showing that this network is not only involved in recognizing meaningful actions within a single modality, but also compares the information across the auditory and visual modality.

MOTION

- ◆ **A model for motion perception depending on the minimal contrast**
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The Elaborated Reichardt Detector (ERD, van Santen and Sperling, 1984 *Journal of the Optical Society of America A* 1 451) and the functionally equivalent motion energy model (Adelson and Bergen, 1985 *Journal of the Optical Society of America A* 2 284–299) predict that motion detection thresholds depend on the product of contrasts of the input signals. However, in psychophysical studies, this dependence has been observed only at or near contrast detection threshold (Chubb and Morgan, 1999 *Vision Research* 39 4217–4231). Otherwise, minimal contrast predicts motion detection thresholds over a wide range of contrasts (Allik and Pulver, 1995 *Journal of the Optical Society of America A* 12 1185–1197). Here we develop a neural network for motion detection without multiplicative processing. Using addition and subtraction, time delay, and rectification we defined a model with a minimal number of neurons that responds to motion but not to flicker. The resulting network consists of two neurons receiving input from spatial filters, an inhibitory delay neuron and an output neuron. In contrast to the ERD, the network output does not depend on the product of contrasts but on the minimal contrast of the input signals.

- ◆ **Directional uncertainty reveals differences between lateral and radial motion**
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Our performance in many visual tasks (eg modifying thresholds, slopes or reaction times) can be affected by the presence of uncertainty and its change captured by the slope of a psychometric function (larger slope with more uncertainty) as predicted by signal detection theory and uncertainty models (Pelli, 1985 *Journal of the Optical Society of America A* 9 1508–1532). Here we show

how direction discrimination could be affected by directional uncertainty. We modify the number of alternative directions (uncertainty) of random dots stimuli and subjects had to discriminate the direction of motion in two conditions: 2AFC (left vs right or expansion vs contraction) and 4AFC (all four directions present). We observed that when there are two alternatives detectability grew linearly with amplitude of dots displacement (slope not different of one) for both radial and lateral motions. For 4AFC, however, we found that the slope did not change for radial motion but it did for lateral motion (slope larger than one). We suggest that this increase is caused by the partial activation of 2-D radial motion detectors when only right or left alternatives were shown in the 4AFC.

◆ **Ternus group motion without an interstimulus interval**

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Ternus motion displays are well known to evoke two qualitatively different motion percepts. Group motion is typically reported for interstimulus intervals (ISIs) larger than a critical value of about 50 ms, while ISIs less than that produce the alternative percept of element motion. According to Braddick's two-process theory of motion processing, element motion occurs at brief and zero ISIs because low-level motion detectors signal the stationarity of the middle element(s). Breitmeyer and Ritter's account similarly points to the fact that the correspondence problem is trivially solved in favour of element motion at a zero ISI. Contrary to what one would expect based on these theories, we found that group motion can be evoked with a zero ISI: using multiple-frame stimuli moving in a single direction, group motion occurred even when the middle stimulus element(s) had no temporal gap. Additionally, we found that group motion turned into element motion again when we introduced an offset – onset asynchrony between the outer elements. A possible explanation for this finding is that only in this case the stimulus is compatible with the perceptual inference that all elements are moving at the same speed.

◆ **Collinear smooth eye pursuit disrupts detection of coherent motion in younger and older adults**

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Previous studies show that detection thresholds for retinal motion are elevated in older human subjects. We examined whether this age effect persists during smooth pursuit eye movement. Coherence detection thresholds were measured with a standard 2AFC technique using stimuli containing signal dots moving in a coherent direction and noise dots moving in random directions. Young (mean 20 years) and old (mean 68 years) observers were tested in fixation and pursuit conditions. In the latter, the stimulus moved horizontally with a small pursuit target, approximately equating retinal motions in the two conditions. The subjects' task was to identify which of two intervals contained coherent motion. Two signal directions were investigated: horizontal, where signal moved left or right (collinear with pursuit) or vertical, where signal dots moved up or down (orthogonal to the pursuit). We found that detection of coherent motion significantly increased during pursuit compared to fixation, with the effect larger in the older group. In addition, all observers found it more difficult to detect coherent motion when it was collinear with the eye movement. The results suggest that the age-related decline in motion sensitivity is enhanced during pursuit and that sensitivity depends on relative direction.

◆ **Smooth pursuit eye-movements suppress motion processing**

P U Tse (Psychological and Brain Sciences, Dartmouth College, Hanover, USA; e-mail: Peter.Tse@dartmouth.edu)

If retinal motion signals arising from smooth pursuit were not discounted, smooth pursuit eye-movements could generate large magnitude spurious motion signals. Data will be presented that shows that radial motion appears to subjectively slow down quite dramatically during smooth pursuit eye movements. Stimuli were concentric 'expanding' and 'contracting' sinusoids. Using the method of constant stimuli, subjects equated the speed of a given stimulus expansion/contraction with and without smooth pursuit. Stimuli had to have much greater speed during smooth pursuit to be subjectively equivalent in perceived motion magnitude to the same stimulus presented during static fixation. A model will be described to account for the results.

◆ **Transparency and corrugated motion: the effect of the spatial layout**

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Recently, we showed that the spatial layout of a stimulus affects our ability to locate the border defined by two adjacent surfaces with different speeds. However, this effect does not appear or is very weak when the task is to discriminate a transparent stimulus (Martin, Barraza, Colombo,

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2009 *Vision Research* in press). We wondered whether this result reflects a difference in the mechanisms involved in these two cases of segmentation or it just reflects an effect of the task. In order to address this question, we measured a speed increment threshold as a function of the band size in a corrugated stimulus, for three spatial configurations defined by the angular separation among patches (120°, 60°, 45°), and for two tasks. In the first task they had to discriminate between corrugated and transparent motion. In the second task they had to discriminate whether the pattern was displaced up or down respect to a spatial reference. Results show that increasing the angular distance among patches reduces the speed difference necessary to perceive corrugation without affecting the spatial scale of the transition between transparency and corrugation. This suggests that the spatial layout affects corrugated but not transparent stimulus.

◆ **Visibility of an approaching object in periphery visual field**

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Perceptual properties of an approaching object in periphery visual field were investigated in direct relation with the motion in real 3-D space. Stereoscopic visual stimuli were generated from a 3-D space model including an approaching object directing in different orientations on horizontal plane. We found that the perceptual performance takes V curve and it was noticeably worse for the object moving toward the middle point of two eyes even moving distance was several times longer. When the object was occluded for one eye or fell on the blind spot of one eye, the visibility was increased. Even the case of the object directing to the middle point of two eyes, it was increased: which was coincide with Tyler's result but in different visual field (Tyler, 1971 *Science* 174 958). We inferred that not the change disparity but some simple combinations of the monocular information of two eyes, such as the vector sum of two eyes' image motion, might be used in periphery visual field; these findings could provide one clue for clarifying the mechanism of curious phenomena such as cross-traffic accidents at intersection without any obstacles and difficulty in playing catch for a ball approaching toward the middle point of two eyes.

◆ **Changing disparity and interocular velocity cues in time-to-contact judgments**

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In this study we sought to differentiate between two potential sources of binocular information for time-to-contact (TTC): changing disparity (CD) and interocular velocity difference (IOVD) (see Harris et al, 2008 *Spatial Vision* 21 531–547). We investigated whether CD or IOVD exert more influence on TTC judgments, and if there is an advantage from combining the two. Observers were presented with random dot stimuli that simulated an approaching object. This enabled us to manipulate the availability of CD and IOVD within the stimulus, which also loomed on approach. The stimulus disappeared at some point along its path, and after a variable duration the screen flashed and the observer made a 2AFC response as to whether the stimulus would have contacted them before or after the flash, had it continued in its trajectory. Results indicate that binocular information reduced TTC estimates for five of seven observers. However, the effect of CD, IOVD and combined cues differed between them. This suggests that mechanisms involved in TTC judgment are able to make use of both CD and IOVD, but that individual differences occur in the susceptibility to particular sources of binocular information.

◆ **Predictive modulation of visual sensitivity ahead of moving objects**

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Modulations of visual processing in the vicinity of moving objects have been suggested to underlie a variety of perceptual phenomena (eg the flash-lag effect, motion-induced distortions of perceived position and form). To directly investigate the nature of these changes, we measured contrast sensitivity for the detection of a drifting test grating presented adjacent to a suprathreshold (but otherwise comparable) inducer grating. Relative to performance with no inducing grating, detection thresholds at the trailing edge of the inducer were elevated by ~ 0.15 log units, irrespective of the relative spatial phase of the stimuli (general suppression). In contrast, performance at the leading edge was highly phase-dependent. Thresholds for test patterns that were in-phase with the inducer grating exhibited little or no suppression, whereas anti-phase test patterns were strongly suppressed (~ 0.30 log units). These results suggest a predictive modulation of sensitivity ahead of moving objects—the detectability of test patterns consistent with extrapolation of the inducer grating along the motion trajectory is increased at the cost of reduced detectability for patterns that are inconsistent. We further demonstrate that this modulatory effect extends over a limited region of space, the extent of which is inversely proportional to the stimulus spatial frequency.

◆ **The use of multiple visual cues in cuttlefish camouflage**

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Cuttlefish are ideal for studying visual perception as they exhibit rapidly changing camouflage patterns which are under neural control and are primarily visually driven. To produce the right body pattern for a given context they co-ordinate the expression of about 30 'chromatic components'. This behaviour shows great flexibility, allowing the animals to produce a very large number of patterns and giving unrivalled access to visual perception in a non-human species. To reveal what visual information is salient in the expression of different camouflage patterns we use behavioural assays, testing sensitivity to well-defined image parameters such as spatial frequency, orientation and spatial phase. We will report findings of several laboratory studies on edge and texture detection by cuttlefish. We show that information from multiple parameters such as edginess, size and contrast of objects in the environment is used to 'decide' what camouflage pattern to use, and propose mechanisms by which such parameters are detected. We discuss how these cephalopods integrate information about cues to classify the substrate on which they are resting, which provides us with a unique insight into how the animal perceives and responds to its visual environment.

◆ **Are feature-selective and spatial attention independent?**

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In three studies we investigated three different possible interrelations of feature-selective and spatial attention. In all studies, we assessed the attentional deployment to multiple concurrently presented random dot stimuli differing in spatial location and/or color by recording steady-state visual evoked potentials (SSVEPs) elicited by these flickering stimuli together with behavioral data. Our results show that (i) features can be directly selected without mediation by spatial attention; (ii) feature-selective attention and spatial attention enhance stimulus representations independently and additively; and (iii) splitting feature-selective attention across different locations is not possible, ie features are selected across the entire visual field, even when this explicitly conflicts with task demands. Taken together, these results strongly suggest that feature-selective and spatial attention operate independently at early levels of visual processing.

◆ **Differential vulnerabilities of first- and second-order motion processing**

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It is controversial whether the perception of physically different motion cues relies on common or separate mechanisms. We studied vulnerabilities of first- and second-order motion perception when challenged by neural constraints. We investigated the effects of ageing and brain lesions on detection thresholds for motion defined by either luminance or contrast modulations. Our sample comprised 102 subjects ranging from 20 to 82 years. Threshold signal-to-noise ratios for detection increased continuously across age for both motion types, but data confirmed a stronger effect on second-order motion perception. We found correlations with age of $r = 0.46$ and $r = 0.79$ for first- and second-order motion, respectively. Results support a dissociation between perception of first- and second-order motion. Separability of processing mechanisms was further clarified by perceptual performance of eighteen patients with brain lesions. We determined selective first-order motion deficits in two patients, selective second-order motion deficits in three patients, and deficits for both motion types in four patients. Overall, findings suggest that first- and second-order motion processing share basic mechanisms, but also involve specific neural substrates that contribute to differential vulnerabilities.

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◆ **Separate motion-detecting mechanisms for first- and second-order patterns revealed by rapid forms of visual motion priming and motion aftereffect**

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Fast adaptation biases the perceived motion direction of a subsequently presented ambiguous test pattern (Kanai and Verstraten, 2005). Depending on both duration of the adapting stimulus (range 10–100 ms) and duration of the adaptation-test blank interval, the perceived direction of an ambiguous test pattern can be biased toward the same or the opposite direction of the adaptation pattern, resulting in rapid forms of motion priming or motion aftereffect, respectively. These findings were obtained employing drifting luminance gratings. Many studies have shown

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that first-order motion (luminance-defined) and second-order motion (eg, contrast-defined) stimuli are processed by separate mechanisms. We assessed if these effects also exist within the second-order motion domain. Results show that fast adaptation to second-order motion biases the perceived direction of a subsequently presented (second-order) ambiguous test pattern, and that these effects have similar time courses to that obtained for first-order motion. In order to assess if a single mechanism could account for these results, we ran a cross-order adaptation condition. Results showed little or no transfer between the two motion cues and probes, suggesting a certain degree of separation between the neural substrates subserving fast adaptation of first- and second-order motion.

◆ **Target detection on the apparent motion trace**

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Flashing two spatially separated stimuli in rapid succession induces the perception of apparent motion. We investigated the detection of targets presented on the apparent motion trace, both when targets appear in time and out of time with the virtually moving token. Previous experiments using low contrast, near-threshold targets showed that in-time targets are detected better than out-of-time targets, suggesting that the prediction of a moving token along the trace improves detectability. Here we show that the same pattern of results exists with high-contrast targets well above threshold, confirming the strong expectancy effect along the apparent motion path. The results also confirmed that the trajectory of the moving token is likely to be linear, an effect that was ambiguous with previously employed low contrast targets due to potentially slower processing latencies.

◆ **Reversed motion perception during blinks**

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Eye blinks bring about short blank periods in our vision. However, we rarely notice the blanks, not because of their briefness but because of visual suppression (blink suppression). We report that a moving stimulus is seen to reverse the motion direction during a blink although veridical motion is perceived before and after the blink. We tested the effect by inserting physical blanks (ISIs) during optical flow presentation. The perceived motion reversals occurred even when there was no correlation in dot arrangements between the flows before and after ISIs. This result invalidates the hypothesis that the reversed phi between the negative afterimage caused by the ISI and the subsequent motion frame produces the effect. In the same way, the wagon wheel effect can also be rejected as a likely hypothesis. Because expansion or rotation induces the phenomenon, the effect is not explained by eye movements. The present phenomenon demonstrates that the motion processing system remains active during blinks in spite of the large brightness changes during blinks being perceptually suppressed. We propose that the application of blink suppression is limited to lower-level visual functions and that higher-level motion processing produces a kind of motion aftereffect even during blinks.

◆ **Orientation and motion aftereffects are in retinotopic not world coordinates**

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We investigated the reference frame of orientation and motion aftereffects. Adaptation to a stimulus produces a change in local sensitivity and, as a consequence, test stimuli with similar features appear shifted away from the adapted values. When an eye movement is made between adaptation and test, the aftereffect can be measured at the same retinal location as the adaptation or the same spatial location in the world. In addition, to control for non-specific adaptation, the aftereffect can be measured at a control location that is neither the retinotopic nor spatioptic location of adaptation. For both orientation and motion, we find that when saccades intervene between adaptation and test, strongly retinotopic aftereffects are seen, consistent with the known retinotopic organization of the neural levels at which information in these domains is analyzed. In contrast, following eye movements, we find no robust aftereffects at the spatial location of adaptation once the effects of non-specific adaptation are removed. We conclude that adaptable, feature-specific visual sensitivity is based in retinotopic and not in spatioptic coordinates. Our results indicate that the mechanisms behind visual stability do not include the retention of feature gain control in world coordinates.

◆ **Temporal characteristics of flicker-induced motion with stationary patterns**

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Visual patterns containing elements of different luminance can elicit illusory motion although the patterns remain stationary. Contrary to the view that this type of illusory motion results from differences in response latencies of low-contrast and high-contrast elements we observed illusory motion in flickering stationary patterns even when the contrast of the elements were matched. Here we show that the direction and intensity of perceived motion with flickering stationary patterns not only depends on the contrast of the pattern elements but also on the duration of on- and off-phases. For intermediate on- and off-durations motion was perceived from dark to bright elements. No illusory motion or motion in the opposite direction was perceived for longer on- and off-durations. Our findings suggest that illusory motion in stationary patterns results from differences in both on- and off-responses of the pattern elements. Illusory motion as observed here cannot, or only partially, be explained by contrast-dependent latency differences. Alternatively, we discuss the possibility that illusory motion results from differences in the accumulative on- and off-responses to dark and bright pattern elements.

◆ **The role of scene-based versus image-based information in motion correspondence**

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We asked whether motion correspondence relies only on image-level information or whether it is mediated through object-level representations. We used Ternus displays in which a set of three adjacent discs were presented in alternation with the same set of discs translated horizontally. For long interstimulus intervals (ISI), the discs tend to be perceived as moving together (group motion). For short ISIs, the displays tend to be perceived as one disc jumping from one end of the row to the other, while the other discs remain stationary (element motion). Size differences in the discs can cause a bias to perceive element motion. However, when a scene-based reason for the size differences was provided—an occluder with a small window behind which the discs appeared to move—the bias was substantially reduced. At the level of image-level information, the bias should have been the same (ie, toward element motion). At the level of the objects within the scene, however, the objects appeared to be all the same size, and thus at this level there was no basis for an element bias. These findings suggest that motion correspondence can be resolved at an object-based level of processing.

◆ **The tuning of simultaneous motion contrast and of motion adaptation**

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We measured the directional tuning of simultaneous motion contrast. A target grating (diameter 3.1°) was embedded in a surround grating (diameter 12.4°). The surround grating moved at 1.1 deg s^{-1} and the test at 0.28 deg s^{-1} . The direction of motion of the surround grating varied in different blocks from 0° to 330° in 30° steps. Under these conditions, the tuning curves were surprisingly broad: the apparent speed of the test grating was reduced whatever the direction of the surround motion. We also measured tuning curves for motion adaptation where the speed of the test grating was again 0.28 deg s^{-1} and the speed of the adapting grating was 1.1 deg s^{-1} . The adapting grating had the same outer diameter as the surround in the contrast experiment. The tuning curves for motion adaptation were also broad. Under our conditions, the reduction in perceived speed in motion contrast and motion adaptation seems not due to channels that are strongly directionally-opponent or directionally-tuned. Prima facie, the results also do not favour Bayesian or constancy explanations. Instead, the tuning curves suggest that channels tuned to speed or to temporal frequency rather than to velocity are largely responsible for generating the reduction in perceived speed.

◆ **Transient stimuli reduces saccadic induced autokinesis**

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In complete darkness, a still light appears in motion after a few seconds of fixation. This is a well known phenomenon called autokinesis. We used a psychophysical procedure to estimate the spatial mislocalization of a steady dot. Observers were asked to compare the position of a test dot with that of a reference displayed at different physical locations. After each trial, expert helicopter pilots, flight assistants, and control observers were required to execute a saccade to fixate and identify a small digit shown 10° below fixation in order to strain the eye muscles asymmetrically along the vertical axis. Downward saccades are frequently executed in pilots wearing night-vision goggles to check the cockpit. In an half of the trials, four transients balanced around

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the fixation dot were briefly presented, to assess whether their presence could optimize the task. We show that the mislocalization of the dot depended on the saccade direction and was greatly reduced by an appropriate layout of transient stimuli, which probably decreases the instability of fixation. This occurred in all groups independently of expertise. Reduction of autokinesis by the use of external cues may be fundamental in eliminating one of the major factors of spatial disorientation.

◆ **Visualizing one's involuntary eye movements: The 'Railroad Illusion'**

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Several methods to visualize one's involuntary eye movements have been described, such as the projection of a foveal afterimage upon a target. We studied the 'Railroad Illusion', making use of binocular fixation instability and eye dominance. Fixate a target 10–15 m away next to a pair of railroad tracks. After several seconds the rails appear to move sideward, suggesting that fixation is no longer steady. Occasionally, the rails appear to bend. This instability is reminiscent of bodily sway. Once started, it continues. We simulated this phenomenon in the laboratory, using a pair of 2 m long white strips inclined 15° to the right or left. Subjects fixated an LED 1 m away and 10° right or left of the midline. They signaled when the strips appeared to move. Eye movements measured concurrently indicated a correlation of perceived drift and binocular fixation instability. Amplitudes of left or right drifts were consistent with eye-dominance. Results agree with earlier findings showing binocular vergence stability up to 5–10 s, followed by vergence translations. Note that lateral translation and bending occurred only in peripheral vision, suggesting that in foveal vision involuntary eye movements are compensated for, whereas in the periphery they are not.

◆ **Smooth retinal motion inhibits illusory motion of 'Rotating Snakes'**

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'Rotating Snakes' is an artwork produced by A Kitaoka. This image is seen to rotate in peripheral vision against their physical stillness. The illusory motion stops after a few seconds of steady fixation and restarts after a saccade. Therefore, it is believed that saccades are useful for keeping illusory motion perception irrespective of the source of the illusion. We measured the illusory motion duration when 'Rotating Snakes' jumped to a new location after a standstill of 1 s (jumping motion condition, simulating the retinal motion of saccades) or when 'Rotating Snakes' moved smoothly and continuously (smooth motion condition). In the jumping motion condition, the average duration of seeing the illusory motion was 4.9 s, ie 49 % of the presented duration. While, in the smooth motion condition, the average duration of seeing the illusory motion was 1.8 s, ie only 18% of the presented duration. Thus, the illusory motion is hardly seen when 'Rotating Snakes' moves smoothly and continuously although it is clearly seen when 'Rotating Snakes' jumps. These results paradoxically indicate that the illusion needs a period during which the retinal image stands still without refresh.

◆ **Global motion processing in migraine-with-aura**

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Migraine-with-aura is a neurological disturbance, characterized by unformed visual hallucinations that herald the onset of an episode. Migraineurs show subtle differences in visual processing, including deficits in detecting coherent motion in the presence of motion noise. These deficits could be due to impaired integration of global-motion information. We used the classification-image approach to measure perceptive fields for global motion in ten migraineurs and ten headache-free controls. Observers were presented with a 5 × 5 array (size of 10.6 deg × 10.6 deg) of high contrast dots (0.3-deg diameter) moving to the left or right of vertically. The motion direction of each dot had also a random component (Gaussian motion direction noise, SD = 15°). Subjects indicated whether the near-threshold global-motion direction was to the right or left of vertical. Classification images were calculated by summing (element-by-element) noise samples eliciting 'right' responses and subtracting samples producing 'left' responses. Results show that the controls had a narrow perceptive field, using mainly the central moving dot in decision-making. Migraineurs-with-aura, however, used a wider field to detect global-motion direction. This resembled the perceptive field of an ideal observer utilising information for all moving dots. These findings suggest that migraineurs-with-aura could have reduced inhibition within motion processing mechanisms in areas beyond V1.

◆ **Tracking multiple objects across abrupt viewpoint changes**

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Observers are able to track several independently moving objects among identically looking distractor objects. Multiple object tracking in a 3-D-scene is robust against smooth movements of the whole scene, which has been taken as evidence that tracking mechanisms rely on scene-based coordinates. However, there is also evidence from experiments that studied the effects of display translations across the retina suggesting an important role of low-level mechanisms and retinocentric coordinates in multiple object tracking. In a series of experiments, we tested the effect of abrupt viewpoint changes on the attentional tracking of multiple objects in dynamic 3-D-scenes. Abrupt viewpoint changes affect only retinocentric coordinates and—as our results show—impair tracking performance considerably if they exceed a certain amount. Small viewpoint changes seem to be compensated by low-level mechanisms. After large viewpoint changes, scene-based coordinates are used to recollect targets. Tracking targets as a group may yield static scene elements less important as a spatial reference in recollecting targets. Our results suggest that perceptual grouping was used mainly when observers tracked three targets. We explored the interplay of tracking mechanisms by varying the predictability of viewpoint changes, the availability of scene information, and object visibility.

◆ **Eye movements across viewpoint changes in multiple object tracking**

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Observers can visually track multiple independently moving objects even if the scene containing the objects is rotated in a smooth way. Abrupt scene rotations makes tracking more difficult but not impossible. For non-rotated stable dynamic displays, looking at the centroid of the target group is a spontaneous strategy in visual tracking. This has been taken as evidence that tracking multiple targets is supported by grouping them into a higher-order object and tracking its centroid. But which factors determine successful visual tracking across abrupt scene rotations that cause a non-stable dynamic display? We recorded participants' eye movements in two experiments while they tracked multiple objects. In half the trials, an abrupt scene rotation was introduced. While gaze time spent on the targets was significantly reduced for 500 ms following the scene rotation, gaze time spent on the centroid was more stable. These results indicate a process of realigning the targets as a group. In the second experiment we additionally manipulated object speed. In addition to replicating the result of the first experiment, we demonstrated a significant increase in gaze time spent on the centroid with higher object speed. This reflects the increasing importance of grouping.

◆ **What can we learn from failures in multiple object tracking?**

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Multiple object tracking (MOT) is used to study the limits of visual attention. However, because the computational problem has not been specified, it is difficult to determine which tracking failures reflect visual attention limitations, and which reflect the information available in the task. Here, we define an ideal observer for the computational problem posed in MOT—a variant of the 'aircraft tracking' problem: given a series of noisy observations, and an assumption about object dynamics, an observer must solve for the correspondence between time-steps. We find that the ideal observer predicts basic aspects of human tracking performance, as these reflect the information available in the task: tracking is easier when objects move slower, are further apart, have associated colors, or are more predictable. However, the number of targets tracked does not affect the simple ideal observer. For the observed speed/number-tracked tradeoff to arise from the ideal observer, a flexible resource limitation must be postulated. We consider several candidate resources and give the ideal observer the ability to optimally allocate them, thus avoiding ad hoc linking assumptions between resource and performance limitations. Our results suggest that limited measurement or memory fidelity results in the speed/number-tracked tradeoff.

◆ **External noise reveals crowding in detection**

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Crowding a target with similar flankers is known to impair its recognition, but is typically found to have no impact on its detection. This suggests that processes required for recognition are

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pooling information surrounding the target making them vulnerable to flanker interference; whereas the earlier detection processes do not. Since crowding effects can be enhanced when combined with other masking paradigms (ie supercrowding), we investigated whether crowding could occur for a detection task when combined with a separate masking paradigm. We measured detection thresholds for a vertically oriented sine wave grating (target) surrounded by four sine wave gratings (flankers) as a function of the external noise masking the target. The flankers were either vertically (crowding) or horizontally (non-crowding) oriented. Crowding only occurred for detection when the noise significantly masked the target. That is, in high-noise conditions, detection thresholds were higher by a factor of about 2 when the flankers were vertically rather than horizontally oriented, but the flankers' orientation had no or little impact in low-noise conditions. Based on this novel crowding effect found for a detection task, we conclude that adding external noise engages additional processes, which are pooling information surrounding the target.

LIGHTNESS, BRIGHTNESS, AND LUMINANCE

◆ **The effect of Vicario's size illusion on lightness**

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In 1971 Vicario showed a geometric optical illusion that can be considered a combination of the Delboeuf and the Ebbinghaus illusions. The illusion consists of two pairs of concentric circles as in Delboeuf's illusion, however the equal size target circles are both centred inside larger circles that differ in size, one being much larger than the other. This configuration produces a size contrast effect similar to the Ebbinghaus illusion: the target circle surrounded by a smaller concentric circle looks bigger than the target circle surrounded by a larger concentric circle. We transformed Vicario's outline configuration into a lightness display: targets (Ts) where two middle grey disks placed both either on a dark grey (increment Ts) or on a light grey (decrement Ts) background. Inducers were outlined concentric circles that differed in size; these were light grey on dark backgrounds, and vice versa. We ran an experiment with naive observers using a paired comparison paradigm and forced choice. Results show that for increment Ts the target that looks bigger looks also brighter, while for decrement Ts the target that looks bigger looks also darker. We report PSEs for our configurations and discuss the data with reference to current lightness models.

◆ **Is the human primary visual cortex change-blind?**

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Previous studies revealed contradicting results regarding the relation between neural activity in primary visual cortex (V1) and perceptual awareness. It remains unclear to what extent V1 is part of the neural correlate of conscious visual perception. The change blindness phenomenon provides an excellent opportunity to study this question since here perceptual processes are clearly dissociated from purely sensory ones. We used event-related fMRI in combination with a visual change detection task inducing strong change-blindness effects where subjects had to detect substantial increases in luminance contrast. The activity level of V1 neurons is known to be generally correlated with luminance contrast intensity. Preliminary statistical comparisons of the retinotopic fMRI data of three subjects within V1 during detected and undetected changes yielded equal amounts of BOLD signal increases resulting from increases in luminance contrast, irrespective of their detection by the participants. This indicates that although under certain circumstances conscious perception can be remarkably blind to extensive changes in luminance contrast, the activity of V1 neurons does not reflect this blindness. Why in these contexts visual perception is unable to use the correct information provided by V1 neurons remains to be investigated. These results speak against a general involvement of V1 in the neural substrate of conscious visual perception.

◆ **The influence of texture segmentation on brightness computation on the articulated surrounds**

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Brightness of a gray target can be affected by the luminance of a surrounding field. Moreover, the effect of surrounding luminances can be enhanced by articulating the surround (ie, breaking it into many small regions of different luminances) even if the spatially averaged luminance is kept constant. The present study asked if this articulation effect is governed by spatial closeness or affected by region segmentation such as texture segmentation. The target in the experiments was a

texture patch composed of vertical line segments having the same luminance. The surround was composed of similar texture patches but different ones had different luminances. The orientation of the surrounding elements was either vertical or horizontal. In the latter case, the target was easily segmented, although the target-surround interval was kept nearly constant. Results showed clear influences of texture segmentation on the articulation effect. When the target could not be segmented based on the orientation difference, the articulation effect was found; eg, the target on the articulated light surround appeared dimmer than on the uniform light surround. However, when the target could be segmented, the effect disappeared. These findings suggest that spatial organization of the display could affect brightness computation on the articulated surrounds.

◆ **A diffusion based computational model and computer simulation for the lightness illusions**

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Let I_1 be an input image, and I_2 its convolution with the Laplacian kernel. It can be proved, that if I_2 serves as the source for a linear homogeneous diffusion process, then the I_3 equilibrium equals I_1 . If, in a computer simulation, a slight nonlinearity is included in the diffusion channels, and/or some leaking conductance is introduced, the I_3 image will be somewhat different from I_1 . I have set the parameters of nonlinearity and leaking conductance so that the three basic lightness illusions—simultaneous contrast, Munker–White, and COC illusions—are reproduced by the same fixed parameter values: the intensities on the resultant I_3 are in accordance with human perception. Without any change, the same parameter values also reproduce a significant proportion of the known lightness illusions (eg Chevreul, Vasarely, Todorović, Logvinenko, Zavagno's glare, grating induction, checker frame, Adelson's checker shadow, plaid, snake, anti-snake illusions). For some other illusions, eg Ehrenstein, the parameter values had to be changed manually; this needs further investigation. The algorithm is applicable to real pictures without modification of the parameter values. The algorithm differs from the Grossberg-type of models in that no preliminary edge detection or segmentation is being used. For successful modelling, it is not even necessary to involve Gestalt principles or higher-order processes.

◆ **The strength of Vasarely and SLC illusions depends on line straightness**

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It was shown (Geier et al 2004) that the Hermann grid illusion disappeared when straight lines were changed to wavy or serrated lines. We used this idea to study two other visual illusions—the Vasarely illusion and the simultaneous lightness contrast (SLC) illusion. We used six modifications of lines between right angles: three different wavy lines and three different serrated lines. To study the strength of both illusions we used a two-alternative forced choice discrimination task. Eleven naive subjects were tested. The scales of the illusion strength depending on type of lines were obtained. Our results show that the strength of the illusory effect depend on the type of lines: wavy lines decrease the illusory effect while serrated lines increase it. Thus a slight distortion of the lines change the appearance of the illusions. The results suggest that illusions such as Vasarely and SLC, which have been explained on the basis of lateral inhibition, should be conceived as a result of cortical processing.

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◆ **Brightness perception in migraineurs and non-migraineurs and its possible link to photophobia**

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Depending on their spatial configuration, objects containing luminance gradients evoke a brightness effect which makes them appear 'glowing' and therefore brighter than luminance matched objects without gradients. Anecdotally, this brightness effect causes photophobic reactions in migraineurs. To understand better the origins of this alleged photophobic behaviour, we investigated whether migraineurs and non-migraineurs differed in: (i) their objective and/or subjective brightness thresholds; (ii) their temporal sensitivity to the build-up of this brightness effect; and (iii) their attentional orienting toward stimuli containing a brightness effect. Participant groups differed in neither objective brightness thresholds nor temporal brightness sensitivity. However, migraineurs reported objects as 'glowing' at lower luminance thresholds. Moreover, migraineurs' attention was drawn toward stimuli containing luminance gradients as compared to luminance-matched control stimuli, irrespective of whether these gradient stimuli actually induced 'glow' or not. Non-migraineurs did not show any preference for gradient containing stimuli. These data suggest that low-level sensory processing of brightness induction does not differ between migraineurs and non-migraineurs. Rather, top-down cognitive processes, such as subjective sensitivity to 'glow' and automatic attentional orienting toward stimuli that might potentially induce 'glow', appear to be responsible for photophobic reactions in migraineurs.

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◆ **Visual cues on food freshness perception: How luminance influences the freshness perception of vegetables**

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Freshness perception is a quality discrimination process used frequently in food selection. Several of the most relevant sensory attributes influencing consumer perception of freshness are related with vision. To investigate which visual cues command the freshness perception in vegetables, we took digital pictures of the freshness degradation process of cabbages and strawberries in a controlled environment. In the first experiment, we randomly presented those pictures to subjects who had to rate their perceived freshness using a visual analogue scale. The results of the freshness perception were highly correlated with statistical features of the luminance distribution in the images. In the second experiment, we manipulated the original images only by modifying their luminance distribution and keeping intact their colour information. When we presented the resulting images, using the same psychophysical experiment setting, the subject's results showed that the perceived freshness also changed concordantly with the changes of the luminance distribution. These results support the hypothesis that the freshness perception of vegetables is highly influenced by the luminance distribution in that food texture. Although pattern cues should also be considered for definitive understanding of the human visual mechanism for freshness perception, these findings can help design implementations of automatic food freshness estimators.

◆ **The effect of glare on visual performance and visual perception**

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The presence of a peripheral glare source produces a darkening of the perceived stimulus that could be associated to an equivalent variation of luminance. This reduction of luminance should lead to a predictable impairment of the visual performance. To check it we performed two experiments measuring reaction time (RT) as a function of the contrast (C) for sinusoidal gratings foveally presented as stimulus. Experiment 1 was performed for three different levels of glare illuminance (EG) measured on the eye (EG = 0, 15, 60 lux; angle = 10°; stimulus mean luminance: L=0.14 cd m⁻²). Experiment 2 was carried out for four levels of stimulus mean luminance without glare (L = 0.9, 0.14, 0.05, 0.014 cd m⁻²). Both sets of data were adjusted by using the equation $RT = RT_0 + k(1/C)$. Results show that k increases with increasing EG and decreasing L. We have calculated the equivalent luminance for each level of glare by comparing the values of k . We found that the darkening effect of glare measured through RT visual performance corresponds to a reduction of luminance of around 10 times. This reduction is much larger than that previously determined by measuring brightness perception. This result suggests that visual performance and brightness perception may be reflecting very differently the darkening effect of glare. [Supported by ANCyP PICT2006 N°1920 / CIUNT 26/E410.]

◆ **Motion and disparity information improves gloss constancy**

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Using monocularly presented, rotating computer generated 3-D-surfaces within a matching experiment, Nishida and Shinya (1998 *Journal of the Optical Society of America A* **15** 2951–2965) found that observers were unable to achieve a reliable match of the reflection characteristics between two complex curved surfaces unless the surfaces shared similar 3-D structures—a result that generally could be confirmed in our replications of their experiments. In matching experiments with similar stimuli (but a different kind of object rotation), we tested whether and how 'gloss constancy' performance (ie the invariance of perceived reflectance properties under changing 3-D surface structures) is influenced by (i) the availability of motion induced information (static vs dynamic stimulus presentation), and (ii) the availability of disparity information (with the levels 'monocular', 'surface disparity', and 'surface + highlight disparity'). The task of the subjects was to match the perceived lightness and glossiness between two surfaces with different 3-D structures by manipulating the diffuse component and the exponent of the Phong lighting model in one of the surfaces. Our results indicate that both the availability of motion and disparity induced information improves the constancy of glossiness matches. The results concerning the lightness matches are less clear-cut.

◆ **Computing lightness within a plane: coplanar ratio principle vs anchoring theory**

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Using variations of the dihedral display of Gilchrist (1977), we tested competing predictions of the coplanar ratio principle (Gilchrist, 1980) and the anchoring theory (Gilchrist et al, 1999) about the role of (i) articulation, (ii) adjacency, (iii) multiple fields of illumination within a plane, and (iv) luminance range in depth effect on lightness. Consistent with the predictions of the anchoring theory, we find that: (1) Articulation can substantially increase the depth effect; (2) target lightness depends not simply on its adjacent luminance but on the highest coplanar luminance, irrespective of its position relative to the target; (3) when two or more levels of illumination are present in a plane, target lightness depends on the highest luminance in its framework of illumination, not on the highest luminance in its plane; and (4) the magnitude of the depth effect depends on the luminance ratio between the highest luminance values in the two planes, not on the overall luminance range across the planes; strong depth effects can be obtained with a luminance range no greater than 30 : 1.

◆ **Measuring the meter: On the robustness of the Munsell Neutral Value Scale with different surrounds**

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In the field of achromatic colour perception, lightness is often measured with matching paradigms that employ a scale consisting of Munsell Neutral Value papers. In such studies the achromatic Munsell scale (MS) is often conceptualized in terms of a veridical 'meter' for measuring achromatic colour, ie not subject to perceptual alterations due to external luminance factors. However, MS is actually a lightness scale and theoretically it may therefore show constancy failures due to variations in its level of illumination and/or in its surround. We tested the robustness of a 16 step Neutral Value Munsell scale with regards to surround variations in two experiments. In both experiments MS surround was a between factor and simultaneous lightness contrast displays (SLC) were within comparison stimuli. MS and SLC were illuminated by the same spotlight. In Experiment 1 we employed three achromatic surrounds for MS: black, white, and black and white checkers. In Experiment 2 we employed both achromatic and chromatic checkered surrounds: black and white, red and green, and yellow and blue. The factor surround produced a significant effect only in Experiment 1. Results are discussed with reference to the concepts of 'veridicality' and 'error' in visual sciences.

◆ **Both illumination and the material of context objects influence perceived glossiness**

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Human observers seem to robustly and effortlessly classify material properties, even when the optical input changes completely due to changes in illumination. We investigated the effects of both the nature of the illumination and the presence of matte or specular context objects on the perceived glossiness of a reference object. Subjects viewed a grey reference object in that was either photographed in isolation or placed in complex scenes consisting of multiple fruits, vegetables, and vases that were either spray-painted specular grey, spray-painted matte grey, or retained their original colour. The illumination of the reference scenes could be either collimated or diffuse. Subjects matched the material of this reference object to that of a test object that was photographed in isolation on a matte background with collimated light. We found a huge underestimation of glossiness of the object when it was illuminated with a diffuse light source, compared to when it was illuminated with a collimated light source. This underestimation was slightly reduced when context objects were present. When illuminated with the same light source as the reference objects, the presence of context objects, whether matte or specular, did not seem to have an effect on perceived glossiness.

◆ **The role of perceived illumination in the articulated simultaneous lightness contrast**

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The simultaneous lightness contrast (SLC) is the condition whereby a grey patch on a dark field appears lighter than an equal patch on a light field. Interestingly, the perceptual lightness difference between these patches undergoes to a substantial augment when the two fields are articulated giving rise to the articulated-SLC, although maintaining the same luminance average.

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In this project two competing models explaining the articulated-SLC have been contrasted: the layer and the framework. The layer model claims that the articulated-SLC is due to the number of luminance pairs sharing the same polarity (Soranzo and Agostini, 2006 *Perception & Psychophysics* **68** 102–113); whilst the framework model claims that it is caused by the difference in the highest luminance in the two fields (Gilchrist et al, 1999 *Psychological Review* **106** 795–834). In a psychophysics experiment observers' lightness has been measured by systematically manipulating both the number of luminance pairs sharing the same polarity and the highest luminance in the two fields. Results show that the SLC persists even when the two backgrounds share the same anchor and its strength is inversely proportional to the pairs of luminance ratios sharing the same polarity, supporting the layer approach to lightness perception.

◆ **From impossible to possible: a peculiar illusory transparency in the absence of stratification index only due to motion**

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The aim of the present study was to explore the effect of motion introduced in patterns perceived as non-transparent in static presentation. The stimuli were two movies differing from each other only because of the colour combination and consisted by a rectangle composed by three coplanar rectangles with the same height, changing their widths over time. One colour combination was plausible for the interpretation of the pattern as two squares in which a square is transparent and slowly covers and uncovers the other square, the other colours combination was implausible. Ten subjects served as observers in two experimental sessions. In the first session, a randomised series of the static frames composing the two movies was presented. All subjects reported perceiving three vertical adjacent rectangles: no transparency or stratification was perceived. In the second session, the two movies were presented and transparency and stratification was always perceived also in the pattern with implausible colours for transparency. These results show how transparency is perceived in the absence of stratification indexes and with implausible colours combination just by introducing motion. Further experiments demonstrate that transparency is present also with motion implausible for the interpretation of two moving squares highlighting the surprising strength of the effect.

PERCEPTUAL LEARNING

◆ **Discrimination thresholds for time-to-collision**

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In a seminal paper, Todd (1981 *Journal of Experimental Psychology: Human Perception and Performance* **7** 795–810), having tested trained observers in a 2AFC paradigm, had reported discrimination thresholds for Δt_c ('time-to-collision') corresponding to a Weber fraction of 0.016. Most subsequent work obtained values seven to ten times higher. We replicated, and elaborated upon, Todd's original experiment and observed the following: (a) Naive subjects' performance improved during the course of the experiment, demonstrating perceptual learning; (b) trials in which size and velocity was the same for the two approaching objects were responded to much more correctly than any others, suggesting that subjects, on these trials at least, responded to $\Delta\theta$ (momentary difference of visual angle) rather than Δt_c , or its optical specifier τ ($\Delta\theta/d\Delta\theta/dt$). Logistic regression, however, showed this to be the case for the other trials. Eventually, performance was also affected by different optical specifications of object shape (random dots vs dots aligned along the objects' rims), suggesting different mechanisms to be at work (registration of optic flow as such vs object perception).

◆ **Contextual cueing of pop-out visual search**

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Visual context information can guide attention in complex visual displays. When participants are repeatedly presented with identically arranged ('old') visual displays, search reaction times are faster relative to newly composed ('new') displays, an effect which has been referred to as contextual cueing (Chun and Jiang, 1998 *Cognitive Psychology* **36** 28–71). While almost all prior studies have investigated the effect within 'serial' search tasks, here we asked the question whether the effect can also be observed in 'parallel' (absent/present) search tasks and if so, to which processing stage (attentional guidance vs response selection; cf Kunar et al, 2007 *Journal of Experimental Psychology: Human Perception and Performance* **33**(4) 816–828) the effect can be attributed to. The results were that discernment of target presence was accomplished faster if the target was presented within 'old' relative to 'new' displays and this effect was evident for both target-present

and target-absent trials. Of note, the presentation of pop-out targets in old (relative to new) displays also led to increased response accuracy as assessed with signal detection techniques. The data thus suggest a contribution of attentional guidance in contextual cueing. Visual context information is likely to enhance feature contrast computations at the overall (ie, supra-dimensional) saliency representation stage (cf Wolfe, 1994 *Psychonomic Bulletin and Review* 1 202–238).

◆ **Psychophysical and electrophysiological evidence of distinct mechanisms for texture grouping and segmentation**

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Similar local elements are perceptually grouped into global contours/surfaces and segmented from a background of dissimilar elements. Neurophysiological data show that lateral interactions between neurons can either facilitate or inhibit grouping (Polat et al, 1998 *Nature* 391 580–584) and segmentation (Nothdurft et al, 1999 *Visual Neuroscience* 16 15–34), depending on local–global orientation congruency. We use a global–local congruency paradigm to isolate, in humans, the psychophysical and electrophysiological correlates of these modulatory effects in tasks of grouping and segmentation of texture-figure/contours. Whereas elements of similar orientation in background and texture-figure impair segmentation, iso-oriented and congruent elements in the figure (Caputo and Casco, 1999 *Vision Research* 39 1597–1610; Casco et al, 2005 *Vision Research* 45 2384–2396) or contour (Casco et al, 2009 *Vision Research* 49 583–593) facilitate grouping and, in a similar way, segmentation. Despite the absence of changes in the stimulus or perception, D-waves (segmented–uniform texture ERPs) reflect a task-dependent sign of polarity change (Casco et al, 2009)—early (75–150 ms) increased positivity for grouping, late (140–250 ms) increased negativity for segmentation—indicating distinct task-dependent neural mechanisms for congruent facilitation. Indeed, attention (Casco et al, 2005) and explicit experience (Casco et al, 2004 *Neuroscience Letters* 371 18–23) affects congruency modulation of segmentation and associated D-waves, but not of grouping, since, we now show, passive experience modulates featured gradient but not grouping response.

◆ **Temporal patterning of ‘unlearnable’ stimuli types does not always enable learning**

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Presenting two or more stimulus types randomly interleaved, so-called roving stimuli, disrupts perceptual learning in many paradigms. It was recently reported that learning with disrupting stimuli types is possible when stimuli are presented in an alternating sequence, ie stimulus from type A, then type B, then type A, etc. In our experiment we used bisection stimuli, but found the opposite pattern of results. Presentation of bisection stimuli in a sequence disrupted perceptual learning. We tried to explain these seemingly contradictory results by conducting a meta-analysis. Participants who initially performed the task at a low level, ie ‘bad performers’, were able to learn, whereas the ‘good performers’ did not (good performers were still outside the ceiling range). Therefore, interleaving stimuli may not abolish perceptual learning, they may just make it more difficult and more prone to interact with other factors, such as the initial performance level.

◆ **Brain plasticity associated with supervised and unsupervised learning**

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This fMRI study aimed to investigate perceptual learning by using a paradigm with coherently moving dots presented simultaneously in each visual quadrant (either creating extracting or contracting moving dots). In the learning condition a quadrant deviating with respect to the movement direction of the other three had to be detected. We investigated whether the presence of feedback had an influence on the learning success. Behaviourally data of four subjects (two with/two without feedback) showed improved performance with increasing practise. Feedback improved learning. Biophysical neural modeling could predict our behavioural findings. Preliminary fMRI data reveal enhanced activation in frontal and parietal areas, which can be associated with attentional processes (‘neuronal scaffolding’) in early learning phases. Activation in these areas shows a negative correlation with increasing task performance. Furthermore an area in the middle temporal lobe sensitive for motion perception was identified by using a specific functional localizer. A region of interest analysis of this area showed increased activation during an early learning phase, while in later learning phases this activation decreases.

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◆ **Spatial frequency discrimination learning in adults with amblyopia**

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Perceptual learning effects demonstrate that the adult visual system retains neural plasticity. If perceptual learning holds any value as a treatment tool for amblyopia, trained improvements in performance must generalise. Here we investigate whether spatial frequency discrimination learning generalises within task to other spatial frequencies, and across task to contrast sensitivity and letter acuity. Before and after training, we measured spatial frequency discrimination (at a range of base frequencies 1, 2, 4, 8, 16 cycles deg^{-1}), contrast sensitivity, and letter acuity. During training, normal and amblyopic observers were divided into three groups. Each group trained on a spatial frequency discrimination task at one base frequency (2, 4, or 8 cycles deg^{-1}). Normal and amblyopic observers who trained at lower frequencies showed a greater magnitude and rate of within-task learning (at their base frequency) compared to those trained at higher frequencies. Compared to normal observers, amblyopes showed greater within-task learning at the trained base frequency (on average approximately 20% greater), and broader transfer to other frequencies. Amblyopes also showed greater transfer of learning to contrast sensitivity and letter acuity measures. This broader generalisation of learning in amblyopia provides further support for the therapeutic efficacy of this approach.

◆ **Reading/writing directions prime letter recognition**

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An advantage for word recognition in the right visual field and in some case in the upper right visual field has been shown by Darker et al [2004 *Brain and Language* 89(3) 593–600] and Hagenbeek et al (2002 *Brain Cognition* 49(1) 34–44]. The interpretation of these visual field asymmetries is in terms of directional scanning tendencies arising from reading habits. Nevertheless, in a previous experiment we showed that the recognition of a printed letter is primed by the coincidence between fixation point and handwriting starting point. Thus, visual field asymmetries seems to reflect both reading and writing habits. To further explore this hypothesis we carried out an experiment on Arabic and Italian people who are characterized by opposite script directions. We investigated whether short presentations of four rotations of the character C (C, U, O, D) presented in upper right, upper left, lower left, and lower right visual fields provide additional information about the influence of reading and writing habits on character recognition. Participants were asked to recognise as quick as possible the character (U, O, D) or the direction (down, up, left, and right). The results confirm an advantage of the upper right visual field. Besides, a difference between the Italian and the Arabic performance was found.

◆ **Re-learning face recognition: evidence for efficient strategies without holistic processing**

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In previous experiments, we showed an advantage for visual over haptic face recognition. Promoting serial encoding in vision using a novel gaze-restricted display, we found that these differences are due to modality-specific encoding strategies (holistic in vision vs serial in haptics), and that serial encoding leads to featural (vs holistic) processing. Here, we test how the observed encoding and processing differences might be affected by expertise. Participants were trained on five consecutive days on a set of 19 faces using an old/new recognition task for which three faces were learned with feedback, followed by four test-blocks. On days 1 (pre-test), 4 (post-test), and 5, the task consisted of two upright and two inverted test-blocks. On day 5, we tested participants on a different set of faces. Performance for upright faces was low on day 1, but improved significantly through training ($d1' = 1.11$, $d4' = 3.75$). Importantly, this learning effect generalized to a new face-set on day 5 ($d5' = 3.07$). Although performance significantly improved through training, we found no inversion effect on any day ($d1' = 1.70$, $d4' = 3.54$) indicating no change in processing strategies. Our results show that participants can develop efficient, generalizing strategies to compensate for encoding differences, and that these strategies do not require holistic encoding.

◆ **Two separate mechanisms in motion speed learning revealed by task difficulty manipulation**

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The difficulty of a task is believed to be an important factor in determining the specificity of perceptual learning: difficult tasks usually yield more specific learning to the practiced stimulus.

We reported motion sensitivity generalized across directions after practice in speed discrimination in a single direction (Tseng et al, 2007 *Perception* **36** Supplement, 53), in contrast to the literature revealing specific/limited motion learning. This may be due to our task being too easy, or speed learning may involve different learning mechanisms. We investigated whether we can induce similar specific learning by increasing the difficulty of our speed discrimination task by method A, replacing 50% of the single-direction signal dots with random-moving dots, or method B, by lessening speed difference between the standard and the comparison moving displays. Our results show that method A or method B alone did not generate direction-specific learning, and that easier conditions produce larger sensitivity enhancement (30%) than the more difficult conditions (19%). However, method A and B together did generate a notable M-shaped tuning curve centered at the practiced direction. Our results suggest at least two mechanisms are involved in speed discrimination learning: one increases the motion detector sensitivity and the other narrows the filter tuning by excluding external noise during speed learning.

◆ **Categorical-learning influences on visual discrimination abilities: The view from Enactive Psychology**

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The assumption according to which visual perception is not a passive 'copying' process of the external world dates back at least to the New Look Psychology's emergence. Then, the role of different types of expectations on various aspects of visual judgment was investigated. In more recent times, Enactive Psychology, considering in a more global perspective interactions between psychological and/or physiological processes has contributed—though being still a very minor trend in both psychology and vision sciences—to the modeling of vision within systems (ie, in relation to cognitive, emotional or motor processes) and therefore to renew systemic approaches to vision. However, enaction is sometimes criticized when it is thought of as a simple epistemological 'posture' lacking clear experimental foundations. In this presentation, we consider categorical-learning influences on perceptual discrimination as examples of states of the coupling dynamics between non-visual and visual processes. Recent experiments by our team show that categorical learning (ie, labeling) of complex visual scenes—which has been poorly investigated in its relations to vision—actually modifies the subsequent ability of participants to correctly make same/different judgments of such scenes. Visual performance and experience are strongly modulated by the 'ecology' or 'die Umwelt' of individuals, which functionalize (and are a consequence of) vision.

CLINICAL VISION

◆ **Brain responses of patients with cerebellar lesions in a memory-guided saccade task**

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Working memory performance is impaired in patients with lesions in the cerebellum (Ziemus et al, 2007 *Neuropsychologia* **45** 2016–2024). Here we applied functional magnetic resonance imaging to determine cortical activations in patients with cerebellar lesions while they performed a memory-guided saccadic task (MGT). Subjects viewed displays containing four rectangles (one in each quadrant), which differed in their colour and orientation. After a delay of 2 s participants were prompted to saccade to the previously encoded position of a target that matched on both dimensions a centrally presented probe. In a control condition the probe was presented prior to the four rectangles and subjects saccaded to the location of the matching target. In controls, brain regions specifically responding (p corrected < 0.05) to the increased memory load in the MGT were the dorsolateral prefrontal cortex (DLPFC), posterior parietal areas, anterior insular, and cingulate cortex. Cerebellar patients exhibited significantly less left hemispheric DLPFC activation compared to controls. Our findings support the existence of a cognitive cortico-cerebellar circuit (Schmahmann and Sherman, 1998 *Brain* **121** 561–579). [Supported by German Federal BMBF (project 01GW0653).]

◆ **fMRI in patients with central visual field scotomas reveals higher activation in visual cortex associated with pseudo-fovea**

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In patients with central visual field scotomas, a large part of visual cortex is not adequately stimulated. Patients often use a new eccentric fixation area on intact peripheral retina ('preferred

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retinal locus'—PRL) that functions as a pseudo-fovea. We used fMRI to examine whether stimulating this pseudo-fovea leads to increased activation in visual cortex in comparison to stimulating a comparable peripheral area of the retina in the opposite hemifield. So far, six patients were tested, all having a central scotoma between 5 and 20 degrees in diameter due to retinal dystrophy (Stargardt disease, cone-rod dystrophy). Results show that direct stimulation of the patients' PRLs with flickering checkerboards leads to increased activation in striate and extrastriate cortex (middle occipital gyrus, cuneus, lingual gyrus, and fusiform gyrus), in comparison to stimulating a matching peripheral area in the opposite hemifield. In an additional visual search task, where the letter 'L' had to be detected between a number of 'T's arranged radially in the central visual field, some of the patients also show higher activation in lingual and fusiform gyrus and better performance than healthy controls, when the target stimulus appears in an area of the visual field corresponding to their PRL, suggesting a role for neural plasticity.
[Supported by DFG: FOR 1075.]

◆ **Schizophrenic and bipolar patients reveal identical backward masking deficits**

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In visual backward masking, a target is followed by a blank screen (ISI) and, then, a mask which deteriorates target processing. Schizophrenic patients show strong but complex processing deficits in visual masking compared to healthy controls. There is evidence for a shared genetic etiology in bipolar disorders and schizophrenia prompting the question whether both groups of patients show also analogous information processing deficits. Here, we examined whether the complex masking effects we found previously in schizophrenic patients are also found in bipolar patients. Eleven bipolar, twenty-three schizophrenic patients, and fifteen healthy controls participated in various variants of the shine-through masking paradigm. Both groups showed a very similar pattern of masking deficits. (i) Masking was strongly prolonged compared to controls: schizophrenic patients needed ISIs of 110 ms, bipolars of 95 ms, and controls of only 27 ms. (ii) These prolonged As two further experiments show, ISIs were not caused by deteriorated spatial or temporal resolution. We suggest that schizophrenic as well as bipolar patients suffer from similar dysfunctions in early visual processing. These similar dysfunctions may also have similar genetic causes.

◆ **Visuo-motor processing with abnormal V1-input**

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The consequences of abnormal V1 input on cortical processing during a visuo-motor task were assessed with fMRI in patients with albinism. Fourteen patients with albinism and fourteen controls were investigated with fMRI at 3 Tesla. During the scans the subjects solved a visuo-motor task: During monocular central fixation a coloured target (red or blue) embedded in a blinking array of distractors ($6.5 \times 6.5^\circ$; centred 5.5° lateral from fixation) was presented for 250 ms in either the left or right hemifield. After a variable delay the subjects pressed the upper and lower key for targets in the upper and lower field, respectively, with the right or left thumb for red and blue targets, respectively. In both groups hit rates of 96% were obtained in the visuo-motor task. In seven patients with albinism a strong abnormality of the visual field representation was evident in V1. While this abnormality reached into the intraparietal sulcus, lateralisation patterns in the somatosensory and motor cortex were unaffected. In albinism the visuo-motor task was solved with an abnormal visual field representation that affects great expands of the occipito-parietal cortex. This integration of abnormal input for visuo-motor processing highlights the plasticity of this system.

◆ **Compensatory brain activation in parietal patients during attentional tracking of independently moving objects**

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Previous studies have shown that area hMT+ and parietal regions (precuneus, intra- and subparietal sulci) are involved in attentional tracking of moving objects (Culham et al, 1998 *Journal of Neurophysiology* **80** 2657–2670). In our study we compared the cortical activations in patients

with parietal lesions to those of healthy controls using 3T fMRI to determine the role of the posterior parietal cortex in attentional tracking. Subjects viewed an expanding optic flow field, in which two dot clusters formed and moved independently to the left and right. Participants fixated a small stationary dot in the centre of the display and attentionally tracked these independently moving objects (IMOs). In the control group the presence of IMOs in the flow field led to an activation pattern associated with attentional tracking (hMT+, precuneus; p corrected < 0.05). Compared to this, patients exhibited more activation in clusters in the right V3a and kinetic occipital (KO) area. These areas appear to play an important role in the estimation of trajectories (KO) and depth (V3a) and therefore might promote the detection of IMOs given that parietal processing resources are limited.

[Supported by German Federal BMBF (project 01GW0653)]

- ◆ **Visual motion perception in patients with unilateral parietal brain damage: an fMRI study**
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Previous research has demonstrated that the human parietal lobe contains several motion responsive areas (eg Sunaert et al, 1999 *Experimental Brain Research* **127** 355–370). To explore the extent to which damage in the parietal cortex affects visual motion processing, eight patients with unilateral parietal lobe lesions and eight healthy control were examined using fMRI. We applied a selection of the experimental tasks used by Vaina et al (2002 *European Journal of Neurology* **9** 463–477) to locate brain areas involved in: (i) motion processing (moving versus static dots), (ii) coherent motion detection (CM), (iii) recognition of biological motion (BM), and (iv) detection of 3-D-structure from motion (SFM). Compared to controls, the behavioural data show an impairment of patients' ability to detect CM and SFM stimuli. The fMRI results indicate that patients showed increased activity in motion responsive temporal areas like the superior temporal sulcus during BM and in frontal areas associated with visual attention in the CM task. This could represent a neurophysiological substrate of compensatory mechanisms. Our findings suggest that the parietal lobe plays an essential role in the processing of complex motion stimuli.

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- ◆ **Recovery from cerebral blindness: learning to use already present residual capacity?**
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During the last two decades, the possible recovery from cerebral blindness after acquired brain damage is subject of discussion. Repetitive stimulation of the affected visual fields often results in visual field enlargement. We tried to falsify the possibility that visual fields really recover after training and become available again for conscious use. However, we still found visual field enlargement while we were able to exclude eye movements and/or a developing pseudofovea as possible artifacts. Therefore, we searched for a more objective measure of visual fields than the subjective method of standard perimetry: we assessed the visual fields before training based on activations found with fMRI retinotopic mapping. Such fMRI perimetry often points to the presence of a potentially larger visual field than is found with standard perimetry. This potential could be attained and made use of for a subject by visual training, thus making the idea easier to accept that recovery from cerebral blindness is possible. By presenting stimuli in the regained visual field areas, we were able to show that these areas can actually be used for colour and shape perception. Furthermore, subjects with visual field enlargement showed significant improvement in daily-life activities, such as faster reading, improved peripheral detection of moving objects in a traffic scene, and more frequent eye movements towards their affected side when driving a car in a simulator.

- ◆ **Magnocellular-dorsal pathway and sub-lexical route in developmental dyslexia**
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Developmental dyslexia (DD) is frequently associated to a phonological deficit, although the underlying neurobiological causes remain undetermined. One prominent hypothesis suggests a specific deficit in magnocellular-dorsal (MD) pathway. In the present study we investigated the visual MD and parvocellular-pathway in seventeen dyslexics and in twenty-four chronological age- and IQ-matched normally reading children by measuring dynamic (ie, spatial frequency doubling illusion) and static stimuli sensibility, respectively. The results revealed a specific deficit of the MD-pathway in dyslexics. More importantly, the MD-deficit was selectively presented in

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poor non-word readers, suggesting the specific role of MD-pathway on phonological decoding ability. Accordingly, we further showed that in dyslexic children, individual differences in the MD-sensibility accounted for 29% of unique variance in non-word reading fluency after controlling for age and IQ. Finally, MD-deficit appears to be frequent because the 75% of poor non-word readers were at least 1 standard deviation below the mean of the controls. These results suggest that a MD-deficit—probably linked to middle-temporal areas dysfunction—might impair the sub-lexical mechanisms that are critical for reading development.

◆ **Measuring subjective visual acuity in normal subjects with simulated visual disorders**

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The influence of different visual disorders on visual acuity in normal subjects was investigated. We implemented mathematical models based on the underlying physics to degrade the visual stimuli themselves, using a Fourier-optical approach for defocus and a contrast-reducing scattering model for cataract. In eight subjects we obtained acuity estimates with simulated defocus ranging from 0 D to 4 D and with cataract strength ranging from weak to severe. Different types of test stimuli, namely Landolt Cs, gratings, and pictures of faces, were assessed. Psychophysical acuity decreased monotonically with increasing defocus. With cataract, acuity remained nearly unaffected for weak and moderate cataract. We found gratings to yield higher acuity values than the other stimulus types irrespective of the kind of visual disorder. High-pass filtered face images were more sensitive to image degradation than other stimulus types, especially with cataract. The results suggest that all tested stimuli are suitable for acuity measurements, though frequency-filtered faces may have advantages in resolving effects of cataract.

◆ **The effects of hyperbaric oxygen on the human retinal standing potential**

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Marmor et al (1985 *Documenta Ophthalmologica* **60** 347–352) have shown that the retinal standing potential rises with hypoxia, and falls abruptly when oxygen saturation returns to 100%. Since using hyperbaric oxygen is considered as a treatment option for several eye diseases including diabetic retinopathy, we decided to expand their study by evaluating changes in the standing potential under hyperbaric conditions. We estimated the changes in the standing potential by measuring EOG using Ag/AgCl electrodes and an AC amplifier with high pass frequency setting at 0.05 Hz. The recordings were performed in a hyperbaric multi-place chamber breathing air at 1 ATA and 2.5 ATA and then 100% oxygen at 2.5 ATA. A control group was tested in the chamber with identical time and light conditions, but while breathing atmospheric air. The results showed that under our mesopic testing conditions the standing potential of the eye undergoes spontaneous changes similar in both the control and the experimental groups. Breathing air at 2.5 ATA (PO₂ ~ 400 mm Hg) or 100% oxygen at 2.5 ATA (PO₂ ~ 2000 mm Hg) does not seem to affect those changes which emphasizes the relative insensitivity of the standing potential to hyperoxia.

◆ **Visual attention and phonological processing are both impaired in preschool children at risk of dyslexia**

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According to cognitive models of reading acquisition, the mastery of automatic grapheme-phoneme mappings (ie, the basis of phonological assembly) is a crucial prerequisite for the development of skilled reading. Phonological assembly—leading from a visual input to a linguistic output—requires, in addition to awareness of speech sounds, a graphemic parsing (GP) process that segments a letter string into graphemes. Indeed, both phonological segmentation and GP were found to be impaired in dyslexic children when compared to the age and reading level matched controls. A causal hypothesis suggests that the visuo-attentional mechanisms involved in GP are already compromised in preschoolers at risk of developmental dyslexia. To investigate this hypothesis, we measured the efficiency in orienting visual attention to a brief spatial exogenous cue when subjects were engaged in a task that required the identification of a target flanked by lateral noise (ie crowding condition). Our results show, for the first time, that children at risk of dyslexia ($N = 20$) compared to controls ($N = 67$) present a marked disorder of visuo-attentional orienting, in addition to the typical syllabic segmentation deficit. These results support the hypothesis of a causal link between a deficit of multi-sensory attention and developmental dyslexia.

◆ **Humans magno- and parvo-systems and selective abnormalities in their function**

S V Muravyova, Y E Shelepin, R V Maximov¶ (Pavlov Institute of Physiology, Russian Academy of Sciences, St Petersburg, Russia; ¶ Department of Neurology, St Petersburg State Medical University, Russia; e-mail: mlanka@freemail.ru)

In psychophysical and electrophysiological investigations we tested the hypothesis that in patients with glaucoma and with multiple sclerosis (MS) on its early stage either magnocellular pathway or parvocellular pathway are disordered. The spatial-frequency contrast sensitivity has been measured in the healthy subjects and in the patients with early stage of diseases to static and dynamic gratings. The decrease in sensitivity at low and high spatial frequency indicates the changes in parvo- and magno-system activity. In electrophysiological investigations (visual evoked potentials recordings) we used checkerboard patterns of main different spatial frequency and different contrast presented on the uniform background. Electrophysiological data in patients with MS were separated into two clusters. The result from the first group of patients with MS was compared with data from group of patients with glaucoma. It is known that glaucoma patients have disordered magno-system. The amplitude of positive wave P100 is decreased in patients with both types diseases comparative to healthy subjects. The amplitude of negative wave N80 is decreased in the second group of MS patients with disordered parvo-system. Electrophysiological changes in patients are in good accordance with psychophysical measurements of contrast sensitivity, specific for magnocellular and parvocellular pathway.

◆ **Assessment of fusional reserves by means of interactive software: the effect of stimulus velocity**

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Using interactive software for assessment of fusional reserves allows the control of target velocity and, therefore, the velocity of convergent/divergent eye movements. In a pilot series of experiments, we measured fusional reserves in ten subjects at varying velocity of the displayed images in the range of 0.7–28 mm s⁻¹. The viewing distance was 0.50 m. Test stimuli were Snellen E of two sizes (5 and 20 mm) and random-dot stereograms. Critical values of convergence and divergence were assessed using the criterion of binocular image breakup. In most cases, increasing stimulus velocity led to significant increase (1.5–2 times) of convergent fusional reserves. The critical values of convergence either increased monotonously or reached a peak at intermediate velocities. In measuring divergent fusional reserves, dependence of quantitative results on target velocity was absent or weak. However, as concern physiological comfort, targets moving with moderate velocities appeared most suitable for measuring both components of fusional reserves. On the one hand, such stimuli provided rather fast measurements and produced minor visual strain. On the other hand, they gave enough time for response. These findings could be important for optimizing conditions of measurements and parameters of treatment exercises aimed at improving fusion capabilities.

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◆ **Vision restoration hot spots after brain damage are influenced by local topographic interactions**

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Vision restoration training (VRT) in hemianopic patients improves vision only in some areas of the visual field ('hot spots'). Because receptive field plasticity might contribute to this recovery, we studied if residual function from the immediate surround has an influence on restoration. Perimetry charts of twenty-three hemianopic stroke patients were analyzed before vs after 6-months VRT. We then studied the influence of topographic features of the baseline charts with self-organizing maps (SOM) for all hot ($N = 688$) and cold spots ($N = 3426$) including (i) distance to the scotoma border, (ii) local residual function, and (iii) residual function of the immediate surround. The probability of a baseline spot to become a restoration hot spot was high if (i) it were located in areas of residual vision, (ii) with few absolute defects in the surround, and (iii) being located less than 4 mm away from the scotoma border in cortical coordinates. Vision restoration is thus influenced both by local residual activity and residual activity in the immediate spatial neighborhood. This is compatible with the hypothesis that training effects are influenced both by local residual function and residual activity of the immediate surround, possibly through receptive field plasticity and lateral interactions in visual cortex.

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- ◆ **Adaptation of a Bayesian algorithm to visual acuity measurement in clinical practice**
A E Belozarov (Sensory Information Processing Laboratory, Institute for Information Transmission Problems, Russian Academy of Sciences, Moscow, Russia;
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Bayesian adaptive estimation methods (QUEST, bestPEST, ZEST) may be successfully adapted to clinical practice for reasons of speed and robust behaviour. Our purpose was to develop a computer method of visual acuity (VA) measurement for a standard ophthalmic exam, very fast and reasonably accurate. The psychometric function parameters that we used were the position parameter (VA), slope, and lapse rate. Examination conditions allow to get prior information about threshold to start hereabout, so every trial provides substantial information. The rule of best choice of discrete size of Snellen E for every trial and the termination rule were determined by Monte Carlo simulation. Inaccuracy of the a-priori slope assignment results in an almost linear and modest VA estimate displacement, so we set slope constant and corresponding to our empirical data. Our simulations show that the lapse rate is best set to the largest value practically occurring, it leads to only a small displacement of VA estimates to higher values. In the final algorithm, 10% dispersion can be achieved on average after 9–12 trials, depending on measurement conditions. For high VA values, when only two optotypes fall into the inclined part of the psychometric function, measurement takes about twice the time. In 90% of practical cases, 6–18 presentations are required for a measurement.

THURSDAY

TALK SESSION A

VISUAL NEUROSCIENCE

◆ **Surround-suppression: can you keep a good idea down?**

C R Aaen-Stockdale, B Thompson¶, P-C Huang¶, R F Hess¶ (Department of Optometry, University of Bradford, UK; ¶ Vision Research, McGill University, Montreal, Canada; e-mail: c.aaen-stockdale@bradford.ac.uk)

A simple psychophysical measure of the strength of cortical surround-suppression has recently been advanced (Tadin et al, 2003 *Nature* **424** 312–315) and used with several clinical groups including the elderly, schizophrenic and depressed patients, low vision populations and children. Support for the use of this technique comes from neurophysiological studies of surround-suppression in area MT, which show that the short duration stimuli used in the psychophysical technique may be preferentially targeting surround-suppressed neurons. We have found an identical effect at durations well beyond the range at which surround-suppressed neurons in MT are preferentially activated. Having normalized our stimuli relative to contrast threshold, we show that our results can be entirely explained by the relative contrast of the stimulus, with the ‘suppressive’ effects explained by the fact that observers are tested at progressively higher supra-threshold contrasts as stimulus size increases. We speculate that these low-level factors may have played a role in previous work, which may limit the clinical usefulness of this technique.

◆ **Global contour processing in younger and older adults**

A M McKendrick, A E Weymouth, J Battista (Department of Optometry and Vision Sciences, The University of Melbourne, Australia; e-mail: allisonm@unimelb.edu.au)

Our experiments explore whether global contour processing is altered by healthy ageing. Contour processing was measured using a closed figure (circle or ellipse) constructed of Gabor patches presented either in noise or on a blank background. Three experiments were conducted: (i) we fixed the number of Gabors (10, 12 or 15) comprising the contour and measured the aspect ratio required to distinguish between shapes (circle or ellipse); (ii) we fixed the aspect ratio (three times individual threshold aspect ratios) and measured the threshold number of elements required to determine the shape; and (iii) we added orientation jitter to the Gabor elements and measured the aspect ratio required to distinguish the shape. For all tasks, the Gabors were presented at five times the individual’s contrast threshold, aiming to eliminate differences in contrast sensitivity. Nineteen older (aged 61–80 years) and eighteen younger (aged 22–33 years) adults participated. Older adults had elevated thresholds for shape perception presented in noise ($p < 0.05$) and required a larger number of elements to perceive the global contour when presented in noise ($p < 0.05$), even when matched for contrast sensitivity and aspect ratio threshold. This finding is consistent with other recent work showing deteriorations in cortically mediated visual processing with age.

◆ **Visual task performance and difficulties with daily activities in age-related macular degeneration**

C S Barnes, W De l’Aune¶, R A Schuchard§ (Department of Ophthalmology [§ Department of Neurology], Emory University, Atlanta, USA; ¶ Rehabilitation Research & Development Center of Excellence, Atlanta VA Medical Center, USA; e-mail: cbarne3@emory.edu)

As part of an ongoing study of ‘everyday function’ in age-related macular degeneration (AMD), performance was compared for two functional tests (face discrimination and visual search), and related to visual function and self-report scores of difficulty with daily activities. Twenty individuals with AMD (aged 64–87 years) were tested binocularly. Accuracies and response times (RTs) were measured for a search test (locate target objects in crowded photographs), and a face-discrimination test (match test-face photographs to continuously presented reference photographs). Eighteen of the subjects also provided answers to the NEI-VFQ-25 questionnaire’s ‘activity’ questions. Subjects showed lower contrast sensitivities ($p < 0.01$), but not significantly lower visual acuities than a group of fourteen age-similar controls. The four test measures (two RTs, two accuracies) correlated significantly both within and between tests ($r \geq 0.65$). The predictive value of visual acuity and contrast sensitivity for these test measures reached $r^2 \geq 0.37$. Rather unexpectedly, the RTs, particularly for Faces, correlated ($r \geq 0.65$) with more of the NEI-question scores than did the test accuracies. Conclusions: Large correlations were found between RTs and accuracies for these tests. These exploratory analyses highlight a possible role for response timing in the determination of self-ratings of functional ability, which will be investigated further as this study proceeds.

◆ **Decoding neural response dynamics in the human brain**

C W Tyler, L Likova, S Nicholas (Brain Imaging Center, Smith-Kettlewell Eye Research Institute, San Francisco, USA; e-mail: cwt@ski.org)

To estimate the neural signal dynamics in the human brain we propose a biophysically-based approach that we term Bayesian nonlinear dynamic forward (BNDF) optimization, constrained

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by a plausible parametrized model of neural population response dynamics. The forward model of a coupling through the metabolic/hemodynamic is fit to the blood oxygen-level dependent (BOLD) responses for a wide range of temporal durations, providing strong constraints on the parameters of the neural model for local neural populations in each cortical region. BOLD responses were measured throughout the human brain using a GE Signa 3T scanner with a 1 s sampling rate and a randomized event-related design for stimuli consisting of continuous spiral motion with durations from 17 ms to 4 s in increments of factors of 2. Overall, the BOLD analysis revealed that most BOLD waveforms (128 free parameters) could be characterized to > 90% of the variance with predictors based on the nonlinear neural-to-BOLD model with only 7 free parameters. The neural population response had a predominant transient peak with a duration of ~50 ms, a sustained plateau with an amplitude of ~5% of the transient peak amplitude, and a positive off response, matching the known properties of monkey cortical population responses.

◆ **Dependence of a visual categorization task on acetylcholine**

N C Aggelopoulos, S Liebe, N K Logothetis, G Rainer (Department of Neurophysiology, Max Planck Institute for Biological Cybernetics, Tübingen, Germany; e-mail: Nikolaos.Aggelopoulos@tuebingen.mpg.de)

The nervous system is adaptive, so that its neuronal properties can be modified by learning to respond to new categories of stimuli. This is a crucial function of the nervous system not only in children but also in adults and its malfunction can lead to a severely disabling mental disease known as Alzheimer's or senile dementia. Acetylcholine (ACh) is one of the modulators implicated in the brain's adaptive behaviour. Indeed ACh plays an important role in many cognitive functions, including attention (Sarter and Bruno, 2000 *Neuroscience* **95** 933–952; Furey et al, 2008 *Neuropsychopharmacology* **33** 913–923; Herrero et al, 2008 *Nature* **454** 1110–1114), cue detection (Parikh and Sarter, 2008 *Annals of the New York Academy of Sciences* **1129** 225–235), learning (Sarter et al, 2003 *Neurobiology of Learning & Memory* **80** 245–256), short term-memory (Miller and Desimone, 1993 *Neuroreport* **4** 81–84; Thomas et al, 1999 *Neuropsychologia* **46** 2476–2484), and long-term memory retrieval (Sarter et al, 2003 *Neurobiology of Learning & Memory* **80** 245–256; Rosier et al, 1999 *European Journal of Neuroscience* **11** 3701–3714), as well as in Alzheimer's disease. We have examined the effects of scopolamine—an antagonist of muscarinic ACh receptors—on object recognition in macaques. The animal was taught a categorization task, ie to classify stimuli to categories by appropriate behavioural responses. The paradigm involved a fixation task during which an image that belonged to one of the categories was presented. The macaque used levers to categorize the stimulus. Performance of this task was disrupted following injections of scopolamine. When presented with stimuli that belonged to one of these categories but had not been seen before, scopolamine significantly impaired performance in the categorization task. The monkey was still able to carry out the task with a set of familiar stimuli, ie stimuli that it had previously categorized successfully. Performance deteriorated as the stimulus became less salient by increasing the level of visual noise. Scopolamine, however, had no significant or long-lasting effect on performance with familiar stimuli at the different noise levels. In our attempt to localize the effects of ACh we used an analogue of scopolamine that cannot cross the blood brain barrier. The analogue (butyl scopolamine) mimicked the peripheral actions of scopolamine but caused no cognitive deficit. The cognitive changes, therefore, reflect ACh's effect in the brain. The exact site of the effect has not yet been established but is likely to depend on forebrain mechanisms.

◆ **Cholinergic enhancement in healthy humans increases magnitude and specificity of perceptual learning**

A Rokem, M A Silver[¶] (Helen Wills Neuroscience Institute [[¶]School of Optometry], University of California, Berkeley, USA; e-mail: masilver@berkeley.edu)

Increasing cortical release of acetylcholine (ACh)—either with pharmacological manipulation or basal forebrain stimulation—facilitates learning and cortical plasticity in animal models. In humans, administration of the cholinesterase inhibitor donepezil (trade name: Aricept) increases synaptic ACh levels by blocking the enzyme that metabolizes ACh in the synaptic cleft. We report here that cholinergic enhancement with donepezil increases the magnitude and specificity of visual perceptual learning in healthy human participants. We conducted a double-blind, placebo-controlled, crossover study, in which each participant trained twice on a visual motion direction discrimination task, once while ingesting donepezil and once while ingesting placebo. For both pharmacological conditions, learning resulted in an improvement in discrimination performance for the trained direction of motion and at the trained visual field locations. However, this behavioral improvement was significantly larger when training occurred under donepezil compared to placebo.

Furthermore, learning under the influence of donepezil was more specific for the direction of motion that was trained and for the visual field locations where the training occurred. These results indicate that ACh can play a facilitatory role in neural plasticity associated with perceptual learning, both augmenting it and directing it towards particular populations of cells that encode behaviorally-relevant features of the stimulus.

◆ **Visual sensations in blind subjects elicited by electrical stimulation with a wireless intraocular retinal implant**

S Klauke, M Goertz¶, U Thomas§, F Bremmer, T Wachtler, EpiRet Group§ (Department of Neurophysics, Philipps University, Marburg, Germany; ¶ Fraunhofer IMS, Duisburg, Germany; § EpiRet GmbH, Giessen, Germany; e-mail: susanne.klauke@physik.uni-marburg.de)

Electrical stimulation of retinal neurons has been shown to be a feasible way to elicit visual percepts in patients blind from degenerative diseases of the retina. The EPIRET3 retinal implant has been developed as a wireless intraocular implant for epiretinal stimulation, and stimulation tests have been performed during a clinical trial at the eye clinics of Aachen and Essen to evaluate the safety and efficacy of the implant. Six blind retinitis pigmentosa patients were included in the study. The implants were successfully implanted and activated, and all subjects reported visual percepts as a result of electrical stimulation with the implant. Stimuli were charge-balanced square current pulses of various durations and current amplitudes. Thresholds for eliciting visual percepts varied between individuals but were below the safety limits of electrical stimulation. For suprathreshold stimuli, perceived brightness correlated with current amplitude. In three subjects, we applied stimuli to electrodes defining lines on the electrode array with orientations that differed by 20 or 60 degrees, respectively. Subjects were able to distinguish these stimuli. Furthermore, subjects perceived different stimulus positions at different positions in the visual field. The results indicate that stimulation with the EPIRET3 system can elicit percepts useful for artificial pattern vision.

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◆ **Non-invasive alternating current stimulation for the treatment of visual field defects in optic neuropathy: a single-centre trial**

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Non-invasive electrical stimulation is known to induce cortical plasticity. We investigated if non-invasive, repetitive transorbital alternating current stimulation (rtACS) improved visual functions in patients with optic nerve damage. In a prospective, placebo-controlled trial, patients were randomized to a rtACS ($N = 42$ eyes) or placebo group ($N = 20$ eyes). Stimulation was carried out on ten consecutive days using a non-invasive device generating AC-current bursts with amplitudes < 1000 A at 10–50 Hz and measured visual field and acuity before and after treatment. Analysing the post-treatment minus baseline differences of primary outcome measures, significant increases of stimulus detection rates were observed in the rtACS but not in the placebo group in visual field examinations (rtACS group 3% vs placebo 0.2%) and visual acuity (rtACS = 0.06 vs placebo = 0.02 Landolt-C-test). The increase of stimulus detection performance and visual acuity remained constant at a 2-months follow-up. We propose that visual field enlargements in patients with visual field defects through non-invasive electrical stimulation may be due to increased neuronal synchronization in higher visual areas. Our results are compatible with the view that pulsed, repetitive, non-invasive stimulation induces LTP-like strengthening of synaptic transmission in residual tissue and thus restores some of the lost vision.

TALK SESSION B

RIVALRY

◆ **Does colour undergo the same reversed contrast effect observed for lightness in Agostini and Galmonte's Necker cube display?**

T A Agostini, O Da Pos¶, A C G Galmonte§, A Mauri (Department of Psychology, University of Trieste, Italy; ¶ Department of General Psychology, University of Padua, Italy; § Department of Psychology and Cultural Anthropology, University of Verona, Italy; e-mail: agostini@units.it)

Agostini and Galmonte (1997 *Perception* 26 Supplement, 27; 2002 *Perception* 31 Supplement, 7) presented a reversed-contrast display where a grey region surrounded by a black area appears darker than an identical grey region surrounded by white. Both higher- and lower-level factors affect simultaneously this configuration, but higher-level grouping factors prevail in determining the effect, that cannot be explained by assimilation. The present work investigates whether global

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grouping factors induction can be found also for colour. Agostini and Galmonte's display was reproduced by using red/yellow inducing colours (backgrounds/corners), whereas induced regions (dashed lines) were orange. There were also two control conditions: (i) inducer corners were the same orange as targets; (ii) disks having same area and colour (red/yellow) replaced the inducer corners. In these cases, we did not expect any effect. Observers had to judge the colour of the induced regions on a red/yellow Munsell Scale. Results replicate those obtained for lightness: Global factors determine the target perceived colour; ie, orange appeared reddish in the yellow corners/red background display, whilst it was perceived yellowish in the opposite configuration. No statistically significant difference was found for both controls. Therefore, we conclude that global induction overcomes local induction also for coloured displays.

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◆ **Predicting binocular-rivalry alternations electrophysiologically**

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When each eye views different images, perception alternates irregularly between them: binocular rivalry. Interrupting rival stimuli by a short gap can prompt alternations. We showed rival gratings for 1000 ms, then a 200-ms gap, then the same stimuli for another 1000 ms; this yielded about 50% alternations and about 50% of no alternations. We also showed fusion stimuli (identical images for the two eyes) whose orientation we changed at the gap on 50% of trials. We compared event-related potentials from conditions in which perception changed with those in which perception stayed the same. At about 820 ms before the gap, we could predict from occipital electrodes which rivalry presentations would yield an alternation. The first negative deflection (N1) was larger when there was a later alternation than when not. We found no such difference with changes in orientation from fusion stimuli. We propose that the enhanced response to rival stimuli is a marker of greater adaptation that makes it more likely that some perturbation, such as a gap, will lead to an alternation.

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◆ **How many paths to awareness in binocular vision?**

M A Georgeson, T S Meese (School of Life & Health Sciences, Aston University; e-mail: m.a.georgeson@aston.ac.uk)

Two eyes are better than one. Current models based on binocular summation of signals from each eye, with interocular contrast gain control, predict well the detection, discrimination and perception of monocular and binocular contrast. We now ask whether monocular signals also remain available to perception. We presented horizontal 1 cycle deg^{-1} sine-wave gratings of contrast C to both eyes for 500 ms in a 2AFC discrimination task, to determine whether contrast increments ($C + \delta C$) in one eye were made more difficult to detect when accompanied by contrast decrements ($C - \delta C$) in the other eye. Simple summation or averaging over the two eyes should make these opposite changes cancel each other. Results from two experiments (means of 5–6 observers) at 3 pedestal contrasts ($C = 0, 1, 10\%$, always binocular) consistently showed no cancellation. Binocular increments or decrements were more detectable than monocular ones, as expected. But thresholds for the hybrid increment/decrement condition were close to those for monocular contrast change (on the binocular pedestal). This absence of cancellation suggests that monocular signals remain available to the final stages of perception and decision, alongside the combined binocular signal. Optimal use of information from 3 independently noisy left-eye, right-eye, and binocular channels predicts the pattern of thresholds fairly closely.

◆ **Reading out the perceptual status during binocular rivalry using eye movement responses: application of the quadrature motion display**

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Binocular rivalry is a useful psychophysical tool to investigate neural correlates of visual consciousness because the perceptual alternation between the left and right eyes' images occurs without visual input change. The conventional experiments on binocular rivalry require for the participants to voluntarily report their perceptual state. The participants' reports, however, may not be reliable particularly if the participants are non-human primates. Instead of asking participants to report, Logothetis and Schall [1990 *Vision Research* 30(10) 1409–1419] used reflexive eye movements, known as optokinetic nystagmus (OKN), as an objective indicator of the perceived motion direction during binocular rivalry between two opponent motions and found that the direction of the OKN at a time is highly correlated with reported motion direction.

Here, we expanded their paradigm for the investigations on binocular rivalry between different object images, where a different image with quadrature motion (Shadlen and Carney, 1986 *Science* **232** 95–97) was used as visual input for each eye. In our display, one eye received leftward motion while the other eye received rightward motion although both eyes' images remained centered in each frame. The image aware at a time can be reliably predicted from eye movement responses since the direction of OKN corresponds to the motion direction associated with an image.

◆ **Adaptation-related changes during binocular rivalry phases: Dominance sensitivity declines, suppression sensitivity improves**

D Alais, J Cass, R P O'Shea¶, R Blake§ (School of Psychology, University of Sydney, Australia; ¶ School of Health and Human Sciences, Southern Cross University, Lismore, Australia; § Vanderbilt Vision Research Center, Vanderbilt University, Nashville, USA; e-mail: davida@psych.usyd.edu.au)

Reciprocal inhibition models of binocular rivalry suggest adaptation causes perceptual alternations: a weakening dominant response can inhibit the suppressed stimulus less. We test this by mapping probe detection over dominance and suppression periods. Probes were brief contrast increments of the rival target in the upper or lower half (2AFC). Previous studies failed to show predicted sensitivity changes within rivalry phases, but measured only early and median time points. In a new 'reverse correlation' approach, subjects tracked rivalry continuously over 3min sessions with probes every ~3 s. Off-line analysis (1500 probes; 25 sessions) determined whether probes occurred in dominance or suppression phases, and time since onset of that phase. Results showed probe sensitivity does change over time in dominance and suppression, mostly late in rivalry phases (explaining previous failures). This was clearest when probe timing was expressed as a proportion of the rivalry phase (normalising all phase durations), not as absolute time since the phase began. Consistent with adaptation over time in a rivalry phase, probe sensitivity falls during dominance and improves during suppression. Probe sensitivities tend to converge just prior to dominance changes, correlating with rivalry state changes. These findings square with adaptation operating within a reciprocal inhibition model of rivalry.

◆ **Unbound rivalry: When the mind's eye just can't get it together**

D H Arnold, H Erskine, W Roseboom, T S Wallis (Department of Psychology, The University of Queensland, St Lucia, Australia; e-mail: d.arnold@psy.uq.edu.au)

Human vision relies on diverse neurons that respond differently to common input. Usually this does not create perceptual conflict. Here, however, we show that a rapidly rotating coloured surface can induce a rivalry between conflicting illusory forms. Each illusory form intermittently dominates perception while the other is suppressed from awareness. One of the two illusions is generated by mechanisms sensitive to rapid movement but insensitive to fine spatial scale colour changes. The other is driven by mechanisms with reversed sensitivities. When exposed to rapid movement, such mechanisms can signal the presence of blurred forms elongated along the trajectory of motion—motion streaks. This new phenomenon shows that moving form and motion streak signals can engage in a dynamic competition for perceptual dominance. It also provides a dynamic situation that can be exploited to target distinct spatiotemporal mechanisms to explore how they contribute to the determination of conscious visual awareness and to the formation of coherent visual sensations.

◆ **Non-retinotopic rivalry in an object-based reference frame**

J J A van Boxtel, C Koch (Division of Biology, Caltech, Pasadena, USA; e-mail: j.j.a.vanboxtel@gmail.com)

Visual rivalry occurs when two or more possible percepts exist given the perceptual context, causing the visual system to alternately prefer one and then the other percept, resulting in perceptual fluctuations. So far, visual rivalry invariably involved spatial conflict, at some scale. Contrary to this centuries-old paradigm, we constructed a stimulus that allows for rivalry in a retinotopic coordinate frame, and in an object-centered coordinate frame. Both could be independently manipulated, allowing for a full factorial design. We show that visual rivalry may occur in an object-centered reference frame without spatial or temporal conflict. The rivaling stimulus was the ambiguous motion quartet (the two main percepts being two dots moving horizontally, or vertically, relative to each other), and the object-centered reference frame was provided by the Ternus display (three horizontally-aligned disks alternately moving left and right, allowing for group motion (all disks are perceived to move together) or element motion (the outermost disk repeatedly jumps over the other two disks which remain stationary)). Stimulation was binocular. The perception of group-motion in the Ternus display supported object-based rivalry when the motion quartet moved along with the group (inside the central disk), and it hampered retinal-based

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rivalry when the motion quartet remains stationary. The perception of element-motion in the Ternus display disrupted object-based rivalry when the motion quartet moved. Thus, the visual system continuously uses object-based processing when resolving visual conflict.

◆ **The perceptual dynamics of tristable stimuli**

G Wallis, S Ringelhan¶ (Human Movement Studies, University of Queensland, Brisbane, Australia; ¶ Department of Psychology, University of Tübingen, Germany; e-mail: gwallis@hms.uq.edu.au)

One of the great challenges to human perception is that there is no simple relationship between the image received by our eye and the objects and events in the world which produced that image. Although we are usually able to build a correct impression of an external stimulus, there are situations in which inherent stimulus ambiguity makes this impossible. The perceptual vacillation which results is particularly evident when viewing visual conundrums such as the Nekar Cube and face/vase illusion, or during binocular rivalry. Faced with an irresolvably ambiguous stimulus, the visual system switches continuously and indefinitely between different interpretations of the stimulus. Models of perceptual rivalry have traditionally focused on trying to explain the switching process in binocular rivalry or for patterns with two stable interpretations. In practice, bistable systems can be created from a myriad of oscillatory network models making it difficult to isolate the most appropriate model. We provide switching data from a collection of tristable stimuli which offer a far more powerful and yet tractable data set for investigating the explanatory and predictive power of these models. One of the many findings from our work is that switching in cyclical patterns (A–B–C) happens more quickly than return switching (A–B–A), which appears consistent with adaptation models of rivalry. We also find no evidence for hub-based switching in which one state is preferred over the other two, a fact that appears inconsistent with inter-hemispheric switching models.

SYMPOSIUM I

MULTISENSORY INTEGRATION

◆ **Multi-sensory perception of space and time, in adults and in children**

D C Burr (Dipartimento di Psicologia, Università degli Studi di Firenze; e-mail: dave@in.cnr.it)

Many studies have shown that our perceptual systems integrate information from different senses optimally. Here I will overview some recent work from our laboratory studying the how visual, haptic, and auditory signals about size, orientation, motion, and time are integrated perceptually. I will also review recent work showing that the capacity to integrate visuo-haptic information develops late, at about 8 years of age. Evidence from blind and low-vision subjects suggests that the late development could reflect cross-sensory calibration in the developing brain.

◆ **Auditory objects, visual objects, and audiovisual objects**

M Kubovy (Department of Psychology, University of Virginia, Charlottesville, USA; e-mail: kubovy@virginia.edu)

I will discuss two kinds of linkages between vision and audition. The first is a duality. The visual system detects and identifies surfaces; the auditory system detects and identifies sources. Surfaces are illuminated by sources of light; sound is reflected off surfaces. However, the visual system discounts sources and the auditory system discounts surfaces. These and similar considerations lead to the Theory of Indispensable Attributes that states the conditions for the formation of gestalts in the two modalities. The second linkage involves the formation of audiovisual objects, integrated crossmodal experiences. I will describe research that reveals the role of crossmodal causality in the formation of such objects. These experiments use the canonical example of a causal link between vision and audition: a visible impact that causes a percussive sound.

◆ **Crossmodal interactions in visual perception and learning**

L Shams (Department of Psychology, Interdepartmental Neuroscience Program, NeuroEngineering Program, University of California, Los Angeles, USA; e-mail: ladan@psych.ucla.edu)

Humans are generally considered as visual animals. Visual perception, however, can be strongly and qualitatively altered by other modalities. We have found that sound can radically change visual perception, and ERP, MEG, and fMRI studies show that this alteration can occur at short latencies and as early as primary visual cortex. These findings together with a wealth of other recent findings have established that crossmodal interactions are ubiquitous in human perception and can occur at various levels of processing, including very early stages of sensory processing. Therefore, we asked whether crossmodal interactions play a role in perceptual learning. We compared visual training with auditory-visual training for learning of a low-level visual task, and discovered

that auditory-visual training accelerates and enhances performance in a visual task even in the absence of sound. An fMRI study of this multisensory learning suggests that a vast network of brain areas are affected by this type of learning. Altogether these findings implicate that understanding multisensory mechanisms is essential in understanding visual perception and learning.

◆ **Multisensory contributions to the perception of motion**

S Soto-Faraco (ICREA & Universitat Pompeu Fabra, Barcelona, Spain;
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There is increasing recognition of the importance of multisensory integration to achieve accurate and coherent perceptual representations. Some of the classic demonstrations are based on the perceptual consequences of presenting conflicting information to different senses, such as the ventriloquist illusion or the McGurk effect. However, these traditional lines of research have often focused on spatially static stimulation, in contrast with the highly dynamic nature of everyday life environments. Here I discuss some of our recent work addressing the contribution of multisensory integration processes to the perception of direction and speed of motion. My initial studies showed that motion direction judgments in one sensory modality (ie, audition) can be strongly influenced by the direction of motion in other modalities (ie, vision). As in other multisensory phenomena, these influences are not always bi-directional and extend to other modality combinations. Furthermore, I will present several lines of evidence to support the idea that integration of motion information has a perceptual basis and cannot be accounted for solely by local interactions occurring at the level of static information (ie, the ventriloquist illusion). I will try to draw some conclusions regarding the neural underpinnings of such interactions and, finally, I will discuss the relevance of this research in the context of audiovisual media applications and virtual reality environments.

◆ **The multisensory perception of synchrony**

C Spence, J Navarra, A Vatakis, J Hartcher-O'Brien, C Parise (Crossmodal Research Laboratory, Department of Experimental Psychology, Oxford University, UK;
e-mail: charles.spence@psy.ox.ac.uk)

The last few years have seen a rapid growth of interest in issues related to the temporal aspects of multisensory perception. We will highlight recent research that has investigated people's sensitivity to temporal asynchrony for both simple (eg, beeps, flashes, punctuate touch, laser pain) and more complex stimuli (eg, speech, music, object action video clips) using both simultaneity and temporal order judgment tasks. We will review some of the latest findings to have emerged from our laboratory looking at how the brain responds (ie, adapts) to various kinds of on-going asynchronous stimulation (again using both simple and complex stimuli). Recent findings demonstrating the effect of the 'unity effect' on multisensory temporal perception will be outlined, as will research showing that synesthetic correspondences can modulate multisensory integration (both temporal and spatial) in normal participants.

SYMPOSIUM II

NEUROPHYSIOLOGICAL BASIS OF BOLD SIGNALS

◆ **Neurometabolic coupling in the cerebral cortex**

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In non-invasive imaging such as fMRI, the blood oxygen level dependent (BOLD) signal is used to infer changes in neural activity. To help establish a direct connection between hemodynamic measurements, and neuronal events, we have developed a technique by which we are able to make simultaneous co-localized measurements of tissue oxygenation and single cell neural activity within the visual cortex. Our findings show that increases in neuronal spike rate are accompanied by decreases in tissue oxygen. This decrease may be used to predict fundamental characteristics of visual processing such as orientation selectivity and ocular dominance. Our results indicate a coupling between neural activity and oxidative metabolism and this may be applied to interpretation of data from functional magnetic resonance imaging. In a separate approach, we have interfered with normal neural processing by use of a relatively noninvasive technique, transcranial magnetic stimulation (TMS). We have applied TMS to the visual cortex, while measuring neural and hemodynamic consequences. Short term pulses can create a prolonged suppression of neural activity. With TMS, there is generally a presence or an absence of spontaneous discharge. These response patterns are partly connected to state-dependent effects. Higher pre-TMS, activity is connected with larger post-TMS response. Our results suggest that the relatively long-lasting neural changes initiated by TMS may be monitored by hemodynamic based neuroimaging.

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◆ **Ongoing neural activity and hemodynamics**

M Jones (Department of Psychology, University of Sheffield, UK;
e-mail: m.jones@sheffield.ac.uk)

BOLD fMRI has revolutionised cognitive neuroscience as it allows the functional architecture of the brain to be mapped as human subjects perform cognitive or perceptual tasks. However, such techniques rely on the changes in cerebral blood flow, volume and oxygenation (collectively referred to as the hemodynamic response) that accompany evoked neural activity. As such data from imaging experiments have been difficult to interpret in terms of underlying brain activity. Fortunately, animal studies using combinations of electrophysiological, optical, and MR techniques have begun to understand the quantitative stimulus-evoked neurovascular coupling that underpins fMRI. In addition to task-related signals there are spontaneous low frequency fluctuations in neuroimaging signals that occur in the absence of stimuli. These fluctuations are increasingly used to infer ongoing pre-stimulus activity and brain connectivity. Their relationship (although implicitly assumed) with underlying neural activity has seldom been investigated. To investigate this issue, optical imaging spectroscopy and multi-channel electrophysiology were used to measure ongoing hemodynamics and neural activity in the somatosensory cortex of anaesthetised rodents. We find that selectivity averaging ongoing hemodynamics at time points corresponding to negative deflections in the ongoing LFP trace results in an identical hemodynamic response function to that observed following presentation of sensory stimuli.

◆ **Pathway-specific variations in neurovascular and neurometabolic coupling in rodent brain**

M Lauritzen (Department of Neuroscience and Pharmacology, University of Copenhagen, Denmark; e-mail: marlau03@glo.regionh.dk)

Brain blood flow and oxygen metabolism are vital for normal function in the mammalian nervous system, and provides the basis for functional neuroimaging. The presentation will focus on recent progress in our understanding of how neuronal signalling, and in turn information processing, impacts vascular regulation and oxygen metabolism in rat and mice primary somatosensory cortex and cerebellum. Evoked activity induces brief and local changes in blood flow and oxygen metabolism which may be controlled by rapid Ca^{2+} rises in both pre- and postsynaptic cellular elements, and possibly astrocytes. The high level of energy consumption and blood flow in the resting state is incompletely understood, but non-signalling house-keeping activities play a more important role than hitherto believed. Our data suggest that all types of nerve cell activities use energy, and that there is a linear correlation between synaptic activity and oxygen consumption in most networks. In comparison, the relation between synaptic activity and rises in blood flow is most commonly non-linear. Neurovascular and neurometabolic coupling vary between networks due to activation of different cell types by different synaptic inputs. This is likely to be reflected in the response amplitude and phase of the evoked BOLD signal.

◆ **Neurovascular coupling: insights from physiology, neuropharmacology and electrical microstimulation**

N K Logothetis (Max Planck Institute for Biological Cybernetics, Tübingen, Germany;
e-mail: nikos.logothetis@tuebingen.mpg.de)

In my talk I shall describe our current understanding of the neurophysiological and hemodynamic signals, and of the functional neurovascular coupling in the anesthetized and alert behaving monkey. The neurovascular coupling was studied by means of physiological and fMRI experiments, during neuropharmacological blocking of pyramidal cell activity, and with combined electrical microstimulation and fMRI (esfMRI).

◆ **Neurometabolic coupling varies with cortical lamina**

A Viswanathan, R D Freeman¶ (Max Planck Institute for Biological Cybernetics, Tübingen, Germany; ¶ Group in Vision Science, School of Optometry, University of California, Berkeley, USA; e-mail: ahalya.v@gmail.com)

The blood-oxygen-level-dependent (BOLD) signal in functional magnetic resonance imaging (fMRI) is a hemodynamic measurement, which is used to make implications about neural processing. In cerebral cortex, BOLD responses to sensory stimuli are generally averaged across layers. There are clear anatomical and functional differences in laminar cortical organization which imply corresponding variation of BOLD responses. This has been reported in previous visual and somatosensory investigations, but without concurrent measurements of co-localized neural activity. We have modified a multichannel electrode to provide simultaneous measurements of tissue oxygenation and neural activity in different layers of primary visual cortex. We find laminar differences in tissue oxygen response amplitude. In the middle cortical layers, these differences are independent of local variations in neural activation. Our results suggest that neuro-metabolic coupling differs across cortical lamina.

SIEMENS LECTURE◆ **In vivo connectivity: MRI, paramagnetic tracers and electrical stimulation**

N K Logothetis (Max Planck Institute for Biological Cybernetics, Tübingen, Germany; e-mail: nikos.logothetis@tuebingen.mpg.de)

Neuroanatomical cortico-cortical and cortico-subcortical connections have been examined mainly by means of degeneration methods and anterograde and retrograde tracer techniques. Although such studies have demonstrated the value of the information gained from the investigation of the topographic connections between different brain areas, they do require fixed, processed tissue for data analysis and therefore cannot be applied to animals participating in longitudinal studies. Capacities such as plasticity and learning are indeed best studied with non-destructive techniques that can be applied repeatedly and, ideally, combined with neuroimaging or electrophysiology studies. The recent development of MR-visible tracers that can be infused into a specific brain region and are transported anterogradely transsynaptically is one such technique. Simultaneous electrical stimulation (ES) and fMRI (esfMRI) is another. In fact, esfMRI offers a unique opportunity not only to study connectivity, but also to visualize networks underlying electrostimulation-induced behaviors, to map the neuromodulatory systems, or to develop electrotherapy and neural prosthetic devices. In my talk I'll present new data on MR-visible tracers and esfMRI that show the capacity of these methods for the study of connectivity, of cortical microcircuits, and of cortical network reorganization induced by long term potentiation of synapses in subcortical structures, eg in hippocampus.

POSTER SESSION**CONTOURS**◆ **Poggendorff illusion with Kanizsa-like subjective contours**

A Bastianelli, A Spoto, R Actis-Grosso[¶], G Vidotto (Department of General Psychology, University of Padua, Italy; [¶] Department of Psychology, University of Milano Bicocca, Italy; e-mail: alessia.bastianelli@unipd.it)

Previous studies have shown that the Poggendorff illusion is still perceived when the parallels are not present, but are replaced by Kanizsa-like subjective contours (ie anomalous surface; Tibber et al, 2008 *Investigative Ophthalmology and Visual Science* **49** 474–478). An experiment is presented aimed at testing whether the Poggendorff illusion persists when not only the parallels but also the transversal line consists of anomalous surfaces. A configuration in which both the transversal segment and the parallels are composed by Kanizsa-like subjective contours (A) was compared with a similar configuration where the transversal was a line segment (B). Two analogous configurations are used as control conditions in which due to rotation of the pacman tokens, the parallels are absent (C and D, respectively). The method of constant stimuli was used with seven variations for each condition and seven replications for a total of 196 trials. Thresholds for symmetry were calculated using the Bootstrap technique. Results confirm the presence of a response bias in the direction of the Poggendorff illusion for every condition but D, where the transversal line is an anomalous surface and no parallels are present. Results are discussed in the context of Petter's rule and perceptual lightness differences between anomalous line and its background.

◆ **Contour awareness revealed in ERP error trials**

G Volberg, A Wutz, M W Greenlee (Department of Experimental Psychology, University of Regensburg, Germany; e-mail: gregor.volberg@gmx.de)

Contour integration is an intermediate step of object recognition by which segmented contours are integrated into continuous contours. While much research has been devoted to the identification and linking of single contour segments, little is known about how subjective awareness of the global contour line emerges. To investigate contour awareness, we had subjects detect a segmented contour of Gabor patches embedded in an array of randomly oriented Gabors and compared event-related potentials towards trials where the absence of a contour was correctly detected (correct rejection) with trials where subjects missed a contour (miss) or indicated the presence of a contour that was objectively not presented (false alarm). The detection was made difficult by misaligning the Gabors from the ideal contour line. Overall, errors occurred in 24% of trials. Misses evoked a negative wave 220–330 ms after stimulus onset at left parietal sites. In contrast, false alarms evoked a negative wave after 600 ms with a left frontal topography. The results suggest that the presence of possible contour elements is coded independently of the global percept of a contour, and that subjective contour awareness emerges not before 600 ms.

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◆ **The role of vertical mirror-symmetry in visual shape detection**

B Machilsen, J Wagemans (Laboratory of Experimental Psychology, KU Leuven, Belgium; e-mail: bart.machilsen@psy.kuleuven.be)

With a simple psychophysical task and a set of controlled stimuli we investigated the role of vertical mirror-symmetry in perceptual grouping and figure-ground segregation. We asked participants to indicate which of two sequentially presented Gabor displays contained a visual shape. The shape was defined by a subset of Gabor elements positioned along the outline of an unfamiliar shape. Adding orientation noise to these Gabor elements reduced the saliency of the shape percept. Across all noise levels, symmetric shapes were easier to detect than asymmetric shapes. This finding indicates that vertical mirror-symmetry acts as a cue in perceptual grouping.

◆ **Crowding and contour integration: the dark and bright side of feature integration**

R van den Berg ¶, J B T M Roerdink ¶, F W Cornelissen (Laboratory for Experimental Ophthalmology, University Medical Center Groningen, The Netherlands; ¶ Institute of Mathematics and Computing Science, University of Groningen, The Netherlands; e-mail: r.van.den.berg@rug.nl)

Recognizing an object in the peripheral visual field becomes more difficult when it is surrounded by other objects. This so-called 'crowding' effect limits performance on numerous tasks, including object recognition and visual search. Currently there is a growing consensus that crowding results from feature integration over an inappropriately large area that includes not just the object of interest; however the underlying mechanism and functional origin of the effect are still not fully understood. Here, we present a model that implements feature integration as a weighted summation of neural population codes. Simulation data demonstrate that the model exhibits crowding behaviour when closely-spaced features from separate sources are presented (eg, a vertical and oblique line segment), while signal-to-noise ratios are improved and contour integration facilitated when the integrated features share a common source (eg, two vertical line segments). Our results suggest that crowding is a by-product of a more general mechanism aimed at improving signal quality in early vision.

◆ **Global shape processing: which parts form the whole?**

S Hancock, J Bell ¶, F A A Kingdom ¶, J W Peirce (School of Psychology, The University of Nottingham, UK; ¶ Department of Ophthalmology, McGill University, Montreal, Canada; e-mail: sarah.hancock@nottingham.ac.uk)

Research suggests that detection of low frequency radial frequency (RF) patterns involves global shape processing, and that points of maximum curvature (corners) contribute more than points of minimum curvature (sides). However, this has only been tested with stimuli presented at the threshold of discriminability from a circle. We used a combination of the radial frequency amplitude aftereffect (RFAAE, Bell and Kingdom, submitted), with a compound adaptation method (Hancock and Peirce, 2008 *Journal of Vision* 8(7):11), to examine the critical features in a supra-threshold, appearance-based task. We measured the perceived amplitude shift of an RF test pattern after prolonged exposure either to a higher-amplitude pattern or to various combinations of its parts (minima; maxima; points of inflection). We found a greater RFAAE after adaptation to a 'whole' pattern than after adaptation to its component parts, which alternated to produce equal net contrast. Furthermore, when adapting to specific parts of the shape in isolation, we found that each part generated RFAAEs of similar magnitude. Although the whole is clearly greater than the sum of the parts, we find that minima, maxima, and points of inflection contribute equally to global shape processing, a fact that is only apparent when using a supra-threshold, appearance-based task.

◆ **Pictorial relief of objects represented by contour drawings**

H de Ridder, A J van Doorn, L van der Meer (Department of Industrial design, Delft University of Technology, The Netherlands; e-mail: h.deridder@tudelft.nl)

The pictorial relief of 3-D-objects represented by 2-D-images has been found to depend on a variety of depth cues (shading, texture gradient, contours, etc). We investigated how pictorial relief will vary when one of the depth cues (contours) is manipulated while all other cues have been removed. To this end, three types of contour drawings were deduced from gray-scale photographs of a plastic model of a female torso in three different poses. These poses differed by 45 degrees of angle rotation about the vertical. The contour drawings were line drawings containing (a) the outer contour, (b) the outer contour plus inner contours (ie lines where a hidden part of the object becomes visible from behind another occluding part of the object), (c) the outer contour, inner contours, plus extra lines representing some of the sharp luminance transitions in the original photographs. The participants assessed the pictorial relief in the grayscale photographs and the contour drawings by means of a local surface attitude probing task and a correspondence task. Results suggest that the pictorial

relief becomes flatter when the number of contours is reduced. Furthermore, indications were found for a piecewise organisation of the depth impression in the contour drawings.

◆ **Hysteresis in dynamic ambiguous figures**

S Gori, E Giora, R Pedersini¶ (Department of General Psychology, University of Padua, Italy; ¶ Brigham and Women's Hospital, Harvard Medical School; e-mail: gori@psico.univ.trieste.it)

In two sets of experiments we used ordered, discrete series of ambiguous figures varying along a single parameter. The first set studied the dynamics of figure-ground segregation and the second the Petter's effect, in which two overlapping figures of the same color appeared alternately in front of each other depending on the ratio of the sides of the overlapping part's area and subjects were required to press a key when they experienced a reversal. For low frame presentation speeds, the series were perceived as sequences of discontinuous, static images, while for high speeds they were perceived as movies. Hysteresis, the effect of past states on the present state of a dynamical system, was almost absent for the series perceived as a sequence of static images, but it increased progressively with speed. We conclude that using movies (i) results in stronger hysteresis, and (ii) minimises temporal instability (spontaneous switches) compared to the matched static stimuli. The additional evidence that the size of the hysteresis effect depends on trial duration is consistent with the stochastic nature of the dynamics governing figure-ground segregation and suggests that alternative figure-ground organisations are resolved via low-level, dynamical competition.

HIGHER CORTICAL PROCESSING

◆ **Is the extrastriate body area involved in action perception?**

A J Wiggett, I Kontaris, N N Oosterhof, P E Downing (School of Psychology, Bangor University, UK; e-mail: a.wiggett@bangor.ac.uk)

Recent studies have suggested that the role of the extrastriate body area (EBA) goes beyond a simple, static representation of bodies (Peelen et al, 2007 *Social Cognitive and Affective Neuroscience* 2 274–283; see also Urgesi et al, 2006 *Nature Neuroscience* 10 30–31) and extends to a direct involvement in action perception and representation. It has been suggested that EBA distinguishes between actions [Kable and Chatterjee, 2006 *Journal of Cognitive Neuroscience* 18(9) 1498–1517], and between the source of body movements (Astafiev et al, 2004 *Nature Neuroscience* 7 542–548; Jackson et al, 2006 *Neuroimage* 31 429–439). We present two fMRI experiments investigating the functional role of EBA. In Experiment 1 (a replication and extension of Kable and Chatterjee, 2006) we showed movies of simple actions (eg kicking) and tested for action- and actor-specific adaptation. In Experiment 2, participants viewed and executed simple hand actions in the scanner, and we tested whether EBA is sensitive to whether seen actions are self-generated or not. Experiment 1 showed that the EBA response is lower to previously seen compared to unseen actions. However, this finding was not specific to EBA—the same pattern was present across many higher-level visual areas. Experiment 2 showed no evidence that EBA responds preferentially to self-generated actions. Taken together, our results are consistent with a primarily visual, and static, representation of bodies in EBA.

◆ **Functional MRI of olfactory perception in patients with idiopathic Parkinson's disease**

C Mößnang, G Frank, J Klucken¶, U Bogdahn§, R Rutschmann, M W Greenlee (Department of Experimental Psychology [§ Department of Neurology], University of Regensburg, Germany; ¶ Department of Molecular Neurology, University of Erlangen, Germany; e-mail: caromoessnang@gmx.de)

Sensory disturbances have been reported in patients with idiopathic Parkinson's disease (IPD), including changes in visual contrast sensitivity, colour perception, and in sensations associated with proprioception (Doty et al, 1995 *Neurodegeneration* 4 93–97). The most consistent sensory deficit, however, is olfactory impairment which is used for clinical diagnosis (Tissingh et al, 2001 *Movement Disorders* 16 41–46). To promote the understanding of underlying pathological changes, this study aimed to isolate brain regions in patients with IPD which show altered activation in response to olfactory stimulation compared to healthy controls. For this purpose, fMRI was conducted with sixteen early-stage IPD patients and sixteen matched controls during an odour detection task using air dilution olfactometry. Data analysis revealed significantly increased activation at all levels of olfactory processing in patients with IPD, including a pronounced shift in lateralization. However, analyses of time course of activation revealed that these hyperactivated brain regions were not able to discriminate between odour and non-odour trials in terms of BOLD percent signal change, thereby explaining the behavioural deficit. These results demonstrate both neural plasticity within disturbed functional networks in terms of compensatory up-regulation, as well as the failure of this compensatory attempt.

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◆ **Optimal haemodynamic response to a standard visual checkerboard stimulus mapped over the posterior parietal and occipital cortices: a preliminary study**

S Wijekumar, M A McIntosh, U Shahani, A Nesbitt, D L McCulloch, V Manahilov
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It is known that the first stage of visual processing occurs in V1. Using the 10–20 International system of Electrode Placement, oxy- and deoxyhemoglobin activity over the posterior parietal and occipital cortices was recorded. Preliminary data was collected on a two-channel near-infrared Spectroscopy (NIRS) relying on the frequency domain multidistance method. Multiple trials were recorded from two young healthy subjects. An ISCEV standard checkerboard (stimulus ON) of reversal frequency 7.5 Hz (15 rps) and visual angle 15 min of arc was alternated with a grey screen (stimulus OFF) of equal luminance for 30 s each, over a period of 10 minutes. The biggest increase in oxyhemoglobin levels was observed at a distance of 5% both right and left of Oz and decreased steadily over the post parietal regions in the vertical direction, 5% above V1 area. The deoxy changes monitored were substantially smaller. Optimal signal characteristics were estimated for the locations by examining latencies, amplitudes, baseline changes, rate of change, and slopes for each hemisphere. These changes in hemoglobin responses as a function of distance indicate the area of activation of brain tissue as a result of visual stimulation. Work is ongoing to map haemodynamic response characteristics with other stimuli.

◆ **Anisometropia and binocular evoked potential in visual cortex**

G Krumina, K Caune (Department of Optometry and Vision Science, University of Latvia, Riga, Latvia; e-mail: papelba@cfi.lu.lv)

Anisometropia can influence quality of binocular vision. If a subject does not wear vision correction he/she adapts to see the world with one eye. Our aim was to evaluate binocularity in the visual cortex using the visual evoked potential (VEP) method to measure neural activity of subjects with anisometropia. We measured changes in VEP amplitudes and changes in information flow in the visual cortex at different anisometropic levels. A lens (+0.5 D to +3.0 D) was used for one eye to induce anisometropia. A similar procedure was carried out on subjects with real anisometropia (corrected or uncorrected). Visual cortex activity was measured with standard VEP. Temporal frequency was 1 Hz (two reversals per second). The size of the black vertical grating stimuli varied from 6–35 cycles deg⁻¹. The main results showed that anisometropia greater than 1.0 D changed binocular evoked potential amplitude. At the same time we found that latency was not influenced by anisometropic value but is influenced by the size of stimuli. The latency of binocular response to stimuli of higher spatial frequency (> 20 cycles deg⁻¹) is greater than for stimuli of low spatial frequency. Binocular VEP amplitudes for degradation of image quality of dominant eye were smaller than for degradation of non-dominant eye. A possible explanation may relate to subjective feelings: subjects feel visual comfort decreases when visual acuity in the dominant eye is reduced by 0.25 D. At the same time subjects do not feel the visual acuity decreases if the non-dominant eye refraction difference is 2.0 D.

◆ **Different involvement of face sensitive brain regions in famous face identification**

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Our study explores the neurofunctional correlates of famous face recognition. An important focus was placed on the contribution of different brain regions to the process of perception and recognition of famous and non famous faces. The event-related fMRI experiment was conducted in a 3-Tesla-scanner (Siemens) with a visual projection system. We investigated thirteen young healthy volunteers. Visual stimuli were taken from the Famous Faces Test (Hennig-Fast et al, 2009, Göttingen: Hogrefe). Functional data were processed using SPM5 and the SPM toolbox MarsBaR for a ROI analysis. Fusiform gyrus was activated by faces independent of whether the faces were of famous or unknown persons and the demands of the experimental task. In contrast the amplitude of the BOLD signal in the parahippocampal gyrus, hippocampus, and posterior cingulate cortex was marked higher for famous faces compared to non-famous faces and during face recognition compared to a visual control condition. We find that whereas the activity of parahippocampal gyrus, hippocampus, and posterior cingulate cortex is modulated by memory demands and motivational aspects, fusiform gyrus seems to be located on a comparably low stage of the ventral visual stream and is engaged in perceptual face processing independently of the semantic and task related context.

◆ **The use of phase-encoding techniques in object space: investigating the organization of the cortical object vision pathway**

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Research into the organization of high-level visual cortex has mainly used discrete object classes (eg faces and buildings). In contrast, the lower levels of the visual cortex have also been studied using phase-encoding techniques with gradually changing rotating wedges and expanding/contracting rings. The gradual stimulus changes cause traveling waves on the cortical surface, and time delays of each cortical location are related to stimulus preference. We propose to extend this method to study higher-order properties of visual objects. We validated this method with a face/house morphing continuum. We also included contracting/expanding rings cut out from natural scenes. Face- and house-selective regions (fusiform face area or FFA; parahippocampal place area or PPA) were defined with traditional block-design localizers. The method worked as intended: activity in FFA corresponded to presentation of face(-like) stimuli, and activity in PPA corresponded to the presentation of building(-like) stimuli. Additionally, confirming existing literature with discrete object classes, activity in FFA and PPA was time-locked to the presentation of foveal and eccentric rings, respectively. The results, however, contradict large-scale continuous maps across the ventral visual stream. Nevertheless, the results show that phase-encoding techniques can be applied to stimuli with feature variations more suited to investigate high-level visual regions.

◆ **Retinotopic mapping of the human occipito-parietal cortex at a magnetic field strength 7 T**

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Functional imaging at 7 T allows for retinotopic mapping with higher sensitivity than at lower magnetic field strengths. However, magnetic field inhomogeneities are a serious confound for large volume mapping at 7 T. Here we used 7 T anatomical and functional scans for robust large volume retinotopic mapping. Portions of a phase reversing circular checkerboard (diameter: 15 deg) were stimulated during T2*-weighted echo planar imaging to obtain eccentricity maps with expanding rings (width: 1 deg) or polar angle maps with rotating wedges (width: 90 deg). In two subjects 50 axial slices were acquired every 2.4 s with 23 mm³ voxels using a 24-channel head coil. After motion and distortion correction, the fMRI signals were Fourier analysed, correlated with the stimulus fundamental frequency, and projected to the flattened representation of T1 weighted inhomogeneity corrected images. Robust signals were obtained from a great expanse of occipito-parietal cortex. Eccentricity mapping revealed several distinct eccentricity maps comprising clusters of visual hemi-field representations in the occipital lobe and the intraparietal sulcus evident from polar angle mapping. In conclusion, high sensitivity retinotopic mapping of large volumes entirely based on 7 T scans promises further insight into the organisation of the occipito-parietal cortex.

◆ **Predicting the scalp potential topography in the multifocal VEP by fMRI**

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Visual evoked potential amplitude and polarity from localized stimuli depend on the subject's individual folding of the primary and secondary visual cortex which confounds the VEP as a measure of neural activation. To cross-validate three non-invasive imaging approaches for primary visual areas, we were interested to predict multifocal VEP amplitude on the scalp from retinotopic fMRI and EEG data. To obtain retinotopic information we stimulated the central visual field using three same sets of segmented dartboard patterns (rings, wedges and segments) in both fMRI and EEG recordings. The results are used to predict evoked potentials from multifocal methods, where orthogonal time-series stimulation allows decomposing the single-electrode EEG signal into components attributable to each stimulus region. A retinotopic map of areas V1 and V2 has been obtained on an inflated cortical surface generated after preprocessing of the fMRI data in Brain Voyager. We have also developed a Matlab graphical user interface. This shows the scalp potential distribution of a certain dipole generator obtained from fMRI along with its location and orientation in the brain after solving the EEG forward problem in a two-layer (cortical and scalp surface) real-head model. For the same brain, with stimulation

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at specific visual-field locations, we computed dipoles from multi-electrode EEG obtained using sLoreta. Our results are hoped to improve the validity of the VEP as an objective measure of visual brain activation.

◆ **fMRI correlates of saccadic adaptation**

S P Blurton, M Raabe, M W Greenlee (Institute of Experimental Psychology, University of Regensburg, Germany; e-mail: steven.blurton@psychologie.uni-regensburg.de)

Experimentally induced saccadic adaptation gradually changes saccadic gain as a consequence of intrasaccadic target displacements. We employed a double-step paradigm (McLaughlin, 1967 *Perception & Psychophysics* 2 359–362) for inward adaptation in an fMRI experiment and in-scanner oculomotor recording with twelve subjects. While the subjects performed a saccade to a peripheral target, this was displaced by 30% against the direction of gaze shift. In adaptation trials, the target step remained undetected and caused an average gain reduction of 18%. Activity during adaptation was contrasted against control trials with the same, but delayed target step. Our comparisons revealed two clusters located bilaterally in the posterior insular cortex to be significantly (p corrected < 0.05) less suppressed than during control trials. This region has been associated with the processing of vestibular signals (Eickhoff et al, 2006 *Human Brain Mapping* 27 611–621). A ROI analysis of cerebellar activation yielded significant effects related to saccadic adaptation, probably constituting motor learning processes. Our results suggest a lowering of perceptual threshold for vestibular information to guide the re-calibration of eye-head movements triggered by the post-saccadic error.

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◆ **Viewpoint sensitivity of visual representations of the human body in the extrastriate cortex**

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People are easily able to perceive the human body across changing viewpoints, but the neural mechanisms underpinning this ability are currently unclear. We used fMRI adaptation to study the view-invariance of representations in the extrastriate and fusiform body areas (EBA and FBA) cortical regions that have been shown to be sensitive to visual depictions of the human body. The BOLD response to sequentially-presented pairs of bodies was treated as an index of view invariance. Specifically, we compared trials in which the bodies in each image held identical poses (seen from the same or different views) to trials containing different poses EBA and FBA adapted to identical views of the same pose and both showed a progressive rebound from adaptation as a function of the angular difference between views, up to approximately 30 degrees. These effects were substantially reduced or eliminated by pattern masking. Furthermore, manipulation of the timing of the mask onset revealed different patterns of adaptation in EBA and FBA. Our results show that body selective cortical areas exhibit a similar degree of view-invariance as other object selective areas. They also indicate how view invariance in body representations develops over the first few hundred milliseconds following stimulus onset, remaining sensitive to disruption by masking in that period—a pattern of findings that is consistent with reentrant accounts of object representation.

◆ **Relevant factors of flow field perception on models of computation neuroscience explored with dynamic causal modeling**

P Spachtholz, F Acs, M Raabe, M W Greenlee (Department of Psychology, University of Regensburg, Germany; e-mail: pspachtholz@gmx.de)

The lateral intraparietal area (LIP) is known as a key area in perceptual decisions in tasks where the subject has to determine the heading direction of a subset of coherently moving dots in a larger set of random moving dots. We expanded this approach to flow field perception of a three dimensional field of spheres with similar constraints. Some computational models suggest that also the quantity of visible moving dots has an influence on the perceptual decision in LIP caused by competing pools of neurons, and not only the motion coherence level. We investigated this in two experiments. First a behavioural reaction-time experiment with forty subjects, which showed no significant influence of the number of dots in the random-dot field. A connectivity analysis with dynamic causal modeling (DCM) for fMRI time course data in four subjects showed that the connectivity of the human middle temporal area (hMT+) to LIP was influenced by two factors. The coherence level and the number of dots seem to influence the input in LIP in a non-linear, inverted U-shaped, fashion. This finding speaks against a linear effect of coherence level and number of dots earlier put forth by computational models of decision making in LIP.

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- ◆ **Decision center for pattern discrimination in the human brain—localization and tractography**
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Our goal was to localize the decision center for pattern discrimination with different spatial properties and minimum emotional meaning, and visualize its interconnection with occipital cortex. For sixteen volunteers aged 18–55 years, anatomical, functional, and diffusion-tensor MRI were performed on 1.5 T MR-scanner. We used two experimental paradigms: (i) passive viewing, and (ii) active discrimination of primary orientation of Gabor elements that were organized in a matrix. The matrices varied in complexity, according to the number of elements with similar orientation. The dominant orientation of the matrix changed randomly, so that the observer's motor response was independent from decision response. We compared the BOLD response to matrices where elements had an ordered orientation with the response to a randomly organized matrix. In both passive and active paradigms, the more-random matrix produced additional activation in occipital and parietal lobes, and partially in temporal lobes. In active paradigm we localized the decision centers for ordered and random patterns in different but neighboring parts of the frontal cortex. By use of diffusion-tensor tractography and post processing software we reconstructed white matter fiber tracts, starting from occipital cortex—to the decision center in frontal cortex that was localized using fMRI.

- ◆ **Non-retinotopic feature integration has a neural pace of its own, as revealed by electrical brain imaging**

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When elements appear in quick succession they can integrate across space and time. Using high-density EEG techniques we show that such non-retinotopic feature integration is not time-locked to stimulus onset, but has a timing of its own. We presented a central line, containing a small vernier offset, quickly followed by pairs of non-offset flanking lines. Although the central line itself stays invisible, observers can discriminate its offset within the two resulting motion streams. Observers attended only one stream while we gave one of the flanking lines an offset opposite to that of the central line. Only when this flank offset was in the attended stream did it integrate with the central offset. This unconscious integration was reflected in voltage topographies time-locked to the behavioural response, between 650 and 250 ms before key press. At these latencies statistical parametric mapping of current densities revealed integration effects in high-level visual, prefrontal and central areas. A separate stimulus-locked analysis revealed no such effects. The results show that endogenously timed processes, rather than stimulus-locked, bottom-up processes, underlie non-retinotopic feature integration. The results furthermore show how high-density EEG can monitor visual information with good spatial and excellent temporal resolution.

CENTRAL VISUAL PATHWAYS

- ◆ **Flickering light affects functional activity level in neurons of the kitten area 17**
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Sources of flickering light are components of the artificial visual environment created by humans. Our aim was to investigate the influence of 15-Hz flickering light onto the functional activity level in the kitten area 17. In an earlier study (Merkul'eva and Makarov, 2008 *Neuroscience and Behavioral Physiology* 39 449–455), using the cytochrome oxidase (CO) activity method revealed regularly distributed loci of high optical density (CO domains) in cortical layer IV in the norm. The contrast between CO domains and interdomains zones was estimated in kittens stimulated daily (2-hour sessions) during 7 days from postnatal week 4 (group 1), week 6 (group 2), and week 12 (group 3). In all animals a significant increase of the CO domains contrast was revealed in peripheral vision field representations: 0.085 ± 0.005 vs 0.065 ± 0.005 , ($p < 0.001$) for group 1; 0.068 ± 0.004 vs 0.049 ± 0.008 , ($p < 0.001$) for group 2; 0.064 ± 0.01 vs 0.031 ± 0.003 , ($p < 0.001$) for group 3. In the central visual field representation, an increase of contrast was revealed in group 1 (0.075 ± 0.005 vs 0.053 ± 0.008 , $p < 0.001$) and group 2 kittens (0.053 ± 0.002 vs 0.047 ± 0.004 , $p < 0.01$). We have proposed that flickering light leads to an increase of functional activity in certain neuronal assemblies which may be related to the Y cells.

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◆ **Cortical changes in haemoglobin concentration quantified using the frequency domain multi-distance method of functional near infrared spectroscopy**

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The aim of this study was to investigate the validity of using the frequency domain multi-distance (FDMD) method of functional near infrared spectroscopy (fNIRS) to assess quantitative in-vivo haemoglobin concentration changes in the visual cortex induced by a standard visual stimulus. An FDMD near infrared oximeter (Oxiplex TS, ISS) with four pairs of NIR emitters and one detecting optode was placed over the visual cortex. The stimulus was a high-contrast reversing checkerboard (temporal frequency of 7.5 Hz, check size of 15 min of arc) displayed for 30 s and then replaced by a grey control screen for a further 30 s. This cycle was repeated ten times. Initial data from five participants showed that when the stimulus was applied, the oxyhaemoglobin concentration increased by approximately 2% (mean 0.5 μm) compared to its level in response to the control grey screen. This indicates that the FDMD method can be used to quantify absolute changes in haemoglobin concentrations over the visual cortex, on a single trial basis. In conclusion, it is apparent that fNIRS is a valuable tool with potential applications in both clinical and research environments to assess the haemodynamics of the visual cortex.

◆ **Training-induced changes of the oculomotor system: task-dependency or transfer effects?**

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About 70% of patients with homonymous visual field loss after postchiasmatic injury suffer from impaired visual scanning and reading. Spontaneous recovery or successful strategic adaptation occurs rarely. By systematic practice of compensatory oculomotor strategies, patients can regain efficient scanning and reading. However, it is still unclear whether there is transfer of oculomotor adaptation from scanning to reading, and vice versa, or whether training-induced changes to the visual system and thus oculomotor adaptation are task-dependent. By comparing the performance of twenty patients with homonymous hemianopia before and after systematic training of scanning and reading, we found significant improvements for both visual abilities, but no transfer. Thus, both visuo-cognitive abilities require specific training. We conclude that the oculomotor system is functionally specialized in a material-dependent, and, thus task-dependent way.

◆ **Learning to discriminate visual stimuli within the blind field following neuro-eye therapy**

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Neuro-eye therapy (NeET) has been developed for rehabilitation of vision loss following brain injury. It involves performing a daily discrimination task using visual stimuli with precise spatial and temporal properties. The stimulus parameters are derived from our previous psychophysical investigations of hemianopic patients. The participants' task was to report the presence of a temporally modulated vertical sinewave grating (1 cycle deg^{-1} , 10 Hz) in a temporal 2AFC task. Stimuli were positioned within the blind field as determined using an automated visual field analyser. The task was carried out with and without positive feedback in the form of an auditory beep after a successful discrimination. Results: One hemianope was not given any feedback. Nevertheless, the performance, initially at chance level, consistently reached above 86% correct after 5000 trials. A second hemianope showed some improvement in the first 5000 trials. The addition of feedback resulted in further increases in sensitivity as indicated by maintaining high discrimination despite lowering the stimulus contrast in the subsequent 10000 trials. A third hemianope was given positive feedback at the beginning and showed marked improvement over the first 2500 trials. Conclusions: Learning can take place within the hemianopic field following repeated stimulation using neuro-eye therapy.

◆ **A comparison of different ICA algorithms on a retinotopy fMRI data-set**

M Goldhacker, I R Keck, V Fischer¶, E W Lang (Institute of Biophysics, CIML Group [¶ Institute for Experimental Psychology], University of Regensburg, Germany, Germany; e-mail: ingo@ingoheck.de)

Independent component analysis (ICA) has proven to be a valuable tool for exploratory analysis of functional magnetic resonance imaging (fMRI) data. A vast amount of ICA algorithms exist that can be used for this task, however little is known about the differences in the quality of the results that these different algorithms will produce. For the comparison we used the fMRI data from a retinotopic study in V1–V4 where the activation of the brain in the visual cortex can be estimated to be directly correlated to the stimulus. In a first analysis we compared the results

of ICA and general linear model based statistics concerning their level of local spatial activation. We found that ICA shows a more spatial focused activation in the results. In a second analysis we compared the results of different ICA algorithms on the same data set relative to the given number of sources in the data and the correlation to the estimated temporal activation in the visual cortex.

◆ **Blind for the blind spot**

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Rationale: Blind spots should perceptually stand out when two cross-polarized monocular fields flickering in counterphase are viewed through Polaroid goggles. Assuming binocular summation, one should see an apparently steady field except in the region of the physiological blind spots, which should be flickering. Method: Two counter-phased large fields whose brightnesses were sinusoidally modulated between 2 and 100 Hz were presented in dichoptic vision. Results: Below 55 Hz, observers saw flicker at twice the monocular frequency, whereas above 55 Hz, the binocular field appeared steady. Under no condition was there a demarcation of the blind spot area. It could neither be visualized by phase shifts between both eyes, nor when color contrast was added by anaglyphic glasses, or when a moving random-dot pattern and its mirror image were superimposed by looking through a prism in front of one eye. Instead, the pattern and its mirror image were seen to move in opposite directions including the blind spot area. Conclusion: The blind spot typically fills in when both eyes look at the same surface. Although in our experiment, the surfaces presented to the left and right eye differed in luminance phase or motion direction, filling-in occurred despite rivalling information from the contralateral eye.

◆ **The relationship between parvocellular cell firing and prepotentials in the macaque LGN**

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Extracellular recordings have demonstrated a linear relationship between the firing rate of the incoming signal from a retinal ganglion cell (the prepotential spike train) and the subsequent firing rate of a cell in the macaque lateral geniculate nucleus (LGN). Later studies have shown a substantial threshold clipping of the LGN response, particularly for small test fields alternated with a larger adapting background. The clipping of the LGN response occurs at a rather high firing rate (often around 30 impulses s⁻¹) of the prepotential. These studies have confirmed the linear relationship for responses above the clipping level, and in addition points to the necessity of taking into account this threshold non-linearity in quantitative models of parvocellular cell firing in the LGN. Possible consequences for studies of signal transmission and neural correlates to perception will be briefly discussed.

NEURAL MECHANISMS

◆ **Motion distorts position coding of flashes in primary visual cortex**

G W Maus, J Fischer¶, D Whitney¶ (Center for Mind and Brain [¶ Department of Psychology], University of California – Davis, USA; e-mail: gwmaus@ucdavis.edu)

Visual motion can shift the perceived position of a flash, even in distant regions of the visual field (Whitney and Cavanagh, 2000). Little is known about the underlying neural mechanisms of this ‘flash-drag’ effect. Using fMRI pattern analysis, we investigated how motion influences the coding of the flash position in visual cortex. While performing an attentionally demanding task at fixation, participants viewed a concentric grating that oscillated between inward and outward motion. The moving grating was visible only in wedge-shaped segments along the visual field meridians. Task-irrelevant bars ($0.1^\circ \times 1^\circ$) were flashed in the empty spaces between the grating segments, either during inward or outward motion, at physically constant locations (distance from the grating segments $> 0.8^\circ$). In separate localizer conditions, the flashes were presented in positions physically shifted by one bar’s width toward or away from the fovea without any motion present. We computed a contrast map of BOLD responses to the localizer flashes shifted toward versus away from the fovea, and a separate map for flashes (in physically constant locations) during inward versus outward motion. The resulting patterns of differential activity were significantly correlated with each other within early visual areas, including V1. This indicates that physically shifted flashes and flashes ‘dragged’ by motion in the same direction elicit similar BOLD patterns. Whether the position shift originates in higher areas or from local interactions remains a subject of study.

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◆ **Contrast polarity reversals in L-junctions: Disrupting basic ‘corner’ processing?**

M M Schira, B Spehar (School of Psychology, University of New South Wales, Sydney, Australia; e-mail: mark.schira@gmail.com)

Scene segmentation depends on interaction between geometrical and photometric factors. It has been shown that reversals in contrast polarity at points of highest orientation discontinuity along closed contours significantly impair shape discrimination performance, while changes in contrast polarity at straight(er) contour segments do not have such deleterious effects (Spehar, 2002 *Vision Research* 42 343). Here we compare high-resolution fMRI responses to simple corner elements (L-junctions) with multiple contrast polarity changes in five subjects. ‘Valid’ L-junctions have contrast polarity changes only on the straight flanks, while ‘invalid’ ones have a contrast polarity change at tip of the rectangular angle. Subjects can easily distinguish valid from invalid L-junctions, though both appear ‘normal’. We find a stronger BOLD-response for valid L-junctions than for invalid L-junctions in V2 (0.4%) and V4 (0.3%), but no significant responses in any other visual area investigated. The responses in V2 and V4 are seemingly spotty, only within a small number of voxels. We suggest this response originates in V2 cells or cell networks specified for detecting corners such as suggested by Hegde and Van Essen (2004 *Journal of Neurophysiology* 92 3030). This would imply that contrast polarity changes disrupts basis geometrically based feature analysis of visual scenes.

◆ **Scale-invariant image processing in the cat primary visual cortex**

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When we look at the natural scene, the spatial frequency profile of a given object dynamically changes with increasing or decreasing distance from observer. In general, decreasing viewing distance makes retinal image size larger and the spatial frequency profile of the image lower. Therefore, to achieve scale-invariant image processing, a visual system may change the dynamic range of spatial frequency tuning according to a change of viewing distance of objects. In this study, we investigated whether neurons in the primary visual cortex (V1) exhibit scale-invariant image processing or not. For 40 neurons (simple cell = 13, complex cell = 27), we measured the spatial frequency tunings of V1 neurons for 7 or 10 size conditions in anesthetized and paralyzed cats. We found that many complex cells changed their spatial frequency tuning depending on stimulus size: at large stimulus size, their optimal spatial frequency was significantly lower than at small stimulus size. On the other hand, almost all simple cells exhibited constant values of optimal spatial frequency regardless of stimulus size. Our results suggest that scale-invariant image processing already starts from complex cells in V1. We infer that the simple cells with wide variety of spatial frequency tuning converge with a complex cell to achieve their scale-invariant tuning property.

◆ **Motion-form and form-motion interaction in perceptual disambiguation**

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Problem: Motion integration and disambiguation appears early in the cortical dorsal pathway and elaborates over time (Pack and Born, 2001 *Nature* 409) combining unambiguous feature motions with normal flow estimates along elongated shape boundaries. Overlapping bars moving in opposite directions are segregated while adding occluders at bar ends leads to vertical pattern motion perception (Chopstick illusion; Anstis, 1990 *AI and the Eye* chapter 5). Little is known about the mechanisms involved when figure boundaries are purely motion defined. Method: When bars and background are defined by random-dot textures with dot items moving in one of four cardinal directions, component motion is solely defined by boundaries. In another stimulus the boundaries of figural bars are defined by occlusions/dis-occlusions. Subjects decide whether perceived motion is horizontal or vertical for displays with or without occluders. Results and conclusion: Perceived bar motion is horizontal for opposite directions, while occluders change perception into vertical pattern motion (significance $p < 1.0 \times 10^{-13}$). This demonstrates that movement-defined elongated items can still be integrated and segregated to yield coherent perceptual interpretations. Local motion estimates need to be integrated and interpreted in the form pathway which in turn helps to disambiguate and segment the display into coherent shape motions. The results challenge simple bottom-up models of motion detection and subsequent pooling. We suggest that bidirectional interactions between motion and form representations at multiple levels contribute to create distributed representations of moving form.

◆ **Functional importance of motion opponency in velocity tuning**

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Evidence for motion opponent mechanisms has generally been based on perceptual experiments. Such mechanisms have been included in models of motion perception to account for neural responses to counter-phase sinusoidal stimuli or paired dots (Simoncelli and Heeger, 1998 *Vision Research* **38** 743–761). Moreover the energy model of Adelson and Bergen uses motion opponency at its final stage to derive velocity. In our model of motion perception, based on hierarchical processing of motion information in the LGN, V1, MT, and MST areas of the primate brain, we have incorporated motion opponency at the MT stage, where motion opponent mechanisms play an integral role in velocity tuning. We suggest that the effect of opponent inhibition on a velocity tuned unit is equivalent to the role that anti-phase inhibition plays at the preceding V1 stage. That is, both processes subtract un-tuned response from the overall activity of the cell and account for contrast independent tuning. We conclude that similar processes are repeated along the hierarchy in the visual motion pathway; V1 cells use LGN afferents for spatiotemporal and direction selectivity and incorporate anti-phase inhibition to enhance tuning. Likewise MT cells use V1 afferents for velocity tuning which is augmented by opponent inhibition.

◆ **Regional cerebral blood flow as a response to a pattern reversal stimulus is independent of its contrast or temporal frequency**

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We investigated the relation between the physical strength of a visual stimulus and the volumes of cerebral blood flow around visual cortex using an optical imaging technique. Stimulus was a radial checker pattern with the contrast either of 0.1, 0.3 or 1, reversing with 7.5 Hz. Reversal patterns at 3.75 and 15 Hz with the contrast of 1, were also used. In an experimental session, one of the five stimulus conditions was randomly chosen. The stimulus was presented for 15 s and repeated 5 times with 30 s resting intervals. Observers were required to fixate at the center of the radial patterns during the presentation. Each observer tested the five conditions within a day, over three days. The oxyhemoglobin concentration change at around occipital lobe during stimulus observation was monitored by a Near Infrared Spectroscopy (Hitachi, ETG-4000). The oxyhemoglobin concentration in the region significantly increased during the stimulus presentation in all the 5 conditions. However, there was no significant difference in activation level between the conditions. The result indicates that, unlike BOLD measure (eg Boynton et al, 1996), oxyhemoglobin concentration increased in similar amounts to the visual stimuli with various strengths.

◆ **Visual shape discrimination and shape similarity in rats**

B Vermaercke, V Smaers, H P Op de Beeck (Laboratory of Experimental Psychology, Department of Psychology, KU Leuven, Belgium; e-mail: ben.vermaercke@psy.kuleuven.be)

Rats have low visual acuity. Nevertheless they can use vision for complex tasks and their cortex contains multiple areas devoted to vision. We are studying to what extent shape recognition in rats can be seen as a low-acuity version of shape recognition in primates. Six male Brown-Norway rats were trained in a two-choice water maze with six shape pairs that were learned successively. They discriminated simple geometric forms that were previously used in monkey research comparing neural responses in different brain areas (Lehky and Sereno, 2007 *Journal of Neurophysiology* **97** 307–319), leading to straightforward and area-specific predictions about the relative difficulty of individual shape pairs. There was a partial relationship between shape similarity in monkey inferior temporal (IT) cortex and discrimination errors made by rats: the most similar pair for monkey IT neurons was very difficult to learn for rats. This relationship was area-specific, as it was not found for shape similarity based on monkey parietal cortex. So at least in some cases the neurophysiologically derived similarity for two stimuli in monkey IT cortex can be related to the behaviorally measured similarity in rats. These results suggest a partial correspondence between monkeys and rats in how visual shapes are represented.

◆ **Amantadine (PK-Merz) influence on the nerve impulse conduction within optic nerve in patients with multiple sclerosis**

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More than a half of patients with multiple sclerosis (MS) complain about easy fatigability or decrease of muscle strength, which causes difficulties in movements and decrease in work

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performance. The main cause is demyelination of nerve fibers within central nervous system which result in decrease or even complete blockage on nerve impulse conduction. Visual evoked potentials (VEPs) are implemented to determine alterations in conduction velocity. Amantadine is used in treatment of pathological muscle fatigability in patients with MS, but mechanisms of its action are not known. Presumably the positive clinical effect is connected with reversible blockage of NMDA receptors. In this study we attempted to reveal specific influence of PK-Merz on the nerve impulse conduction within central nervous system using the VEP method. Ten patients (aged 29 ± 12 years, 3–4 points on Kurtzke Expanded Disability Status Scale, disease duration: 2–16 years) with relapsing-remitting definite MS according to the McDonald [Polman et al, 2005 *Annals of Neurology* **58**(6) 840–846] criteria participated. Subjects were introduced consecutively 4-chequer reversal patterns with spatial frequencies 0.61; 1.21; 2.43, and 4.85 cycles deg^{-1} to both eyes separately. Reversal rate was 50 per minute. Data were collected before treatment and after a 3-days course of intravenous PK-Merz 200 mg daily. The P1 component was analyzed. Definite decrease of P1 latency at low (1.21 cycles deg^{-1}) and medium (2.43 cycles deg^{-1}) spatial frequencies was established after the treatment with PK-Merz. Nine of ten patients and six of ten patients had decreased latencies in one and two spatial frequencies accordingly. The results suggest facilitating effect of Amantadine on the nervous impulses conduction within central nervous system.

◆ **Late re-entrant modulation of human early visual cortex relates to successful report from iconic memory**

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Modulations of sensory processing in early visual areas play a crucial role in determining whether a visual stimulus is consciously perceived. They may reflect endogenous fluctuations in baseline activity, or top–down signals related to attention. But to date most studies have focused on effects occurring before or during visual presentation. Several emerging theories now postulate that sensory processing and conscious visual perception also crucially depends on re-entrant top–down influences arising after a visual display. To provide a direct test of this hypothesis, we adapted the classic iconic-memory paradigm to functional MRI. After confirming that the ability to report a target at a specific spatial location in a visual display was enhanced by symbolic auditory post-cues occurring after that display, we now showed that these post-cues can enhance target-specific signals in early visual cortex (V1 and V2). Critically, within the typical 'iconic memory' time window (< 1000 ms after visual offset) this target-specific enhancement was specifically associated with correct conscious report and accurately predicted individual levels of performance. Our results indicate that, within a critical time window after a physical stimulus has disappeared, conscious report of a visual stimulus is influenced by re-entrant modulation of ongoing sensory processing in early visual cortex.

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◆ **Decoding the motion aftereffect in human visual cortex**

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After adapting to visual motion in a particular direction, a stationary pattern appears to move in the opposite direction: the motion aftereffect (MAE). Although human visual areas are activated by visual motion and show specific directional responses for the adaptation direction, it is less clear what kind of activity is present while observers are perceiving the illusory motion associated with the MAE, especially in area MT/V5. Using fMRI pattern analysis, we demonstrate that it is possible to decode the adapted motion direction from the pattern of activity in area MT/V5. When a stationary test image is presented, illusory motion is observed in the opposite direction. We show that the pattern of activation associated with this illusory motion is not similar to the pattern of activation evoked by real motion in the same direction. Instead, the activation pattern evoked by illusory motion was especially dissimilar to motion in the opposite, adapted direction. These results support the distribution-shift model and show that—as expected—area MT/V5 is critically involved in the illusory motion (the MAE). However, the pattern of activity questions the assumed role of area MT as the neural correlate of the perceived illusory motion direction.

◆ **Is this real or fake? An fMRI investigation of material properties**

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We often have to make decisions about the authenticity of the objects surrounding us by perceiving their material properties. It has been shown that the perception of material properties can be as fast as object or scene recognition (Sharan et al, 2008 *Vision Sciences*). Here we investigated the behavioural and neural correlates of material perception using Sharan et al's image database of 'real' and 'fake' objects. These objects belonged to three distinct categories (desserts, flowers, or fruits) and objects could be either genuine/real (made of natural materials) or fake (made of plastic, felt, wood, clay). Both colour and Sharan et al's studies found that participants could efficiently categorise these images into real/fake based on rapid exposure (ie 40–500 ms) of the images. Using a similar design to the one described by Sharan et al, we acquired functional data while participants conducted an object or a material categorization task on images of objects. Preliminary results show that areas within the lateral occipital cortex were activated during object recognition whereas areas normally involved in texture perception were activated during material categorisation. Our results provide evidence that the rapid detection of fake objects is underpinned by distinct neural mechanisms.

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◆ **Magneto-encephalographic response to the second-ordered visual attributes**

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In a visual stimulus, the second-order attributes (illusory contour, shape, objects, etc) are considered to be a compound of the first-order attributes (dots, orientations, colors, motions, as such). The compound features (thus, the second-ordered attributes) are known to have columnar representations in the cortex according to several animal studies. In order to elucidate such localized representations in a human visual perception, we conducted magneto-encephalographic (MEG) measurements and current dipole estimation. Although MEG measurements are expected to be useful for that purpose, it is necessary that the influence by the first-order attributes should be eliminated for us to obtain MEG response to the second-order attributes. We presented to the subjects rotating Gabor patterns paved over visual field that form a shape and/or illusory contours in a moment (17 ms). So the first-order MEG-response to the visual motion is suppressed by the adaptation that the second-order responses can be separated from original data. The second-order responses are located in a few centimeters apart from V1 response showing two peaks in the time-course for all the subjects. The one appears 44–68 ms earlier than the trigger time at which a shape and/or illusory contours are formed. The other one appears in the latency 44–101 ms.

◆ **Interpreting the neural code with formal concept analysis**

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Unravelling the neural basis of perception hinges on an understanding of the neural code. In the sensory system, the neural code defines what pattern of neural activity corresponds to a represented information item, eg a visual stimulus. Neural decoding is the attempt to reconstruct the stimulus from the observed pattern of activation. We propose a novel application of formal concept analysis (FCA) to neural decoding: instead of just trying to figure out which stimulus was presented, we demonstrate how to explore the semantic relationships in the neural representation of large sets of stimuli. FCA provides a way of displaying and interpreting such relationships via concept lattices. We analyse neurophysiological data from high-level visual cortical area STSa, using an exact Bayesian approach to construct the formal context needed by FCA. Prominent features of the resulting concept lattices are discussed, including hierarchical face representation and indications for a product-of-experts code in real neurons. The robustness of these features is illustrated by studying the effects of conceptual scaling: increasing the resolution of the feature (or attribute, in FCA terms) computed from the neural response could distort the semantic relationships. We find that the main semantic components are preserved under scaling.

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- ◆ **Dependence of Vernier acuity on the presence/absence of aberrations of a human eye**
V Karitans, M Ozolinsh, S Fomins (Department of Optometry and Vision Science, University of Latvia, Riga, Latvia; e-mail: variskaritans@gmail.com)

We tested the ability of the human visual system to detect breaks in straight edges (called Vernier acuity). It is known that the angular size of the break is much smaller than the distance between adjacent cones (30''). A very precise localisation of a line projected onto the retina may be possible due to interpolation in the visual system over a certain area of the retina. A stimulation of such an area is achieved if the image of a straight line is blurred. We therefore suggest that by correcting aberrations of an eye beyond a certain level, the Vernier acuity could be impaired rather than improved, because the visual system's ability to interpolate the signal is reduced. We tested this hypothesis by using adaptive optics so reducing the blur of the retinal image. We obtained psychometric curves and analyzed their spread which indicates the threshold for detecting the width of the break. The value of the ordinate indicates how frequently the subject considered the moveable edge to be placed to the right from the fixed edge rather than to the left. When higher-order aberrations were corrected some subjects reported that localisation of the edge was more difficult. By correcting the aberrations up to 6th order whether we did not observe improvement in Vernier task, or observed an elevation of threshold by about 10 arc seconds.

- ◆ **The amygdala selects information for emotional decision making**
R H A H Jacobs, R J Renken, F W Cornelissen (Laboratory for Experimental Ophthalmology, University Medical Center, University of Groningen, Ede Netherlands; e-mail: r.h.a.h.jacobs@med.umcg.nl)

The amygdalae are commonly viewed as emotion processors. Recently, the amygdalae were shown to be critical for guiding the eyes to emotionally relevant aspects of faces, while emotion perception per se appeared to be intact. This finding led us to hypothesize that the amygdalae might play a key role in selecting visual information that is relevant for making emotional decisions. The amygdalar role in guiding eye movements might extend beyond spatial shifts of attention to feature-based attention. To test this idea, we presented healthy participants with visual textures, stimuli in which features are omni-present, thereby obviating the need for spatial shifts in attention. Different tasks served to direct attention to emotionally and non-emotionally relevant features. These tasks were beauty judgments (emotional) and roughness judgments (non-emotional). Amygdalar activity was monitored using functional magnetic resonance imaging. Results showed that the left amygdala had higher activation during the beauty judgment than during the roughness judgment, consistent with the hypothesis. This implies that the amygdala is involved not only in spatial, but also in non-spatial, feature-based, forms of attention, when it serves emotional decision-making.

TEMPORAL PROCESSING

- ◆ **Tracking the time course of processing spatial prepositions using response trajectories**
F T van Vugt, P Cavanagh (Laboratoire Psychologie de Perception (LPP), Université Paris Descartes, Paris, France; e-mail: f.t.vanvugt@gmail.com)

We used a variant of the Stroop task in which subjects reported whether a spatial preposition word ('above', 'below') was above or below a cross. The word's position either conflicted or agreed with its meaning (which subjects were instructed to ignore). We measured not only the subject's reaction time but also the trajectory of the mouse as the subject moved the cursor from the bottom of the screen to the appropriate top-left or top-right corner to register the response. These trajectories constitute a continuous measure of response processing; when the word's position and its meaning conflicted, the response path could deviate toward the wrong corner before finally reaching the correct corner. This deviation was measured as trajectory curvature, and it was significantly greater in the conflict condition. Final response times also showed a conflict effect, but the response trajectories showed that this interference began very early, with paths for the conflicting and non-conflicting conditions diverging significantly at 250 ms after stimulus presentation.

- ◆ **The effect of adaptation on visual sensitivity and cortical response to amplitude-modulated flicker**

Y Okamoto, S Nakagawa¶ (Japan Society for the Promotion of Science (JSPS), Tokyo, Japan; ¶ Institute for Human Science and Biomedical Engineering, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan; e-mail: yos-okamoto@aist.go.jp)

For a sinusoidal flickering light amplitude modulated (AM) sinusoidally, flicker at a frequency of the modulator (envelope periodicity) is detected, although no frequency component at the flicker frequency is included in the AM flickering light. We investigated the effect of adaptation on the visual sensitivity and magnetoencephalographic (MEG) responses to the envelope periodicity of AM flickering light. Sinusoidal flickering lights with a low (2 Hz) and a high (1 Hz) temporal frequency

and steady light were used as adapting stimuli. Following adaptation processes, the sinusoidal flickering lights and an AM flickering light with a carrier frequency of 16 Hz and a modulation frequency of 2 Hz were presented as test stimuli. The results showed that the sensitivity and MEG responses to the sinusoidal flicker were reduced more when the adapting and test stimuli had frequency components at the same rather than different frequency. On the other hand, although the AM flickering light had frequency components at the carrier frequency but not at the modulation frequency, the sensitivity and MEG responses to the envelope periodicity of AM flickering light were reduced more after adapting to the modulation frequency rather than the carrier frequency.

◆ **The time course of visual masking: A critical analysis**

T Elze, S Poppe (Research Group Complex Structures in Biology and Cognition, Max Planck Institute for Mathematics in the Sciences, Tübingen, Germany; e-mail: Tobias.Elze@mis.mpg.de)

In visual masking, a target stimulus is presented in close spatiotemporal proximity to a mask stimulus. The mask reduces the target visibility for certain stimulus onset asynchronies (SOAs). Masking might be an important indicator of the functioning of the early visual system, therefore its exact time course deserves particular consideration. Decades ago (Kolers 1962) proposed two types (A and B) of time course functions, depending on the types of stimuli for target and mask. Recently (eg Francis and Cho 2007, 2008), several studies report on various counterexamples where target/mask combinations yield the 'wrong' type of masking function. An extended replication of several of these experiments for more SOAs and with more subjects shows: (i) It is unclear which of the two types of functions the results yield; (ii) over different experimental conditions, results of very different levels of statistical certainty are compared. We suggest a re-examination of the time course of masking that questions the classical type A/B taxonomy. We show that this is hard to achieve with the established experimental sampling schemes, and we suggest Bayesian approaches to adaptive sampling to address these questions and to lay a grounding for future masking experiments.

◆ **Time-course contingencies in the identification of fragmented object outlines**

K Torfs, S Panis, J Wagemans (Laboratory of Experimental Psychology, University of Leuven (KU Leuven), Belgium; e-mail: katrien.torfs@psy.kuleuven.be)

The dynamic interplay between different component processes involved in the identification of static 20% fragmented object outlines has been investigated using a discrete-identification paradigm (Panis and Wagemans, 2009 *Journal of Experimental Psychology: Human Perception and Performance* in press). Here we address this issue using a dynamic build-up paradigm with fragments increasing in length in 10 steps during 20 s. The stimulus set consisted of 150 object outlines (Wagemans et al, 2008 *Perception* 37 207–244) fragmented in 9×2 ways (9 deletion levels, and 2 fragment types: low or high curvature). We recorded the lowest presentation number (1 to 10) that resulted in correct naming by the participants ($N = 84$). Survival analysis was used to investigate whether and when different types of information such as fragment properties (low versus high curvature), stimulus complexity, global symmetry, and object class (natural versus artificial) influenced the timing of identification. The results indicate an identification advantage for symmetrical objects (optimal bottom-up grouping), high complex objects (low number of activated candidates), and objects from natural object categories (efficient top-down matching).

◆ **Matching of facial features: effects of timing, orientation, and face context**

G Meinhardt, B Meinhardt-Injac¶, M Persike (Department of Psychology, Johannes Gutenberg University, Mainz, Germany; ¶Department of Psychology, University of Zürich, Switzerland; e-mail: meinharg@uni-mainz.de)

In face matching tasks subjects were instructed to attend either to internal features or external features and matched two consecutive test faces, which were either same or different, or coincided and differed just in the features to be attended. Matching of faces was generally fast, reaching saturated performance within the first 175 ms, independent of face inversion and the kind of features to be focused. Matching of facial features was slower, saturating after about 300 ms at poorer levels of correctness. A strong face inversion effect (FIE) was observed at brief exposure durations in all conditions, but immediately vanished for external features at longer presentation times. For internal features, however, we found a strong and constant FIE independent of exposure duration. Further, better matching of faces compared to matching of features was found when focussing on internal features. The data show that judging facial features independently of orientation and facial context is difficult for internal features, and much easier for external features. The differential time course of the FIE for internal versus external features indicates that configural information enters earliest after about 120 ms, and is well developed when the first 200 ms have elapsed.

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◆ **Fixational drift speed is tuned for sharp vision**

A Paakkonen (Department of Clinical Neurophysiology, Kuopio University and University Hospital, Finland; e-mail: ari.paakkonen@kuh.fi)

Even when we fixate upon a tiny object, our eyes are constantly moving. Recently, Rucci et al (2007 *Nature* 447 851–854) provided evidence that these movements improve visual perception of fine spatial detail. They claimed that this improvement originates from the temporal modulations that jittering fixation produces on the retinal image. I argue that it is not jitter but the speed of movements that is responsible for sharp vision. Perceived sharpening for a moving blurred edge is mostly defined by the biphasic temporal impulse response of the visual system. Retinal motion spreads the temporal impulse response function spatially modifying the effective spatiotemporal filter. I present modelling data showing that for all retinal velocities up to $\sim 1 \text{ deg s}^{-1}$, a retinally drifting sharp edge is seen as sharper than a stabilized edge. This velocity range covers that of fixational drift, which is present for 95–97% of fixation time. The passband of the effective filter corresponding to optimal drift extends to higher spatial frequencies than that for zero drift. I conclude that there seems to be an optimal match between fixational drift speed and temporal filtering in the visual system for seeing visual detail at its finest.

◆ **Influence of retinal eccentricity on disability glare recovery**

I Arranz, B M Matesanz, L A Issolio¶, J A Menéndez§, S Mar, J A Aparicio (Departamento de Física Teórica, Atómica y Óptica [§Departamento de Estadística e Investigación Operativa], Universidad de Valladolid, Spain; ¶ Instituto de Luminotecnia, Luz, Ambiente y Visión—CONICET, Universidad Nacional de Tucumán, Argentina; e-mail: iarranz@opt.uva.es)

The evolution of the detection threshold is well known to depend on the time between onset of a transient adaptation field and that of a signal detection stimulus (SOA). Most of the existing information concerns foveal response and the scarce available data concerning extrafoveal behaviour show that in this area the adaptation process is slower than in the fovea [Bichao et al, 1995 *Journal of the Optical Society of America* 12(10) 2252–2258]. This work provides information about the disability glare effect on different retinal eccentricities considering mesopic range of adaptation. A two maxwellian view system has been designed which allows to measure detection thresholds in presence of transient or steady adapting beams. Detection thresholds (td) were measured for 0°, 3°, 6°, 9°, 12° and 15° of temporal eccentricity considering dark adaptation (DA), steady light adaptation (LA) and transient light adaptation (SOA 300) in two normal subjects. Results show that there is a range of eccentricities between 3° and 10° where the periphery adapts faster than the fovea and the further periphery. The rise of the thresholds at the periphery for steady light adaptation indicates the prevalence of cones and the density and the sizes of them in each retinal location could explain our findings.

◆ **Disrupting the perceived time between visual events**

S C M Quinn, R Goutcher¶, R J Watt¶ (Department of Psychology, University of Nottingham, UK; ¶ Department of Psychology, University of Stirling, UK; e-mail: sandra.quinn@nottingham.ac.uk)

We report a study concerning judgments of the time interval between two flashed lines (baseline condition). When an interleaved line is presented at a random interval between them (condition 1), the just-noticeable difference (JND) of the judged timing between flashes 1 and 3 of a 3 flashed sequence is the same as the baseline condition. Participants were then asked to judge the timing from the 2nd to 3rd and 2nd to 4th lines in a sequence of 4 and 5 flashed lines, respectively. The results showed a small increase in the JND for judging the time interval from the 2nd to 3rd lines in the sequence of 4 flashed lines. Comparatively, the JND was larger when observers judged the time interval from the 2nd to the 4th lines in the sequence of 5 flashed lines. These findings suggest that judging a time interval is possible from the first flashed line to the next (from flashes 1 to 2 and 2 to 3) and from the first to last (1st to 3rd flashed line). However, performance is poorer when observers have to judge the time interval from one flash to the next but one.

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◆ **How well can people judge whether two changes happened at the same time?**

E Brenner, J B J Smeets (Faculty of Human Movement Sciences, Vrije Universiteit, Amsterdam, The Netherlands; e-mail: e.brenner@fbw.vu.nl)

People make systematic errors when comparing different kinds of stimuli within tasks that require temporal judgments, such as aligning flashed and moving targets. In interpreting such errors it is often implicitly assumed that people can judge simultaneity, so the errors are attributed to differences in the time taken to process the separate stimuli. But how well can people really judge simultaneity? Is perceived simultaneity not simply inferred from an absence of

(apparent) motion signals? The precision of simultaneity judgments is highest when the stimuli involved are close together, which is in line with a role of motion signals. To test this we compared temporal order judgments for colour changes in static targets with similar judgments when one of the targets was moving. The separation between the targets at the moment that the colour changed was identical in both cases, but in the latter the fact that one target was moving masked any motion signals. The temporal resolution was very good (< 20 ms) when the targets were static. It was considerably poorer (> 50 ms) when one target was moving. This suggests that the human visual system does not have specialised pathways for evaluating synchrony but detects asynchrony from motion signals.

◆ **Audio-visual speech timing sensitivity can be enhanced by crowding**

W Roseboom, D H Arnold (Department of Psychology, The University of Queensland, St Lucia, Australia; e-mail: d.arnold@psy.uq.edu.au)

Humans often interact in crowded environments, with many people talking at once. One might expect this situation to be confusing, as the apparent timing of audio and visual events is mutually attractive (temporal ventriloquism). To assess un-crowded audio-visual timing sensitivity, we presented a voice speaking a syllable either synchronously with, preceding, or succeeding (166 ms) a matching visual speech sequence (Vstd). Observers then completed forced choice synchronous/asynchronous judgments. To assess crowded timing sensitivity, we presented two visual speech sequences. Vstd was accompanied by an identical adjacent sequence (Vad), presented before or after (166ms). The auditory voice was synchronous with either Vstd or Vad. We found that participants were better at deciding which of two faces had coincided with a voice than they were at deciding if a single face and voice had been synchronous. These data are consistent with a selective temporal ventriloquism that brings the temporally closest, matching, audio-visual pair into perceptual register, thereby creating a sensory segregation between these and the unmatched sensory event. Such a process is highly relevant in real world scenarios. For example, making unrelated sensory events seem less related may make it easier to follow a conversation in a crowded room.

◆ **Spatial frequency affects perceived temporal duration**

M Panichi, N Megna, S Baldassi (Department of Psychology, University of Florence, Italy; e-mail: michelapanichi@gmail.com)

There is good evidence that different spatial frequencies are processed by the visual system through relatively independent channels with different temporal properties. In this study we use the method of Single Stimuli to test whether the subjective temporal duration of luminance modulated Gabor patches varies with spatial frequency. Subjects were presented with a stream of stimuli of varying spatial frequency (0.5, 2, 4 cycles deg^{-1}) and durations (175–425 ms), and reported whether that stimulus seemed to be longer or shorter than the average presented so far. Each Gabor stimulus was followed by a white noise mask to minimize afterimage effects, and stimulus contrast was adjusted to balance visibility across frequency. Psychometric functions were obtained for each spatial frequency, giving estimates of perceived duration. The results show that the duration of high spatial frequency stimuli is overestimated by about 10% compared with control (noise) and low spatial frequency stimuli. The possibility of different spatial frequencies being temporally encoded by independent clocks will be discussed. We are currently using classification images to verify the idea that a spatial frequency bias occurs for items classified at shorter or longer than their actual durations.

◆ **Time course adaptation at different retinal eccentricities**

B M Matesanz, I Arranz, L A Issolio¶, J A Menéndez§, S Mar, J A Aparicio (Departamento de Física Teórica, Atómica y Óptica [§Departamento. de Estadística e Investigación Operativa], ¶Instituto de Luminotecnia, Luz, Ambiente y Visión—CONICET, Universidad Nacional de Tucumán, Argentina; e-mail: beatriz@opt.uva.es)

Previous measurements developed by this group and shown at this conference prove that at retinal eccentricities between 6° and 9° especially fast adaptation to sudden changes in retinal illumination is produced. The aim of this work is to provide the time course of adaptation for these eccentricities as well as foveal. A two maxwellian view system has been designed which allows to measure detection thresholds in presence of transient or steady adapting beams. Detection thresholds were measured for 0° , 6° and 9° of temporal eccentricity considering dark adaptation (DA), steady light adaptation (LA) and transient light adaptation (SOA 0, SOA 50, SOA 150, and SOA 300). Results show that while the fovea does not end to adapt during the time presentation of the flash (500 ms), the adaptation is completed into the first 300 ms for 6° and into the first 150 ms for 9° . A possible explanation for these results may come from the different spatial distributions of cones and rods as well as their different temporal responses (Plainis et al,

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2005 *Optometry and Vision Science* **82** 682–688; Stockman and Sharpe, 2006 *Ophthalmic and Physiological Optics* **26** 225–239) specially if the mesopic conditions of the adapting field (around 5 cd m^{-2}) are considered.

- ◆ **Local and global integration of direction information in constant and varying direction displays**
N B Bocheva (Mechanisms of Perception, Institute of Neurobiology, Sofia, Bulgaria;
e-mail: nbbocheva@hotmail.com)

The ability of the human visual system to pool directional information across space and time was studied using the method of equivalent noise. Two experimental conditions were used. In the first, each moving element in the displays had a constant predefined direction of motion, while in the second the moving elements randomly changed direction on every frame. The motion directions were selected from normal distributions of directions with different directional variance. The task of the observers was to estimate whether the global direction of the moving elements was to the left or to the right from vertical downward motion. The directional thresholds for mean direction of motion were estimated as a function of the directional variance. The results suggest that the local neural noise in direction integration of the motion signals is less when the moving elements changed their direction of motion in the sequential frames than when the motion direction was constant over the whole period of motion. The global integration of the directional information was not affected significantly by manipulation of the motion direction of each individual element. These findings differ from existing data on motion coherence where no effect of noise type on the direction thresholds was obtained. The present results imply that the local grouping of directional information is limited when the individual elements move over extended trajectories.

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OBJECT MOTION AND OPTIC FLOW

- ◆ **Independent processing of rotational and translational motion in the perception of moving objects**
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An ellipse rotating at a fixed angular velocity appears to rotate faster as its aspect ratio increases. Here we continue our investigation of this form-motion interaction by examining the relationship between contour curvature and translational motion. Specifically, in a series of 2AFC psychophysical experiments we examined how aspect-ratio influences the perceived speed of ellipses that are either translating or simultaneously rotating and translating. Results: (A) Unlike the case for rotational motion, ellipses of different aspect ratios translating along circular trajectories appeared to move at the same speed. (B) Skinny ellipses translating along circular trajectories while simultaneously rotating appeared to move faster than rounder ellipses. This was especially true when the ellipse was oriented 'point on' like a car going around a track, rather than 'edge on' like the hand of a clock. (C) Skinny ellipses rotating while translating vertically appeared to move faster than rounder ellipses. The degree to which this interaction was observed was independent of the translational velocity. Conclusions: Perceived speed, at least in the conditions studied here, arises from independently processed translational and rotational motion. Furthermore, the perception of rotational but not translational motion relies upon the processing of form features such as contour curvature.

- ◆ **Intra- and inter-modal completion of a visual motion representation**
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We investigated how an occluder, which makes a moving visual object temporarily invisible, disrupts the persistence of the visual motion representation and whether auditory information can maintain the visual motion representation against the occluder. Kanai et al (2007 *Vision Research* **47** 937–945) showed that a transient gap of a smoothly moving visual stimulus could be easily detected if it occurred soon after motion onset ($< 200 \text{ ms}$), but less so if it occurred later ($> 300 \text{ ms}$). This suggests that motion representation evolves gradually and that once it is fully constructed, the gap can be filled in. In our experiments, an occluder of various lengths was added in the middle of a motion path (800 ms). The results showed that gaps after occlusion was detected occurred less frequently with a shorter occluder (47 ms), while detection became easier as the length of the occluder increased. However, with a motion sequence accompanied by auditory motion simulated by changing the interaural level difference, detection remained low even with a longer occluder (173 ms). These findings suggest that both intra- and inter-modal completion processes are involved in the persistence of a visual motion representation.

◆ **Attentional load decreases the strength of vection**

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e-mail: seno@design.kyushu-u.ac.jp)

It has been shown that cognitive factors affect vection. We examined whether vection induction requires attentional resources by imposing two kinds of cognitive tasks during presentation of motion stimuli, the RSVP (rapid serial visual presentation) and MOT (multiple object tracking) tasks. We compared vection strengths between the active-performing condition and the passive-viewing condition. In performing the RSVP task, no change in vection strength was measured by button pressing while the magnitude of subjective vection strength decreased. In performing the MOT task, the vection latency was elongated. Similarly, the duration and estimated magnitude of vection strength decreased during performing the task. The effective decrease in vection strength during the MOT task can be explained by the decrease in attentional resources because the MOT task also requires attention-related motion mechanisms. In addition, when the performance of the MOT task was higher, the measured vection strength was weaker. Thus attentional resources for vection induction and MOT may be shared and an amount of attention distributed to motion stimuli did affect vection induction. The results also revealed that motor responses themselves were not the cause of the decrease in measured vection strength. We conclude that vection does require attention.

◆ **Change in speed of movements affects interpretation of motion in 3-D scene**

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When rotation of viewpoint is simulated by movement of a ground plane and a small object synchronously moves horizontally above the ground, the visual system interprets the object as stationary on the ground. We found that addition of the depth movement to the viewpoint rotation induces the illusory depth movement of the moving object. We think this would be caused by the bias to perceive objects stationary in an allocentric reference of frame. In the present study, we investigated how the visual system separates the object motion from the movement of viewpoint by using this illusory depth movement. In our stimulus display, a ground-plane rotated and moved in depth and the dotted object synchronously traversed. We prepared four types of movement, which were (a) the object moved in a constant speed, (b) movement generated by subjects, (c) replay of the movement (b), and (d) randomly varied speed. Movement in the condition (b) was synchronized with finger movement on a touch panel. Subjects were asked whether they perceived the depth movement of the objects synchronized with the ground movement. The results showed that the subjects perceived depth movement more frequently in conditions (b) and (c). These results indicate that the change in the speed of movement affects the visual system separating local motion from global motion.

◆ **Visual steering of human behaviour in navigation: a modeling investigation**

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Problem: Human behaviour in navigation has been studied psychophysically by tracking observer trajectories during task performance (Fajen and Warren, 2004 *Perception* 33). Different levels of behaviour have been identified, such as steering towards a static goal or intercepting a moving target while avoiding obstacles (Duchon et al, 1998 *Adaptive Behavior* 6). It has been demonstrated that an active observer shows specific fixation patterns during navigation tasks (Rothkopf and Ballard, 2009 *Visual Neuroscience* 26). It remains unclear what particular visual information is utilized in different tasks and which neural representations are involved. **Method:** We utilize a neural model architecture to compute visual information related to various aspects of spatial navigation from observer perspective. The model has been probed with image sequences generated for an observer moving in a cluttered scene approaching a target object (goal post, stationary or moving) and avoiding obstacles (stationary). **Results and conclusion:** Model simulations successfully reproduce observer approach towards a goal at different locations and avoiding individual obstacles showing trajectories consistent with those of human subjects. A scenario including independently moving objects requires the segregation of moving objects from the static ground. In our model object segregation is achieved through the feedforward/feedback interaction of cells in model areas MT, MSTd, and MSTl. Initial investigations of flow fields with gaze fixations suggest potential simplifications in figure-ground segregation. We conclude that this segregation provides information necessary for successful visual steering in complex environments.

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◆ **Top – down influence of size cues on the perceived visual speed of self-motion**

D Berger, P Pretto, H H Bülthoff, J-P Bresciani (Department of Human Perception, Cognition and Action, Max Planck Institute for Biological Cybernetics, Tübingen, Germany; e-mail: bresciani@tuebingen.mpg.de)

Size cues are known to affect the perceived distance between objects. If the physical distance between two objects remains constant, the larger the retinal image of the objects is, the closer to one another they are perceived to be. We tested whether size cues affect the perceived visual speed of self-motion. Ten subjects sitting in front of a panoramic screen ($230 \times 125^\circ$ of field of view) were presented with constant-speed translations of the visual scene, which simulated a forward translation of the body. The physical size of the objects present in the scene was systematically varied, and the subjects had to estimate the speed of the translations. We used a 2IFC task, ie, two stimuli were presented successively and the subject had to indicate which one was faster. The experiment had four conditions, with two main factors: object size (big/small) and object familiarity (absolute size known/unknown). Eye and horizon heights were constant throughout all conditions. We observed a main effect of object size, with speed being underestimated for larger objects. Interestingly, this effect was significantly stronger for objects whose absolute size is known. These results suggest a top–down influence of size cues on the perceived visual speed of self-motion.

◆ **Computations governing the spatiotemporal pooling of local motion directions**

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To form purposeful decisions, cortical pathways combine ('pool') visual information across space and time. Yet we have a poor understanding of the algorithms which govern the pooling process. We have previously tested the idea that the visual system simplifies the combinatorial calculations by deriving summary statistics of complex moving images in order to guide perception. Our results suggested that spatial pooling of motion signals is better characterised in terms of structured decoding of neuronal population activity in visual cortex rather than motion statistics. Here we ask whether motion statistics characterise performance on a task that requires observers to combine motion directions over time. Observers discriminated the global direction of motion of random-dot-kinematograms composed of asymmetrical distributions of directions with distinct temporal statistics. Perceived global direction coincided with the vector average of direction signals accumulated over time. To reconcile these discrepant results, observers performed a global motion task in which we manipulated the relative proportion of dots that were pooled over space and time. Perceived global direction was accurately predicted by an adaptive process that translates between a vector average read-out of direction signals accumulated over time and a maximum likelihood read-out of direction signals combined over space.

◆ **Pre-exposure to moving forms transiently improves objective sensitivity to static forms**

T S Wallis, M A Williams[¶], D H Arnold (School of Psychology, The University of Queensland, St Lucia, Australia; [¶] Macquarie Centre for Cognitive Science, Macquarie University, Sydney, Australia; e-mail: t.wallis@psy.uq.edu.au)

Motion-defined form can seem to transiently persist after the cessation of movement, before apparently fading back into a background of static noise. We asked whether this phenomenon is subjective or objective. We used a stimulus consisting of an array of circular 'signal windows', through which parts of moving forms could be seen. These were intermingled with noise. By manipulating the signal to noise ratio, observers could be rendered insensitive to static but sensitive to moving forms. When movement ceased, a static percept of the previously moving form seemed to transiently persist. We found that this could not be ascribed to bias, as pre-exposure to moving form facilitated objective measures of static form sensitivity. This could not be ascribed to a greater number of perspectives, as scrambled animations did not produce the facilitation. Finally, the enhanced sensitivity could not be ascribed to local luminance adaptation, as it occurred when the positions of both the signal and noise arrays were jittered. Our data suggest that the phenomenal persistence of motion-defined form is driven by a transient facilitation of static form sensitivity by motion-based pattern interpolations. Results from brain imaging (MEG) will also be discussed.

◆ **The role of cortical feedback in a hierarchical model of object perception**

S Durabernal (Centre for Theoretical and Computational Neuroscience, University of Plymouth, UK; e-mail: salvador.durabernal@plymouth.ac.uk)

I present a model which stems from a well-known cortically inspired object recognition model (HMAX), and show how this feedforward system can be extended to include feedback based on a recently proposed architecture which reconciles Biased Competition and Predictive Coding

approaches. Moreover, I demonstrate that the extended model is consistent with a probabilistic interpretation using the Bayesian Belief Propagation algorithm. Simulation results show successful feedforward object recognition, including cases of occluded and illusory images. Recognition is both position and size invariant. The model also provides a functional interpretation of feedback connectivity accounting for several observed effects such as enhancement, suppression and refinement of activity in lower areas. The model can qualitatively replicate responses in early visual cortex to occluded and illusory contours; and fMRI data show that high-level object recognition reduces activity in lower areas. Additionally, a mechanism based on collinearity, co-orientation, and good continuation principles is proposed for illusory contour formation which can adapt a single high-level object prototype to Kanizsa's illusory figures of different sizes, shapes and positions. Overall the model provides a biophysiological plausible interpretation—supported by current experimental evidence—of the interaction between top-down global feedback and bottom-up local evidence in the context of hierarchical object perception.

◆ **Inhibition of return (IOR) observed on the object trajectory**

Y Shiozaki, S Ohtsuka (Department of Psychology, Saitama Institute of Technology, Japan; e-mail: satoko@sit.ac.jp)

By using dynamic displays, Tipper et al (1994) clearly demonstrated that the detection performance is suppressed when the target is presented in a cued object (object-based IOR) and at a location where the object was cued (location-based IOR). The present study aimed to investigate the detection performance on along the path the cued object traveled. In the first experiment, four square items were arranged around the fixation point and rotated similarly to the Tipper et al's experiment. The cue presentation was followed by the target with an SOA of 1000 ms. The target was presented in the cued item, at the cued location, at where the cued item passed through, or at the other. Observers pressed a key as soon as they found the target. As a result, IOR was most pronounced at the passed-through location. No location-based IOR was observed. In other experiments the rotation rate was reduced or the items were colored differentially. The results were the same as for the first experiment, except that the object-based IOR became significant. This suggests that mental tracking of the object is not necessarily close. Updating the visual representation would depend on the dynamic properties of the scene.

◆ **When and why does masking affect long duration targets?**

A Gellatly, D Guest, M Pilling (Department of Psychology, Oxford Brookes University, UK; e-mail: agellatly@brookes.ac.uk)

In visual masking experiments, the stimulus to be reported is usually presented only fleetingly, with brief presentation having generally been assumed to be a necessary condition for obtaining visual masking. Recently, however, Wolfe et al (2006 *Visual Cognition* 14 749–780) obtained chance performance when observers reported the orientation of one bar in an array of thirty two that had been presented for 500 ms or more before the target was cued and masked. Conversely, we (Gellatly et al, 2009, submitted) have observed that a robust OSM effect obtained with a briefly presented array is greatly reduced or completely eliminated when search displays are presented for 500 ms prior to the target being cued and masked, though performance remains well below ceiling. In this paper we report three experiments investigating possible reasons for such directly conflicting results. Our findings suggest that whether or not masking can be obtained with long duration targets is determined more by the nature of the discrimination than by display size, type of mask employed or the precise temporal relationship between target offset and cue/mask onset.

◆ **Effects of task-irrelevant texture motion on time-to-contact judgments**

D Oberfeld, H Hecht (Department of Experimental Psychology, Johannes Gutenberg-Universität, Mainz, Germany; e-mail: oberfeld@uni-mainz.de)

Task-irrelevant distractor objects cause systematic biases in time-to-contact (TTC) judgments (Oberfeld and Hecht, 2008 *Journal of Experimental Psychology: Human Perception and Performance* 34 605–623). For task-irrelevant motion within a target object we expected local and global motion to be averaged. In Experiment 1, observers viewed a disk with a spiral texture pattern, approaching them on the mid-sagittal plane. Rotation of the spiral texture in a direction causing an impression of contraction resulted in a significant TTC overestimation in a prediction-motion task, relative to a condition without texture rotation. Surprisingly, rotation in the opposite direction (causing an impression of expansion) had no significant effect at the shortest presentation duration (500 ms). At the longest presentation duration (2000 ms) the expanding texture even resulted in a significant overestimation. In Experiment 2, a vertical cylinder moved in the frontoparallel plane as if rolling. Observers judged its TTC with a finishing line. The cylinder was textured with stripes oriented in parallel to the main axis. It was either not rotating, rotating such that the visible stripes moved towards the finishing line, or rotating in the opposite

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direction so that the stripes moved away from the finishing line. Both texture motions caused a significant TTC overestimation compared to the non-rotating condition. In conclusion, local and global motion are neither simply averaged nor processed independently.

SELECTION AND MODULATION

◆ **Attentional modulation of orientation discrimination across spatial frequencies**

N Megna, S Baldassi (Department of Psychology, University of Florence, Italy;
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Attention improves spatial resolution (Carrasco et al, 2006 *Perception & Psychophysics* **68** 1004–1012). We investigated whether this attentional effect impacted orientation encoding by measuring orientation discrimination for a Gabor target presented with a distractor at different spatial frequencies. The two patches were displayed to the right and the left of fixation for 130 ms, with varying spatial frequency (SF) and eccentricity and we modulated contrast to balance visibility across conditions. In half of the trials a location cue was displayed 52 ms before the stimulus. The effect of attention depended on SF, independent of eccentricity. Averaging data across eccentricities reveals an attentional performance improvement of orientation discrimination by a factor of 1.7 to 2 at SFs between 1 and 2 cycles deg^{-1} , and a much lower effect at SFs of 0.5 and 4 cycles deg^{-1} (< 1.4). Moreover, analyzing orientation discrimination thresholds as a function of SF, the peak of sensitivity shifts, with attention, towards higher spatial frequencies. Data were confirmed when the gaussian aperture of the grating was scaled with SF to show a constant number of periods. A biologically plausible model will be discussed.

◆ **A direct comparison of visual suppression by transcranial magnetic stimulation and metacontrast masking**

H M Railo, M Koivisto (Department of Psychology, University of Turku, Finland;
e-mail: hmrail@utu.fi)

The conscious visibility of a stimulus can be suppressed by visual masking or transcranial magnetic stimulation (TMS). It has been suggested that both methods interfere with the same neural processes. We directly compared metacontrast and TMS suppression in a within subjects design ($N = 10$) using the same behavioural measures for both methods. Participants were asked to detect the location (left/right hemifield) of a small grey dot presented for 17 ms, and then rate its visibility. The visibility of the stimulus was manipulated by metacontrast masking or by focal occipital (biphasic) TMS, both presented at 13 different stimulus onset asynchronies (SOA). The site of TMS was determined in a session prior to the experiment. The results showed that metacontrast masking suppressed the target visibility maximally at an SOA of 33 ms, whereas maximal TMS suppression was observed at 83 ms SOA. Thus, if one assumes that retinocortical transmission takes 50 ms, the suppressive time windows coincide. This latency estimate is short, but is supported by human and animal data. The results of the localization study showed that suppression by TMS was stronger when a visual stimulus was presented bilaterally, when compared to unilateral presentations. We explain this by increased attentional competition.

◆ **Object representations maintain attentional control settings across space and time**

D Schreij, D N L Olivers (Department of Cognitive Science, Vrije Universiteit, Amsterdam, The Netherlands; e-mail: dschreij@gmail.com)

Previous research has revealed that we create and maintain mental representations for perceived objects on the basis of their spatiotemporal continuity. An important question is what type of information can be maintained within these so-called object files. We provide evidence that object files retain specific attentional control settings for items presented inside the object, even when it disappears from vision. The objects were entire visual search displays moving into and out of view. We demonstrated that search was speeded when the target position was repeated from trial to trial, but especially so when spatiotemporal continuity suggested that the entire display was the same object. This finding was extended by showing that response times for repeated target features (eg shape) were modulated by spatiotemporal continuity of an object as well. We conclude that complete spatial and featural attentional biases can be stored in an object file.

◆ **The times they are a'changin: Affective images impact time perception**

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Previous research suggests that attention distorts perceived temporal duration (Tse, Intriligator, Rivest, and Cavanagh, 2004). Using a simple 'oddball procedure' (rarely occurring items embedded in a stream of other items), they showed that odd (attention-grabbing) events appear to persist longer. To date, researchers have only employed 'neutral' (ie non-affective) stimuli.

We now investigate the contribution of affective information to the distortion of perceived duration. Participants initially rated numerous affective stimuli. Their most-positive, most-negative, and most-neutrally-rated stimuli were included in an adaptive oddball procedure where interleaved staircases controlled oddball duration (Seifried and Ulrich, in press). Afterwards, sigmoidal functions were fit to extract performance parameters (eg PSE, JND, and temporal distortions). All oddball items were perceived to last longer, but this distortion effect was moderated by the affective nature of the stimuli. This effect was seen both in the amount of temporal distortions (overall PSEs) and in the steepness of the derived psychometric function (JNDs). We also found large individual differences. We discuss our results in relation to other studies of time distortion, to the neural systems involved, and to recent ERP research that has demonstrated affect's influence on the P300 using a related psychophysiological oddball procedure (eg Cano, Class, and Polich, 2009).

- ◆ **BOLD signal in intraparietal sulcus covaries with magnitude of implicitly driven attention shifts**
J Schultz, T Lennert¶ (Human Perception, Cognition and Action, Max Planck Institute for Biological Cybernetics, Tübingen, Germany; ¶ Graduate School of Neural and Behavioral Sciences, International Max Planck Research School, Tübingen, Germany;
e-mail: johannes.schultz@tuebingen.mpg.de)

A lot is known about the neural basis of directing attention based on explicit cues. In real life however, attention shifts are rarely directed by explicit cues but rather generated implicitly, for example on the basis of previous experience. Here, we aimed at studying attention shifts dependent on recent trial history. We asked observers to detect targets in a stream of visual stimuli with three feature dimensions: colour, shape and motion. Critically, target occurrence probability was always higher in one stimulus dimension than in the others, and probabilities switched between dimensions over blocks of trials. After each probability switch, target detection times decreased exponentially for high-probability targets and increased for low-probability targets, compatible with gradual shifts in attention dependent on trial history since the switch. BOLD signal in left prefrontal and intraparietal sulcus regions was higher in the early phase after the switch, while anterior cingulate, cuneus, precuneus, temporal and more anterior frontal regions showed more activation later after the switch. These findings are compatible with expectation about engagement of regions involved in the establishment and maintenance of attentional sets. BOLD signal in left intraparietal sulcus correlated with the size of the performance changes consecutive to the detected targets, suggesting that it reflects the size of attention shifts induced by updating target probabilities over recent trial history.

- ◆ **Mechanisms of location- and object-based attention as revealed by the external noise paradigm**
W-L Chou, C-C Chen, S-L Yeh (Department of Psychology, National Taiwan University, Taipei, Taiwan; e-mail: basilpudding@gmail.com)

We adopted the external noise paradigm to the Egly double-rectangle display to examine the mechanisms of location- and object-based attention. Participants were required to detect a Gabor target superimposed on the noise pattern in a 2-interval forced-choice task. The target either occurred at the cued location (valid), the uncued location within the cued object (invalid/same, IS), or the uncued location within the uncued object (invalid/different, ID). Results showed that the threshold-versus-noise contrast (TvC) functions were flat at low contrasts and increased with higher contrasts. Spatial cueing at the valid location shifted the TvC functions downward, suggesting an increase of sensitivity to the target. The TvC function in the ID condition was a leftward shifted copy of that in the IS condition. The TvC functions were fit by a divisive-inhibition model. In this model, target response is determined by the excitation of a linear operator raised by a power and divided by a divisive-inhibition input plus an additive constant. The results suggested that the object effect can be explained by more efficient external noise exclusion in the IS than the ID condition, and the location effect can be explained by both external noise exclusion and internal noise reduction.

- ◆ **Representation of stimulus uncertainty effects on speeded discrimination performance**
J P Thomas, T Endestad¶, S Magnussen¶ (Department of Psychology, UCLA, Los Angeles, USA; ¶ Department of Psychology, University of Oslo, Norway;
e-mail: thomas@psych.ucla.edu)

Stimulus uncertainty effects, while relatively small, provide important information about underlying perceptual processes. In speeded discrimination tasks, uncertainty produces losses in speed, in accuracy, or a combination of smaller losses in both. Decision criteria determine the trade-off between speed and accuracy losses, and variation among observers and conditions may obscure the existence of uncertainty effects when speed and accuracy are analyzed separately. We describe a vector space in which the axes are measures of speed and accuracy losses, each

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measure divided by its standard error. Each vector represents combined losses in speed and accuracy. Vector length indexes reliability and vector orientation reflects trade-off. We illustrate the space with simulated results from a Bayesian response model and with empirical data from speeded visual discriminations of contrast and spatial frequency. In the empirical data, uncertainty effects most often appear as combined accuracy and speed losses; a fact that emphasizes the importance of analyzing the two dimensions jointly.

◆ **Task-irrelevant size nonsingletons affect attentional prioritisation**

A Shirama, A Ishiguchi (Graduate school of Humanities and Sciences, Ochanomizu University, Japan; e-mail: shirama@jcom.home.ne.jp)

A stimulus that is locally unique in some feature dimension is called a feature singleton. It is known that a size singleton captures attention in a stimulus-driven fashion even if this is not always a target [eg, Yantis and Egeth, 1999 *Journal of Experimental Psychology: Human Perception and Performance* 25(3) 661–676]. And a singleton has been used in previous studies of attentional capture. But in order to draw attention, is a singleton necessary on the size dimension? In this study, we reconsidered the effect of task-irrelevant size information in visual search. We set each of all items including a target and distractors to be any one of six sizes at a constant rate. Thus the items of various sizes (size nonsingletons) were presented simultaneously in a display. Stimulus size was not informative to find a target. We also conducted two tasks that had different target discriminability. In the easy search task, observers could detect the target efficiently regardless of target size. This result indicates that the size-independent detection of the target is possible. However in the hard search task, the bigger target was detected more efficiently than the smaller target. This result suggests that the irrelevant size nonsingletons affect attentional prioritisation only in a serial search mode.

◆ **Selective attention modulates motion speed learning by suppressing visible irrelevant stimuli**

S-W Wang, C-H Tseng ¶ (Department of Psychology, National Taiwan University, Taipei, Taiwan; ¶ Department of Psychology, The University of Hong Kong, PR China; e-mail: SWWang@gmail.com)

Selective attention modulates perceptual learning in motion speed, but previous studies were unable to answer whether selective attention modulates learning by enhancing the attended signal, suppressing the ignored signal, or a combination of the two. We investigated this question by separating the attended/ignored signals in two disparity-defined depths. The learning stimuli contain speed change in one specific direction (target direction) at one specific depth plane (target depth), with another depth plane (non-target depth) containing either nothing (control group), or distractor dots moving in random direction (random-direction group) or orthogonal to target direction (orthogonal-direction group). Observers' 80%-correct motion coherence detection thresholds at two depth planes were measured before and after six hourly sessions of speed discrimination. After learning, observers' motion sensitivity increased by an average 23% at target depth plane at all tested directions in all three conditions, as well as at the non-target depth plane when no distractors were present (control condition) (21%). At conditions where clearly visible moving distractors in either non-specific (random) or specific (orthogonal) direction, there is a clear disadvantage at the distractor direction(s) (6%, 0%). Our results strongly suggest that selective attention modulates motion speed learning largely by suppressing visible irrelevant stimuli.

◆ **Attentional capture on locations: Effects across time and distance**

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Transient changes in visual space cause effective stimulus driven attentional capture. Usually, distractors or incongruent features to the relevant task are used and eventually, congruent features but not in a congruent location. We tried to produce capture on locations. We used a same–different discrimination task with a previous placeholder display in which we had produced an exogenous attentional capture through a transient luminance change in an orthogonal location to the stimulus one. So, we have conditions with congruent and incongruent location capture, the same as a condition without capture. We tried to check whether different time delays between capture and stimuli affect in a different way to congruent and incongruent capture. Capture on an incongruent location produced a cost, which varied with distance between the locations and, besides, it depended on the time delay between the transient that produced capture and stimulus display. Across time, accuracy cost was diminished for shorter distances and bigger delays increased beneficial effects of capture on a congruent location. Shorter delays produced greater data variability.

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◆ **Pre-masking is pre-attentive while post-masking is post-attentive**

S-Y Lin ¶, P Cavanagh (Laboratoire Psychologie de la Perception, Université Paris Descartes, Paris, France; ¶ Department of Psychology, National Taiwan University, Taipei, Taiwan; e-mail: d94227106@ntu.edu.tw)

We used moving attention (Cavanagh et al, 2008 *Journal of Vision*) in a masking paradigm to investigate the effect of diverting attention away from the mask. Target-mask pairs were presented in sequence around a circular display so that targets (letters or faces) were seen in motion around the display, each either followed or preceded by a mask. While fixating the center of the display, subjects attentively tracked a moving target so that attention fell on the target but avoided the mask that arrived just before or after it at each location. In contrast, in a static control with no motion, the attention directed to the target undoubtedly also fell on the mask that preceded or followed it at the same location. The accuracy of target identification increased for the post-mask in the moving attention condition compared to the static control, whereas there was no difference between moving and static performance for a pre-mask. These results suggest that the pre-mask has already degraded the target before it can be sampled by attention. However, the effects of the post-mask can be avoided if attention moves away before the mask arrives. We conclude that pre-masking is pre-attentive and post-masking is post-attentive.

◆ **A new object captures attention when you know it is new**

F K Chua (Department of Psychology, National University of Singapore, Singapore; e-mail: fkchua@leonis.nus.edu.sg)

Two explanations have been proposed to explain why an object appearing suddenly captures attention: (a) onset transients automatically trigger attention to the object, and (b) the visual system regards an object appearing suddenly as a new entity, and its novelty captures attention. To dissociate these two explanations, Franconeri et al (2005 *Psychological Science* 16(4) 275–281) introduced a method in which the onset transients were obscured via a contracting annulus. With the onsets now invisible, the question was whether there would be efficient search if this new object were a target, compared to a distractor, letter. Their results showed that the onset transients were critical. Chua (2009 *Attention, Perception & Psychophysics* 71(4) 699–711), however, demonstrated that when observers encoded the placeholders' locations, thereby allowing the new object to be distinguished from the old ones, a new object, even one with its onset transients invisible, captured attention. We extended Chua's results in two experiments. First, when the search set was reduced, a new object with its onsets invisible still failed to capture attention, showing that load was not an issue. The second experiment, a variation of the Franconeri et al's paradigm, made the annulus stationary while the objects moved from the display's center. When they passed under the annulus, a new object was added, again with its onset transients invisible. This procedure probably coaxed observers to track the objects. Now, RTs were independent of search set size when the additional object was the target, suggesting that when observers were able to localize the new object, the latter captured attention.

◆ **fMRI-correlates of the temporal evolution of a split of spatial attention**

V Fischer, M Raabe, F H Hamker¶, M W Greenlee (Institute of Psychology, University of Regensburg, Germany; ¶ Department of Psychology II, Westfälische Wilhelms Universität Münster, Germany; e-mail: volker.fischer@psychologie.uni-regensburg.de)

Visuospatial attention needs not to be restricted to a single location in space but splits, under specific circumstances for noncontiguous locations (eg Bichot et al, 1999 *Perception & Psychophysics*). fMRI-correlates for this split of spatial attention were found in early visual areas (eg McMains et al, 2004 *Neuron*). Some newer findings suggest that this attentional split reflects the early phase of attentional selection and for later phases attention settles at a particular location. We studied this temporal evolution of the spatial attention distribution using essentially the same paradigm used by Bichot et al. Within an array of four stimuli, subjects had to compare two shapes of two red targets among green distractors. After a stimulus-onset asynchrony (SOA), a letter was flashed inside each shape and the performance for remembered letters in each location represented the distribution of spatial attention. fMRI results showed a SOA-dependent activity in the dorsolateral prefrontal cortex and the Cuneus suggesting that these areas play an important role for the temporal evolution of visuospatial attention.

◆ **What is underlying facilitation effect in spatial cueing task?**

Y Matsuda, T Yoshizawa, T Kawahara (Human Information System Laboratories, Kanazawa Institute of Technology, Japan; e-mail: matuyuki@neptune.kanazawa-it.ac.jp)

Since spatial cueing method was provided by Posner (1978, 1980), that cueing method has been thought to be able to investigate the spatial property of attention. Attention that is captured and allocated at the cued position, is believed to facilitate information processing. If this is the

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case, the power of attentional capture would be varied as a function of reaction times (RT) in the valid condition. Our previous results in simple detection task showed significant correlation between the amount of attentional capture and RTs in the invalid condition (Matsuda and Iwasaki 2008). These results suggested a hypothesis that the original account might be incorrect. In this research, we examined this hypothesis in discrimination task and central cueing task. The results showed same pattern of those in simple detection task. These results are not congruent with the idea what spatial cueing method facilitated the information processing of the stimulus presented at the cued location.

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MULTISENSORY PROCESSING

◆ Visual basics: The Tectum opticum in *Gnathonemus petersii*

R Pusch, G von der Emde, J Engelmann (Neuroethology/Sensory Ecology, Institute of Zoology, University of Bonn, Germany; e-mail: roland.pusch@uni-bonn.de)

The mormyrid fish *Gnathonemus petersii* possesses an active electric sense—ie the ability to generate and perceive its electric organ discharge (EOD)—used for orientation, hunting, and communication. This is an adaptation to live under conditions unfavourable for visual orientation; ie nocturnal lifestyle and/or muddy water conditions. Furthermore *G. petersii* evolved a highly specialised visual system: bundled photoreceptors a light gathering tapetum and retino-motoric activity are features which enables it to deal with dim light conditions. Our aim is to understand the neural processing of visual information and possible interactions with other senses to reveal the advantage of this complex visual system. We measured visual evoked potentials (VEP) addressing the question of flicker-fusion-frequency in the optic tectum. These data were compared to VEPs in goldfish *Carassius auratus*. In single cell recordings we characterised response properties of neurons to visual stimuli. Receptive fields of visual neurons were measured and compared to the predicted visual resolution and the anatomical organisation of the ganglion cells. First results suggest that the spatial resolution is comparatively low while the temporal resolution is higher than expected. We investigate if this is achieved by convergence of cone and rod pathways of the duplex retina of *G. petersii*.

◆ Evidence for optimal integration of auditory and visual components in audiovisual temporal rate perception dependent on modulation type

D Murphy, D Alais (School of Psychology, University of Sydney, Australia; e-mail: murfs.au@gmail.com)

Shipley (1964) reported an audiovisual interaction called 'auditory driving' where, using the method of adjustment, the perceived visual rates could be driven by audition to about twice their physical rate. Using a two-interval forced-choice procedure to eliminate response biases, we investigated this effect at frequencies of 4, 7, 10, 13 Hz. In separate modalities, we measured points of subjective equality (PSEs) and discrimination thresholds to quantify accuracy and precision of unimodal temporal perception. In bimodal experiments, slightly disparate (± 0.2 octave around each standard frequency) but perceptually fused frequencies were presented in one interval with a matched frequency pair presented in the other to determine the PSEs and precision (discrimination threshold) of the disparate pair. For single modality intervals PSEs were close to accurate at all frequencies, with a tendency to underestimate 13 Hz in vision. For sinusoidal modulation discrimination thresholds were only marginally smaller in audition than vision, however square modulation resulted in significantly smaller auditory discrimination thresholds (greater precision). Bimodally, PSE shifts were minimal for sinusoidal modulation, while shifts observed with square modulation tended to reflect maximum likelihood estimation predictions (ie, towards the more precise modality—audition) showing strong auditory-driving effects require square modulation.

◆ Enhanced predominance of motion-parallax stimuli in binocular rivalry

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We investigated whether perceiving depth from a motion-parallax stimulus enhances the predominance of that stimulus in binocular rivalry. A horizontally moving random-dot motion-parallax stimulus was presented to one eye and a vertically moving non-motion-parallax stimulus was presented to the other eye. The horizontally moving stimulus was ecologically valid as a motion-parallax stimulus since its direction of motion on the retina was consistent with the observer's lateral head movements. On the other hand, the vertically moving stimulus was ecologically invalid since its direction of motion was inconsistent with the head movements. In the experimental

condition, observers viewed these rival stimuli while moving their heads laterally back and forth; each stimulus motion was yoked to the observers' head movements. In the control condition, observers viewed the same rival stimuli without head movement. The average duration of seeing the horizontally moving stimuli in the experimental condition was longer than that of the control condition. We conclude that an ecologically valid stimulus for depth perception enhances the predominance of motion-parallax stimuli in binocular rivalry.

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◆ **Neural correlates of priming for audiovisual stimulus processing at different levels of categorization**

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Categorization of natural images and sounds are basic cognitive processes we perform mostly unconsciously. While numerous studies have investigated the neural correlates of auditory and visual categorization and audiovisual integration, the categorization of audiovisually presented stimuli remains poorly understood. We used a priming paradigm to assess whether the matching of simultaneously presented congruent or incongruent auditory and visual stimuli to a prime word leads to BOLD-signal increases in regions previously linked to auditory and visual categorization, or whether there is a mutual activation site, indicating that representation of categories in semantic memory is multimodal. Additionally we tested whether there were priming-related top-down processes that were modulated by the level of categorization of the prime, the word being either a basic level or a superordinate level name. Our results indicate that compared to baseline the BOLD-signal increased on congruent trials for categorization of auditory and visual objects. This increase was found bilaterally in posterior cingulate and middle and superior temporal, parahippocampal, and lingual gyrus. There were no significant differences between auditory and visual categorization. Compared to superordinate level, basic level primes led to an increase in BOLD-signal bilaterally in inferior frontal cortex, occipito-temporal cortex and parietal cortex.

◆ **Multimodal combination of visual information about object size with observation of an actor: cue integration by the mirror neuron system?**

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Many studies have shown that humans integrate optimally information from different senses. In this study we investigated whether integration can occur between visual signals of object size with those of observing an actor grasping the object. We measured size discrimination of physical spheres of different diameter (varying around 50 mm), positioned at varied distances from the subjects. Subjects judged (in 2AFC) which of two spheres appeared larger, the standard (presented 60 cm from the observer) or the test at a randomly chosen distance (42–120 cm). In separate sessions we asked subjects to match with their index and thumb the dimension of a sphere, and measured the size of the opening. Size discrimination and matching judgments were then repeated in three other conditions: subjects observed the spheres while an actor reaching to and grasping the object; or reached to the object without grasping; or a static hand holding the object. We also measured performance with conflicting visuo-haptic information to evaluate the integration. Both the psychophysics and grip-matching results show that subjects overestimate object size for distances larger than their haptic workspace. However, the bias decreased and precision improved when subjects observed an actor grasping, implying integration with the action of an actor. The control conditions (pointing and static hand) had little or no effect. We suggest that the 'Mirror system' could mediate this process.

◆ **Sound expands perceived visual duration through pacemaker acceleration**

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Chen and Yeh (2009) used an oddball paradigm and observed asymmetric cross-modal effects in time perception: the visual duration was expanded by a concurrent but irrelevant sound whereas the auditory duration was not influenced by a synchronized disk. As the oddball paradigm emphasized the role of attention on time perception, a two-interval-forced-choice paradigm was used in this study to exclude the attentional effect induced by oddballs. Participants viewed two successive intervals of different durations and judged which lasted longer. When one of the intervals was kept constant to serve as the standard duration, the other one followed the method of constant stimuli as a comparison. The standard was presented in unimodality and the comparison was either in the same modality or with another modality added. The participants were required to judge the duration based on one single modality while ignoring the other one.

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The results showed that similar asymmetric crossmodal effects were observed as in the previous study using the oddball paradigm. Since the effect of attention on time perception can be attenuated in this two-interval-forced-choice paradigm, the results suggest that the crossmodal effect of sound on visual duration comes from the pacemaker modification according to the scalar expectancy theory.

◆ **Cross-modal feature integration shares the same rule as within-modal integration**

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We have found that perceptual feature integration within vision and audition separately follows Minkowski summation with power $m \approx 3$ [(Cue1³ + Cue2³)^(1/3); To et al, 2008 *Proceedings of the Royal Society of London B* 275 2299–2308; To et al, 2009 *Proceedings of the 31st Annual Conference of the Cognitive Science Society*] and have attributed the power to the degree of correlation across neural channels. Here, we examine whether the same rule is applicable across modalities (vision/hearing). Ten subjects were presented with natural image stimuli coupled with natural sounds, and rated the perceptual difference between two slightly different image–sound pairs. Image–sound pairings were either congruous (eg dog image, barking sound) or incongruous (eg dog image, aerosol sound). The stimuli encompassed 216 combination sets, composed of three image–sound changes: (i) images changed, (ii) sounds changed, and (iii) images and sounds both changed. We found that ratings for dual changes could be predicted by Minkowski summation of the ratings for the separate visual and auditory changes, with power $m = 2.62$ (congruous condition) and 2.50 (incongruous condition). The results show that Minkowski summation with power $m \approx 3$ rule can be extended to cross-modal feature integration, and the absence of an effect of congruency suggests a general neural property rather than a stimulus specific phenomenon.

◆ **Asymmetric crossmodal interaction and priming effects in Ternus illusion**

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Visual apparent motion perception has been found to be influenced by visual priming probes and simultaneously presented auditory stimuli. In this study we examined the priming effects and crossmodal interaction using three-token Ternus display. To introduce the priming effects, the middle token was presented twice before the standard Ternus display. The interstimulus interval (ISI) for prime-probe was kept the same as that for Ternus display. For visual Ternus illusion, visual token priming induced a strong percept of ‘element motion’, where the point of subjective equality (PSE) was increased by 35 ms, while the tactile priming degraded the discrimination of two visual motion percepts, where the just noticeable difference (JND) was increased by 5 ms. In addition, synchronous visual–tactile events were demonstrated to bias the visual Ternus illusion to ‘group motion’ and decreased the PSE in visual Ternus display by 34 ms and enhanced the sensitivity of visual motion (JND decreased 6 ms). However, neither visual priming nor synchronous visual events have an influence on the tactile Ternus illusion. We explain this asymmetry of the crossmodal priming and interaction in a manner of the capacity of both facilitation and resistance of ‘bias’ between the two modalities.

◆ **Brightness and definition of pictures seen from between the legs**

A Higashiyama (Psychology Department, Ritsumeikan University, Kyoto, Japan; e-mail: achan@lt.ritsumeikan.ac.jp)

It has been documented that if we see a scene from between our own legs, it appears to be brighter and more definite. In the between-legs perception, the retinal image is inverted and the upper trunk and the head were also inverted. Which inversion, retinal image or head orientation, is critical for the changes in brightness and definition? By three experiments, we sought the factor determining the changes in brightness and definition. In Experiment 1, four upright pictures were seen with the head upside down (ie, inversion of both image and head); in Experiment 2, the inverted versions of the same pictures were seen with the head upright (ie, inversion of image); in Experiment 3, the inverted pictures were seen with the head upside down (ie, inversion of head). As a control of each experiment, the pictures were seen with both image and head upright. About 5% increase in brightness and definition was found for all pictures in Experiments 1 and 3 but was not found in Experiment 2. This suggests that inversion of head orientation is critical. This enhanced brightness and definition is probably a byproduct of an effect of reducing depth in a scene seen from between the legs (Higashiyama and Adachi, 2006 *Vision Research*).

◆ **Effects of visual signal dropout and latency on temporal discrimination of visual – haptic collision**

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Temporal discontinuities and delay caused by packet loss (dropout) or communication latency often occur in multimodal telepresence systems. In order to quantitatively measure the effects of those artifacts on the temporal perception of a multisensory event, we simulated visual signal dropouts and latencies in simple goal-directed hand movements, and investigated subjects' perceptions of temporal inconsistencies of visual-haptic collisions with temporal order judgment task. By systematically varying the proportion of visual signal dropouts, our study demonstrates that the crossmodal synchronous event is very sensitive to the packet loss rate. The perceived time delay of visual event increases linearly with the packet loss rate and is longer than physical stagnation time. Also, the overall delay impression induced by packet loss influence the temporal event judgment. By introducing an additional visual signal latency, we revealed that this latency is reflected on the shift of the perceived delay and has been slightly overestimated. Moreover, both visual signal dropouts and delay affect the perceived delay independently. In the current study, the resolution of the temporal discrimination of visual – haptic event is not influenced by the visual signal latency but is linear related to the packet loss rate.

◆ **Audiovisual interactions in discrimination of intensity changes**

I-F Lin, B G Shinn-Cunningham (Cognitive and Neural Systems, Boston University, USA; e-mail: ifan1976@bu.edu)

Information in one sensory modality often affects perception in other modalities. Here, we investigated across-modality interactions for judgments of changes in light vs sound intensity. Seventeen subjects were presented with paired audiovisual stimuli in a two-interval, forced-choice paradigm. In the auditory session, observers judged which interval containing the louder sound while trying to ignore the light. In the visual session, observers judged which interval containing the brighter light while trying to ignore the sound. In both sessions, the stimulus in the irrelevant modality could be equal in the two intervals of a trial (neutral), could change in the same way as the attended modality (so that the interval that was louder was also brighter; congruent), or could change in the opposite direction (so that the interval that was louder was dimmer; incongruent). Results showed that the ability to discriminate changes in intensity of the target modality was affected by the changes in the irrelevant modality, both when listeners judged sound and light intensity. In both cases, listeners were best at identifying the direction of the intensity change in the attended modality in congruent trials and worst in incongruent trials.

◆ **An invisible face becomes visible with a voice**

Y-H Yang, S-L Yeh (Department of Psychology, National Taiwan University, Taipei, Taiwan; e-mail: allen0607@hotmail.com)

Multisensory integration of face and voice is frequent in daily life and critical to social contact. Separate lines of evidence have shown (i) audiovisual integration of suprathreshold face–voice pairs, and (ii) implicit processing of facial expression with subthreshold faces. We examined whether audiovisual integration could occur for audible affective voice but invisible facial expression by using the continuous flash suppression paradigm. A fearful face was presented to one eye, and dynamic noise patterns were presented to the other eye. Contrasts of the face and the noise patterns were manipulated so that the face was completely invisible in the beginning due to interocular suppression. Participants viewed the visual stimuli while listening to a screaming voice or a beep sound. The time to detect the face compared to the control (inverted-face or no-sound) conditions served as a measure of genuine perceptual integration. Results showed that face detection was facilitated by a voice but not a beep when the face was upright, whereas both voice and beep could facilitate detection of an inverted face. These results suggest that multisensory integration of face and voice occurs with an upright face, even when invisible.

◆ **Disrupting tactile spatial transformations with TMSE**

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Perceiving the location of a fly crawling up the arm is perhaps the most computationally demanding of somatoperceptual tasks, requiring the coordination of several spatial maps. We investigated the physiological basis of these spatial transformations by using single pulse TMS

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over the ventral intraparietal area (VIP). Participants held their left arm flexed with the forearm in vertical position and were asked to judge whether a tap at one of several forearm locations was above or below a preceding tap at their face. Location of the taps and arm posture varied randomly, thus making integration of spatial information from touch and proprioception necessary to resolve the task. Just noticeable differences in this elevation judgment task were poorer following single pulse TMS at VIP than at a control site (vertex), suggesting disruption of tactile remapping process. Participants also consistently underestimated the elevation of arm taps after TMS at VIP, producing a shift in the point of subjective equality (PSE). Our results indicate that parietal disruption selectively impairs remapping of touch into external space. The shift in PSE following VIP stimulation is discussed in terms of reversion of the body schema towards a canonical representation of body posture.

HAPTIC PERCEPTION

◆ Multisensory softness perception of deformable objects

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We investigated multisensory softness perception using a set of custom-made rubber specimens (compliance 0.11 to 0.96 mm N⁻¹). Participants judged the softness of the stimuli under haptic-only, vision-only and visuo-haptic conditions. In haptic and visuo-haptic conditions participants explored the stimuli without and with vision of their exploratory movements, respectively. In visual conditions, participants watched how another person explored the stimuli. Participants well differentiated between the stimuli under all three modality conditions. Stimuli were judged to be slightly softer under vision-only conditions than under haptic-only conditions; visuo-haptic judgments were in-between (average visual weight: 55%). These findings demonstrate that (a) participants can reliably infer softness from indirect visual information alone, and that (b) such visual information has a major contribution to the visuo-haptic judgments. Furthermore, judgments were more variable under visual as compared to haptic conditions; the variability of visuo-haptic judgments was similar to that of haptic ones. The lack of benefit from adding visual to haptic information, and the contrast between relatively high visual weight in visuo-haptic judgments on the one hand and low reliability of visual-only relative to haptic-only information on the other hand, suggest that the integration of visual and haptic judgments was not optimal, but biased towards vision.

◆ Haptic, visual and bimodal volume perception of 3-D objects

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In the present study, human observers compared the volumes of tetrahedrons, cubes and spheres in three conditions: haptic, visual, and bimodal. The stimuli were small enough to fit in one hand, with volume ranging from 2 to 14 cm³. Points of subjective equality were measured by means of a staircase procedure. In the haptic condition, blindfolded subjects explored stimuli, which were presented on stands to eliminate weight cues, by enclosure with their dominant hand. In the visual condition, subjects were only allowed to look at these stimuli. The two comparison stimuli were viewed successively. Finally, in the bimodal condition both vision and touch were used simultaneously. In all three conditions, a tetrahedron was perceived as having a larger volume than either a cube or a sphere, and a cube was perceived as having a larger volume than a sphere. Additional analyses revealed that the surface area of the stimuli was the most determining factor for haptic volume perception, while the longest axis was determining for visual volume perception. Bimodal perception was influenced by either surface area or the longest axis, depending on the subject's strategy. Hence, volume perception is not veridical, but has to be inferred from other object dimensions.

◆ Pseudo-haptic sensation caused by background visual motion

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Recently a haptic interaction technique using visual feedback was proposed, that did not require any haptic device [Lecuyer et al, 2004 *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems—CHI '04* (New York, ACM) pp 239–246]. The technique is based on modifying the motion of a cursor on a computer screen. When the speed of the cursor is suitably changed in an area, the user can feel pseudo-bumps and holes in the area. As an extension of the virtual haptic presentation technique, we have shown that pseudo-haptic interaction can also be achieved without modifying the cursor speed by only changing the speed of background images (Watanabe and Kusachi, IMRF2007). That is, even if the representation of the user's action (the movement of the cursor) is not directly changed, the visual feedback from the relative

motion between the cursor and the background images can cause pseudo-haptic feelings. In the proposed technique, the background image is automatically and continuously moved in a direction, while the user can freely control the movement of the cursor. When the cursor goes into a particular area, the speed of the background image is suddenly reduced, allowing the virtual viscous sensation to be perceived in the area. In this report, the essential parameters of the phenomenon are specified.

◆ **Saccade characteristics reveal the timing of somatosensory encoding**

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To investigate the time course of the integration of touch and proprioception, we analysed eye movements directed to somatosensory stimuli delivered to the hands in a crossed or uncrossed arm posture. To control the timing of saccade onsets, we used both a delayed and a non-delayed response procedure. Four blocks of trials were measured: crossed, non-delayed; crossed, delayed; uncrossed, non-delayed; uncrossed, delayed. We analysed error rates, saccade trajectories, and onset latencies. More errors (saccades to the wrong side) were made when the hands were crossed, indicating the difficulty of the task while assuming this posture. In trials with short onset latencies in the crossed, non-delayed condition, participants sometimes made online corrections, which resulted in curved saccade trajectories. On average, onset latency was longer when the hands were crossed than when they were uncrossed in the non-delayed conditions. In the delayed conditions, onset latencies were similar in both postures. This pattern may indicate that in the crossed-hands condition participants need to wait for touch to be integrated with proprioception, before initiating a saccade to the correct location. Thus, the difference in onset latency between crossed and uncrossed arm configurations is an indication of the timing of integration of touch and proprioception.

OBJECT PERCEPTION

◆ **Crossmodal facilitation of visual target identification at the level of object representation by the presentation of a concomitant sound**

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Recent studies have demonstrated that the presentation of a task-irrelevant sound can facilitate the identification of a simultaneously-presented visual stimulus. In order to examine the possible mechanisms behind this crossmodal facilitatory effect, we adopted the visual backward masking paradigm. Two letters (each 40 ms in duration) were presented sequentially from the same location. Participants had to identify the first letter (the target) and ignore the second (the mask). A pure tone was presented simultaneously with the onset of visual target on half of the trials, while no sound was presented on the other trials. The interstimulus interval (ISI) between visual target and mask were manipulated (from 0 to 133 ms). The results showed that the presentation of the sound only facilitated visual target identification performance at ISIs of 27 and 40 ms. Subsequent experiments showed that this crossmodal facilitatory effect was modulated by the spatial distribution of a participant's attention, manipulated by varying the number of possible locations from which the visual stimuli could be presented. We argue that the presentation of the sound enhanced the visual target object representation, and consequently, the processing of target would be less likely to be interrupted or substituted by that of the mask.

◆ **A visuomotor contribution to enhanced object recognition: compatibility between object rotation and hand movement during active exploration**

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Active exploration of novel objects by rotating them with a trackball facilitates subsequent recognition performance (Harman et al, 1999). We investigated whether this facilitative effect depends on the compatibility between the rotational direction of objects and the movement direction of the hand that rotates them. During active exploration, participants rotated paper-clip objects around the yaw axis either by moving a trackball around the roll axis (Experiment 1), or by moving a turntable around the yaw axis (Experiment 2). Participants' recognition performance was tested before and after active exploration, using a sequential matching task with novel paper-clip objects. We found that the recognition accuracy for yaw-rotated views of the objects was significantly improved only in Experiment 2, where the rotation directions of the hand and objects were compatible during active exploration. Moreover, the magnitude of improvement differed between the clockwise and counterclockwise rotations of the objects. These results

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suggest that (i) the matching between incoming visual information and visuomotor prediction of hand movements plays a key role in improving the ability to generalize recognition to novel views, and (ii) the effect of visuomotor prediction may depend on biomechanical constraints of hand rotation.

◆ **The effect of background texture patterns on size perception**

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We sometimes experience that the size perception of an object changes when the background pattern, such as a wall surface, is changed. In this study we examined the effect of background texture patterns on size perception of objects in the background. We measured the size perception of a spherical object on a grayscale textured background compared with a spherical object of the same size on a uniform gray background, put side by side. Fractal dimension and local fractal dimension of the background textured pattern were calculated using a box counting method to characterize each textured pattern. Experimental results showed that the texture actually affect size perception. Background textures with high fractal dimension generally make spherical object look bigger and background textures with low fractal dimension generally make spherical object look smaller. Moreover, background textures with varying local fractal dimensions over a relatively small area generally make a spherical object look bigger, and those textures with regular fractal dimensions over a relatively small area generally make a spherical object look smaller. These results suggest that the type of textural background patterns affects size perception of objects.

◆ **Performance of macaque monkeys in a two-alternative forced-choice body/object visual categorization task**

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Macaque monkeys are the most widely used animals to study neural basis of visual object recognition. But little is known about their visual object categorization capabilities. Here we trained monkeys for a two-alternative forced-choice body/object categorization task. Stimuli were presented in 5 noise levels. After monkey fixated on a monitor for 400 ms, a noisy image was presented for 70 ms, followed by 500 ms blank interval and then two response targets were presented in the left and right of screen centre indicating body and object responses, respectively. Monkeys had to make a saccade to the correct target no later than 300 ms after target onset. Behavioral d-prime analysis showed a linear performance decline as noisier stimuli were presented. But for a given noise level there was a difference in the amount of performance decline between body and object. Also there was a correlation between performance and reaction time. Reaction time increased significantly as noisier images were presented. The mean difference between reaction time of the least and most noisy images was about 30 ms. These results suggest that macaques have highly developed visual category discrimination capability.

◆ **Age-related changes in matching objects across viewpoints**

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Many studies have shown that changes in viewpoint affect object recognition. Here we investigated how the effects of viewpoint change with age. Older and younger subjects matched the identity of novel objects—consisting of six parts distributed randomly across the surface of a sphere—during a sequential matching task. On each trial, objects differed by rotations of 0, 36, 72, 108, 144, and 180 deg either in the picture plane or in the depth plane (ie, around the object's vertical axis). For 0 deg changes in viewpoint, both age groups were equally accurate. Overall, however, older subjects responded more slowly and less accurately than younger subjects. In addition, both age groups responded faster and more accurately for rotations in the picture plane than for rotations in the depth plane. However, the effect of the type of rotation differed across age groups: for older subjects the relation between reaction times and viewpoint difference was similar for both rotation types, whereas for younger subjects the increase in reaction times related to increased changes in viewpoint was smaller for picture-plane rotations than in-depth rotations. These results suggest that older and younger adults use different strategies for object matching across viewpoints.

◆ **The effect of head-direction and inversion of object images on visual recognition**

E-K Ko, W H Jung, S-T Hwang (Department of Psychology, Chungbuk National University, South Korea; e-mail: koeun0811@hotmail.com)

Previous studies suggested that a picture of a left-headed animal is recognized faster and more easily than with a frontal view or right-headed image (Palmer, Rosch, and Chase, 1981; Jung, Lee, and Jung, 2008). This aim of this study was to investigate whether a picture with a left-headed object could be recognized faster than a right-headed one, even when the picture was upside down (180° rotation). The response time (RT) among the following four conditions were compared using a word/picture matching task: (i) upright left-headed, (ii) upright right-headed, (iii) inverted left-headed (180° rotation of the upright left-headed picture), and (iv) inverted right-headed condition (180° rotation of the upright right-headed picture). Both animals and tools were used as stimuli. The results showed that RT was faster for condition (i) than for condition (ii), and for conditions (iii) than for condition (iv), but only when animals were used. No effect was found when tools were used. These findings might be due to the fact that a left-headed image is a basic representation, and not because of a preference to look at the left side as a result of reading habit. Possibly mental rotation was involved for the inverted conditions.

◆ **Non-target scenes can influence the recognition of target objects**

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Some studies suggest that natural scenes facilitate memories of target objects in those scenes, while others report that scenes disturb memories. However, little is known about the difference of these two cases. To distinguish them, we conducted two delayed match sampling recognition tasks with non-target scenes. In Experiment 1, we asked participants to recognize objects with/without non-target scenes which had been presented in learning phases, without observing any scenes, and to recognize entire scenes including objects. The result showed that object recognition without previously presented scenes was lower than in the other three conditions. It indicates that the same scene as learning phase facilitate object recognition. In Experiment 2, we added a condition in which scenes were different between learning and testing phases. Object recognition in this condition was not higher than that in the condition testing without presented scenes. This suggests that scenes which are invalid clues for recognizing objects, in turn, disturb the recognition. These findings indicate that the information of non-target scenes affects the retrieval of target objects, but that the direction of the effect depends on whether the scenes are congruent clues for object recognition.

◆ **Pigeons' perception of Zöllner illusion: the tendency is opposite to that of humans**

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We examined whether pigeons perceive Zöllner illusion in which parallel lines look non-parallel due to numbers of short hatches superimposed on the lines. First, we used a pair of non-parallel lines and trained two birds to peck the narrower (or wider) of the two gaps at the ends of the lines. After adapting the subjects to the target lines with random-oriented hatches (which cause little illusion, at least to humans), we tested the pigeons' responses in randomly inserted probe trials, in which hatches that should—by human standards—induce Zöllner-like illusion replaced the random-oriented ones. The tentative results suggest the possibility that pigeons do perceive an illusion from Zöllner figures, but the tendency is contrary to that of humans. Comparative geometric studies like this study may reveal the evolutionary genesis of human perception.

◆ **Trompe-l'oeil painting compared with photography**

R L Gregory, P F Heard¶ (Department of Experimental Psychology, University of Bristol, UK; ¶ Department of Psychology, University of the West of England, Bristol, UK; e-mail: richard.gregory@bris.ac.uk)

Normal objects and pictures present the eyes with simple cues and subtle knowledge-based clues, for guessing what is out there and what is represented in art. 'Bottom-up' information from the eyes is interpreted by 'top-down' brain processes, to create visual worlds combining fantasy with reality—perhaps most dramatically in trompe-l'oeil paintings. Can digital photography rival optimally chosen and lighted objects, viewed directly, for 'realism' Can trompe-l'oeil artists do better than photography? This will be tested in conjunction with a major exhibition at the Palazzo Strozzi in Florence, starting October 2009.

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◆ **An illusory figure with contextual arcs**

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The three-spot stimulus with three distracting circular arcs has been used to study the strength of the illusion of extent as functions of the arc length (0° – 360°) and the arc radius (0–30 min of arc). The centers of the arcs coincided with the appropriate stimulus spots. The width of the arc line and diameter of the spots were 1.5 min of arc. The stimuli (2° length and 75 cd m^{-2} luminance) were seen against a black background. Subjects made errors when matching the two stimulus intervals: one with the inside arcs and the other with the outside ones. Slightly asymmetric bell-shaped curves were obtained with the maximum error values (on average 9 min of arc) at the 110° – 130° arc length with the 8 min-of-arc radius, and at the 18–25 min-of-arc radius and 180° arc length. It is suggested that the distortions of perceived length can be interpreted in terms of the centroid biases concept. The employed computational model [Bulatov et al, 2009 *Journal of Higher Nervous Activity* 59(3) 259–268 (in Russian)] accurately predicted the present experimental data.

◆ **EEG study on the perception of bistable Necker cube gratings**

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Ambiguous figures (eg Schroeder stairs) are static pictures which reverse their appearance during prolonged viewing and can be seen in two (or more) perspectives. In EEG based experiments on reversible figures perceptual changes typically elicit an ERP deflection called reversal negativity (RN) peaking around 200–250 ms from stimulus onset. It is still not clear what the RN represents: it may reflect either the attentional processes of selection between the available views of the figure, or it may reflect the subjective visual awareness of the perceptual change as such. In the present study, ERPs in response to endogenous unilateral or bilateral reversals of two Necker lattices were compared with exogenously induced reversals of unambiguous lattices. The RN neither resembled the attention-related N2pc response, nor the visual awareness negativity related to subjective perception. Thus, we conclude that the RN is likely to reflect perceptual processes specific to perceptual switches induced by bistable stimuli.

◆ **Age-related changes in perceptual rivalry**

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Ageing is associated with reductions in sensory and cognitive function, the mechanisms of which are not fully understood. We investigated the dynamics of perceptual rivalry of a bistable image (Rubin vase/faces). Young ($N = 18$; 24.4 ± 4.12 years) and elderly ($N = 16$; 69.2 ± 6.90 years) adults performed passive rivalry tasks and tasks requiring attentional control by holding or switching the dominant percept using exogenous and endogenous cues. Exogenous cues constituted superimposed dots either on the face or the vase, whereas for the endogenous condition only verbal instructions were given. Dominance durations of elderly subjects in the passive rivalry task increased significantly by 50% over those of young subjects. This could be due to increased strength of recurrent excitation of neurons representing the dominant percept, slower adaptation of excitatory neurons due to reduced strength of after-hyperpolarizing currents, or both factors. Dominance durations of both age groups in hold conditions were similar. Elderly adults showed significantly longer dominance durations in switch conditions with exogenous cues (78%), but this difference in switch conditions with endogenous cues (29%) did not approach significance. These results suggest impaired attentional control of suppressive processes in normal ageing, which is weakened mainly in lower-level stimulus-driven attentional tasks rather than in higher-level goal-dependent tasks.

◆ **A mathematical function describing assimilation and contrast**

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Several size illusions are usually explained via the effects of assimilation and contrast. The Delboeuf illusion is investigated experimentally and described by an algebraic function, which gives the deviation of the apparent size of a test circle (radius r) from the true size as a fraction of 1. Three effects are considered: (i) Assimilation, the change of the apparent size of the test circle with the radius of another, concentric circle (radius R), is described by a proportionality term, $\Delta r_{\text{perceived}}/r \sim A \cdot (1 - R/r)$, where $\Delta r_{\text{perceived}}$ is the difference between perceived and actual size. Then (ii), it is assumed that the assimilation effect reduces with increasing gap between the

circles, proportionally to $\exp[-B \cdot \text{abs}(1 - R/r)]$. (iii), the contrast effect is interpreted as being due to size constancy. This is taken into account by a potential term, $C \cdot (R/r)^{-n}$. The size constancy parameter n ($0 \leq n \leq 1$) indicates to which extent the perceived size is rather constant ($n = 1$) or corresponds to the actual size ($n = 0$). A , B , C , and n are parameters to be fitted to the experimental results. The complete function gives the difference between the perceived and the actual size as a fraction of 1:

$$\Delta r_{\text{perceived}}/r = [1 - A \cdot (1 - R/r) \cdot \exp[-B \cdot \text{abs}(1 - R/r)]] \cdot C \cdot (R/r)^{-n}.$$

The parameter n is determined to 0.048 (± 0.021). Concerning the Baldwin (Wilson et al, 1988 *Perceptual and Motor Skills* **66** 195–204) and the Müller-Lyer (Pressey et al, 1977 *Perception* **6** 435–439) illusions, fits are performed employing the experimental results of other authors. In the first case, $n = 0.047$ (± 0.014) is obtained.

◆ **Correlation between individual differences in the symmetry detection and same – different tasks**

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The investigation was aimed at assessing individual differences in various tasks of visual perception and estimating correlation between them. Sixty-six subjects performed two psychophysical tasks—symmetry detection and same–different task. Test stimuli were bilaterally symmetrical and asymmetrical polygons presented briefly (for 50 ms or 100 ms) alone (in symmetry detection task) or simultaneously in pairs (in the same–different task) under backward masking conditions. Two groups of subjects were identified in both tasks: in the symmetry detection task, some subjects more accurately and faster detected symmetry and others asymmetry; in the same–different task, one group of subjects more accurately and faster detected sameness and other group—difference. The correlation between more efficient symmetry and sameness detection, and correlation between more efficient asymmetry and difference detection was found. We hypothesize that majority of subjects adapt the similar strategy by comparing the left and right sides of an image in the symmetry detection and same-different tasks. In addition, we obtained that the performance of the same-different task depends on the stimuli symmetry: sameness was detected more accurately and faster for symmetrical and difference for asymmetrical polygons.

◆ **Anisotropy of filling-in of a moving line segment presented on one side of the blind spot**

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We examined an anisotropy of the amount of filling-in of a moving line segment presented on only one side of the blind spot. The amount of filling-in was measured by the method of constant stimuli, varying the amount of penetration of the line segment into the blind spot. A horizontal (vertical) line segment vertically (horizontally) passed the nasal or temporal (superior or inferior) side of the blind spot. Observers judged whether the line segment when it arrived on the extension of the horizontal or vertical axis of the blind spot became longer or shorter toward the blind spot side than that outside the blind spot. The results showed that the amount of filling-in was significantly larger in the inferior side than those in the other sides. The amount of filling-in in the inferior side reached 2.1 degrees while those in the other sides were around 1.3 degrees in visual angle. The amount of filling-in depends not on the orientation of a line segment but on an azimuth along the edge of the blind spot.

◆ **Priming of object categorisation within and across levels of specificity**

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Object classification can occur at different levels of specificity. What are the interactions between these representational levels and do they rely on the same sequential processes that lead to successful object identification? In this event-related potential (ERP) study, a task-switching paradigm (covert naming or living/non-living judgment) was used. Images of objects were repeated either within the same task or with a switch between the two tasks. While covert naming accesses entry-level, living/non-living judgments rely on superordinate classification. Behavioural results demonstrated clear priming effects within both tasks but asymmetries were found when task-switching had occurred, with facilitation for covert naming but not for categorisation. Late positive component L1 was reduced for repeated presentations both with and without task switching which is characteristic for perceptual priming. Additional repetition effects were found in the N1 component when covert naming was involved. Compared to categorisation, covert naming was also marked by early-starting and persistent enhancements of ERPs (P1 window onwards).

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In conclusion, evidence was found for representational overlap. Changes in ERP markers started early and revealed cross-task priming at the level of object structure analysis (N1) and implicit memory (L1) as well as more intense perceptual and semantic processing for covert naming.

◆ **What can you see in a mirror? Gross errors in people's knowledge about mirror reflections**

R Lawson (School of Psychology, University of Liverpool; e-mail: rlawson@liv.ac.uk)

Two studies investigated people's basic knowledge of what is visible in planar mirrors. In Experiment 1, participants faced a set of covered-up mirrors, all mounted flat on the same wall. They drew what they would see of themselves if the mirrors were uncovered. Many people incorrectly showed their face appearing in multiple mirrors. However, fewer errors were made when participants saw the mirrors uncovered immediately before testing. In Experiment 2, most participants mistakenly believed that another person, represented by a shop-dummy, could see both her own face and the participant's face in more than one co-planar mirror, even though the mirrors were uncovered. Thus many people massively overestimate what a mirror will reflect of the environment. Although co-planar mirrors each reflect a different, non-overlapping area of a scene, people often believe that much the same information is visible in nearby, co-planar mirrors. Many people also do not know the simple heuristic that another person can only see you in a mirror when you can see their eyes in that mirror. They therefore do not understand the social implications of seeing another person's face in a mirror. These findings demonstrate the surprising weakness of people's functional understanding of mirrors.

◆ **Rapid processing of meaningful symbols in an item-counting task**

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When briefly presented, numerals can be processed efficiently. Observers can rapidly indicate the display having the largest average value, or respond to numerals more rapidly than to other items such as letters in an item-counting task (Corbett et al, 2006 *Vision Research* **46** 1559–1573). This study investigated the critical factors mediating the advantage of numerals in the item-counting task. Previous studies suggested that the advantage is unique for numerals because numerical information can be extracted very rapidly. However, it is possible that the advantage would be obtained with other meaningful symbols used highly frequently like numerals. As such kind of symbols, we used Kanji characters. The stimuli included Kanji numerals, Kanji characters with quantitative meaning, those with non-quantitative meaning, and nonsense symbols. Results showed that the advantage was not unique for numerals and that even quantitative meaning was not necessary—characters with non-quantitative meaning could be processed as rapidly as numerals if the frequency of use was as high as numerals. Thus, the critical factor for efficient processing in the item-counting task appears to be the frequency of use, which implies that the item-counting and averaging tasks are at least partly mediated by different processings because averaging requires numerical information.

◆ **Object visual priming by low-pass, band-pass filtered, or normal versions**

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The spatial frequency (SF) critical bandwidth for global shape discrimination of object (horizontal vs vertical) and for semantic categorization (natural vs man-made) was determined using a masked priming procedure. Prime duration varied (30 ms or 70 ms) and four versions of the picture served as prime: the normal non-filtered version, two filtered versions (low-pass or band-pass) and a random phase control prime. Results showed an interaction between task and type of prime: in the semantic categorization task, the three prime were found effective relative to control, and the priming is larger for the normal prime ($m = -47$ ms) than for the band-pass ($m = -20$ ms) and the low-pass ($m = -17$ ms), whereas in the global shape discrimination task, the band-pass priming ($m = -49$ ms) was as high as the normal priming ($m = -44$ ms). An interaction was also found between type of prime and prime duration: priming effects were twice as long (-30 ms to -60 ms for the normal prime and from -15 ms to -33 ms for the low-pass prime) when prime duration increased, except for band-pass priming that did not significantly increase (-29 ms and -38 ms). Altogether, these results indicate that the critical bandwidth depends on the task and has a variable temporal course, irrespective of the classical magnocellular (low SF)/parvocellular (high SF) dissociation.

◆ **Object representation and graphical inversion phenomena**

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Mirror writing is the ability to write from right to left, either individual letters or whole words. Mirror writing has been observed in neurologically unimpaired subjects, as well as in a variety of neurological diseases. Reversing of graphemes and canonical figure drawings is documented. A motor hypothesis, a visual hypothesis, and a genetic hypothesis were developed to account for mirror writing. According to the visual hypothesis, graphemes are represented in each hemisphere. The left hemisphere, dominant for language, holds the normally oriented representation, while the right hemisphere holds the mirrored representation. In order to test the visual hypothesis either for letters or objects, we examined how twenty right- and twenty left-handed subjects, drew 10 stimuli, with each hand, with and without visual control. Results showed that reversing is more common when the left hand was used, and for left-handers, particularly without visual control. Reversing in single traits was more common than in whole stimuli, and some stimuli, such as hands or profile, were more likely to be reversed than others, eg cube. This suggests that the right hemisphere has mirror representations that are more easily accessed with the left hand. The results are discussed in terms of the mirror writing theories.

◆ **Volume perception in motion**

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Volume perception, perception of enclosed partial space occupied with some medium is a crucial issue in visual perception (Idesawa, 1991 *Japanese Journal of Applied Physics* **30-4B** L751–L754; Idesawa, 1997 *Perception* **26** Supplement, 40; Watanabe and Idesawa, 2001 *Japanese Journal of Applied Physics* **40** L958–L960). We studied a frontier subject of this issue, the volume perception of a moving cylindrical object. The motion (rotation, translation, or rolling) of cylindrical object was simulated for with and without the appearing and disappearing part (ADP) in both real and apparent motion. Here, the appearing part is to be visible from the self occluded adjacent part of the object contour according to the object motion, and the disappearing part is to be occluded from the visible adjacent part of the object contour by self occlusion according to the object motion. We found that volume perception could be easily obtained in the stimulus with ADP but it could not be obtained in the stimulus without ADP. This experimental result implies that existence of ADP is an indispensable factor for the volume perception of moving objects: which is just corresponding to the binocular unpaired region for the volume perception in binocular viewing.

◆ **Experience-dependent modulation in the perception of ambiguous objects: priming and aftereffects**

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Sensory information from the external world is inherently ambiguous, and prior experience is often necessary to shape incoming sensory input into a coherent percept. Recent experience can induce complex effects on the subsequent perception of ambiguous ones, ranging from attraction (priming) to repulsion (adaptation aftereffects). Using a well-established paradigm for investigating adaptation aftereffects, in the current study we have tested whether the perception of naturalistic (complex) objects is influenced by recent experience. We used morphing software to create continua between paired images of animals, plants, or artifacts, and we tested how discrimination of an ambiguous image is affected by adaptation to one of the end-points of the morphing continuum. We found that recognition of the ambiguous, morphed images is modulated by the preceding adapting stimulus. The direction of the shift, however, depended on the delay between adaptor and target: with short delays we found a repulsive effect (adaptation aftereffect), whereas the effect turned into priming when the delay was increased. A priming effect was also found when the adaptor itself was an ambiguous image taken from the morphing continuum.

◆ **Finding the semantics in perception**

D Rose (Department of Psychology, University of Surrey, Guildford, UK; e-mail: d.rose@surrey.ac.uk)

Numerous perceptual phenomena have been explained as showing the existence of 'labelled lines' in our sensory systems, such as the ability to identify a stimulus at its detection threshold (eg Watson and Robson, 1981 *Vision Research* **21** 1115–1122). But the meaning of 'label' is not clear, or is defined in different ways by different investigators. One common usage states that the activity of a labelled line always 'means' the same thing. However, the meaning of 'meaning' (and its ontological origin) has long been disputed in linguistics, semiotics, semantics, and philosophy.

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Upon the outcome of this debate depends any sensible usage of the terminology of labelled lines in perceptual theory. Here, I first outline the traditional atomist versus holist positions in the debate about semantics. These would cast the meaning of sensory signals either as fixed 'natural signs', or as complex cognitive or associative interpretations. I then introduce more recent teleological theories, which place the significance of sensory neural activity in an evolutionary context. These analyses suggest that labelled lines can be defined as mechanisms that have evolved for particular purposes. One advantage of this position is that it explains how spurious sensory activity, or misrepresentation, can still have meaning.

BINOCULAR MECHANISMS

◆ **The dorsal visual stream tracks changes in perceived viewing distance**

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Perceived depth is apparent in two-dimensional images due to the presence of monocular depth cues. This feature is frequently overlooked; yet pictures of houses, cars, or faces implicitly suggest three different viewing distances. In fMRI studies using neural adaptation, we investigated how perceived distance is monitored. In both imaging studies, subjects viewed sequentially presented photographs of objects placed at different distances along a table, while performing an object categorization task. In Experiment 1, whole-brain group analyses showed that only bilateral clusters in the superior occipital lobe adapted parametrically to the amount of change in perceived viewing distance. Experiment 2 used retinotopic analyses and novel stimuli including some stereograms. Dorsal visual stream areas showed sensitivity to changes in perceived distance. Ventral visual areas were not sensitive to changes in perceived distance. Dorsal stream areas were also sensitive to shifts between monocular and binocular distance cues. In Experiment 3, we sought converging evidence from a neuropsychological patient with bilateral superior occipital damage. The patient was impaired when judging perceived viewing distance, although she accurately made categorization judgments for each object. These data support the view that dorsal stream areas process monocular and binocular distance cues and track perceived distance.

◆ **The role of focus cues in disparity scaling**

P A Duke, D Buckley¶ (School of Psychology, University of Leicester, UK; ¶ Academic Unit of Ophthalmology and Orthoptics, University of Sheffield, UK; e-mail: pad11@le.ac.uk)

It is widely supposed that focus cues (accommodation and retinal image blur) exert only a small effect on perception of 3-D shape and distance, perhaps no effect with strong conflicting cues, eg binocular disparity. Watt et al (2005 *Journal of Vision* 5(19): 834–862) showed focus cues can influence depth perception via distance scaling (gains ~ 0.1 – 0.6 at 57 cm convergence distance). We examined the effect of focus cues on a stereoscopic curvature nulling task. Images were presented via mirror stereoscope. Accommodation distance was manipulated by placing the monitors at a distance between 40.3–80.6 cm. Convergence distance (57 cm) and image size were constant. We used observers' responses to calculate the distance they used to scale disparities. In Experiment 1, accommodation demand was equal in the two eyes. Gains for accommodation distance on disparity scaling were exceptionally large; often above 1, up to ~ 1.9 . In Experiment 2 accommodation demand was unequal in the two eyes. Gains were large, though less than in Experiment 1. Greater-than-unity gains on accommodation found here point to multiple roles for focus cues. We suppose they play at least three roles in depth perception: (i) Their gradients over a surface may be used as 3-D shape cues; (ii) they may provide an absolute distance estimate in disparity scaling; and (iii) the accommodative-convergence drive signal may influence the registered convergence distance used in disparity scaling. The results may be explained by the computation of a distance estimate that is based on that supplied by focus cues which is then modified by efference copy before use in disparity scaling.

◆ **Influence of haptic stimulation on binocular rivalry**

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Signals arising from the different sensory modalities are integrated by our nervous system in order to coherently perceive the external world. We investigated whether haptic stimulation influences binocular rivalry, a special case of perceptual bistability triggered at an early stage of processing. Rival visual stimuli were orthogonally oriented (vertical/horizontal) Gabor patches. While reporting visual perception, subjects touched a sinusoidal milled Plexiglas which spatial frequency was matched with the visual stimuli. The overall dominance proportion and the mean

dominance phase duration of the vertical visual stimulus significantly increased when subjects touched the vertical stimulus. For brief periods of haptic stimulation (3.5 s), the probability of making one inversion of dominance significantly decreased when visual and haptic stimuli were congruent; it significantly increased when the visual and the haptic stimulus were incongruent. The dynamics of inversions revealed that touch had the effect of preventing perceptual inversions when visual and haptic stimuli were congruent. Our results indicate that haptic stimulation influences binocular rivalry by promoting dominance of the congruent visual percept. We suggest that the integration of haptic and visual signals facilitates dominance of the visual percept congruent with haptic stimulation by boosting its signal, leading to the disambiguation of a bistable percept.

◆ **Blur, distance, and the perception of plastic depth**

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When viewing a scene with two eyes, perceived depth appears more qualitatively vivid than with one eye. This quality is traditionally ascribed to binocular mechanisms and referred to as 'stereoscopic depth'. However, such qualitative vividness is also reported in the absence of disparity signals (Schlosberg 1941; Koenderink et al 1994) challenging the idea that it is primarily a function of binocular vision. We theorize that this perceptual quality—'plastic depth'—is the phenomenal signature of the statistical reliability of egocentrically-scaled absolute depth estimates. Since absolute depth is derived from relative depth cues scaled by distance estimates, the theory predicts that plastic depth will diminish with the decreasing reliability of distance cues. It also predicts that the quality will be absent in pictures (where distance cues signal the picture surface) unless a reliable distance cue can be introduced into pictorial space. We have shown previously that extra-foveal blur gradients provide a robust quantitative cue to perceived distance (Vishwanath 2007, 2008), and we have found their effects largely independent of the relative depth structure indicated by other cues. Consistent with our theory, the quality of depth in 2-D images in the presence of blur gradients appears more vivid. We demonstrate the effect and report results for observers tested on depth judgments of 2-D images at different viewing distances indicating greater perceived plastic depth under monocular than binocular viewing, and with blur rather than without; these differences were larger at farther viewing distances.

◆ **Maximum disparity and interocular differences in retinal-image quality**

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The aim of this work is to evaluate the role of interocular differences in retinal-image quality in stereoscopic depth perception. To characterize retinal-image quality, we took the Strehl ratio from a double-pass device (OQAS, Visiometrics, Spain). Strehl ratio provides information on diffraction, aberrations, and ocular scattering. This ratio ranges from 0 to 1, a lower value indicating a lower retinal-image quality due to a greater influence of aberrations and scattering. Stereopsis was quantified measuring maximum disparity with a mirror estereoscope using random-dot stereograms (RDS) displayed in a monitor. Maximum disparity is the greatest disparity that can be perceived by an observer, a larger maximum disparity indicates a more effective stereopsis. Maximum disparity was determined with an up-down staircase procedure with 6 reversals. Data were taken for 25 normal observers (both eyes) with ages ranging from 21 to 61 years. Maximum disparity (ranged from 24.6' to 37.1') shows a significant descending correlation ($r = 0.74$, $p < 0.001$) with interocular differences in the Strehl ratio. The lower interocular differences in Strehl ratio, the higher maximum disparity; this confirms that as the interocular differences augment, the effectiveness of stereopsis diminishes. No significant dependence between maximum disparity and age was found.

◆ **Pupillary light responses correlated with changes in brightness rather than luminance during binocular rivalry**

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This study reports that the pupillary response shows percept-related changes when different brightness changes are produced with identical stimulus sequences using binocular rivalry. In the experiments, after one of dichoptic white and black disks became exclusively dominant, the stimulus was changed to one of the followings after a short break; the same dichoptic white and black disks, binocular white disks, binocular black disks, or dichoptic black and white disks (eye switching). When the dominant disk was black and the stimulus was changed to binocular white disks, for example, the corresponding perceptual change would be black to white. However,

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when the dominant disk was white, the perceptual change would be white to white. Results showed that the magnitude of the pupillary response was more associated with the perceptual change; the pupil became smaller when apparent brightness increased more, even if the stimulus sequence was identical. In the eye-switching condition, a large contrast increment produced by the black-to-white stimulus change in one eye seemed to make the white disk dominant after the switching. However, the percept-related changes were still observed. Overall, the present findings support the thesis that the pupillary response could be used to objectively investigate the visual processing underlying perception.

◆ **Depth of binocular-rivalry suppression reduces with time of suppression: Electrophysiological evidence**

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During binocular rivalry one of two dissimilar monocular images is alternately suppressed (invisible), while the other is dominant (visible). Depth of suppression is measured by comparing the threshold to detect a change to one of the stimuli when it is invisible (giving a high threshold) with when it is visible (giving a low threshold). Intriguingly, depth of suppression appears to be constant over time during an episode of suppression. We tested this electrophysiologically by measuring event-related potentials (ERPs). Participants pressed keys to record their perception of orientation during rivalry between orthogonal gratings. Either early (0–200 ms) or late (600–800 ms) after a key press—which indicated a stable percept of one of the orientations—we changed the orientation of one of the rival stimuli to be the same as the other. Depending on the perceptual state, this change was either visible or invisible. When the change happened early, visible changes yielded a larger positive deflection of the ERP at about 100 ms (P1) than invisible changes. When the change happened late, we found no such difference in P1 amplitude. We conclude that—on a neural level—suppression depth declines with time of suppression.

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◆ **Eye-of-origin biases in onset rivalry and dichoptic masking**

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When the stimuli presented to each eye cannot be fused, observers report a fluctuation of awareness between each eye's image. Little is known about how one image initially overcomes the other (onset rivalry), and it is plausible that this process shares mechanisms with dichoptic masking. We tested this idea by comparing eye preferences in onset rivalry and monocular contrast thresholds, with and without simultaneous dichoptic masking. First, we measured monocular contrast detection thresholds (75% correct) with a staircase procedure using Gabor patches (45° , 4 cycles deg^{-1} , 1° aperture) randomly presented to left and right fovea in a forced two-interval procedure. Interocular differences were minimal. Then, we repeated the procedure with a simultaneous orthogonally oriented mask (contrast 30% higher than average baseline thresholds) in the other eye. Now, threshold was differentially elevated for each eye. In the third experiment, dichoptic Gabor patches ($\pm 45^\circ$, contrast as in the previous experiment) were presented in forty 10-s observation periods. Interocular differences in onset rivalry were larger than 40% in six out of eight subjects and negatively correlated with interocular differences in threshold elevations. No other correlation was significant. Our findings suggest that dichoptic masking and onset rivalry are mediated by the same inhibitory mechanisms.

◆ **Perceptual quality of reconstructions of digital holograms: extending depth of focus by binocular fusion**

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Reconstructions of digital holograms have a very shallow depth of focus. In order to obtain a perceptually greater depth of focus, we explored a computationally simple approach, suggested by Lehtimäki and Naughton [*Proceedings of the 3-DTV Conference 2007, Kos, Greece* (New York: IEEE Press)], where the perceptual depth of focus is obtained by dichoptic viewing of near focused and far focused holographic reconstructions. In particular, we sought an answer to the question of to what extent does each dichoptically presented image contribute to the perceived sharpness. At the upper half of the display the subjects saw the near and far focused images dichoptically, which by binocular fusion produced a perceptually increased depth of focus. At the lower half of the display they saw a computationally fused image, which consisted of locally

weighted averages of the near and far focused images. The extent to which sharp parts in each image was blended to the computationally fused image could be varied in real time by using a graphical slider on the display. The task of the observers was to match the computationally fused image to the binocularly fused image with respect to sharpness. The results suggest that in the perception of the binocularly fused image, the in-focus areas of each image, ie, sharp parts, had a relatively greater contribution than the out-of-focus areas, ie blurred parts. However, the dominance of in-focus areas was not complete. The fused perception seemed to be a point-wise weighted mean of the dichoptic image pair where the weighting is dependent on the local high spatial frequency energy of the near and far focused images.

◆ **The anatomical asymmetry of interhemispheric connections is retained in animals with impaired binocular vision**

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In cat cortical areas 17, 18 callosal fibers are connecting retinotopically corresponding but anatomically non-symmetric loci which receive projections from the retinal naso-temporal overlap zone (Olavarria, 1996 *Journal of Comparative Neurology* **366** 643–655). These data are confirmed by HRP injections into the single ocular dominance columns (ODCs). ODCs of areas 17, 18 receive inputs from callosal cells located in the transition zone 17/18, and the transition zone ODCs receive inputs from callosal cells located in areas 17 and 18 (Alexeenko et al, 2001 *Perception* **30** Supplement, 115). We investigated the pattern of interhemispheric connections of single ODCs in monocularly deprived cats and in cats with early convergent or divergent strabismus. It was revealed that the impairment of binocular vision does not change the asymmetric connectivity rule of eye-specific interhemispheric connections in areas 17, 18. However callosal cells zones were enlarged. The expansion was (i) more pronounced for ODCs located in areas 17, 18 than for transition zone ODCs and (ii) more variable in monocularly deprived cats. We suggest that expanded callosal connections may provide for more reliable binding of two visual hemifields. The influence of binocular rivalry process is proposed.

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◆ **Recognition of binocularly rival letters can be modulated by the prior presentation of one letter**

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When two letters are presented dichoptically for 200 ms or less, our recognition tends to change randomly trial by trial; at some trials one letter is recognized, at other trials, another letter or both letters. However, letter recognition can be modulated by monocularly presenting one of the rival letters prior to the dichoptic presentation. Our results using Japanese Kanji or Kana letters showed that a newcomer was seen at a very high rate: participants tended to recognize almost exclusively the letter not presented previously. Moreover, this effect was not affected by reducing the size of the prior letter. These findings indicate that the physical characteristics of letters alone could not account for the effect, and thus suggest that letter-level knowledge could be used to resolve binocular competition. But we also found that the effect was largely decreased by presenting a masking pattern during the interval between the prior and the dichoptic letters, or by displacing the prior letter upward relative to the dichoptic letters. Further investigation of the nature of this newly found recognition modulation effect might allow us to identify the processing stage where language information, like letter-level knowledge, could affect binocular rivalry.

◆ **Horizontal/vertical anisotropy in sensitivity to relative disparity depends on stimulus depth structure**

I Serrano-Pedraza, J C A Read (Institute of Neuroscience, Newcastle University, UK; e-mail: i.s.pedraza@ncl.ac.uk)

Bradshaw and Rogers (1999 *Vision Research* **39**) showed that sinusoidal depth corrugations defined by horizontal disparity are easier to detect when the corrugations are horizontal than when they are vertical. We replicated their results for frequencies from 0.1–1.2 cycles deg⁻¹. We also determined disparity thresholds for square-wave corrugations. As in sinusoidal corrugations, sensitivity differed as a function of the modulation spatial frequency but the anisotropy with respect to the orientation of the corrugation was now much weaker, with some subjects detecting vertical corrugations as easily as horizontal. In a second experiment we measured the sensitivity to the relative disparity between two rectangular (2 × 8 degrees) patches of random dots.

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The surfaces were either directly adjacent, or separated by a gap of either 3.5 or 7 degrees. The orientation of the patches, and the depth boundary between them, was either horizontal or vertical. In the zero-gap condition, sensitivity was similar for both orientations, but as the gap increased, performance declined more rapidly for horizontal than for vertical orientations—the opposite anisotropy to that observed with sinusoidal depth corrugations. Thus, vertical/horizontal anisotropy in stereo thresholds appears to depend critically on the depth structure of the stimulus. [Supported by the Medical Research Council and the Royal Society.]

◆ **Binocular summation of contour integration thresholds**

L Shono, C M Suttle, S Khoo, L J Asper (School of Optometry and Vision Science, The University of New South Wales, Sydney, Australia; e-mail: lama.shono@gmail.com)

Binocular summation is established in contrast sensitivity but is not reported in contour integration in the literature. We aim to investigate binocular summation in contour integration and contrast sensitivity. Four subjects (three normal, one amblyopic) were tested monocularly and binocularly. Contour integration was tested using Gabor elements. The test was repeated at different Michelson contrast settings (0.2, 0.4, and 0.8). The subject's task was to detect which of two briefly presented images contained the Gabor string (8 cycles deg^{-1}). To test contrast sensitivity we used a two-alternative forced-choice double-staircase method (step size: 5 db, staircases starting points: -5 and 15 db, spatial frequency 8 cycles deg^{-1}). Binocular summation ratios were calculated as: binocular sensitivity/mean monocular sensitivity. A ratio of > 1 indicated summation, whereas a ratio of < 1 indicated inhibition. Results: The mean contour integration ratio for normal subjects was 1.05, 1.04, and 1.05 at 0.2, 0.4, and 0.8 contrasts respectively. The mean contrast sensitivity ratio was 1.17. The contour integration ratios for the amblyope were 1.14, 0.89, and 1.02 for the same contrast levels. The contrast sensitivity ratio was 1.33. Our preliminary results suggest insignificant binocular summation of contour integration thresholds in our normal subjects and one amblyopic subject.

◆ **Compensatory changes in interocular alignment and cortical neuronal connections caused by early divergent strabismus**

S V Alexeenko (Vision Physiology Laboratory, Pavlov Institute of Physiology, Russian Academy of Sciences, St Petersburg, Russia; e-mail: binocularity@yandex.ru)

Midline symmetry is a characteristic feature of sensory and motor structures in vertebrates. Neuronal connections in the brain are ordered providing strict correspondence of sensory and motor maps. Strabismus violates positional correspondence between neuronal activity in visual and other systems since the central binocular axis is shifted from the head primary position. We investigated compensatory mechanisms directed to overcome this impairment. The dynamics of interocular alignment was determined using photographic method and neuronal connections of single ocular dominance columns (ODCs) in cortical area 17 were evaluated in cats with unilateral divergent strabismus induced by tenotomy of extraocular muscle at the age of 13–16 days. Interocular alignment was changing up to 100 postnatal days. At the end of this period the alignment was normal in 7 animals (Group 1), while 3 animals (Group 2) remained slightly exotropic (the maximal deviation—15 deg). Length of long-range neuronal connections was investigated at the age of 5–6 months. It was indistinguishable from normal in Group 1 cats, while in Group 2 neuronal connections for deviated eye ODCs were shortened and for intact eye ODCs enlarged. Thus in case of early paralytic strabismus the adaptive brain reactions are: (i) changes of interocular alignment, and (ii) suppression of deviated eye activity.

[Supported by the RFBR grant 09-04-01284.]

FRIDAY

TALK SESSION A

VISUALLY GUIDED EYE AND BODY MOVEMENTS

◆ **Ultra-fast saccades to faces: A temporal precedence effect?**

S Crouzet, M Mathey, S J Thorpe (Centre de Recherche Cerveau et Cognition (CerCo), CNRS—Université Toulouse 3, France; e-mail: simon.thorpe@cerco.ups-tlse.fr)

When human faces and vehicles are simultaneously flashed left and right of fixation, subjects can make very fast and reliable saccades towards the side with the face, with the earliest reliable saccades occurring only 100 ms after stimulus onset. In contrast, it is much harder to saccade towards the vehicle. Could this asymmetry reflect differences in the time course of neural responses to faces? By introducing a variable delay between the onset of the two images we determined how much temporal difference was needed to cancel the face advantage. Thirteen different offsets were used (−70 to +70 ms), and subjects had to target either the face or the vehicle in separate blocks. Saccading towards faces was very easy, and only became difficult when the vehicle image was presented at least 30 ms before the face. Likewise, saccading towards the vehicle was difficult unless the target image preceded the face by a similar amount. Furthermore, mean saccadic reaction times to faces were under 150 ms over a wide range of offset values, whereas reaction times with vehicles were 20–30 ms slower even when the vehicle appeared well in advance. The pattern of results fits with the hypothesis that neural responses to faces in extrastriate areas are 20–30 ms faster than to other stimuli and suggest a very short route from visual activation to oculomotor response.

◆ **Concurrent control of target selection and visual cortical representations by frontal eye field neurons**

B Noudoost, T Moore (Department of Neurobiology, Stanford University, USA; e-mail: tirin@stanford.edu)

The control of attention is thought to depend on neural circuits involved both in the filtering of sensory signals and in the selection of appropriate motor behaviors. We manipulated the activity of frontal eye field (FEF) neurons of behaving monkeys and simultaneously measured its effects on saccadic target selection and on visual cortical representations. We found that activation of FEF neuronal activity with local intracortical infusions of a dopamine (D1) antagonist increased target selection for spatially corresponding visual stimuli. This manipulation also increased both the magnitude and selectivity of visual responses of area V4 neurons with spatially corresponding receptive fields. In contrast, inactivation of FEF neurons with a GABA_A agonist reduced target selection and also reduced the visual selectivity of area V4 neurons. Our results demonstrate the direct role FEF neurons play in the filtering of incoming visual signals and also suggest how prefrontal catecholamines contribute to the regulation of sensory signals and attentional control.

◆ **Accurate remapping of saccade targets to non-foveal locations**

M Rolfs, T Collins[¶], H Deubel[§], P Cavanagh (Laboratoire Psychologie de la Perception, Université Paris Descartes, Paris, France; [¶]Biological Psychology and Neuropsychology, Universität Hamburg, Germany; [§]Abt. Psychologie, Ludwig-Maximilians-Universität, Munich, Germany; e-mail: martin.rolfs@gmail.com)

Saccades cause abrupt changes in the visual input stream and perceptual continuity across these shifts may rely on remapping mechanisms to predict post-saccadic object locations. However, saccades are quite variable and almost never land right on the target. These deviations may be part of the saccade plan or the result of execution errors. If they are planned, the target should be remapped accurately—its location will be known relative to the saccade landing, no matter where the saccade lands. To measure the spatial accuracy of remapping, we asked participants to compare the pre- and post-saccadic locations of a visual target. Targets were extinguished during the saccade and reappeared after a short blank, counteracting saccadic suppression of displacement. Localization of targets after saccades was nearly veridical despite substantial variation in actual landing site, indicating that predicted location for the saccade is often not the fovea and this is taken into account for post-saccadic localization. These results suggest that much of the saccadic deviation from the nominal target is known in advance and is included in the efference copy used to recover a remapped target location which is accurate but, surprisingly, most often not foveal.

◆ **Bayesian analysis of perceived speed during smooth pursuit eye movement**

T C A Freeman, R A Champion, P A Warren (School of Psychology, Cardiff University, UK; e-mail: freemant@cardiff.ac.uk)

Objects appear to move more slowly when tracked by a smooth pursuit eye movement (Aubert-Fleischl phenomenon, AFP). This suggests a lower gain on pursuit-based speed estimates—but why? Recent Bayesian models claim perceived speed is the product of a slow-motion prior and

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a likelihood function that depends on the reliability of motion signals. Unreliable signals yield broader likelihood functions and so the slow-motion prior dominates. Assuming reliability reflects internal stochastic noise, we tested whether Bayes could explain AFP by comparing speed-discrimination thresholds for pursued and fixated stimuli. We used a standard 2AFC speed-matching paradigm, consisting of intermixed trials containing two intervals of pursuit–pursuit (EE), fixation–fixation (FF) or pursuit–fixation (EF). Psychometric functions for EF showed large AFP across a range of standard speeds. Psychometric functions for FF and EE showed higher discrimination thresholds during pursuit, thus providing qualitative support for Bayes. To explore further, we constructed a model comprising an initial measurement stage with common speed transduction [$f(v) = v^a$] and separate noise [$\sigma(v) = b_i f(v)^{c_i}$, $i = E, F$]. This was followed by a Bayes estimator (σ of prior free to vary). Using signal detection theory, we found the model fit the data reasonably well. Limitations of this particular Bayesian approach will be discussed.

◆ **Split attention during simultaneous eye and hand movements**

D Jonikaitis, H Deubel (Allgemeine und Experimentelle Psychologie, Ludwig Maximilians University, Munich, Germany; e-mail: djonikaitis@yahoo.com)

In every day situations we frequently reach and look at different objects at the same time, but it is not clear how reaching and saccades are coupled. We addressed this question by asking participants to point and look to different locations while we measured attention allocation to movement objects. In line with previous research, we first demonstrated that when participants are asked either to look or point at an object, attention is allocated to that object before the movement is initiated. Second, when participants make simultaneous eye and hand movements to different locations, attention is allocated in parallel at both locations, with no cost arising from the need to plan two movements instead of one. Therefore even though eye and hand systems are linked together, this is not due to attentional limits when planning movements. Finally, delaying eye movement with respect to hand movement, leads to the delay of attentional deployment at corresponding object, which indicates that attentional mechanisms for eye and hand may be even dynamically independent. To sum up, we demonstrate parallel attention allocation before eye and hand movements and propose that attentional mechanisms for those two systems are partially independent.

◆ **‘Strategic’ changes in grasping in response to visual uncertainty**

B D Keefe, S J Watt (Department of Psychology, Bangor University, UK; e-mail: b.keefe@bangor.ac.uk)

In normal grasping, increasing perceptual uncertainty leads to increased grip apertures. This makes sense because opening the hand too little is more likely to result in failure than opening the hand too wide. That is, the expected cost of decreasing vs increasing grip aperture is asymmetrical. Here we examine whether this is actually a ‘strategic’ response by examining the effect of uncertainty on three different grasping tasks, with different ‘cost landscapes’: (i) normal grasping, (ii) grasping U-shaped objects, by pushing the outside of the finger/thumb against the inside of the object (this task was designed to reverse the cost asymmetry associated with normal grasping), and (iii) grasping objects by placing the fingers in small gaps (here opening the hand too wide or too little is equally likely to result in a failed grasp). Perceptual uncertainty was increased both by removing binocular cues, and blurring the scene. We found that the cost landscape of the task determined responses to increased uncertainty. For normal grasping, grip apertures increased. However, in the U-shaped condition grip apertures were smaller, and in the ‘small-gap’ condition grip apertures were unchanged. These results suggest that grasp programming responds strategically to perceptual uncertainty, taking into account task demands.

◆ **Neural populations in the parietal and premotor cortices of humans perform abstract coding of motor acts: a TMS-adaptation study**

J V Schwarzbach¶, M Sandrini, L Cattaneo (Center for Mind/Brain Science [¶] Department for Cognitive Science and Education], University of Trento, Italy; e-mail: jens.schwarzbach@unitn.it)

Neuroimaging studies have shown that watching an individual acting upon an object activates a parieto-frontal network comprising the inferior parietal lobule and the ventral premotor cortex (PMv) in the observer. Here we investigate by means of TMS-adaptation whether this network encodes the effector or the abstract act. We induced adaptation in twelve subjects by exposing them repetitively to movies of one of two actions (grasping or pushing) performed by one of two effectors (a hand or a foot). Participants were then shown test pictures on which they had to respond whether the depicted action was the same or different to the one seen in the adapting movies. Single TMS pulses were delivered synchronously with the test pictures, in separate blocks over the vertex, the supramarginal gyrus (SG) and PMv. We analysed reaction times. Results showed

a clear adaptation effect of the observed action and a reversal of this effect by TMS over SG and PMv, but not over the vertex. The identity of effectors between the adaptation and test stimuli did not induce any effect in both behavioural and TMS trials. Our data show for the first time in humans causal evidence for a population of neurons in SG and PMv that play an active role in abstract coding of action.

◆ **Evidence for distinct roles of posterior superior temporal sulcus and inferior frontal areas in audiovisual action recognition**

G F Meyer, S M Wuerger, M W Greenlee¶, R Rutschmann¶ (Department of Psychology, University of Liverpool, UK; ¶ Department of Psychology, University of Regensburg, Germany; e-mail: georg@liv.ac.uk)

Two distinct polymodal neural systems have been implicated in the recognition of human actions: the posterior superior temporal sulcus (pSTS) and the mirror neurone system in premotor cortex. Here we investigate whether different auditory-visual integration mechanisms and sites exist for audiovisual speech and body motion. We compared brain activations for bimodal body motion, speech and meaningless stimuli; the auditory and visual modality signalling either semantically congruent or incongruent actions (eg visual speech and auditory footsteps). First we identified regions of audiovisual convergence (Experiment 1). A conjunction analysis of the unimodal responses revealed areas in bilateral pSTS (BA22), premotor (BA6), left SMA (BA6), left IFG (BA44), and IPL (BA40). We then compared responses for congruent and incongruent audio-visual signals within these regions (Experiment 2). We found significant interactions between speech and body motion in all ROIs, except in premotor cortex, but no interactions for meaningless stimuli. A subsequent EEG study (Experiment 3) identified early interactions in temporal and later interactions in more frontal areas for the same stimuli. In conclusion, we propose a role of the pSTS as a sensory memory buffer for passive action recognition, and a role of the IFG in reconciling incongruent signals in a generative recognition model.

TALK SESSION B

VISUAL – HAPTIC PROCESSING

◆ **Is tactile temporal processing based on somatotopic or spatiotopic space?**

S Kuroki¶, J Watanabe¶, N Kawakami, S Tachi§, S Nishida¶ (Graduate School of Information Science and Technology, The University of Tokyo Japan; ¶ also NTT Communication Science Laboratories, NTT Corporation, Kyoto, Japan; § Graduate School of Media Design, Keio University, Japan; e-mail: Shinobu_Kuroki@ipc.i.u-tokyo.ac.jp)

It is crucial for the tactile system to encode temporal relationships among different skin locations in order to perceive the spatiotemporal structure of the touched object. It is known for vision that an increase in inter-stimulus spatial separation reduces the accuracy of relative timing judgments. Here we investigated whether this space–time interaction is also observed in touch. Touch is a unique modality with regard to its spatial representation. Mechanoreceptors are distributed throughout the entire body, and the body parts move around dynamically. Therefore, tactile separation can be defined in two space coordinates, somatotopic space defined by cortical topography, and spatiotopic space defined in the environment. In four experiments, we asked participants to judge the simultaneity, temporal order, motion, and interval between two electro-tactile stimuli given to fingers, while systematically changing the stimulated fingers and finger position. For all the tasks we tested, the temporal accuracy was reduced as the somatotopic distance was increased. The accuracy however remained the same when only spatiotopic distance was increased by a finger position change. The results suggest that timing judgment is mechanically similar between vision and touch, and that tactile timing perception is generated on the somatotopic representation, not on the real-world physical representation.

◆ **Exploring visual and haptic object categorization**

N Gaisert, C Wallraven, H H Bülhoff (Human Perception, Cognition and Action, Max Planck Institute for Biological Cybernetics, Tübingen, Germany; e-mail: nina.gaisert@tuebingen.mpg.de)

Humans combine visual and haptic shape information in object processing. To investigate commonalities and differences of these two modalities for object categorization, we performed similarity ratings and three different categorization tasks visually and haptically and compared them using multidimensional scaling techniques. As stimuli we used a 3-D object space, of 21 complex parametrically-defined shell-like objects. For haptic experiments, 3-D plastic models were freely explored by blindfolded participants with both hands. For visual experiments, 2-D images of the objects were used. In the first task, we gathered pair-wise similarity ratings for all objects. In the second, unsupervised task, participants freely categorized the objects. In the third,

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semi-supervised task, participants had to form exactly three groups. In the fourth, supervised task, participants learned three prototype objects and had to assign all other objects accordingly. For all tasks we found that within-category distances were smaller than across-category distances. Categories form clusters in perceptual space with increasing density from unsupervised to supervised categorization. In addition, the unconstrained similarity ratings predict the categorization behavior of the unsupervised categorization task best. Importantly, we found no differences between the modalities in any task showing that the processes underlying categorization are highly similar in vision and haptics.

◆ **The effect of clustering on haptic numerosity judgment**

M A Plaisier, W M Bergmann Tiest, A M L Kappers (Helmholtz Institute, Utrecht University, The Netherlands; e-mail: M.A.Plaisier@uu.nl)

In vision, numerosity judgment is fastest when the items are arranged into clusters of small numbers of items (< 4). This range of small numbers is termed the subitizing regime. We have previously shown that subitizing also exists in the haptic modality when subjects have to judge the number of spheres in their hand (Plaisier et al, 2008 *Perception* 37 Supplement, 86). In the present study we divided the spheres (1 to 12) into two clusters. Subjects grasped a set of spheres in each hand simultaneously and responded the total number. When the total number of spheres was outside of the subitizing range and the individual sets were inside this range, response times decreased by a factor of 3 compared to when all spheres were in one hand. When both clusters had roughly equal numerosities outside the subitizing range, response times decreased by only a factor of 1.5. This suggests that subjects could count the items partly in parallel for both hands and/or that smaller numbers of spheres were easier to handle. We conclude that, similar to what is found in vision, haptic numerosity judgment is fastest when items are arranged into clusters that each can be subitized.

◆ **Dynamic and static haptic perception of mass**

W M Bergmann Tiest, A M L Kappers (Helmholtz Institute, Utrecht University, The Netherlands; e-mail: W.M.BergmannTiest@uu.nl)

In vision, the perception of physical properties often depends on the way they are observed. For instance, judgment of depth may depend on the viewpoint. In haptic perception, this may also be the case. There have been indications that judgment of mass depends on the mode of perception: either statically, through gravitational cues (weight), or dynamically, through inertial cues (Ross and Reschke, 1982 *Perception & Psychophysics* 31 429–436). In the present study, subjects matched masses held statically in the hand to masses dynamically accelerated sideways and vice versa, using a staircase procedure. In this way, the shift in perceived mass depending on the mode of perception could be studied. The magnitude of the masses ranged from 0.1–0.7 kg. The masses to be accelerated were suspended by thin wires from a high point, limiting the gravitational component of the pushing force to no more than 10%. Gravitational mass was perceived to be a factor of two larger than inertial mass of the same physical magnitude. This shows that Einstein's equivalence principle does not hold for perceived mass and that physical laws regarding mass are not intuitively clear to the human perceptual system, indicating how the concept of mass is intrinsically treated by the cognitive system.

◆ **Size-sensitivity in visual and haptic object recognition**

M Craddock, R Lawson (School of Psychology, University of Liverpool, UK; e-mail: m.craddock@liv.ac.uk)

A sequential shape-matching task was used to examine the effects of size changes on unimodal and crossmodal visual and haptic object recognition. Participants felt or saw 3-D plastic models of familiar objects. The two objects presented on same-shape trials were identical sizes or differed in size, with small (75%) and large (100%) versions of each object. Participants ignored size changes and matched on shape alone. Size changes on same-shape trials impaired performance similarly for both visual-to-visual and haptic-to-haptic unimodal matches. Replicating Craddock and Lawson (2009 *Attention, Perception & Psychophysics* 71 910–923), this demonstrated that haptic object recognition exhibits a significant but modest cost of generalizing across size changes. It also provides the first demonstration that size changes impair visual matching of nameable, 3-D objects in a true 3-D context. Size changes also impaired performance on same-shape trials for both visual-to-haptic (VH) and haptic-to-visual (HV) crossmodal matches. The cost of size changes was the same for VH and HV matching. These results are consistent with the hypothesis that the same, size-specific perceptual representations underlie both visual and haptic object recognition, and indicate that crossmodal memory for objects must be at least partly based on common perceptual representations.

◆ **Haptic orientation discrimination is severely impaired in blind and low-vision children**

M Gori, G Sandini, C Martinoli¶, D C Burr§ (RBCS, Istituto Italiano di Tecnologia, Genoa, Italy; ¶ Istituto David Chiossone, Genoa; § Dipartimento di Psicologia, Università degli Studi di Firenze, Italy; e-mail: monica.gori@iit.it)

We recently showed that multimodal integration of spatial information develops late in childhood, at around 8–10 years of age (Gori et al, 2008 *Current Biology*). At earlier ages, either touch or vision dominates, depending on the task: touch for size and vision for orientation. We suggest that the dominance may reflect crossmodal calibration of developing systems, where the more robust sense is used to calibrate the other. To investigate the calibration hypothesis we measured size and orientation haptic thresholds in blind and low-vision children, reasoning that if crossmodal calibration were important, lack of good vision at birth should impact on haptic discrimination, particularly orientation discrimination (that is dominated by vision in normal-sighted children). The results strongly confirmed this idea. In eight blind and low-vision children (aged 5–12), haptic orientation thresholds were greatly impaired, on average 2.8 times worse than age-matched controls, while haptic size thresholds were as good as normal sighted controls. These results provide strong support for the crossmodal calibration hypothesis.

◆ **Perceptual face space in vision and haptics**

C Wallraven (Max Planck Institute for Biological Cybernetics, Tübingen, Germany; e-mail: christian.wallraven@tuebingen.mpg.de)

The idea that faces are represented within a high-dimensional vector space has gained considerable experimental support both from physiological and perceptual studies. More generally, recent work has shown that the brain possesses a surprising acuteness in extracting such high-dimensional spaces from both visual and haptic stimuli. Here, we investigate the degree to which visual and haptic face spaces might be similar. For this, we created a face space consisting of 6 laser-scanned individual faces, their morphed average, 50%-morphs between two individual faces, as well as 50%-morphs of individual faces with the average, resulting in a set of 19 faces. We then gathered either visual or haptic pairwise similarity ratings of 3-D face masks from two groups of fifteen participants. Faces were explored 6 s visually, and 10 s haptically with one hand, respectively. Correlations between haptic similarity ratings were lower than between visual ones indicating the difficulty of the haptic task. Importantly, however, multidimensional scaling analyses showed that both modalities preserved critical topological relationships of the original space in a 3-D perceptual space. Our data demonstrates how the brain can extract high-dimensional shape properties of complex stimuli in both vision and haptics.

◆ **Comparison of the haptic and visual deviations in a parallelity task**

A M L Kappers, W B Schakel (Physics of Man, Helmholtz Institute, Utrecht University, The Netherlands; e-mail: a.m.l.kappers@uu.nl)

When subjects are asked to orient a test bar in such a way that it feels parallel to a reference bar, systematic deviations of more than 90 degrees can be found (Kappers, 2003 *Acta Psychologica* **114** 131–145). Somewhat smaller but still systematic deviations were reported in a visual parallelity task in a different setting (Cuijpers et al, 2000 *Perception* **29** 1467–1482). In both studies, the size of the deviations was strongly subject-dependent. Here we investigate whether the sizes of the deviations in the two conditions are correlated. Our set-up consisted of two metal plates with bars on top that were placed 60 cm to the right and left of the subject and 20 cm in front. In the haptic condition, subjects were blindfolded. In the visual condition, subjects were not allowed to touch the bars but they instructed the experimenter to rotate the bar to the desired orientation. So far, twelve naive subjects participated. Deviations in the haptic condition were about three times as large as those in the visual condition. However, the correlation between the deviations in the two conditions was only small, indicating that the underlying mechanisms must be (at least partially) independent.

SYMPOSIUM

NEURAL CORRELATES OF CONSCIOUSNESS

◆ **Conscious and unconscious visual processing of faces, bodies, and tools**

S He (Department of Psychology, University of Minnesota, USA; e-mail: sheng@umn.edu)

Humans are experts in extracting important visual information from faces (identity, expression) and body movements (intention, direction of motion). We are also very efficient in processing visual information of tools for action. In addition, erotic body images are of high arousal values interests to human observers. In a series of psychophysical and neuroimaging experiments using an interocular suppression technique to render images invisible, we show that (1) face orientation

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and facial expression information could be processed automatically in the absence of awareness; (2) invisible images of familiar tools could activate the dorsal cortical regions; (3) invisible erotic images could influence the distribution of spatial attention; (4) humans have sensitive and automatic mechanisms for detecting local biological motion. These results also demonstrate that rendering stimuli invisible through interocular suppression is an effective way to isolate selective neural mechanisms.

◆ **The role of feedback in visual attention and awareness**

S L Macknik (Department of Neurosurgery/Neurobiology, Barrow Neurological Institute, Phoenix, USA; e-mail: macknik@neuralcorrelate.com)

The mammalian visual system includes numerous brain areas that are profusely interconnected. With few exceptions, these connections are reciprocal. Anatomical feedback connections in general outnumber feedforward connections, leading to widespread speculation that feedback connections play a critical role in visual awareness. However, evidence from physiological experiments suggests that feedback plays a modulatory role, rather than a driving role. I will discuss theoretical constraints on the significance of feedback's anatomical numerical advantage, and describe theoretical limits on feedback's potential physiological impact. These restrictions confine the potential role of feedback in visual awareness and rule out some extant models of visual awareness that require a fundamental role of feedback. I will propose that the central role of feedback is to maintain visuospatial attention, rather than visual awareness. These conclusions highlight the critical need for experiments and models of visual awareness that control for the effects of attention.

◆ **Localized neuronal 'ignitions' underlying human visual perception**

R Malach (Weizmann Institute of Science, Rehovot, Israel; e-mail: rafi.malach@gmail.com)

It is remarkable that despite the large influx of information regarding neuronal mechanisms underlying human perception, we are still in the dark with regards to the very basic question—how much of the human brain must be engaged in the generation of a conscious visual percept? A large body of brain imaging work appears to support the notion that such percepts result from a wide spread activation pattern that includes not only visual areas but also fronto-parietal networks as well. However, it is difficult to assess how much of this wide-spread activity is associated with visual perception and how much is engaged during auxiliary functions that occur subsequent to the perceptual event—such as memory, action planning, shifting attention, etc. Here I will present data from fMRI and intra-cranial recordings of the human brain indicating that a conscious visual percept is associated with an early and highly non-linear 'ignition' of neuronal activity which outlasts the visual stimulus. These 'ignitions' are localized to content-specific neuronal groups in high order visual areas. Neuronal activity in non-visual areas indeed emerges in association with conscious percepts, however this activity begins ~100 ms after the onset of activity in visual areas. These results are consistent with the hypothesis that a localized, non-linear, 'ignition' of neuronal activity in high order visual areas is sufficient for the emergence of a visual percept, while the spread of activity to non-visual areas is associated with cognitive processes subsequent to the percept itself.

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◆ **Visual awareness correlates with layer-specific activity in primary visual cortex**

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Whether or not activity in the primary visual cortex (V1) is directly related to the visibility of a stimulus is a long-standing debate. To investigate the basis of existing discrepancies in the literature, we measured the BOLD response, along with electrophysiological signals, in area V1 of two behaving monkeys, and correlated responses there with the perceived visibility of a salient stimulus. We show that stimulus visibility can be reliably derived from the fMRI signal, but not from neuronal spiking activity. We further demonstrate by laminar sampling of V1 local field potentials (LFP) that there is an uneven distribution of percept-related current changes between the different cortical laminae. Thus, we show that fMRI and neurophysiological signals, while generally in good agreement, become uncoupled during perceptual suppression. Furthermore, our data reveals that if a visual stimulus goes unperceived, there is a drop in the membrane currents in the upper layers of V1.

◆ **Is the frontoparietal network necessary for the experience of qualia?**

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The field of consciousness researchers is divided. Indeed, some members of this symposium fall into one or the other of the two camps. Some argue that the frontoparietal network is necessary to have conscious contents, while others argue that this is not necessarily so, and that there can be conscious contents even in the absence of frontoparietal network activity. I will discuss a conceptual framework that can encompass evidence for both of these camps. I conclude that the frontoparietal network allows one to experience qualia in the particular sense of an attended object that is tracked through some representational space. However, even in the absence of attentional engagement, qualia can exist as 'feature soup' (ie unbound and untracked) in the perceptual background, and these experiences can be reported when probed. Such unattended qualia can be realized in the absence of the frontoparietal network's engagement, but are thereby fleeting and easily flushed from short-term perceptual buffers. In addition, I will present related psychophysical and fMRI evidence that allows a characterization of the representational structure of qualia, with particular focus on perceived color in the context of filling-in.

TALK SESSION C

PERCEPTION OF SHAPES, OBJECTS, AND FACES

◆ **Motion and form interact in expression recognition: Insights from computer animated faces**

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Faces are a powerful and versatile communication channel. Yet, little is known about which changes are important for expression recognition (for a review, see Schwaninger et al, 2006 *Progress in Brain Research*). Here, we investigate at what spatial and temporal scales expressions are recognized using five different expressions and three animation styles. In point-light faces, the motion and configuration of facial features can be inferred, but the higher-frequency spatial deformations cannot. In wireframe faces, additional information about spatial configuration and deformation is available. Finally, full-surface faces have the highest degree of static information. In our experiment, we also systematically varied the number of vertices and the presence of motion. Recognition accuracy (6AFC with 'none-of-the-above' option) and perceived intensity (7-point scale) were measured. Overall, in contrast to static expressions, dynamic expressions performed better (72% versus 49%, 4.50 versus 3.94) and were largely impervious to geometry reduction. Interestingly, in both conditions, wireframe faces suffered the least from geometry reduction. On the one hand, this suggests that more information than motion of single vertices is necessary for recognition. On the other hand, it shows that the geometry reduction affects the full-surface face more than the abstracted versions.

◆ **Multistable perception: When bottom – up and top – down coincide**

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When we observe an ambiguous figure our percept changes suddenly although the figure itself stays unchanged. Explanatory approaches assume either bottom – up or top – down mechanisms underlying this phenomenon. Here we investigate the interrelation of two factors strongly modulating the rate of perceptual reversals: volitional control (top – down) and discontinuous stimulus presentation (bottom – up). Paradigm: An ambiguous Necker cube was presented discontinuously with varying off-times. In three conditions participants had to (i) passively perceive the stimuli, (ii) try to hold their current percept as long as possible, and (iii) try to reverse their percept as often as possible. Participants indicated reversals by key presses. EEG events were recorded with high temporal resolution using the gap paradigm. Results: Volitional control and discontinuous stimulus presentation modulate reversal rate independently. EEG signatures related to both the presentation mode and to volitional control occurred earliest at 260 ms after stimulus onset and thus too late to be directly related to the reversal process. Our results suggest that two independent processes underlie endogenous perceptual reversals of ambiguous figures: (i) A slow destabilization process susceptible to both bottom – up and top – down manipulations. (ii) A fast and hard-wired disambiguation process, by necessity leading sometimes to a reversed percept.

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◆ **Neural processing of binocularly suppressed object stimuli**

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When incompatible images are presented to the two eyes, one image can dominate awareness while the other is suppressed and invisible. We investigated the neural representation of binocularly suppressed face and house stimuli in two experiments using high-resolution functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG). fMRI showed that overall responses of high-level ventral visual areas to binocularly suppressed stimuli were weak and did not differ in amplitude. Nevertheless, fine-grained spatial activity patterns within these areas allowed us to predict—significantly better than chance—whether face or house stimuli were presented not only when these stimuli were visible but also when they were suppressed and entirely invisible. In a separate MEG study the M170, a well-established face-specific signal was strongly reduced by binocular suppression. However, there was still a significantly greater signal in response to invisible faces compared to invisible houses at the latency and location of the M170 to visible stimuli. Together, these results show that visual object stimuli undergo category-specific processing in the ventral visual pathway even when suppressed from awareness by binocular competition and thus provide a possible neural basis for how complex stimulus features could contribute to the resolution of perceptual conflict even when suppressed.

◆ **The role of experience for norm-based object encoding in human object-selective cortex**

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Faces and objects from other classes are often encoded in terms of their deviation from a class prototype or norm. An important piece of evidence is a smaller neural population response for this prototype compared to non-prototype objects. We hypothesized that these effects might be modulated or even induced by visual experience. We tested this hypothesis with functional magnetic resonance imaging (fMRI) in human subjects using novel object classes organized around a class prototype. The object distribution within a class was changed across subjects so that the class prototype in one subject was a non-prototype in another subject. This design allowed us to look for effects of experience and stimulus distribution independently from other factors that might affect response strength to individual stimuli. The fMRI scans were preceded by two training sessions with the same stimulus distribution. We found evidence for norm-based object encoding at the behavioral level through behavioral asymmetries during a stimulus comparison task. Likewise, class prototypes were associated with a smaller response in object-selective brain regions compared to non-prototype class exemplars. These findings support the hypothesis that learning is an important factor for the induction of a norm-based encoding scheme for within-class object differences.

◆ **Atypical objects are easier to spot**

G Kayaert, S Panis, H P Op de Beeck, J Wagemans (Laboratory of Experimental Psychology,
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Recent studies have found a larger neural activation for stimuli which are more extreme exemplars of their stimulus class, than for stimuli which are more prototypical. This has been shown for faces as well as familiar and novel object classes. We used a visual search task to look for a behavioral correlate of these findings regarding both simple geometrical shapes and novel object classes. The latter stimulus set enabled us to control for the physical properties of the objects, firmly establishing that the effects are solely due to the positions of the particular stimuli in the shape space of objects belonging to the same object class (ie, at the border vs more central). The results clearly indicate that finding an atypical instance of an object class amongst more typical ones is easier and faster than the other way around. These effects require several presentations of the object class, especially for the novel objects, which suggests that they are not due to short-term adaptation from individual stimuli in previous trials but are linked to habituation for the object class as a whole. In general, these findings point towards a mechanism that can be used to orient oneself towards objects that are somewhat unusual within the environment, ie with properties that are atypical for their object class.

◆ **The development of part-based and configural object recognition in adolescence**

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Children's ability for configural processing when recognizing faces improves substantially during adolescence (eg Mondloch et al, 2004 *Journal of Experimental Child Psychology* **89** 159–181). Whether and to what extent similar changes in dealing with part relations occur for the recognition of non-face objects is unclear at present. In three experiments we assessed, for school children aged 6–16, the ability to judge the correct appearance of familiar animals, artifacts, and newly learned (but previously novel) objects, which had been manipulated either in terms of individual parts or part relations. In all experiments even the youngest children were close to adult levels for the correct recognition of a part change, and were only mildly affected by stimulus inversion. By contrast, it was not until 11–12 years that they achieved similar levels of performance with regard to altered part relations. However, this retarded progression and the associated susceptibility to stimulus inversion only applied to the recognition of animals and artefacts. For novel objects, performance for part-specific and part-relational changes was equivalent throughout the tested age range. The results suggest an unexpected complex trajectory of configural object recognition into adolescence that only partly reflects similar developmental changes in face recognition.

◆ **Revisit the non-specific 'top-heavy' structure bias in young infants**

S H-L Chien, H-Y Hsu, B-H Su¶ (Graduate Institute of Neural and Cognitive Sciences [¶ Department of Neonatology], China Medical University, Taichung, Taiwan; e-mail: sarinachien@mail.cmu.edu.tw)

Simion et al (2002 *Developmental Science* **5** 427–434) and Turati [2004 *Current Directions in Psychological Science* **13**(1) 5–8] suggested that newborns preferred 'top-heavy' stimuli and such bias may account for neonatal face preference. However, a causal link between face preference and 'top-heavy' pattern bias has not been demonstrated within the same infants. Convergent evidence for discriminability between the top-heavy vs bottom-heavy patterns is also lacking. Thus, we intend to reexamine the basic discriminability and preference correlations among various geometric patterns and faces in young infants. The stimuli included digitized 'top-heavy' and 'bottom-heavy' geometric patterns and faces, chosen to mimic the stimuli used in previous studies. Experiment 1 used the forced-choice novelty preference method (FNP) (Chien et al, 2003 *Psychological Science* **14**(4) 291–295) to test basic discriminability between top-heavy vs bottom-heavy patterns in 2- to 5-month old infants. Experiment 2 used visual paired comparison (VPC) technique (Fagan, 1970 *Journal of Experimental Child Psychology* **9** 217–226) to test infant's looking preference for pairs of geometric patterns and faces, and individual infant's preference correlation was assessed. Current results ($N = 28$) showed a balanced and significant discriminability across ages for all pairs. In addition, infants' preference correlations for top-heavy geometric and face patterns were rather weak. Taken together, our findings seem to provide evidence against an intrinsic preference for 'top-heavy' pattern.

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◆ **Neural correlates of high-level adaptation related aftereffects**

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Prolonged exposure to complex stimuli, such as faces, biases perceptual decisions towards non-adapted, dissimilar stimuli, leading to contrastive aftereffects. Here we tested the neural correlates of this perceptual bias using a functional magnetic resonance adaptation (fMRIa) paradigm. Adaptation to a face or hand stimulus led to aftereffects by biasing the categorization of subsequent ambiguous face/hand composite stimuli away from the adaptor category. The simultaneously observed fMRIa in the face sensitive fusiform face area (FFA) and in the body-part sensitive extrastriate body area (EBA) depended on the behavioural response of the subjects: adaptation to the preferred stimulus of the given area led to larger signal reduction during trials when it biased perception than during trials when it was not effective. Activity in two frontal areas correlated positively with the activity patterns in FFA and EBA. Based on our novel adaptation paradigm, the results suggest that the adaptation induced aftereffects are mediated by the relative activity of category sensitive areas of the human brain as demonstrated by fMRI.

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◆ **Decoding bar-codes in images of human faces**

R J Watt, S Dakin¶ (Department of Psychology, University of Stirling, UK; ¶ Institute of Ophthalmology, University College London, UK; e-mail: r.j.watt@stirling.ac.uk)

Dakin and Watt [2009 *Journal of Vision* 9(4):2, 1–10] have shown that the near-horizontal orientations in the human face contain the strongest information for face-recognition and that this horizontal information is organized into structures that resemble one-dimensional bar-codes. These bar-codes have a qualitative structure: they are a definite sequence of light and dark stripes. They also have a quantitative pattern: the spatial extent of the stripes conveys further information. The bar-codes found at coarse spatial scales in an individual are unchanging (given fair illumination), but the bar-codes at finer scales vary from moment to moment as the face moves. We describe how these bar-codes dynamically change as a person speaks and as a face changes expression. The changes that we observe are consistent with the idea that the qualitative sequence of bar types (light and dark) is a powerful cue about the expression of the face. For example, when the eye-brows are flashed upwards, the result is the appearance an additional light stripe between each eyebrow and eye. The quantitative details of the individual stripes are also informative. For example, the mouth generates a dark stripe and the horizontal length/extent of this is a direct cue to the vowel being spoken. We will describe these codes and their perceptual significance.

◆ **Exploring the data limitations associated with face perception in peripheral vision to understand unattended face processing**

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Investigating unattended face processing typically involves presenting faces in peripheral vision. However, peripheral vision is associated with encoding limitations, meaning that experiments investigating peripherally unattended face processing confound encoding and attention related limitations in face perception. The present research investigated face perception in peripheral vision to dissociate encoding and attention related limitations in peripheral face processing. Experiment 1 compared sex categorisation and identification in central and peripheral vision with sex categorisation and fame judgment tasks. Results showed that fame judgment accuracy was affected by presentation location while sex categorisation was not. Experiment 2 assessed the role of prior exposure to face stimuli on peripheral face identification. Participants were exposed to faces in a fame judgment task presented in central vision. These faces later appeared in a peripheral fame judgment task with other non-prior exposed faces. Fame judgment accuracy was higher for the prior exposed than the non-prior exposed faces revealing exposure contingent peripheral face identification. However, identification accuracy decreased when the pose of prior exposed faces was changed, suggesting that the increase in identification accuracy was image specific. These results suggest that unattended processing of peripherally presented faces may be limited to the sex and the identity of prior exposed faces.

POSTER SESSION

EYE MOVEMENTS

◆ **Recasting the relationships between gaze movements and curvilinear self-motion**

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A number of studies analyzed gaze location relative to the tangent point location during curve driving (eg Land, 1998). However, describing the average gaze-tangent point is not sufficient, since (i) the tangent point angular location depends on the driver trajectory, and (ii) the tangent point is immersed in a global optical flow field. In the present study, we propose to describe gaze movements in curves, based on their dependence on the curvilinear optic flow. To this end, we recorded (using a high-precision system) gaze movements in ten subjects, while they were driving, on a fixed-based simulator, along a circuit with bends between 50 and 500 m radius of curvature. After reconstructing the associated optic flow, we observed a systematic optokinetic nystagmus (OKN), while the gaze remains located in the vicinity of the tangent point. We further analyzed the links between the OKN slow phases and the most relevant optic flow parameters (speed, direction). Our results suggest new directions of research concerning a functional link between optic flow, gaze behaviour, and the control of self-motion.

◆ **Head mobility influences gaze behaviour across natural viewing tasks**

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Natural gaze behaviour is often studied under conditions that restrain head movements. Here, we report how the availability of head movement can influence gaze behaviour on wall-sized images

of natural outdoor scenes (field-of-view: $\sim 90^\circ$). Participants performed half of the experiment with complete head mobility and the remaining trials with their heads restrained in a chin-rest. They were required to either rate the images for attractiveness (ie, free-viewing) or to count the visible animals (ie, visual search). On average, more fixations were found on the trials that allowed for head movements (unrestrained: 4.21 fixations s^{-1} ; restrained: 3.75 fixations s^{-1}), which were also shorter in their mean duration (unrestrained: 221 ms; restrained: 252 ms). In addition, unrestrained gaze contained a larger proportion of small amplitude saccades (ie, less than 5°), than head-restrained gaze. Finally, our participants demonstrated a general preference in fixating regions that were close to the central eye-in-head orientation. Altogether, these findings suggest that the availability of head movements allowed our participants to re-orient to regions of interest and sample these regions more frequently. This sampling benefit applied to both visual search and free viewing tasks. The current findings emphasize the importance of allowing head mobility when studying natural gaze behaviour.

◆ **Spatial-frequency selectivity of visual suppression during convergence eye movements**
S Mucke, V Manahilov, N C Strang, D Seidel (Vision Sciences, Glasgow Caledonian University, UK; e-mail: Sven.Mucke@gcal.ac.uk)

The visual system actively suppresses low-spatial frequency information during saccadic eye movements to provide the observer with a stable visual environment. Saccadic suppression is believed to originate from an extra ocular corollary discharge signal which affects the magnocellular pathway at an early stage in visual processing (Burr et al, 1994 *Nature* **371** 511–513). Recently, we found that ocular accommodation suppresses contrast sensitivity only at high spatial frequencies (Mucke et al, 2008 *Current Biology* **18** R555–R556). Previous work (Manning, 1986, *Journal of Neuroscience* **6** 1976–1982) has shown that vergence eye movements suppress sensitivity to uniform light decrements, however, the spatial frequency selectivity of the suppression remains uncertain. We measured contrast sensitivity to low, mid and high-spatial frequency gratings during convergence induced by prismatic lenses in the absence of ocular accommodation. Four subjects aged 18–33 were presented in a two-alternative forced-choice experiment with brief sine wave gratings (1, 4, 9 cycles deg^{-1}) at 1 m distance during dynamic convergence responses (~ 3.5 deg). Results show significantly reduced contrast sensitivity (mean loss 0.26 log units) around the onset of the convergence response, for low- and mid-spatial frequency patterns only. This suggests that the suppression mechanisms occurring during vergence are similar to those which operate during saccades.

◆ **Eye movements of science centre visitors**
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To investigate the influence of context on visual scene exploration, we recorded childrens' and adults' eye movements while looking at: (a) pictures from children's story books, and (b) degraded pictures like the 'Dalmatian'. For (a), both children and adults changed their fixation patterns according to the questions asked, in line with earlier findings that instructions influence scene exploration [Yarbus, 1967 *Eye Movements and Vision* (New York: Plenum)]. Eye movements differed between adults and children, with adults fixating more on faces, depending on the type of instruction (person-related versus material- or action-related) and the type of picture (containing children only or children and adults). Also, without specific instruction, adults fixated faces more often and longer than children. For (b), the number of fixations and fixation duration within the figure strongly increased, and total number of saccades decreased, when participants knew where and what the figure was; furthermore, earlier searches for other figures influenced the explored zone within the picture. Results indicate that, beside instructions, expectation, experience, and age influence eye fixation patterns.

◆ **Eye movement during the observation of novel and familiar faces in infants**
M Kato, T Otobe¶, Y Konishi (Center for Baby Science, Doshisha University, Japan; ¶ Department of Early Childhood Education, Jin-ai Women's College, Japan; e-mail: piekomk@gmail.com)

The present research explored infants' ability for face discrimination with infant-control habituation paradigm and eye-tracking. 5-, 7.5-, 9.5-, and 12.5-month-old infants participated in the experiment. After habituation to one face, that familiar face and a newly-exposed novel face were presented for 30 s each, and the order was counter-balanced between subjects. All age groups dishabituated to the novel face, but the number of saccades from/to face parts for familiar and novel faces were different among ages: The youngest infant group made as much

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saccades for novel faces as for familiar faces, but other older infant groups made saccades more often for the novel faces than for the familiar faces. This result suggests that infants begin to look at faces more analytically with age.

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◆ **Natural viewing behaviour segregates fMRI activity in human visual cortex**

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In natural viewing behaviour, our eyes shift position a few times per second. Behavioural studies suggest that depending on fixation duration and saccade length, eye-movements may have different functions in perception. Hence, it can be expected that eye-movements are important events that influence brain activity. To explore this, in our experiment subjects viewed images of scenes while their eyes were tracked and their brain activity measured using fMRI. We categorised fixations and subsequent saccades into 'scanning' and 'inspection' events based on fixation duration and saccade length. These eye-movement events were used in an event-related fMRI analysis. Results indicate that scanning events were associated with more activity in the medial occipital cortex, while inspection events were associated with more activity in lateral the occipital cortex. Hence, eye-movement events segregate activity in the visual cortex. We argue these findings are in line with the existence of a medially located 'gist-based' recognition mechanism aimed at extracting surface and global scene properties versus a lateral system intended for shape and object perception.

◆ **Change-detection in driving scene images: A comparative analysis of the eye movements of experienced and novice drivers**

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We investigated whether driving experience affects the change-detection performance when viewing images of driving scenes. We prepared ten driving scene images, each one containing an item that gradually appeared and disappeared. Half of the images contained risk-relevant items that drivers should pay attention to when driving, and the other half contained risk-irrelevant items. Experienced and novice drivers participated in this experiment. Their task was to peruse each image so as to detect the gradually changing item located within the scene. During the task, their reaction time (RT) and eye movements were recorded. The results showed that both groups were able to detect the risk-relevant items with shorter RTs; however, only the experienced drivers required longer RTs to detect risk-irrelevant items. Eye-tracking data indicated that experienced drivers were mainly scanning horizontally in the traffic area despite the fact that they knew the item could appear anywhere in the image. In contrast, novices produced random scan paths, which included longer fixations compared to experienced drivers. This suggests that experienced drivers give priority to traffic-related items making it more difficult to search for risk-irrelevant items. Factors affecting searching strategies are likely not based upon driving attitude and sensation but driving expertise.

◆ **Object memory and eye movements are influenced by what you ask and how you ask it**

G M Hübner, B W Tatler¶, K R Gegenfurtner (Department of General Psychology, University of Giessen, Germany; ¶School of Psychology, University of Dundee, UK; e-mail: gesche.huebner@psychol.uni-giessen.de)

We examined how visual memory and eye movement characteristics in a memory task differed depending on how the question was phrased and the kind of information asked. Subjects viewed a circular display consisting of six coloured shapes for 5 s. After each trial, they had to answer a question about the identity, colour, or position of one object. The question was asked by means of a visual cue, a verbal description, or by showing the stimulus again in an identical fashion. As the stimulus material was kept constant across conditions, differences in memory performance and eye movements could all be attributed to the question's style and content. Colour was remembered significantly less than either identity or position. There was a highly significant interaction between the question's style and content. Viewing behaviour varied for each of the three question's content: subjects making more and shorter fixations when they had to remember the identity of objects. Fixation behaviour and performance were not closely linked: even though fixations were not distributed equally on the different positions of the circle, performance was identical on all positions. We conclude that both memory performance and eye movements are influenced by what is being asked, and, importantly, how it is asked.

◆ **Direct estimation of the point of gaze from fMRI data**

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Task compliance tests form an important part in visual functional magnetic resonance imaging (fMRI) experiments. Infrared based eye-trackers are a well proven solution to estimate the point of gaze of the subject, however their use is often time-consuming, costly, uncomfortable for the subjects and sometimes even impossible due to head size and space restrictions in head-only scanners. Here we present a novel analysis technique that quantifies the eye movement directly from the fMRI data without the aid of dedicated eye-trackers. We show that by using the parts of the functional image data that contain the motion artefacts of the subject's eyes and by applying spatial independent component analysis, it is possible to detect eye movement and to estimate the direction of the eyes' point of gaze at the time of data acquisition. By means of various simple saccade experiments we were able to demonstrate that our method yields results comparable to the infrared eye-tracker data within the limitations of temporal resolution from fMRI image acquisition. Finally we present an open source SPM toolbox with the implementation of our technique.

◆ **The eyes have it: Attention allocation in judgments of personality traits for faces—there is an observer sex difference in orientation to salient facial features**

B Kersten, T Roderer (Department of Psychology, University of Bern, Switzerland;
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Successful social and emotional interaction is reliant on the ability to identify and interpret information based on others visual cues. Recently, we showed that the impression formation of personality traits is dissociated from judgments of likeability, which might be connected to harmful intentions, and judgments of success, which might be connected to the power to cause harm. Orienting behaviour is intrinsically linked to emotionally involved processes. In this study observers were shown pairs of emotionally neutral human faces and asked to decide, without time constraint, which face was more likeable or more successful, while their eye movements was monitored. When judging likeability, females showed deeper sensory processing of the eyes of pictures in terms of gaze duration, gaze frequency, or both. Males attended more to the lower part of the face, especially the nose. This gaze bias was (i) significantly weaker in the control task when subjects decided which face was more successful, and (ii) was independent of the average attractiveness ratings of faces based upon evaluation of data collected previously. Scan path results will be discussed in the context of the controversy of whether females are better at judging affective facial pictures.

◆ **Role of perceptual similarity in anchoring creation of conceptual similarities and interpretation of visual metaphors**

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 Technology, Hyderabad, India; e-mail: amitashojha@research.iiit.ac.in)

Studies have demonstrated that metaphors can create new conceptual similarities between source and target. However, the mechanism has not been explained satisfactorily. In our earlier work, we have hypothesized that perceptual similarities between source and target may play a key role in anchoring the creation of conceptual similarities. We present some empirical evidence in support of this hypothesis for visual metaphors. We focussed on visual metaphors because here the images corresponding to source and target are objectively present. Moreover, we use an algorithmic approach to establish perceptual similarity by using an image-based search system that determines similarity based on low-level perceptual features. We asked participants to interpret pairs of conceptually dissimilar images metaphorically. Half of these images were high-similarity and half were low-similarity pairs (determined by algorithm). We also recorded eye movements. Results confirmed our hypothesis: we found that 87% of pairs of perceptually similar images were given a metaphorical interpretation, as opposed to 41% for pairs of images with low perceptual similarity ($F_{1,28} = 39.09$, $p < 0.001$). Moreover, the number of newly created conceptual features correlated strongly with the perceptual similarity between images (mean = 61.78%, $F_{1,22} = 12.04$, $p < 0.01$). Eye movement analysis shows that perceptually similar regions of images get increased attention during metaphorical interpretation.

◆ **Necker cube: correlation between perceived 3-D forms and distributions of gaze fixations**

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 Russia; e-mail: bobby_1@rambler.ru)

In 1978, Hippenreiter investigated gaze fixations in the course of viewing Necker cube and stated that the patterns of fixations revealed two clusters correlated with two variants of perceived

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3-D form. In similar experiments, we performed continuous eye tracking with i-ViewX-System (SMI) in fifteen subjects, but could not reproduce this result. The attention maps appeared to be very variable and most of them did not show two distinct clusters. However, using another experimental paradigm, we recently succeeded in finding a difference between two distributions of fixation points corresponding to perceived 3-D images. The stimulus panel contained a line image of a Necker cube in the centre and two realistic shaded pictures of the solid cubes resembling two perceived 3-D forms on both sides. The subject had to switch on the stimulus and indicate the first perceived 3-D form by means of directing his gaze immediately to the corresponding realistic image. In this case, the crucial fixations could be marked in accordance with perceived 3-D forms. It appeared that differently marked points were situated on two sides of certain diagonal line, ie the whole area of Necker cube could be divided into two parts giving rise to different 3-D forms.

◆ **Individual differences in symmetry detection**

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Humans are very sensitive to symmetry in visual patterns. However it is not known how the processing of symmetry is going on and what mechanisms make the detection of symmetry possible. Symmetry supposedly is a highly salient feature of the image. We performed investigation on symmetry detection presenting images with horizontal or vertical symmetry and asymmetrical images with different degree of symmetry. Thirty-two participants were researched. Our investigation showed that subjects fall in two groups. Majority of subjects detected asymmetry more accurately and faster than symmetry and they detected small deviation from ideal symmetry more precisely. However there were others who detected symmetry better than asymmetry. We hypothesize that while examining the figures subjects of those two groups unconsciously take different strategies. Possibly this difference should reflect itself in different image observation by subjects ie in different way of eye movements. In order to reveal this difference we perform similar investigation of symmetry detection including eye movements tracking.

◆ **Müller-Lyer illusion: fundamental uncertainty of perceptual effect and influence on voluntary saccades**

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Studying the Müller-Lyer illusion (MLI) in children and adults, we found that the mean value of the illusory effect decreased from 36% at age 6–7 to 23% at age 18–25, but variability of the effect remained very high independently of the experimental paradigm (forced choice, adjustment, constant stimuli method) and the subject's age. In all cases the standard deviation of estimates was 2–2.5 times larger than for the same control lines (without wings). We suggest that this high variability is due to the ambiguous nature of the MLI-configuration: it can be interpreted taking into account different features at different moments (eg Necker cube). Various MLI mechanisms discussed (eg Yarbus, 1967; Chiang, 1968; Gregory, 1971; Morgan, 1990) could be treated as not mutually exclusive but as working in parallel with variable contributions to the final percept. Evidence of parallel mechanisms was also found in our study of the MLI effect on voluntary saccades between the ends of horizontal line segments. Eye movements were recorded with i-ViewX-System (SMI). On average, some effect of the MLI was found but, in about 50% of the saccades, the illusory effect was absent suggesting that these saccades were programmed by a mechanism not influenced by the MLI.

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◆ **Do eyes move as a tilt-pan like system? Physical plausibility of the coplanarity of the fixation planes**

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Usually eye rotations have been decomposed into three sequential rotations about hierarchically nested axes (Helmholtz and Fick systems), but these description are strongly dependent on the order of these rotations. Even when quaternion algebra is adopted, Helmholtz or Fick angles are still commonly used to characterize the rotation vector components (Haslwanter, 1995 *Vision Research* 35 1727–1739). A new characterization of eye movements has been developed that is dependent on the coordinates of the fixation point only, independently of the rotation system adopted. Experimental evidence (such as Listing's Law and its binocular extension, L2) have been taken into account. Based on this new characterization, we performed a mathematical analysis to obtain optimal eye movements maximizing both motor efficiency and the perceptual

advantages for stereo vision. The results revealed that the eyes should move both to maintain the coplanarity of the fixation planes (a property of a tilt-pan system) and to reduce the eccentricity of the rotation. Our approach confirms the experimental results found in the literature for large and small vergences, and proposes itself as a general model, forming a bridge between these two extremes (even for non-null version conditions).

◆ **Smooth pursuit in apparent motion testing in different age groups**

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The variability of smooth pursuit (SP) eye movements is interesting from the viewpoint of brain-related information processing. We studied this issue in respect of horizontal discontinuous (apparent) motion (for details see Surovicheva et al, this conference) at velocities up to 25 deg s^{-1} in a large group of subjects of different ages: sixty-six children (mean age 11.5 years), sixty-seven young adults (mean age 20 years); and thirty-five healthy elderly people (mean age 65 years). First, we found that all groups of subjects are distinctly differentiated with respect to the capacity for discontinuous motion SP. The high retesting reliability of the SP estimates allows to consider them to be individual characteristics of types. Second, 11 to 12-year old children exhibited, on average, less smooth pursuit of discontinuous motion than adults at velocities $17-25 \text{ deg s}^{-1}$. Third, the comparison of the efficiency of SP of young adults and elderly people showed that the eye movement system is relatively resistant to the effects of aging except in the increase percentage of old persons with asymmetrical SP. So, testing apparent motion by a method that does not require direct measurements of eye movements provides a novel strategy for evaluating the functional integrity of multiple human brain systems.

◆ **Apparent motion testing for pursuit efficiency in human vision**

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Our previous experiments have shown that in the case of apparent motion the smooth pursuit (SP) program in humans is also initialized. It allowed us to construct a portable device for analyzing the pursuit of apparent motion that does not require the direct measurements of eye movements. The impression of smooth object motion is created by a sequence of flashes of LEDs separated by a fixed interflash interval, Δx about 1° . The flash is chosen long enough (50–70 ms) to modulate the LED brightness as a function of time. It allows to create illusory object as the retinal projection. By choosing the profile of the brightness-vs-time function of a LED, it is possible to form the shape of the apparent object as the combination of dashes and dots. If the difference between target velocity and eye velocity is small (the pursuit is smooth), a stable retinal projection is formed. Since it is formed only as a result of the SP process, correct observer's answer on the object appearance is an objective measure of SP ability. We show that most of the subjects maintain the SP in apparent motion testing but that they strongly differed from one another in the SP efficiency.

◆ **Compression of time during smooth pursuit eye movements**

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The perceived separation of successively flashed bars is compressed during saccadic eye movements (Morrone et al, 2005 *Nature Neuroscience* **8** 950–954). Here we investigated if such a compression of apparent time also occurs during smooth pursuit eye movements. We flashed two pairs of horizontal bars and asked subjects to judge which of the pairs was shorter. The separation of the first stimulus pair (test) was varied following a staircase procedure, while the separation of the second pair (standard) was kept constant at 100, 200, or 300 ms. In the baseline condition, both pairs were presented during fixation. In the experimental condition, the second stimulus pair was presented during steady horizontal pursuit of 10 deg s^{-1} . The horizontal bars were flashed randomized 17 deg above or below the eye movement target, to avoid the perception of motion. The results show a compression of apparent time during pursuit, by about 20% of the standard interval duration. At the same time precision was increased during smooth pursuit. A control experiment showed that the compression does not occur in the auditory domain, which rules out that the compression is caused by a global attention effect.

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Friday

◆ **Localization of speed changes during fixation and smooth pursuit eye movements**

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Human observers are quite good at detecting changes in the speed of a single moving object. However, there are usually several objects moving at different speeds in natural situations, and the observer might be moving the eyes. Two vertically oriented sinewave gratings (27 deg × 9 deg) were moving horizontally at a constant (pedestal) speed. In the vertical (2 deg) gap between the gratings a small fixation spot was either stationary or moved in the same direction as the gratings. During the movement one of the gratings changed its speed for 500 ms. The subject had to indicate whether the top or bottom grating changed speed (localization) or which one of two intervals the speed change took place (detection). While thresholds for detecting speed changes were in the normal range of Weber fractions of 10%–15%, localization thresholds were dramatically increased to Weber fractions of about 30%–40% whenever there was retinal motion due to differences in eye and pedestal speed. The effect was particularly pronounced when the retinal motion was due to the pedestal motion, and less when it was due to the pursuit eye movements. We conclude that localization of speed changes is exceedingly difficult. This is probably due to the dominance of relative motion signals when several objects are moving independently. Smooth pursuit is an effective means to improve performance under these conditions.

◆ **The Filehne Illusion following adaptation to simultaneous smooth pursuit eye movement and spatially non-coincident retinal motion**

J R Davies, T C A Freeman (Department of Psychology, Cardiff University, UK; e-mail: daviesjr3@cardiff.ac.uk)

Comparing estimates of retinal motion and smooth pursuit helps compensate for the retinal effects of eye movement. Recent models claim that the pursuit estimate is based on retinal and extra-retinal components by showing that the Filehne illusion (perceived motion of a stationary background during pursuit) changes following simultaneous adaptation to pursuit and retinal motion. However, this could equally be accounted for by adaptation of retinal motion sensors (the velocity aftereffect, VAE). We tested these models using retinal motion (R) adaptation that was spatially non-coincident with the test stimulus. Observers simultaneously adapted to a pursuit target and retinal motion flanking a central blank strip. Pursuit and retinal motion executed left-right triangle waves, either in-phase or out-of-phase. Test stimuli consisted of pursuit over a central background, background motion was adjusted by a staircase to yield the point-of-subjective-stationarity (PSS). The Filehne Illusion changed for both in-phase and out-of-phase conditions, with the PSS describing an inverted U-shaped function symmetrical about $R = 0 \text{ deg s}^{-1}$. This is difficult to explain using a reference signal, which predicts a monotonic increase in PSS across R. We suggest that non-coincidental retinal adaptation induces a retinal VAE in the central test. Experiments will be reported to test this idea.

◆ **Adaptation of catch-up saccades during the initiation of smooth pursuit eye movements**

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As the eye muscle strength is modulated by several factors, the sensorimotor transformation needed to accurately track the moving target has to be continuously recalibrated. While the plasticity of saccades to stationary targets is well documented, we do not know how both the pursuit and saccadic system adapt for systematic positional undershoots or overshoots in the short term. We tried to adapt the first catch-up saccade that is made during initiation of smooth pursuit of a moving target. In a first experiment we applied a target-step along the direction of motion. In a second experiment, the step was applied orthogonal to the motion direction. We observed an adaptation of saccade amplitudes in the first experiment and an adaptation of the saccade vectors in the second. The post-saccadic pursuit velocity tended to be influenced in a similar way as saccade amplitudes and vectors. Our results add further evidence that pursuit and saccades act in synergy to reduce position errors.

◆ **Influences of task complexity and individual differences on the performance of gaze-assisted human – machine interfaces**

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Human-machine interfaces can be enhanced by incorporating knowledge of the user's current point of regard. For example, Zhai and colleagues (1999) showed that faster task completion times could be achieved on a simple pointing task if the display pointer was translocated according to

the user's gaze. This manipulation removes the need to manually move the pointer and hence, promises time-savings that grows in proportion to display size. Here, we report the findings of applying the same technique on a wall-sized display (2.2 m × 1.8 m), across more complex pointing task. Two main components comprised the four tasks that participants were required to perform, with and without gaze-assisted pointing: Namely, conjunctive search of colored shapes and click-and-drag of items to a circumscribed region. Contrary to previous findings, we found that gaze-assisted pointer placement significantly increased task completion times, relative to manual pointer placement. Detailed analyses revealed that task complexity and individual differences in gaze behaviour and eye-hand coordination had an adverse effect on task performance, which emphasizes the importance of considering these factors in future implementations of gaze-assisted interfaces.

◆ **Connectivity analysis of attention shifting to pursuit and saccade targets with a massive model comparison approach**

F Acs, V Fischer, M W Greenlee (Department of Psychology, University of Regensburg, Germany; e-mail: ferenc.acs@web.de)

We investigated the interplay of higher visual processing areas of the dorsal stream to explore effects of covert attention on connectivity. We were interested in the interplay of the lateral intraparietal area (LIP), frontal eye fields (FEF), and supplementary eye fields (SEF). Overt and covert attention was paid by subjects to one saccade and one pursuit target that were visible at the same time, while subjects were instructed to covertly shift attention between the pursuit and saccade targets. Because little was known about the effects of covert attention on connectivity we explored every possible model (4096 models per subject and hemisphere). The connectivity analysis was performed by dynamic causal modeling (DCM). A sophisticated model comparison approach was used to determine the best models. It was also necessary to implement our own estimation procedure (fast-DCM) to compute the estimations and compare outcomes within six months. The important role of all three areas (LIP, FEF, and SEF) in attention processing could be confirmed. In line with previous monkey neural recordings, the right hemisphere is dominant in covert attention processing and covert saccade processing leads to strong modulation effects in the right hemisphere. Covert attention processing of pursuit eye movements seems to have no significant effect on higher processing areas.

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SACCADES

◆ **Perceiving transsaccadic motion**

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Consistent suppression of transsaccadic motion is vital for perceiving a stable visual scene. This study reports a new visual illusion in which perceptual stability is lost in simple dichoptic displays. The basic stimulus consisted of a low-luminance disk presented to one eye and high-contrast random dots presented to the other eye. When observers made voluntary eye movements while viewing the stationary stimulus, they reported a sense of relative motion: Typically, the disk appeared to jump with respect to a perceptually stable background. From psychophysical experiments, we found that (a) the illusory motion was closely related to a temporal frequency component of binocularly correlated eye movements, and (b) saccadic suppression of the transient change of the stimulus was not reduced in the dichoptic display. These results suggest that the visual system can restore transsaccadic motion, even in the presence of saccadic suppression.

◆ **Slipping under the inhibitory radar? Near-threshold stimuli distract saccades more than higher contrasts do**

A Bompas, P Sumner (School of Psychology, Cardiff University, UK; e-mail: bompasa@cardiff.ac.uk)

The remote distractor effect (RDE), in which irrelevant stimuli delay saccades to target stimuli, is a popular tool for investigating saccadic competition. Here, we measured the effect of distractor contrast on the amplitude of the RDE. From moderate to high contrast levels we found, consistent with a low level account of the RDE, that the effect increases with contrast. However, at a very low contrast, for which distractors are mostly unnoticed, the RDE was as strong as for the most salient contrast level. Then, the amplitude of the RDE was higher at very low contrast levels than for moderate levels and also produced more errors. This surprising result may indicate that unperceived distractors are more efficient because they fail to be inhibited by higher level influence. The relation to previous findings (Cardoso-Leite and Gorea, 2009 *Journal of Neurophysiology* **101** 2822–2836; Born and Kerzel, 2008 *Vision Research* **48** 2805–2816) will be discussed.

Friday

◆ **Inhibition revealed by saccade curvature and masked primes: is it the same mechanism?**

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In masked priming, a prime preceding the target often speeds up responses to the target if features of the prime and the target overlap ('positive compatibility effect'; PCE). However, sometimes similarity of the prime and target slows down responses to the target ('negative compatibility effect'; NCE). It is thought that the PCE occurs when the motor plan activated by the prime is still active during target processing, but the NCE occurs when the motor plan for the prime has been suppressed. Residual activity in the motor map is also thought to be the cause of saccade curvature, so the direction of curvature should be associated with the direction of priming. We asked participants to produce saccades in response to target arrows while ignoring masked prime arrows, but on some trials to make a saccade in the direction orthogonal to the prime direction. The prime-mask timing was manipulated to produce a PCE in some blocks and an NCE in others. However in both, saccades in the orthogonal direction were found to curve away from the prime direction. This surprising dissociation between the pattern of results in response times and saccade curvature suggests that multiple inhibitory mechanisms may be at work.

◆ **Keeping an eye on each other: gaze behaviour in joint action**

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Looking in the right place at the right moment is particularly important while executing movements in coordination with another person. Being able to predict outcomes of the movement of others is even more crucial. We addressed this issue by exploring the gaze behaviour of pairs of participants involved in a simple cooperative task. The two participants were facing each other and each of them had to move an object in the vertical plane around an obstacle and make contact with the object of the other participant repeatedly. Eye movements were simultaneously measured in both participants. A stereotypical gaze behaviour was observed: saccades were regularly directed towards the partner's object in the terminal phase of the movement prior to contact between objects. These saccades started approximately 300–400 ms before contact. By increasing the uncertainty of the contact location we observed an anticipation of the initiation time of the saccades. The phase prior to contact was thus always directed to monitoring the partner's movement. This gaze behaviour seems necessary to establish a closed loop between the two participants allowing a coordinated fine-tuning of the joint action. [Research supported by EU grant (FP7-ICT-217077-Eyeshots).]

◆ **The adjustment of the focus of visual attention is determined at early levels of processing**

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Little is known about how and when size interferes in the selection of visual information. In particular, it has sometimes been reported that the size of an attentional cue affects how quickly a target object can be detected or discriminated. We studied the adjustment of visual attention to the size of a peripheral cue, using different tasks that required an output based on different levels of processing. Participants completed separate experimental sessions for different tasks (simple reaction time, temporal order judgment, and saccade reaction time) with oriented Gabor stimuli or letters as targets. Cue size was manipulated in all experiments. The results showed no influence of cue size on the temporal order perception with letters. With Gabors, the participants did not discriminate the temporal order given the same amount of time as for letters, but with the simple and saccade reaction time tasks, differences were found as a function of cue size. The results suggest that the scaling of visual attention to the size of an object occurs when the system is forced to make a very early response, but not later in terms of processing. [Supported by CNPq (308671/2006-6) & CAPES (3336-08-5), and NSERC & FQRSC to MvG.]

◆ **Memory guided saccade processing in visual form agnosia**

M Harvey, L Szymanek, S H Butler¶, S Rossit (Department of Psychology, University of Glasgow, UK; ¶ Department of Psychology, University of Strathclyde; e-mail: M.Harvey@psy.gla.ac.uk)

According to Milner and Goodale's model [2006 *The Visual Brain in Action* 2nd edition (Oxford: Oxford University Press)] areas in the ventral visual stream mediate visual perception and off-line actions whilst regions in the dorsal visual stream mediate the on-line visual control of action. Strong evidence for this model comes from a patient (DF), who suffers from visual form agnosia after bilateral damage to the ventro-lateral occipital region, sparing V1. It has been repeatedly

reported that she is normal in immediate reaching and grasping, yet impaired when asked to perform delayed or pantomimed actions. Here we investigated whether this dissociation would be upheld when comparing stimulus driven to memory guided saccadic performance in DF. Recent neurophysiological studies in the monkey, as well as TMS work in humans, have shown that the posterior parietal cortex (PPC), on the right in particular, is involved in the control of memory-guided saccades, areas supposedly spared in DF. Surprisingly though, we found that, just as reported for reaching and grasping, DF's saccadic accuracy was much reduced in the memory compared to the stimulus guided condition. These data support the idea of a tight coupling of eye and hand movements and further suggest that PPC/dorsal stream structures may not be sufficient in driving memory guided saccadic performance.

◆ **Perceptions of depth and asynchrony during eye movements**

R Aruga, H Saito, H Ando[¶], J Watanabe[§] (Graduate School of Science and Technology, Keio University, Japan; [¶] Graduate School of Information Science and Technology, Osaka University, Japan; [§] Communication Science Laboratories, NTT, Kyoto, Japan; e-mail: aruga@hvrl.ics.keio.ac.jp)

When humans make saccadic eye movements perpendicular to a rapidly flickering one-dimensional light pattern, a two-dimensional (2-D) image can be perceived due to spatio-temporal integration by the visual system. Different line images on the different retinal locations are integrated into a perceived 2-D image. While ordinary visual images are suppressed during eye movements, images with high contrast and high spatial frequency can be seen even during saccades. Using this phenomenon, 2-D images can be displayed only with 1D light source. However, the relationship between the image spread on the retina and the percepts has received little attention. In this report, we performed psychophysical experiments to investigate how such images are perceived in 3-D space. Images composed of four filled circles were presented by vertically aligned light sources. The arrangements and features of the circles were systematically changed. Subjects were asked to make saccades and to report the perceived shapes, and their relative depth and timing. We found that when asymmetric 2-D images were presented, the nonuniform pattern on the image was perceived as the difference in depth and time of the perceived image. Our results indicate that spatio-temporal grouping on the presented image is related to perceived depth and asynchrony.

◆ **Direct gaze automatically affects the lateral orienting of visual attention**

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Eyes and gaze are crucial social cues and play a pivotal role in social interaction. Humans are particularly sensitive to gaze direction and it has been suggested that they may have an innate attraction to the eye region of the face. Although it is well known that averted gaze induces in the observer automatic attentional shifts in the same direction, the effect of observing direct gaze on capturing and holding attention is still poorly understood. In this study, participants fixated a dot positioned on the nose tip of a central $21.67^\circ \times 16.77^\circ$ female or male face-stimulus depicted with eyes closed or open and directed to the participant. Participants were required to perform single speeded saccadic eye-movements towards a lateral target either on the left or on the right depending upon the face-stimulus' gender. Eye movements were constantly monitored for offline analysis. Results showed that the lateral target was correctly reached with the first eye-movement significantly more when the central face-stimulus had the eyes closed. Furthermore, when the eyes of the face-stimulus were open incorrect first saccades were more often made towards the eye area of the face-stimulus. The data suggest that direct gaze, even if task-irrelevant, automatically captures visual attention.

◆ **Temporal order judgments during saccades**

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If two visual stimuli are presented shortly before or after a saccade, the perceived temporal order of the events reverses (Morrone et al, 2005 *Nature Neuroscience* 8 950–954). It is thought that due to saccadic suppression, the second stimulus is selectively blocked. Thus, the last perceived stimulus which actually is the first one, is misinterpreted as the second stimulus. In the current experiment further we tested this hypothesis. Two horizontal bars were flashed shortly before or shortly after a saccade, one at the top, the other one at the bottom edge of a computer screen. In a 5-AFC task subjects had to judge if the top or the bottom bar was presented first, whether they had only seen the top or the bottom bar or neither of the bars. A reversal of the perceived temporal order was only observed, when subjects reported to have seen two stimuli. Therefore, saccadic suppression can be excluded as a factor to account for the apparent reversal.

Friday

◆ **Response inhibition in hemispatial neglect**

L Szymanek, S H Butler[¶], S Rossit, B Olk[§], M Harvey (Department of Psychology, University of Glasgow, UK; [¶] Department of Psychology, University of Strathclyde, UK; [§] School of Humanities and Social Sciences, Jacobs University, Bremen, Germany; e-mail: l.szymanek@psy.gla.ac.uk)

Patients with hemispatial neglect exhibit visuospatial impairments in the contralesional hemispace, failing to respond to items presented in their left space. Moreover, eye-movements into left space are abnormal with fewer, hypometric fixations and increased leftward latencies. Surprisingly we have recently found that, in an anti-saccade task (where a saccade away from a stimulus is required), neglect patient failed to suppress incorrect pro-saccades to both right and leftwardly presented targets (Harvey et al, 2008 *Journal of Cognitive Neuroscience B* **48** 65). We could not establish whether these bilateral impairments were due to a failure to locate the visual stimulus and reverse its location to specify the goal for the anti-saccade, or whether the patients suffered from an inability to suppress the pre-potent response. We therefore asked neglect patients to either perform pro-saccades (go) towards right and leftwardly presented stimuli or to inhibit their response and maintain central fixation (no-go). The percentage of go compared to no-go trials was varied systematically. We found that neglect patients showed no problems suppressing leftward saccades yet performed worse than control groups in suppressing rightward saccades over all conditions. This suggests that the previously reported involuntary leftward pro-saccade errors were not due to inhibition failure but that the rightward errors were.

◆ **Integration of shape information across saccades in apparent motion displays**

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Real-world perception is typically trans-saccadic: we see the same object across multiple fixations. Yet saccadic eye movements can dramatically change the location in which an object is projected onto the retina. One possible mechanism of visual stability might be trans-saccadic remapping of objects. We tested whether object feature information, or rather just a pointer to object location, is remapped across saccadic eye movements. We found that transformational apparent motion, in which an object is seen to change shape and even move in three dimensions during the motion trajectory, continues across saccades. Moreover, spatiotopic apparent motion was stronger than retinotopic apparent motion. These findings suggest that shape information is indeed integrated across saccades. Trans-saccadic transformational apparent motion provides a new tool to measure the object-based matching of features, such as shape, across saccades.

VISUAL WORKING MEMORY

◆ **Walk-related mimic word activates the extrastriate visual cortex in the human brain:**

An fMRI study

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One of the critical issues in the cognitive neuroscience of language of action processing is the question of the cortical 'seat' of word meaning and related action. For example, generation of action words, using PET, activated a region in the middle temporal gyrus anterior to the area involved in the perception of motion while the generation of color words selectively activated a brain area in the ventral temporal lobe anterior to the area involved in the subjective perception of color in humans (Martin et al, 1995 *Science* **270** 102–105). Meanwhile, mimic words have another potential to selectively and strongly stimulate specific brain regions having a specified 'seat' of action meaning. We present an fMRI study demonstrating that a mimic word highly suggestive of human walking, heard by the ear with eyes closed, significantly activates the visual cortex located in extrastriate occipital region (BA19, 18) and superior temporal sulcus (STS) while hearing non-sense words that do not imply walk under the same task does not activate these areas in humans. We concluded that BA19 and 18 would be a critical region for generating visual images of walking and STS would be a region related to biological motion, respectively, evoked by an onomatopoeia word that implied walking.

◆ **Visuospatial working memory and aging**

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Recent studies focus on age-related neuropsychological diseases like dementia. However, less is known about the reorganisation of brain function in normal aging subjects. The present fMRI

study investigated age-related effects in visuospatial working memory functions that primarily involve activation in the parietal lobe. Forty-nine healthy volunteers aged 21 to 72 years participated in the study. We investigated visuospatial working memory (or visual imagery) in a modified Corsi-block-tapping task. Four blocks were presented in a single row; the subject's task was to repeat a certain sequence indicated by the experimenter. The sequences differed in length and were compared to a stereotypical control tapping condition. First, neural activation in parietofrontal regions including the dorsal visual pathway was found. Second, older subjects made more mistakes and response times increased with age. Third, age-related activation was found in the cingulate cortex at encoding and in the orbitofrontal cortex (gyrus rectus) at retrieval, while a negative correlation with age was found in the DLPFC. However, additional prefrontal activation did not compensate for the disadvantage in visuospatial functioning in older subjects compared to younger ones. We discuss the relevance of additional or decreasing neural activation in older age.

◆ **Visual working memory for abstract shapes**

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Internal noise and storage capacity limit representations in the visual working memory. Hence, in a delayed comparison task, subjects' performance should decline gradually as the retention time and the task difficulty increase, and abruptly when the capacity limit is exceeded. We measured shape discrimination with 2-interval change detection. Subjects indicated whether the intervals were similar or not. The stimuli items were deformed circles, ie, radial frequency patterns (size 2 deg) composed of two components (radial frequencies 2 and 4). A phase difference between the components quantifies the shape. The magnitude of change was individually set to 30–60 deg. The discrimination accuracy, d' , was measured (a) for one item as a function of interstimulus interval (ISI; 500–2500 ms) and (b) for fixed ISI (1500 ms) as a function of the number of items (1–4). The items were presented randomly at four possible locations. The stimulus duration was at least 500 ms/item. The d' 's declined instantly and gradually as the ISI and the number of items increased. In the latter condition, the d' 's collapsed for two items and dropped close to chance level for four items. The results are compatible with noisy representations and the notion of tradeoff between storage capacity and precision.

◆ **Dynamic imagery can enhance contrast sensitivity improvement by imagery**

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Imagery is known to improve contrast sensitivity (Ishai and Sagi 1995), yet its dynamic nature is elusive. We tested psychophysically if contrast sensitivity enhances when we imagine dynamic visual objects such as mental rotation, as well as we imagine static objects. First, participants conducted a 2AFC detection task for the Gabor target. The same Gabor signal was used in the static and dynamic imagery tasks. In each task, memory retrieval was initiated by a pip tone 500 ms prior to the Gabor target presentation. We found that (i) contrast sensitivity of the Gabor target improved by the static imagery task (threshold reduction = 0.15 ± 0.03 log-units, 4 observers). No improvement occurred without imagery; (ii) mental rotation of the Gabor signal produced sensitivity enhancement for rotated targets (-0.14 ± 0.02 log-units); (iii) imagery task after mental rotation indicated persistence of sensitivity improvement (-0.13 ± 0.02 log-units) over hours. The results suggest that (i) not only static but dynamic memory retrieval occurs in low-level visual stage concerning contrast detection, and (ii) active mental operation produces long-term memory persisting hours. The creation of such long-term plasticity by dynamic imagery may be a basis of image training leading to creativity.

◆ **Vertical illusory line motion and implied gravitational attraction**

T L Hubbard, S E Ruppel¶ (Department of Psychology, Texas Christian University, Fort Worth, USA; ¶ Department of Psychology, University of South Carolina-Upstate, Spartanburg, USA; e-mail: timothyeehubbard@gmail.com)

A stationary line preceded by a cue is perceived to 'expand' or 'unfold' from the end of the line nearest the cue to the end of the line most distant from the cue; this has been referred to as illusory line motion (ILM; eg, Hikosaka et al, 1993 *Vision Research* 33 1219–1240). Three experiments examined whether ILM occurred for vertical motion and could be influenced by implied gravitational attraction. In all experiments, a stationary vertical line was presented above or below a cue on each trial, and participants rated (a) velocity of (illusory) motion and (b) whether (illusory) motion was upward or downward. In Experiment 1, distance between cue and line varied. ILM was rated as faster with increases in distance when lines were below cues and slower

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with increases in distance when lines were above cues. In Experiments 2 and 3, SOA between when the cue appeared and line appeared varied. ILM did not occur with 0 ms SOAs, was strongest with 250 ms SOAs, and occurred with 2000 ms SOAs. Results support hypotheses that ILM is a dynamic process that (a) occurs with vertically oriented stimuli and (b) is influenced by implied gravitational attraction.

◆ **Memory modulation of area V1**

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Area V1 is the earliest stage in the cortical processing of visual information where neurons are selective for features such as orientation and spatial frequency. Psychophysical studies of the short-term memory for such simple features indicate that early cortical processing stages, perhaps even V1, are involved in the retrieval of high-fidelity perceptual memory representations. We have tested this hypothesis using event-related fMRI and a region of interest approach. We examined the pattern of neural activation evoked in V1 when subjects performed a delayed spatial frequency discrimination task while simultaneously having to retain spatial frequency information about an irrelevant mask stimulus. The mask affected the accuracy of discrimination depending upon the relative spatial frequencies of the test/reference and the mask, impairing discrimination when it differed in spatial frequency from the test/reference stimuli. This effect, known as memory masking, was observed as a reduced V1 BOLD response during discrimination. We argue that V1 is recruited during retrieval of memory representations of simple visual features. It is proposed that the observed memory masking effect in the V1 BOLD response is the result of lateral inhibitory interactions between competing memory representations.

◆ **Visual short-term memory for abstract patterns across encoding durations: effects of symmetry, element connectedness, and probe quadrant**

H-C Lai, S H-L Chien, S-K Tai, H-Y Hsu (Graduate Institute of Neural and Cognitive Sciences, China Medical University, Taichung, Taiwan; e-mail: sarinachien@mail.cmu.edu.tw)

Previous studies on visual short-term memory (VSTM) often use simple attributes (color, orientation), objects, faces, or natural scenes. With these types of stimuli, it is difficult to rule out the influence of prior knowledge, however. Thus, we intend to explore the nature of VSTM for unfamiliar abstract patterns (on 5×5 grids) using a local-recognition task. The effects of overall symmetry, element connectedness (high vs low), recognition probe quadrant (upper-left, upper-right, lower-left, and lower-right), and encoding duration (100 ms, 300 ms, 750 ms, 3000 ms) were further examined. Each local recognition trial began with a fixation cross, then an abstract pattern of 12 or 13 red squares appeared for a fixed duration, and a probe X located in one of the four quadrants appeared. The subjects' task was to judge whether the X overlapped with the red pattern seen previously. Analysis on accuracy data showed significant and fairly robust main effects for symmetry, element connectedness, and probe quadrant across encoding durations. These findings indicate that the memory was more accurate when the pattern was symmetrical, had a higher connectedness (ie, fewer chunks), and was easier to recall for probes located in the upper-left quadrant. Further data collection is in progress.

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◆ **Recognising random shapes with inverted contrast polarity**

J-F Patri, J Ninio (Laboratoire de Physique Statistique, Ecole Normale Supérieure, Paris, France; e-mail: jacques.ninio@lps.ens.fr)

Six subjects took part in visual memory experiments involving 5×5 random matrix patterns of black or white quadrangles. The images were viewed for 2 s then had to be recognized in the presence of a distractor, the test pair being presented in half the cases with inverted contrast polarity. The recognition error rate increased moderately, from 13% with normal contrast to 15% with inverted contrast on a total of 34 000 tests. The corresponding average reaction times increased from about 1.1 to about 1.4 s. The RT distribution for normal contrast (RT_n) was narrow; that for inverted polarity (RT_i) was wider; it started with the same lag but had a more extended tail. RT_i could be modelled almost exactly as the sum of an RT_n component accounting for 25% of the data, and a modified RT_n component, extended by the addition of a single kinetic step of average duration 0.3 s. This suggests that 25% of the images are recognized without mental inversion of contrast polarity, in agreement with the use of a 'reverse' encoding hierarchy (Ahissar and Hochstein, 2004 *Trends in Cognitive Science* 8 457–464) according to which higher gestalts are more accessible in memory than low-level details.

CROWDING

◆ A visual field asymmetry in crowding

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Previous studies have reported performance advantages in the lower as compared to the upper visual field (Carrasco et al, 2001 *Spatial Vision* **15** 61–75; He et al, 1996 *Nature* **383** 334–337; Liu et al, 2006 *Journal of Vision* **6** 1294-1306) in tasks like orientation discrimination, detection and localization. Here we asked whether there exists an additional visual field asymmetry for the spatial extent of crowding if the asymmetry in spatial resolution is controlled for. To determine spatial resolution, we measured spatial frequency (SF) thresholds for the orientation of single gratings (1 deg diameter, spatially shaped by a static 2-D Gaussian), presented 12° above or below fixation, using a fixed-step-size staircase procedure (two up, one down, ratio $-\Delta/\Delta : 0.5$) (García-Pérez, 1998 *Vision Research* **38** 1861–1881). Next, gratings were flanked by two distractor gratings to the left and right, with SF reduced to $0.75 \times$ threshold. To measure the spatial extent of crowding, we determined the critical distance (Bouma, 1970 *Nature* **226** 177–178; Pelli and Tillman, 2008 *Nature Neuroscience* **11** 1129–1135; Pelli et al *Journal of Vision* 2004 **4** 1136–1169, 2007 **7** 21–36) between target and distractors required to prevent crowding. We observed that when gratings whose spatial frequency in the upper and lower visual field were matched on the basis of SF thresholds, the critical distance was reduced in the lower compared to the upper visual field on average by 0.48°. These results demonstrate that visual field asymmetries are not confined to spatial resolution, but also comprise higher processes such as crowding.

◆ Integration of crowded orientation signals

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It seems well accepted that crowding is related to an integration of feature signals over inadequately large area in visual periphery. However, the exact rules of this integration are far from understood. The present study attempts to understand how the orientation signals from the target and flankers are combined. A target Gabor together with 2, 4, or 6 flanking Gabors was briefly presented in a peripheral location (4 deg eccentricity). The observer's task was to identify the orientation of the target (8-alternative forced-choice). Performance was found to be non-monotonically dependent on target-flanker orientation difference (a drop at intermediate differences). For small target-flanker differences, a strong assimilation bias was observed. The results were not consistent with simple (or weighted) averaging and spatial uncertainty models. The distribution of responses suggests that stimulus pattern may be encoded by a combination of discrete (categorical) and continuous orientation mechanisms.

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◆ On cortical origins of mega surround suppression

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Recently we observed a new powerful type of surround suppression, apparently, due to some form of synergy between pedestal masking and surround masking (VSS08). Conventional surround suppression (masking produced by a matching surround) can be amplified five-fold when coupled with masking produced by the transparently overlaid pedestal. Here we report that when mask and target are shown to opposite eyes the mega suppression is largely unaffected. The dichoptic transfer indicates a cortical origin. On the other hand, the suppression is reduced about two-fold when the mask is presented to the opposite visual hemifield, which indicates that the suppression happens prior to the inferotemporal cortex (TE) level of visual processing, where the neuronal receptive fields are large and mostly bilateral. We also studied the effect of mask onset asynchrony and found that mask shown 40 ms prior to the target produced the strongest suppression. Such forward masking is a distinct feature of the mega surround suppression: masking is simultaneous for the conventional surround suppression and backward for crowding phenomena.

◆ Short-range and long-range linear summation of contrast in central vision: 2 and at least 16 cycles respectively

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At a viewing distance of 1 m, the classical receptive fields (CRF) of typical visual neurons in V1 extend over about 3 mm of the object. Most objects are larger than this meaning that higher visual areas must receive converging inputs from multiple CRFs if they are to encode more elaborate properties of the object by the activities of individual neurons. Contrast detection experiments are a good way of assessing convergence, but most previous studies have concluded that contrast-integration does not extend beyond the short-range of the CRF, and that summation

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beyond this range is purely probabilistic (PS). We challenge this view here by introducing a novel patchy grating stimulus designed to clamp a contiguous region of the retina for integration, thereby controlling for potentially confounding effects of retinal inhomogeneity and neural noise. When interdigitated signals had the same orientation we found short-range linear summation of contrast over about 2 grating cycles, but long-range quadratic summation extending up to at least 16 grating cycles. For orthogonal signals, summation was diminished, consistent with PS across orientations. Model CRFs followed by square-law transduction, additive noise and linear summation computes the long-range contrast-energy here as well as fourth-root summation for other experimental designs, which can masquerade as PS.

SCENE PERCEPTION

◆ Ordinal pairwise method for natural images comparison

J Vazquez-Corral, C Parraga, M Vanrell (Computer Vision Center, Universitat Autònoma de Barcelona, Spain; e-mail: aparraga@cvc.uab.cat)

We developed a new psychophysical method to compare different colour appearance models when applied to natural scenes. The method was as follows: two images (processed by different algorithms) were displayed on a CRT monitor and observers were asked to select the most natural of them. The original images were gathered by means of a calibrated trichromatic digital camera and presented one on top of the other on a calibrated screen. The selection was made by pressing on a 6-button IR box, which allowed observers to consider not only the most natural but to rate their selection. The rating system allowed observers to register how much more natural was their chosen image (eg, much more, definitely more, slightly more), which gave us valuable extra information on the selection process. The results were analysed considering both the selection as a binary choice (using Thurstone's law of comparative judgement) and using Bradley-Terry method for ordinal comparison. Our results show a significant difference in the rating scales obtained. Although this method has been used in colour constancy algorithm comparisons, its uses are much wider, eg to compare algorithms of image compression, rendering, recolouring, etc. [Supported by projects TIN2007-64577, CSD2007-00018 and RYC-2007-00484 of the Spanish Ministry of Science.]

◆ A new cone activation-based natural images dataset

C Parraga, J Vazquez-Corral, M Vanrell (Computer Vision Center, Universitat Autònoma de Barcelona, Spain; e-mail: aparraga@cvc.uab.cat)

We generated a new dataset of digital natural images where each colour plane corresponds to the human LMS (long-, medium-, short-wavelength) cone activations. The images were chosen to represent five different visual environments (eg forest, seaside, mountain snow, urban, motorways) and were taken under natural illumination at different times of day. At the bottom-left corner of each picture there was a matte grey ball of approximately constant spectral reflectance (across the camera's response spectrum,) and nearly Lambertian reflective properties, which allows to compute (and remove, if necessary) the illuminant's colour and intensity. The camera (Sigma Foveon SD10) was calibrated by measuring its sensor's spectral responses using a set of 31 spectrally narrowband interference filters. This allowed conversion of the final camera-dependent RGB colour space into the Smith and Pokorny (1975) cone activation space by means of a polynomial transformation, optimised for a set of 1269 Munsell chip reflectances. This new method is an improvement over the usual 3×3 matrix transformation which is only accurate for spectrally-narrowband colours. The camera-to-LMS transformation can be recalculated to consider other non-human visual systems. The dataset is available to download from our website. [Supported by projects TIN2007-64577, CSD2007-00018 and RYC-2007-00484 of the Spanish Ministry of Science.]

◆ Finding keys under a lamppost: a scene-specific bias for target detection

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There is a tendency for observers to look initially at the centre of an image [eg Tatler, 2007 *Journal of Vision* 7(14):4, 1–17]. The effect has been attributed variously to optimal information processing strategies and artistic bias in test-image selection. It is not clear, however, whether target-detection performance is similarly biased. To address this question, a target-detection task was undertaken with coloured images containing a target at one of 130 possible locations and matched in luminance to its local surround. Each image, subtending approx. 17×13 deg at 1 m, was viewed for 1 s on a computer screen. In all, 20 natural rural and urban scenes were tested. The target was a grey sphere (Munsell N7), subtending approx. 0.2 deg. Detection performance was quantified by the index d' and plotted against target location. A central bias was apparent in performance averaged over scenes, but it disappeared with most individual scenes. For many

scenes, d' correlated positively with local luminance. As a control, when sections of the image were permuted, the position of peak d' migrated with the permutation. For the natural scenes tested here, observers seem better at detecting targets where the image is brighter.
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◆ **Studies of human vision model and recognition: some applications**

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This paper proposes a new method to improve human recognition by artificial intelligence specifically of images without the interference of high frequencies. The human eye is the most delicate optical system. Notwithstanding the dramatic progression of its structure and functions through a long evolution, the capability of visual recognition is not yet close to perfection. This paper is a study, based on the limitations of recognition by the human eye, of image recognition through the application of artificial intelligence. Those aspects which have been explored focus on human vision model, including modulation transfer function (MTF) analysis, noise, lateral inhibition, time/spatial integration of the human eye, human vision recognition characteristics, and various mathematical models for verification. By using images consisting of four black-and-white bands and MTF curve evaluation recognition capability on all the studied models, the optimum model most compatible with the physiology of the human eye is found.

◆ **The perception and aesthetic evaluation of normal and degraded images**

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Relatively few studies have investigated the influence of image quality on the perception and aesthetic experience of photographs. We conducted several investigations that looked at the influence of contrast, sharpness, noise, and colour manipulations on the aesthetic evaluation of natural and human-made scenes. We specifically assessed whether image quality could modulate previous findings showing that people prefer natural scenes such as mountains and forests over human-made scenes such as city skylines and roads (eg, Biederman and Vessel, 2006 *American Scientist* **94** 249–255; Kaplan et al, 1972 *Perception & Psychophysics* **12** 354–356). A large set of high-quality photographs were used, and participants rated normal and degraded versions for liking. Results showed that image quality had an impact on evaluations. For example, high-quality human-made scenes were evaluated more positively than low-quality natural scenes, which confirms the modulating impact of image quality. Additionally, we addressed the individual, paired, and fully combined effects of various aspects of image quality on the aesthetic evaluation of photographs.

◆ **Characterising the spatio-temporo-chromatic (STC) properties of natural scenes**

P G Lovell, C Benton, I D Gilchrist, D J Tolhurst¶, T Troscianco (Department of Experimental Psychology, University of Bristol, UK; ¶ Department of Physiology, University of Cambridge, UK; e-mail: p.g.lovell@bristol.ac.uk)

There is good evidence for an evolved fit between visual systems and the environments within which they have evolved. For example, the peak wavelengths of L and M cones appear to relate to folivory, frugivory, and pelage identification (Sumner and Mollon, 2000, *Journal of Experimental Biology* **203** 1963–1986; Sumner and Mollon, 2003 *American Journal of Primatology* **59** 67–91) and the low-pass spatio-chromatic sensitivities (Parraga et al, 2002 *Current Biology* **12** 483–487) of the primate visual system are well-matched to the task of identifying edible fruit and leaves in a background of natural foliage and branches. However, the ways that the temporal properties of the natural world interact with the spatio-chromatic properties are currently not well understood. We have developed a cone-calibrated high-speed video camera system (200 Hz frame rate) to examine the relationship between the STC properties of natural scenes and the primate visual system. Here we examine how the properties of two classes of temporally varying natural scenes relate to known visual sensitivities: scenes containing behaviourally relevant movement (fruit picking/foraging, changing facial expressions, sign-language communication, tool-use, etc), and potentially behaviourally irrelevant movement (wind-blown grass or trees, water ripples, etc). Our results point to a partial fit between the video spectra and human sensitivity measures.

◆ **Visual perception in aircraft cockpit under real ambient lighting conditions: A procedure for the evaluation of readability and legibility**

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‘Accessibility’ to information is a key issue in the design of any effective display device and human–machine interface in general; this feature is implemented for all foreseen operational

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and environmental conditions. This work focuses on the development of an operative methodology for assessing the readability and legibility of different kinds of display when illuminated with different lighting conditions. During flight, these conditions span across several orders of magnitude, ranging from clear sky with sun in different critical positions, to cloudy sky and to nightlight sky. In every conditions, all cockpit display visual information must be clearly and immediately perceived by pilots. A method based on objective measurements and subjective evaluations to assess display legibility was developed and is presented. The application of the methodology was supported by the use of a Sky Light Simulator (SLS), an innovative ambient lighting facility capable of accurately reproducing the sky-vault diffused luminance, generating a lighting environment as similar as possible to real ambient lighting conditions and to host real aircrafts. With this information we correlate objective measurements and pilot subjective appraisals to identify and propose new indices of visual comfort inside the aircraft.

◆ **Experimental method for verification of formation of centre-symmetrical relations in human visual perception**

S L Artemenkov (IT, MSUPE/MGPPU, Moscow, Russia; e-mail: slart@inbox.com)

Theoretical investigations [Artemenkov and Harris, 2005 *Journal of Integrative Neuroscience* 4(4)] revealed that the process of object recognition taking place during gaze fixation may be characterized by the creation of centre-symmetrical relations (CSR). The dynamic model shows differing behavior for dilating (A) and contracting (B) symmetrical objects changing their size at various speeds: for A the spatial direction of the relation's formation over time does not depend on the speed of dilation; however, for B the direction is naturally opposite for slow speeds and the same for high speeds. This supposes qualitative difference in perception of the A&B objects while size changing speed is increasing and provides an experimental method for verification of the formation of CSR using presentation of these objects within and out of the functional range of motion seeing ($10-55 \text{ deg s}^{-1}$). The results of a brief (10–100 ms) presentation of A&B contoured polygons confirm that for speeds 40 deg/s and higher the perception of A&B demonstrates various predicted effects (eg manifests in reversing the seeing of initial and final locations of A&B objects), which may be used for determination of individual functional limits to the perception of form and movement.

◆ **Modelling visual attention: Putting a saliency model of eye guidance to a test**

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We studied the performance of attention models based on the saliency of low-level image features as proposed by, for example, Itti et al (1998 *IEEE Transactions on Pattern Analysis and Machine Intelligence* 20 1254–1259). Using a change blindness paradigm, thirteen subjects viewed image pairs depicting abstract object arrangements (coloured squares, stars, etc) and complex naturalistic scenes from different categories (landscape, road traffic, desktop). Eye movements were analysed during initial ambient scanning and subsequent focussed viewing of the first image (eg, Pannasch et al, 2008 *Journal of Eye Movement Research* 2 1–19). Cluster analysis of gaze points determined empirical foci of attention. The comparison between these foci and model-generated saliency centres based on stimulus colour, intensity, and orientation produced significant location differences. Even though model foci were significantly nearer to empirical foci than random positions, (geometric) stimulus centres more accurately predicted attention foci than the model. Results throw further doubts on the adequacy of attention models based solely on visual saliency. As suggested by Underwood et al (2006 *European Journal of Cognitive Psychology* 18 321-342) and others, taking into account high-level information such as expected object locations could lead to more adequate modelling of eye guidance and attention processes.

AFTEREFFECTS AND ADAPTATION

◆ **Spatial transfer of 'half-face' aftereffect**

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In a classical face aftereffect paradigm, the right half of a female face was used as the adapting stimulus. Fixation point was located at the centre of the adapting half-face. The strength of the face gender aftereffect was measured for half-face test stimuli in six conditions including the left and right half-faces presented at three non-overlapping positions: centre, left side, and right side of the adapting stimulus. The adapting right half-face produced significant aftereffect for both right and left half-face test stimuli. As expected, the strongest aftereffect was observed for the retinotopic match of the adapting stimulus; the right half-face test presented at the centre. The aftereffect was moderate for both right and left half-faces presented to the left of the adapting

stimulus (the position of the missing half-face of the adapting stimulus). The face aftereffect was minimal for the test stimuli presented to the right of the adapting stimulus. These results suggest that a half-face might excite and adapt a population of neurons that respond to the whole face. The observed spatial asymmetry may reflect nonlinearities of the receptive field structure of face neurons.

- ◆ **Does the protection zone prevent perceptual disappearance in motion-induced blindness?**
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Motion-induced blindness (MIB), is a phenomenon in which perceptually salient stimuli (target) amidst a field of moving dots repeatedly disappear and reappear after prolonged viewing. In MIB, an area surrounding a target and itself surrounded by moving dots is not perceived to disappear; it forms a 'protection zone' that prevents the target from being invaded by the moving dots. In the present study, we presented a shape (with an illusory border or with a solid border) around the target to investigate the protection-zone phenomenon. We manipulated perceptual grouping (shape similarity) and the distance between this shape and the target. The participants were to report the fading of both target and surrounding shape. We found (i) less MIB when the surrounding shape grouped well, than when it grouped poorly, with the target (Experiment 1), and (ii) the MIB increased with the distance between the surrounding shape and the target, and further, not only the target, but also the surrounding shape, was perceived to fade away (Experiment 2). These results imply that the perceived fading is subject to Gestalt grouping, and the formation of the surface by the protection zone affects the perceived fading in MIB.

- ◆ **Ambiguous figures: Different levels of perceptual adaptation**
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Normally our percepts are stable and unambiguous. Ambiguous figures, however, lead to spontaneous perceptual alternations although the figures themselves stay unchanged. After prolonged observation of a disambiguated stimulus variant ('adaptor') the subsequent ambiguous figure is perceived in the alternate variant. This finding is typically explained by low-level adaptation. In the present study we asked at which level of abstraction such adaptation-like mechanisms could be observed. Participants indicated their percepts of three types of ambiguous figures (Necker cube, old/young woman, and face/vase stimulus) after prolonged observation of two classes of adaptors. The first class consisted of unambiguous stimulus variants with only few differences compared to the ambiguous stimuli. The second class of adaptors consisted of highly abstracted stimulus variants (eg the words 'old woman' or 'vase'). The strongest effects of adaptation were found with the Necker cube and there with the first class of adaptors. The other ambiguous and adapting stimuli showed much more interindividual variability. The data suggest that (i) endogenous reversals can be manipulated at different levels along the perceptual processing chain, (ii) the more semantic the ambiguous stimuli and the more abstract the adaptation stimuli are, the more individually the participants behave.

- ◆ **Variance of visual error influences saccadic adaptation**
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Saccadic adaptation is an important method to get insights in motor control. Nonetheless, its exact mechanisms and loci are still under debate. Especially the assignment of adaptation to motor and visual components is a topic of major interest. Recently, the interplay of multiple mechanisms of different time scales explained the time course of adaptation experiments. Whereas there is growing agreement towards the existence of multiple mechanisms, there are diverse suggestions for their interaction. The influence of different forms of noise is a possible regressor on error assignment. Therefore, the accuracy of visual information is supposed to have an effect on the error correction behaviour. Thus, the consistency of visual error is of importance and should lead to different adaptation characteristics. We extended a classical adaptation paradigm with a method of constant error size. In this method, target step sizes are calculated with respect to a predicted landing position. To induce a change in error size, variability was introduced to this target step. Depending on the variability of the presented visual error, variations in the adaptation behaviour were found. This study is contributing to the clarification of the role of the error consistency and the interplay of mechanisms in saccadic adaptation.

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◆ **Retinotopic organization of high-level aftereffects**

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Spatial transfer of visual-form adaptation across saccadic eye movements has been a debate in recent years. In our study, we wanted to demonstrate if there is spatial aftereffect either for viewpoint aftereffects or identity-based aftereffects (after adaptation to an anti-face, an average face is identified as the face opposite to the anti-face with above chance probability). We first established baseline strengths for both of these aftereffects by measuring adaptation while both of the adaptor and the test were presented at the same retinotopic (and spatiotopic) position. We then re-measured the effects, with a saccade intervening between adaptor and test, when the two stimuli were in the same spatial position (spatiotopic) or when in different spatial positions (matched in eccentricity and retinotopic displacement). None of these two high-level adaptations transferred across saccades. Our result is in contrast with some of the previous studies, which demonstrated that the basic shape information is combined across saccades. We propose those spatial aftereffects, which were found in some studies, could be originated from a general, small remote aftereffect that is enhanced specifically at the spatiotopic locus, probably by specific attention toward that point.

◆ **Multistable perception is never memoryless**

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When our visual system switches between multiple interpretations of the visual scene—a phenomenon dubbed multistable perception—the durations of successive periods of stability are thought to be statistically independent. This property is regarded as a hallmark of rivalry, but is very surprising, given the susceptibility of perceptual dominance to adaptation. We investigated this puzzling contradiction by assessing the predictive power of cumulative history, computed assuming a perfect integrator with exponential time constants τ , for future dominance periods. We find a significant correlation between cumulative history and the next dominance phase duration for $0.3 < \tau / \langle T_{\text{dom}} \rangle < 1$ (correlation coefficient 0.2–0.5, where T_{dom} is the mean dominance phase duration, stimuli—binocular rivalry, KDE). The observed dependence is consistent with adaptation: negative for same and positive for dominance duration of an opposite percept. Cumulative history also affects transition phases: their durations as well as likelihood of return transitions peak when histories are balanced. Computational simulations of a simple rate model show that a system like this should operate close to the bifurcation line in a bi-stable rather than oscillatory regime, indicating that noise is indispensable for the phenomenal alternations. In conclusion, multistable perception, even during continuous presentation, depends significantly on history of preceding phenomenal alternations.

◆ **Figure plane binds the depth-after-effect**

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Occluding contours determine figure–ground relations and might be crucial for a surface-based interpretation of depth, associated with relative location invariance of depth representations. We address the extent to which a depth aftereffect is location dependent when figure–ground relations are available in the monocular image. Observers adapted to a random dot stereogram depicting a figure in front of a constant background. Figure–ground relations were defined by local contrast. Next, observers adjusted the depth of a test figure until the distance to its background matched a handheld reference object. We varied the overlap in spatial location and occluding contour between the adaptation and test stimulus by testing with the identical, the inverse figure, or a scaled-down version of one of the two figures. Perception of the test figure's distance to the background was biased in the direction opposite to the distance of the adaptation figure (a depth-after-effect) regardless whether there was overlap in spatial location or contour between the adaptation and test figure. A control experiment, where observers adapted to a small central square, showed that the location-invariance of the aftereffect was not due to surface-interpolation. We conclude that the depth aftereffect is not location dependent. Instead, it is figure-plane specific.

◆ **Centre – surround inhibition and the motion aftereffect in migraine**

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The hypothesis that cortical neural hyperexcitability exists in migraine has received considerable support, however, the underlying mechanism of hyperexcitability is unknown. One controversial theory is that hyperexcitability arises due to reduced cortical inhibition. In this study we indirectly measured cortical inhibition using two visual motion tasks for which performance is believed to be governed by centre-surround inhibitory processes in normal observers (Tadin et al, 2003 *Nature* **424** 312 – 315). These tasks utilize the initially counter-intuitive observation that determining direction of motion is more difficult for stimuli of increasing size and contrast. Likewise, motion-after effects (MAE) are weaker with increasing size and contrast. The hypothesis of reduced inhibition in migraine predicts better detection of motion direction of stimuli susceptible to inhibition, and that the MAE magnitude for larger high contrast patterns will not decrease equivalently in comparison to control participants. Performance was assessed for 22 migraineurs (12 with visual aura) and 20 non-headache controls. Sample size was estimated a priori from the mean and variance of the young adult group of Betts et al (2005 *Neuron* **45** 361 – 366) [assuming a desired power of 0.80, a difference in mean direction discrimination threshold of 30 ms requires a sample of 16 in each group]. Evidence for reduced inhibition in the migraine group was not demonstrated for either the motion direction detection (ANOVA: $p = 0.37$) or MAE (ANOVA: $p = 0.17$) tasks. Our findings do not support the theory of a reduction in cortical inhibitory function in migraine.

◆ **Adaptation to biological motion leads to motion and form aftereffects**

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Motion aftereffects (MAEs) exist not only for low-level first-order but also for high-level second-order motion. We observed two novel kinds of higher level aftereffects, the biological motion aftereffect (BMAE) and the biological motion form aftereffect (BMFAE). We performed two adaptation experiments to walking (forward or backward, Experiment 1) or facing direction (rightward or leftward, Experiment 2). The stimulus was a point-light walker whose points had a lifetime of a single frame to avoid adaptation to local motion signals. After 20 s of adaptation an ambiguous stimulus was presented that was composed of a mixture of points from a forward and a backward walking walker (Experiment 1) or from points of a rightward and a leftward facing walker (Experiment 2). Participants reported the dominant walking or facing direction. By varying the ratio between forward and backward points (Experiment 1), or between rightward and leftward points (Experiment 2) we measured the point of subjective equality (PSE) of the two directions in the ambiguous stimulus. We observed a PSE shift depending on adaptation directions. We conclude that adapting to biological motion induces aftereffects at a perceptual form processing and a body motion analyzing stage.

◆ **Chaser illusion and opponent colour aftereffects**

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In our experiment we use a modified 'Lilac chaser' illusion—a circle of twelve patches on the grey background, arousing the sense of movement by the sequential disappearance of circles. The participants adjust the central circle hue, lightness, and saturation values to match it with the appearing aftereffect colour. Moving around the hue circle in similar steps we determined the opponent colours aroused by the negative aftereffect. The luminances of the test hues are held constant. The fixation point was jittered from side to side of the match circle to avoid local adaptation and to obtain more stable results. Our experiments show that the adjusted hues shift from being linearly opposite to the test hues and tend to cluster around the unique colours.

◆ **Detection of a novel aftereffect: Angle adaptation**

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Low level and high level aftereffects are widely studied while intermediate level adaptation has been neglected. In this study, we examined whether adaptation to angle size (as an intermediate level aftereffect) is detectable while adaptation to line orientation is excluded. Six subjects were first trained to discriminate between obtuse and acute angles. In two experiments subjects were adapted to acute angles and obtuse angles while there was no adaptation phase in the third experiment.

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In the first two experiments, test stimuli were rotated so that low-level adaptation (orientation adaptation) and apparent motion could not interfere with each other. The data from experiments 1 and 2 were pooled and compared to the results of experiment 3 (non-adapted response). The analysis revealed a statistically significant difference between the results of the three experiments. There was also a significant difference between adapted and non-adapted conditions. Mean area between psychometric functions was defined as the adaptation index, which reached 2.81 and was significantly larger than 0 ($p = 0.023$). The results demonstrated an adaptation to angle size in the absence of orientation adaptation, suggesting that there are neurons detecting angle magnitude in the human visual system.

◆ **Re-calibration of subjective reference frame in the tilt illusion**

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Contextual information can have a huge impact in our sensory experience. The tilt illusion is a classic example of contextual influence exerted by an oriented surround on a target's perceived orientation. Gain-control models explain the tilt illusion as the outcome of inhibition between cortical neurons with adjacent receptive fields and a similar preference for orientation. Alternatively, tilted contexts could produce a re-calibration of the subjective frame of reference. Although the distinction is subtle, only the latter model makes clear predictions for unoriented stimuli. In the present study, we tested one such prediction by asking four naive subjects to estimate three positions (4, 6 and 8 o'clock) on an imaginary clock face within a tilted surround. To indicate their estimates, they used either an unoriented dot or a line segment, with one endpoint at fixation in the middle of the surround. The results showed systematic biases consistent with the tilt illusion in both the conditions. Biases were largest when observers attempted to estimate the 4 and 8 o'clock positions, but there was no significant difference between data gathered with the dot and data gathered with the line segment. This finding supports the idea that tilted contexts distort perceived positions as well as perceived orientations. For example, points below fixation actually appear to be below and somewhat to the right of fixation when the context is ~ 25 degrees clockwise of vertical.

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