Universidade do Minho
Escola de Psicologia

Janete Sequeira da Silva

“Everything spins on my head”: Clinical relevance of visual-vestibular integration in Motion Sickness and Acrophobia phenomena

Outubro de 2014

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Professor Doutor Jorge A. Santos

e coorientação do
Doutor Carlos M. Coelho

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Declaração

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Mestrado Integrado in Psicologia da Universidade do Minho

"Everything spins on my head": Clinical relevance of visual-vestibular integration in Motion Sickness and Acrophobia phenomena

Janete S. da Silva

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This study addresses the question of the associations between motion sickness and acrophobia, as visual-vestibular conflict phenomena. Using a Virtual 3D Rod and Frame Test (V3DRFT) and considering previous scoring methods' limitations, it is proposed a new way to measure and represent visual field dependence (study 1). We aim to explore the associations between motion sickness, acrophobia and visual field dependence, as well as the applicability of the developed scoring method (study 2). It was found that PSV shows a linear relationship with frame tilt and that individual slopes seem to be a good indicator of visual field dependence. The bigger the slope, the more dependent is the individual. Motion sickness and acrophobia indicators show high to moderate correlations (Motion Sickness Questionnaire (MSQ) is highly correlated with Acrophobia Questionnaire (AQ) - $r=0.8$, $p<.01$ - and moderately correlated with Behavioral Avoidance Test (BAT) - $r=0.67$, $p<.05$), supporting the hypothesis that these two phenomena share some common etiology. We fail to demonstrate any association between visual field dependence and motion sickness and acrophobia. Although the limitations, we think that our scoring methods show advantages comparing to previous ones and that RFT can be, in future, a good measure of visual-vestibular integration.

Keywords: *Visual-vestibular integration; Motion Sickness; Acrophobia; Visual Field Dependence; Rod and Frame Test.*

Mestrado Integrado in Psicologia da Universidade do Minho

"*Everything spins on my head*": Relevância Clínica da integração visuo-vestibular em fenómenos de Enjoo de Movimento e Acrofobia

Janete S. da Silva

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Carlos M. Coelho

O presente estudo explora a possibilidade de desordens como o enjoo de movimento e medo de alturas partilharem etiologias comuns, nomeadamente um conflito visuo-vestibular. Foi utilizada uma versão virtual 3D do V3DRFT, uma medida da dependência do campo visual. Considerando as limitações dos métodos de cotação prévios, propõe-se uma nova forma de medir e representar a dependência do campo visual (estudo 1). Tem-se ainda por objectivo explorar as associações entre enjoo de movimento, acrofobia e dependência do campo visual, assim como avaliar a aplicabilidade do método de cotação desenvolvido (estudo 2). Os resultados permitiram verificar uma relação linear entre os pontos de verticalidade subjectiva (PSV) e a inclinação da *frame*. O declive dessas rectas parece ser bom indicador da dependência do campo visual. Verificou-se ainda que o enjoo de movimento se encontra moderado a altamente correlacionado com a acrofobia (MSQ e AQ - $r=0.8$, $p<.01$; MSQ e BAT - $r=0.67$, $p<.05$), fortalecendo a hipótese de que ambos partilhem uma etiologia semelhante. Não foi possível demonstrar qualquer associação entre a dependência do campo visual e enjoo de movimento ou acrofobia. Apesar das limitações, consideramos que o método de cotação desenvolvido possui vantagens comparativamente com os anteriores e que o RFT poderá constituir futuramente um bom método de medição da integração visuo-vestibular.

Palavras-chave: *Integração Visuo-vestibular; Enjoo de Movimento; Acrofobia; Dependência do Campo Visual; Rod and Frame Test.*

"Everything spins on my head": Clinical relevance of visual-vestibular integration in Motion Sickness and Acrophobia phenomena

Most of our daily experiences involve synchronous, redundant and complementary information from different sensory modalities, causing our perception of the world to be multisensory by nature (Mahoney, Li, Oh-Park, Verghese, & Holtzer, 2011). For instance, if a talk is heard and seen at the same time, we can have access to multiple lip movements, facial expression, pitch, speed, and temporal structure of the speech sound (Keetels & Vroomen, 2007).This raises the question about how can we form a coherent representation of the world, turning everything clear and understandable.

Many authors have been interested in understanding how brain processes and integrates multisensory information. One critical feature in combining sensory information is the perception of synchrony (Spence & Squire, 2003). A commonly held view about synchrony among researchers is the concept of *Multimodal Integration Window*, which defines the thresholds between two or more unimodal events are best perceived as a unity rather than single events (Vroomen & Keetels, 2010).

Therefore, studies have been concerned about how can we measure and quantify multisensory processes (a)synchrony (Vroomen & Keetels, 2010). Most part of these studies focus three major sensory modalities - vision, hearing and touch -, combining them in *Audio-Visual (AV)*, *Audio-Somatosensory (AS)* and *Visual-Somatosensory (VS)* perception (Mahoney et al., 2011). Interestingly, or even surprisingly, little is known about *Visual-Vestibular (VV)* interaction. This might be due to the difficulty to supress the vestibular channel (Lackner & DiZio, 2009). Nonetheless, a congruent processing of VV interactions is required on a huge variety of daily-required occurrences. For example, those that involve motion and balance and accurate perception of verticality to make judgments about the orientation of an object in the gravitational field (e.g., Anastasopoulos, Bronstein, Haslwanter, Fetter, & Dichgans, 1999; Vingerhoets, De Vrijer, Van Gisbergen, & Medendorp, 2008), to keep stability and control of body and head posture (e.g., Gascuel, Payno, Schmerber, & Martin, 2012; Rosander & Hofsten, 2000) or to perceive and control *self-motion*, orientation and navigation (e.g., Butler, Smith, Campos, & Bülthoff, 2010; Wilkie & Wann, 2005).

Particularly, the interaction between the visual and vestibular systems has a special role when distinguish self-motion and environment's movement, once moving visual scenes may be perceived by an individual as he/she is moving in a stationary environment or is static and surroundings are moving (e.g., *vection illusion*). Still, self-motion happens not only when an individual is in movement himself/herself, but when is moving passively inside a vehicle, a boat or a plane (Brandt et al., 2002). In this last case, confusion about spatial orientation and incongruence between visual and vestibular cues usually happens. Consequently, physiological responses as sickness, nausea, vomits and palpitations arise (Balaban & Yates, 2004). This difficulty to integrate visual and vestibular cues was also related to well-known phenomena like vertigo, motion sickness (Young, 1982) and with fear of heights (Bles, Kapteyn, Brandt, & Arnold, 1980; Coelho & Wallis, 2010).

Accordingly, this work will be particularly focused in motion sickness and acrophobia. We will begin with a short explanation of how VV integration may be an explanation for these two phenomena.

Motion Sickness

Motion sickness is a natural organic and funtional respose of the organism to certain types of real or apparent motion, occuring in environments like cars, boats, airplanes, simulators or space, and is typically charatezied by symptons like nausea, vomiting, pallor and cold sweating (Benson, 1984).

The proposal that motion sickness might be caused by a conflict in processing multisensory cues has been proposed a long time ago (e.g., Claremont, 1930). Since, different theories have been trying to explain the causes of motion sickness. Reason suggested the *Neural Mismatch Theory* (1970), the most accepted at the moment, which sees motion sickness as a response of the organism to a visual-vestibular sensory conflict as the main aetiological factor. This theory suggests that a conflict would not only occur between visual and vestibular signals, but also with the expectations that one anticipates to receive. For example, when somebody is reading inside a vehicle in motion, vestibular and somatosensory cues, provoked by the vehicle motion, differ from those that were expected from visual system since the former signal. According to this theory, the central nervous system, compares the signals from the different sense organs and a neural store of the expected signals and, in this case, would produce a *mismatch signal* causing signals and symptoms of motion sickness (Benson, 1984). This model is represented in the next figure.

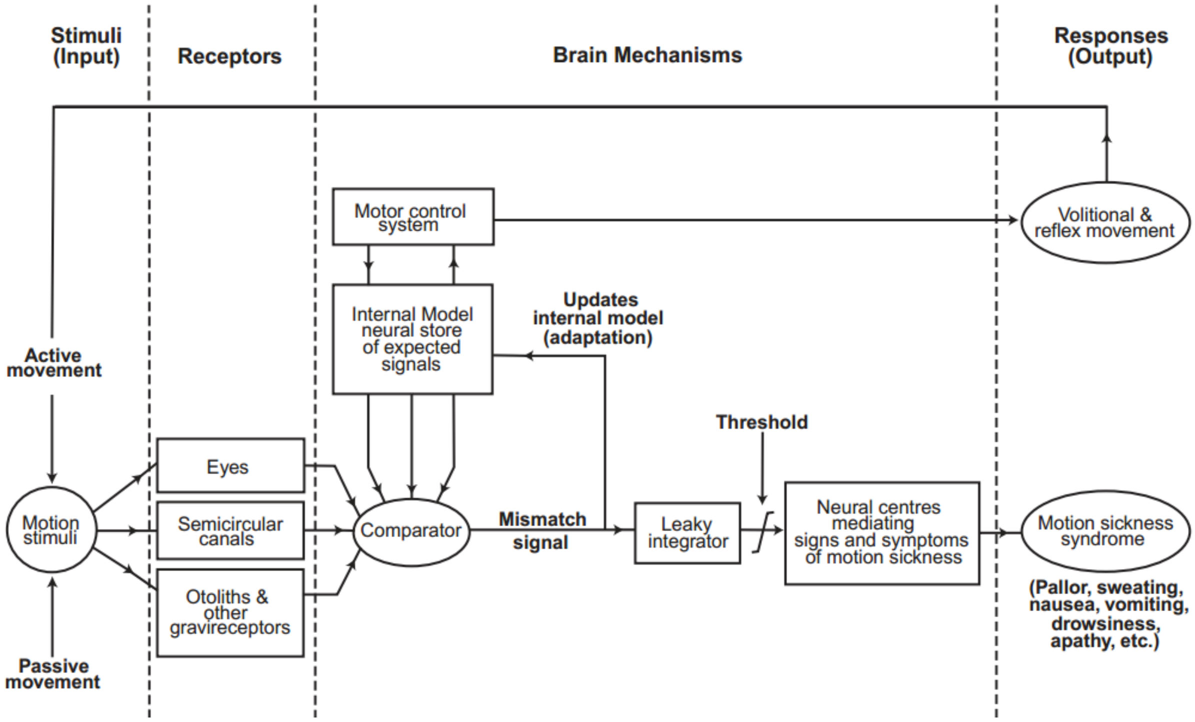


Figure 1. The neural mismatch theory – a heuristic model of motion sickness (Reason, 1970). This figure represents a heuristic model that explains motion sickness through a "neural mismatch" theory. This model considers that motion sickness may occur as an individual response to mismatch signal detection between visual and vestibular systems (eyes, semicircular canals and otoliths and other gravireceptors) during active or passive movement (input). In Benson, 1984 (pp. 397).

This theory also proposes that, because sometimes a person may be exposed to an atypical situation and don´t experience motion sickness, there must be a threshold between the leaky integrator and the neural systems that produce motion sickness. Thresholds represent a key factor in this theory once they allow explaining individual differences in terms of susceptibility and order in which the signals appears (Benson, 1984). We propose that, this threshold might, in fact, be a VV threshold, similarly to the one we discussed previously, relative to multimodal integration and the perception of unity.

Several studies have been supporting the idea underlying the Heuristic model of motion sickness (Reason, 1970), showing that visual vestibular conflict may not only be related to this phenomenon, but also represent an aetiological factor (e.g., Kennedy & Fowlkes, 1992; Stanney & Salvendy, 1998). Similarly to motion sickness, Bles et al. (1980) suggested that fear of heights might also be due to a conflict between visual, somatosensory and vestibular senses.

Fear of heights

Acrophobia is an anxiety disorder in which patiants show an extreme fear of being exposed to heights. Acrophobia characteristically involves the avoidance of apartments and workplaces located in high buildings, bridges and elevators. This disorder has a high prevalence, afecting 1 in 20 people (Depla, ten Have, van Balkom, & de Graaf, 2008), disturbing daily and social life.

Currently, the phobias are conceptualized by two main approaches. These theories are basically discussions about the origin of phobias, hung up on the question of what is learnt and what inherited. One, based on cognitive models, considers that phobia occurs when feelings of anxiety are learn to be an evidence of actual danger, even when it's not (e.g., Arntz, Rauner, & van den Hout, 1995). By other side, an evolutionary based theory defends that fear are not learnt, but represents a sample of manifestations that were evolutionarily programmed to occur when facing threat stimuli. However, and beyond criticisms, these approaches leave behind an answer to a fundamental question: "What are the precise causes of acrophobia?" (Coelho & Wallis, 2010).

Recently, concerned about this question, Coelho and Wallis (2010) explored a hierarchical perspective of acrophobia and found that visual field dependence, postural

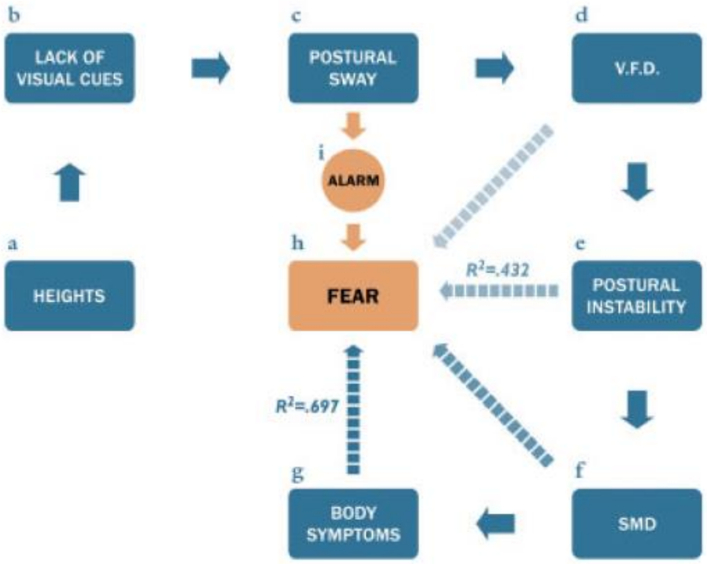


Figure 2. Acrophobia physiological and psychological precursors. In heights (a), the distance between the observer and the objects in the visual field becomes too large, decreasing available visual cues (b), resulting in postural sway (d). Fear seems to appear when individual tends to be visual field dependent – VFD (d) and postural instability (c), to experiment space and motion discomfort – SMD (f), and a strong negative reacting to body symptoms (g). In Coelho and Wallis, 2010 (pp. 869).

instability, space and motion discomfort, and body symptoms seems to be the dimensions underlying acrophobia, independently of any underlying trait anxiety (figure 2). Previously, Coelho et al., (2008) observed that participants exposed to heights showed more fear while moving along the balcony than when they were in higher heights or viewing the fear-evoking scene without movement. These results seem to suggest that trait anxiety may not be appropriate to explain fear of heights in a large number of individuals and yields the suspicion that acrophobia should be related with some visual-vestibular trigger.

Motion Sickness, Acrophobia and Visual Field Dependence

Visual Field Dependence was a term that emerged on the 50's with the development of a well-known and very popular methodology at that time, the Rod and Frame Test (RFT) (Asch & Witkin, 1948a, 1948b). In this task, participants typically are asked to align a bar (rod) that is located inside a frame square in to a subjective vertical position, as shown in figure 3. What is interesting in RFT is that through this method we can see that subjective vertically tends to be influenced by the frame tilt, usually in the same direction (RFT effect), and it allows to distinguish individuals which are less or more influenced by the frame tilt, usually called visual field independent (VFI) and visual field dependent (VFD), respectively. VFD seems to dependent a lot on visual cues to judge vertically, while VFI seems to use mainly vestibular information to do the same judgment. So, this method is privileged in measuring VV integration windows, once subjective verticality seems to depend both on visual and vestibular cues, as earlier mentioned.

As we are considering motion sickness and acrophobia as visual-vestibular phenomena, it seems relevant to study the associations between them and RFT, and even more when previous studies have found some controversial results. Barrett and Thornton (1968) and Kennedy (1975) revealed that VFD individuals (performed on RFT) are less susceptible to feel motion sickness, while Long, Ambler and Guedry (1975) found exactly the opposite. Concerning acrophobia, it was found

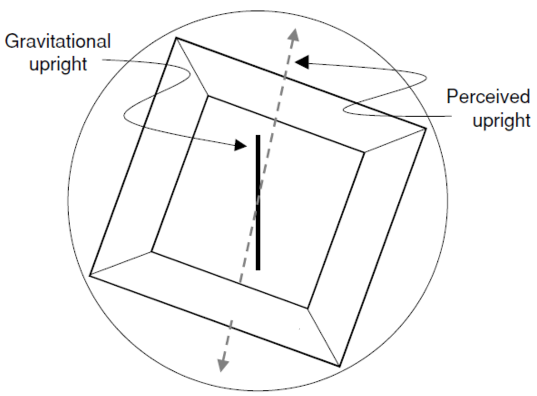


Figure 3. Eye view of RFT apparatus. This image shows the RFT effect produced by a frame tilt of 15° (right). The perception of the upright or the subjective vertical differs from the gravitational upright, typically in the direction of the frame tilt. In Corbett & Enns, 2006 (pp. 161).

that VFD subjects are more susceptible to fear heights than VFI (Coelho & Wallis, 2010; Willey & Jackson, 2014).

In that sense, this dissertation project will try to answer general questions like "Do acrophobia and motion sickness share a common explanation based on VV integration?", "If so, do they seem to co-occur?", "What's the relation between them and visual field dependence?" and "Can we use VFD instruments to measure VV integration?".

Although RFT, as a measure of visual field dependence, has been frequently used and replicated (Oltman, 1968; Isableu, Gueguen, Fourré, Giraidet, & Amorim, 2008), some limitations in scoring methods should not be ignored. The most common and conventional one is the mean degrees absolute deviation (AD) (Witkin et al., 1967 as cited in Reger et al., 2003), which represents the average distance to mean values of subjective vertical. Comparing to AD, Algebraic scoring method (ALG) shows the advantage of considering the direction of rod placement tilt relative the frame rotation (Morell, 1976 as cited in Reger et al., 2003). Handle even proposed another method that reflects the separation of the errors that are given in the direction of the frame (TERR) and on the opposite direction (AERR) (Morell, 1976 as cited in Reger et al., 2003). Considering the advantages and limitations of each one, we'll try a new approach on analysing RFT scores and representing visual field dependence. Therefore, we aim to 1) find a new and fairly scoring method to represent visual field dependence; 2) assess the associations between motion sickness and acrophobia as visual-vestibular phenomena; and 3) understand the relationships that motion sickness and acrophobia established with visual field dependence, as an attempt to clarify previous findings.

Study 1. Visual Field Dependence – A new scoring method

The purpose of this first study was to find a new objective way to analyse and represent the results of RFT. We thrive to find a function that represents the results and works like a continuous representation of the visual field dependence, with the ability of predict intermediate values. Also, it is expected that this method represents an effective way of reducing the uncertainties associated to previous measurements.

Materials and Methods

Subjects. Were collected data from 17 participants, 9 male (M_{age}=27,2; SD=6,12). Participants were students and had normal or corrected to normal vision and no postural or vestibular problems. They were informed about the aim of the study and gave informed consent to participate as required by Helsinki declaration and the Ethics Committee of University of Minho.

Behavioral Measures. In this study we intended to use RFT as a measure of visual field dependence. However, despite of re-inventions and corrections done this methodology during all these years (e.g., Oltman, 1968; DiLorenzo & Rock, 1982), methodological inconsistences still be reported (e.g., Reger et al., 2003; Lester, 1968). Following Reger et al. (2003) findings, we decided to use a recent replication, the Virtual 3D Rod and Frame Test (V3DRFT). This method has proved its capacity to measure visual field dependence, showing good validity and reliability, and improving previous glitches. Still, following Butler et al. (2010), V3DRFT uses a new way task, replacing the typical adjustment task for a dual-forced choice task (2FCT), a more reliable psychophysics task.

Materials. This study was developed in the Laboratory of Visualization and Perception (LVP), CAVE (Cave Automatic Virtual Environment), a dark room where 3D graphics are projected, creating an immersive environment.

We used 3 PC's Cluster with NVIDIA® Quadro FX 4500 Graphic Boards, with Biomose, a custom made software which displays accurate stimuli based on VR/Juggler and OpenGL, specially designed to perform psychological tests. Each PC is connected to a DLP projector Christie Mirage S+4K, with a resolution of 1400x1050 pixels and a frame rate of 96 Hz in stereo mode. The images are continuously projected on a PowerWall-like surface with a dimension of 3x9m. Long range infrared emitters and Stereographics/RealD Crystal Eyes3 eyewear were used to visualize the 3D immersive environment.

Stimuli. Stimuli were programed in a XML format file and projected through Biomose. The standard measures of RFT followed Asch and Witkin (1948a) procedures. The frame is virtually represented in the form of a parallelepiped with dimensions 30x30x60cm, 1cm wide, occupying 46% of the visual field, once participants were placed at 60cm of the screen. The rod is 20cm long and 1cm wide.

The definition of frame and rod tilts was based on previous procedures (Zoccolotti, Antonucci, & Spinelli, 1993; Isableu et al., 1997, 1998). Once the goal of this first study was to find a function that would be able to represent and predict the results of each participant, we found that 7 points should be appropriate to find a good fit. Consequently, in this study, possible values of frame tilt are -9º, -6º, -3º, 0º, 3º, 6º and 9º and rod tilt are -5°, -3°, -1°, 1°, 3° and 5º.

Combining 7 possible frame tilts and 6 rod tilts, repeated 10 times each, the final design was *7x6x10*, resulting in 420 total trials.

Apparatus. The data were collected in a dark silent room. Participants were using Stereographics/RealD Crystal Eyes3 eyewear. A chair was placed in a position aligned with the center of the projection scene and at 0.6m of distance from the screen. A chinrest was used to maintain the head in a vertical and stable position. This support was placed in a platform in a way that eyes level coincides with 1.2m heights, the centre of the projected image. A table was located in the right side of the subject, where was a mouse pad used to give the responses to RFT task. All the apparatus, including the subject, were covered with a black cloth to avoid any reflection from the screen, which could introduce visual artefacts.

Statistical analysis. Data analysis was performed using OriginPro8® and EXCEL.

Procedure. Participant was invited to fill a demographic questionnaire and to report any visual, postural or vestibular problem that could preclude her/his participation. The main goals of the study were explained and the consent to participate was filled. The participant was informed that had the right to give up from her/his participation at any time. The participant was routed to the apparatus scene and sat on the chair and put the Stereographics/RealD Crystal Eyes3 eyewear.

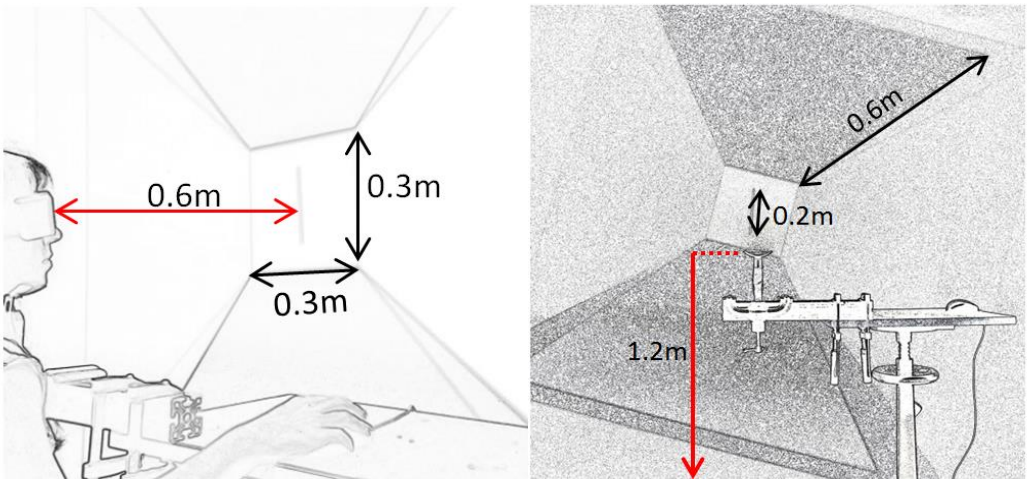


Figure 4. Representation of the apparatus. On the left, it is represented the RFT projection with 0.3x0.3m. The participant is sited at 0.6 of the screen, using Stereographics/RealD crystal eyes3 eyewear and giving answers using a mouse pad. On the left, is represented a far view of the same scenario. The rod has 0.2m length and the eyes are 1.2m distant from the ground.

Before the beginning of the experience, subjects were present submitted to a control procedure. This was made to see if the participant was able to see stereoscopic images and, if so, if any visual discomfort was felt, typically associated to a) accommodation-vergence conflict, b) parallax distribution, c) binocular mismatches, d) depth inconsistencies, and e) cognitive inconsistencies (Tam, Speranza, Yano, Shimono & Ono, 2011). There are no standard methodologies for the measurement of visual comfort for stereoscopic images, so, at least, recommendations that consider picture and depth quality were followed (Tam et al., 2011). It was used an example of a stimulus, continuously presented during some minutes. Participants were asked to describe what they were seeing and to locate the rod bar in depth.

After the control procedure, participants were informed about the following instructions: "*As I notice you earlier, you´ll participate in a perception study. You will be presented with stimuli analogous to this one you were seeing, in which you have a bar inside a frame. We want you to focus the bar because you´re task is to make a judgment about its position, using the mouse pad you have on this table. If you think the bar is tilted left, you should press the left mouse key. Instead, if the bar appears to be tilted to the right, you press the right key. The stimuli presentation will be fast, so we would like you to give an answer as fast as possible, right after the stimulus presentation. Try not to miss any trial, being as accurate as possible. During all the experiment, you should maintain your head in a vertical position, putting your chin in this chinrest*".

The first part of the experiment was a training procedure which ended when the task was perfectly understood and no missing values were being done (more than twenty consecutive trials with no missing values). The experimenters were able to follow the participants' answers and observe when the participant was adapted.

After training, participants were informed about the beginning of the experiment. The experiment included a block of 420 trials presented randomly. Following Thorpe and Fabre-Thorpe (2001) results, each trial has the duration of 1s, 0.5s to stimulus presentation and 0.5 of Inter Stimulus Interval (ISI), once 0.5 was found sufficient to process complex stimuli. The experiment takes approximately 11 minutes to complete.

Results

Eight participants were excluded due to an excessive number of missing values (more than 3) or response bias (number of responses to the left or to the right above 55%). The remaining 9, 5 were females, with Mean age of 28.8 (SD=6.2).

During the experiment, a count of the number of right and left responses for each rod tilt stimulus was recorded. For each rod angle value, the proportion (p) of right responses was computed and a psychophysical function was constructed (S-shaped logistic psychometric curve) by fitting data to a Cumulative Distribution Function (CDF).

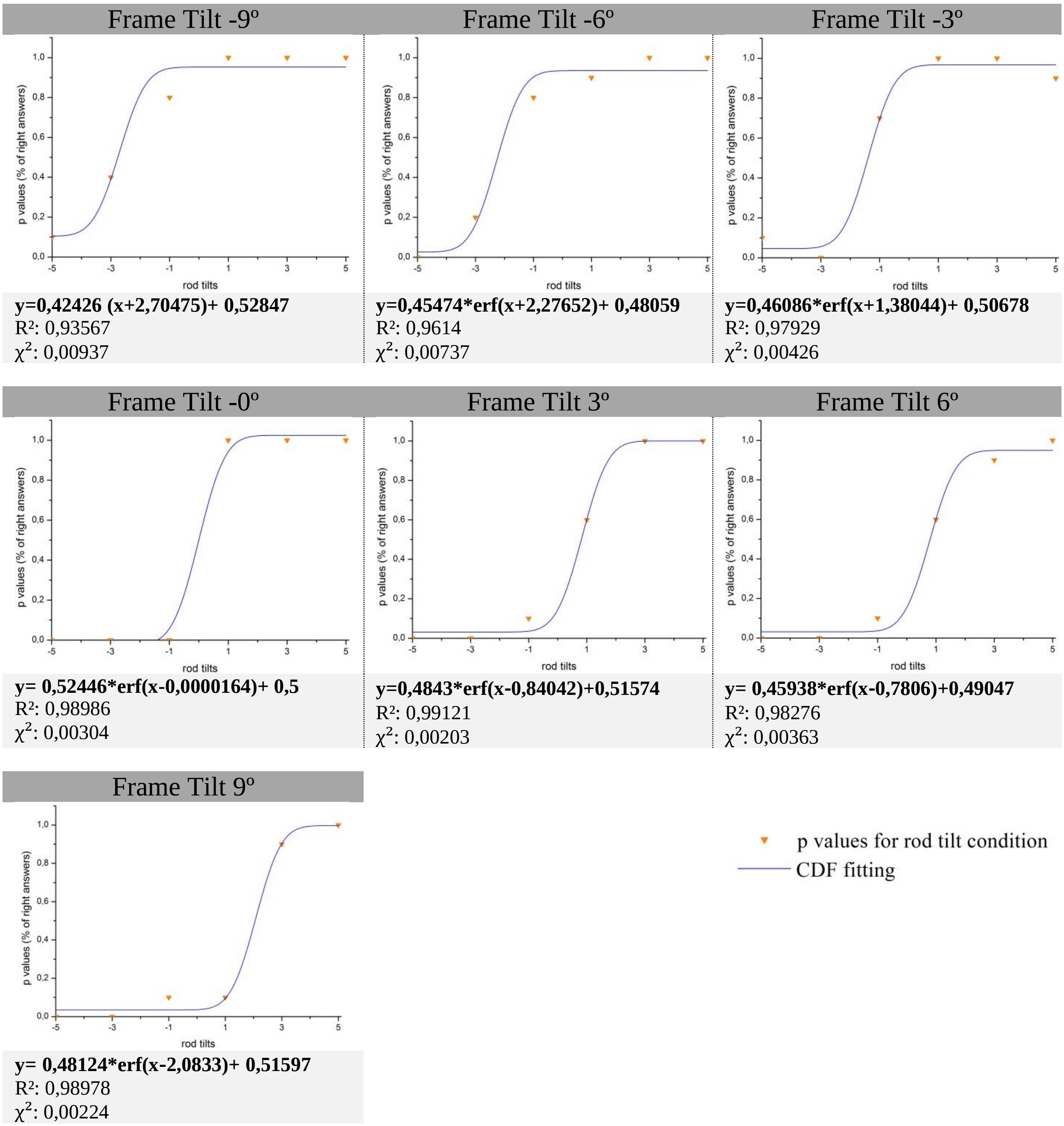


Figure 5. Example of cumulative distribution function (CDF) fit (p1 data). This image represents the CDF fitting of p values (% of right answers) as a function of rod tilt for each frame rotation condition. Relevant information about the fit is shown below graphs (equation of each function in the form *y=A*erf(x-x0)+y0* and quality of the adjustment: R^2 - adjustment r-square – and χ^2 - reduced chi-square).

This function is represented by the expression *y=A*erf(x-x0)+y0*, where y means the proportion of right answers, y0, A e x0 are constant values and *erf* is the error function, given by $\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}}.\int_0^x e^{-t^2} dt$ (Gescheider, 1997). This procedure was repeated for each frame tilt condition and each participant (see figure 5 example).

CDF fitting allows the determination of Point of Subjective Vertical (PSV) as we named it. PSV represents the rod tilt that is seen as vertical, which is represented by p values of 0.5 (see figure 6). This means that the percentage of right side answers is the same as the left side one. We determined the PSV values for each frame tilt, resulting on 11 PSV values for each participant. These values were extracted from the resulted CDF fitting and are represented on table 1.

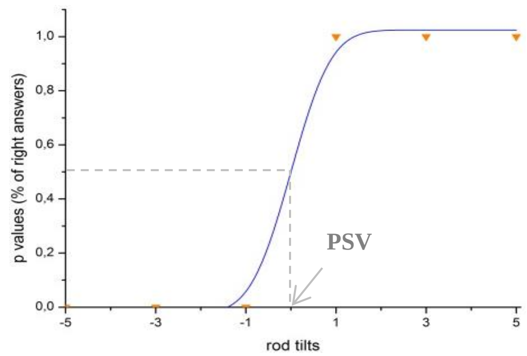


Figure 6. Point of subjective vertical (PSV) determination. This image represents an example of CFD fit. Y axis represents p values (% of right answers) and x axis the rod tilts (in degrees). PSV is the rod tilt value which corresponds to a p value of 0.5. In this case, PSV is approximately 0 for a frame with 0º of tilt.

Table 1

Individual PSV values relative to each frame tilt condition.

	Participants								
Frame Tilt	p1	p2	p3	p4	p5	p6	p8	p9	p12
-9º	-1,54	-3,69	0,315	-3,379	-3,659	-2,768	-3,378	-4,93	-5,00
-6º	-0,78	-3,66	-2,998	-4,799	-2,998	-2,237	-2,998	-3,178	-3,719
-3º	-0,78	-0,996	0,465	-0,996	-2,047	-1,396	-0,566	-1,827	-1,406
0º	-0,13	-0,986	1,226	0,746	0,746	0,005	0,816	-0,015	-0,365
3º	0,33	1,767	1,767	1,006	1,507	0,816	0,606	2,017	1,286
6º	2,06	2,608	1,687	1,316	1,326	0,796	1,687	3,589	3,539
9º	2,99	-	3,679	3,038	4,997	0,996	1,336	4,998	4,919

The next image shows PSV values in function of the frame tilt for each participant. Data were fitted to a linear function, represented by the expression $f(x) = ax + b$, where $f(x)$ or y represents PSV values, x represents the frame tilt, a is the slope and b the intercept.

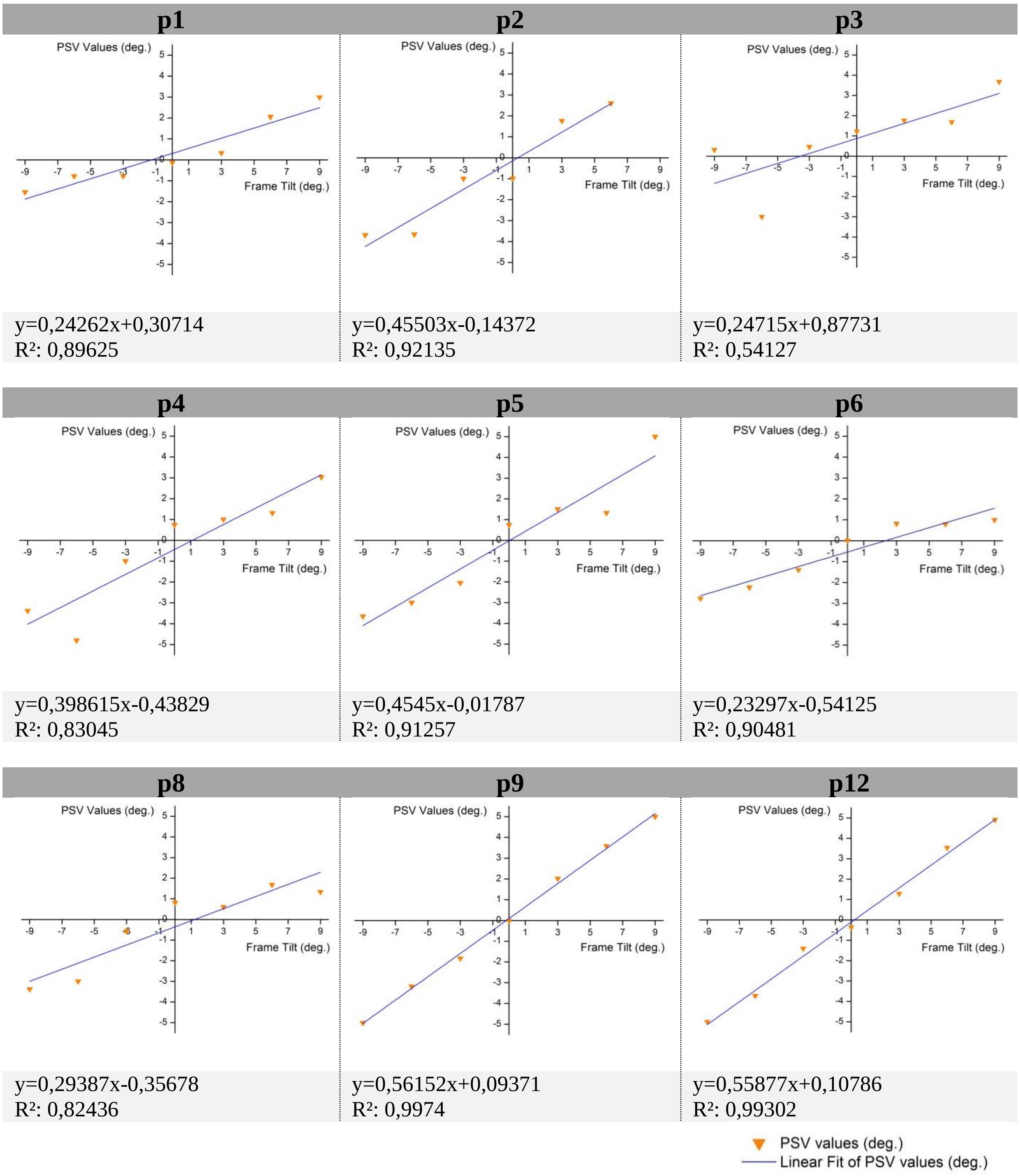


Figure 7. Linear fit of all participant data. This graph represents PSV (degrees) as a function of frame tilts (degrees) for each participant. Linear functions are represented by the expression $\boldsymbol{f(x) = ax + b}$.

To test the quality of slope's determination, it was calculated the statistical relative uncertainty for each participant by the expression: $\delta\,(\%) = \frac{\text{Uncertainty}}{a} \times 100$. Slopes' uncertainty was obtained from the fit. These values may be consulted on table 2. Relative uncertainty varies between approx. 2.08% and 35.18%, with a mean of approx. 14.41% (σ=9.63). Intercept (b) values are considered approximately 0. Individual slopes and its uncertainty are represented in figure 8.

Table 2

Algebraic expression of each participant adjustment and information about the quality of the adjustment (R^2) and uncertainty of slope's determination

Participants	Linear Function Definition	Adj. R-Square	Slope Values (a)	Uncertainty of a	Relative Uncertainty (%)
p1	y=0,24262x+0,30714	0,89625	0,24262	0,03338	13,75814
p2	y=0,45503x-0,14372	0,92135	0,45503	0,05895	12,95519
p3	y=0,24715x+0,87731	0,54127	0,24715	0,08695	35,18106
p4	y=0,398615x-0,43829	0,83045	0,39861	0,07231	18,14054
p5	y=0,4545x-0,01787	0,91257	0,4545	0,05698	12,53685
p6	y=0,23297x-0,54125	0,90481	0,23297	0,03058	13,12615
p8	y=0,29387x-0,35678	0,82436	0,29387	0,05442	18,51839
p9	y=0,56152x+0,09371	0,9974	0,56152	0,0117	2,08363
p12	y=0,55877x+0,10786	0,99302	0,55877	0,01912	3,421801
				Mean	14,41353
				SD	9,634645

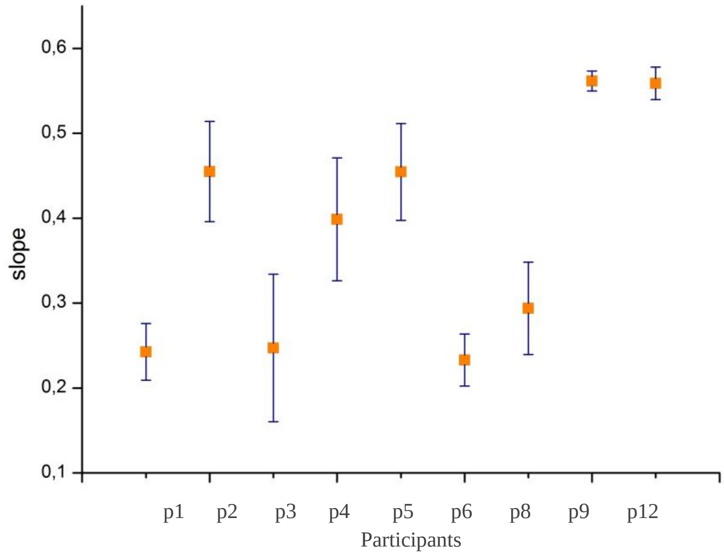


Figure 8. Representation of participants' slopes. This image shows the slopes of each participant as an indicator of visual field dependence. Error bars represents the statistical uncertainty of slopes determination.

Discussion

In this first study we were succeeded in implementing a new scoring method for RFT and finding a way to represent visual field dependence, improving the limitations of previous scoring methods. This new approach considers individual data and includes the next steps:

- CDF fit of proportion of right side answers (%) as a function of rod rotations;
- Determination of PSV values, which indicates us the subjective vertical position of the rod for each frame tilt;
- Linear fit of PSV values as a function of frame rotations.

Surprisingly, we found that individual PSV values are extraordinary well represented by a linear function, once all the adjustments (with exception of p3) had very high R^2 (between 0.82 and 0.99). PSV values show a proportionally relationship with frame tilt and, far as we know, this has never been reported. In fact, this was very surprising once a linear function representation is so clear and simple, not only in a theoretical point of view, but also for a visual representation. Additionally, a linear representation, as continuous measure, has the advantages of allowing the use of only some frame values and predicting intermediate PSV values.

So, in this linear representation, we found that slopes theoretically represent the degree of visual field dependence. A big slope includes a wide range of values which are considered vertical at some point, representing a very visual field dependent person (e.g., p9 sees vertical between approx. -5º and 5º). A smaller slope value represents someone that is not that much influenced by the visual field (e.g., p1 considers that rods are in a vertical position between approx. -1.5º and 2.5º). We found that using slope as an indicator of visual field dependence is in fact a very good option. Slopes show low uncertainty on its determination (uncertainty mean is about 14.41%). We think that this low uncertainty was found because in our study we used seven PSV values, corresponding to seven frame tilt conditions, what give us plenty information about the visual field dependence pattern of each participant. When doing the linear adjustment, a function is depicted, reflecting fluctuations and weighs for all conditions, pondering them. So, it seems acceptable to compare individuals' visual field dependence by their slope values.

As we already mentioned, visual field dependence has been typically represented by individual mean errors using different methods (e.g., AD, ALG, TERR and AERR). Despite the mentioned limitations, we found that the most part of the studies uses mean values to compare or form groups of individuals concerning on their visual field dependence never reporting any individual variance measure. However, we think that the statistical uncertainty

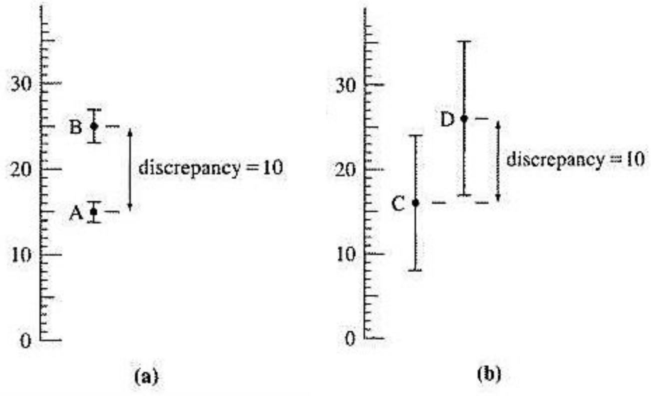


Figure 9. Comparison participants – the importance of uncertainty. This image compares situations (a) and (b). Dot points A, B, C and D represent participant's best estimates of visual field dependence. Range of probable values is represented by the vertical error bar (uncertainty). The best estimates allows us to compare participants concerning visual field dependence, but only the uncertainty says to us if their distinguish makes any sense. Based in Taylor, 1982 (pp. 15).

of these estimates, whatever they are (means, slopes, etc.), may be a key factor in scoring methods discussion, once no method seems consistent without using dispersion measurements. Let's consider the example of figure 8. We were trying to distinguish two participants concerning visual field dependence. (a) represents visual field dependence best estimates (e.g., mean values, slopes, etc.) of subjects A and B. (b) shows the same representation for participants C and D. As we may notice, although participants for both (a) and (b) situations show the same discrepancy (difference between the best estimates) of 10 unities, (b) measurements shows larger uncertainties and state margins overlap. This means that (b) situation may not be appropriate to distinguish participants, once they share quite information. There's no reason to doubt that situation (a) would be more advisable, once participants are perfectly distinguished.

According to this explanation and to the representation of the slopes and uncertainties founded in our study (see figure 8), it seems acceptable to think that our scoring method can work as a representation and distinguish of individual concerning their visual field dependence.

Study 2. Motion Sickness, Acrophobia and Visual Field Dependence Associations

Although motion sickness and acrophobia seem to have the same etiology, associated to a conflict between visual, vestibular and somatosensory cues (Bles at al., 1980), at our knowledge, no studies have been observed their comorbidity. However, concerning to visual field dependence, as we already mention, some controversial results was found. While some studies reveal that VFD individuals (performed on RFT) are less susceptible to feel motion sickness or "simulator sickness" (e.g., Barrett & Thornton, 1968; Kennedy, 1975), others found exactly the opposite (Long, Ambler and Guedry, 1975). Concerning acrophobia, it seems to be more consensual results, showing that VFD subjects tend to be more susceptible to fear heights than VFI (Coelho & Wallis, 2010; Willey & Jackson, 2014).

Considering the hypothesis that motion sickness and acrophobia co-occur, it seems contradictory that the same individual shows a negative correlation between RFT and motion sickness and positive correlation between RFT and acrophobia. More, it seems a paradox that an individual who can perform well in a situation of visual-vestibular conflict like RFT, ignoring the frame's movement, be the one that feels motion sickness when visual field maintain static but postural conditions differ, for instance (Long, Ambler and Guedry, 1975).

So, in this second study, we were interested in addressing this issue and trying to understand the associations between these variables. Even, we wanted to test the use and applicability of our new scoring method (slopes as an indicator of visual field dependence) – study 1 - on clinical samples.

Material and Methods

Subjects. 16 individuals ($M_{age}=22.7$, SD =4.75), university students, voluntarily participate in this study. All had normal or corrected to normal vision and no postural or vestibular problems. Once again, they were informed about the aim of the study and gave informed consent to participate.

Measures. The participation on this second study consisted on fulfill some questionnaires about acrophobia and motion sickness, as well as realize some behavioral measures, like V3DRFT or BAT.

Demographic Questionnaire.

Acrophobia Questionnaire (AQ) (Baker, Cohen & Saunders, 1973). AQ is a self-administered questionnaire, constituted by 20 sentences that describe typical situations associated to acrophobic individuals (e.g., "*Being on the roof of a building of 10 floors*"). Each item is evaluated in a Likert scale (0=no anxious; 4=extremely anxious), reflecting the anxiety that she/he would probably feel if leaving that situation.

Behavioral Avoidance Test (BAT) (Abelson & Curtis, 1989). BAT is a subjective measure of fear of heights. Participants ascend an external stairway with 14m high, with 7 landings. At each landing, they explore the environment and indicate us how discomfort they are, through a Likert scale of 10 points (0=no disagreeable sensation; 10=the worst disagreeable sensation). The test is over when they rise to the top or feel too discomfort.

*Motion Sickness Questionnaire (MSQ) (Gianaros, Muth, Mordkoff, Levine & Stern, 2010).*Self-administrated questionnaire with 16 items that evaluate the frequency of motion sickness symptoms in gastrointestinal, central, peripheral and sopite-related dimensions in a Likert scale (1=never; 4=always).

Virtual 3D Rod and Frame Test (V3DRFT). Contrasting to V3DRFT of Study 1, we used only 5 frame tilts of -15º, -7.5º, 0º, 7.5º and 15º. We thought that with a larger range we could easily capture subject's behavior and achieve a better representation of it.

Statistical Analysis. As the previous study, data analysis was performed using OriginPro8® and EXCEL.

Procedure. Procedure was similar to the previous one. However, in this study, beyond V3DRFT, participants also fulfill some questionnaires (AQ and MSQ) and realize BAT. Counterbalancing was made relative to the order of the administration of questionnaires and tests and to the gender.

Results

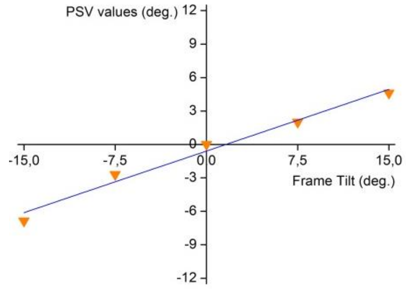
4 participants were excluded from data analysis due to excessive missing values. RFT results were scored by the method described on study 1. PSV values were fitted with a linear function, as can be seen on image 9. Individual slopes and respective uncertainty were determined (table 3). Mean of uncertainty's slopes is 7.88% (σ=2.27).

Table 3

Algebraic expression of each participant adjustment and information about the quality of the adjustment (R^2) and uncertainty of slope's determination

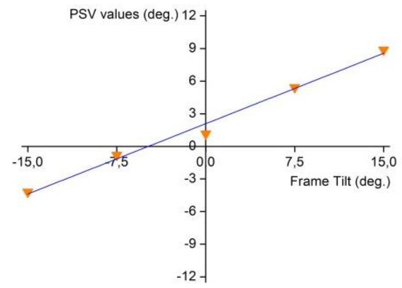
Participants	Linear Function Definition	Adj. R-Square	Slope Values (a)	Standard Error of a	Uncertainty (%)
p2	$y = 0,36878x - 0,58979$	0,97468	0,36878	0,02963	8,034601
p3	$y = 0,43155x + 2,08924$	0,98578	0,43155	0,02587	5,99467
p4	$y = 0,30272x + 0,54856$	0,96889	0,30272	0,02701	8,922437
p6	$y = 0,52787x - 0,63584$	0,98102	0,52787	0,03662	6,937314
p8	$y = 0,49396x - 0,15475$	0,96689	0,49396	0,04551	9,213297
p9	$y = 0,37755x + 1,80901$	0,97472	0,37755	0,0303	8,025427
p10	$y = 0,75019x - 0,24885$	0,99142	0,75019	0,04009	5,34398
p11	$y = 0,22559x + 3,04925$	0,98855	0,22559	0,01212	5,372579
p12	$y = 0,29378x - 1,84446$	0,98855	0,29378	0,0332	11,30097
p14	$y = 0,52557x + 2,66507$	0,99304	0,52557	0,02198	4,182126
p15	$y = 0,25049x + 0,38118$	0,97232	0,25049	0,02106	8,407521
p16	$y = 0,15861x - 0,86947$	0,94708	0,15861	0,01862	11,73949
				Mean	7,877874
				SD	2,268288

p2



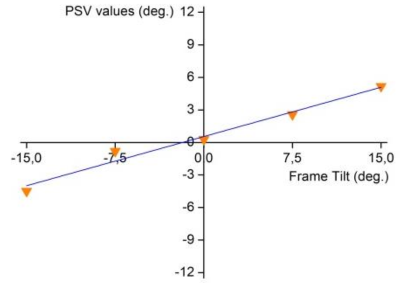
$y = 0{,}36878x - 0{,}58979$
R^2: 0,97468

p3



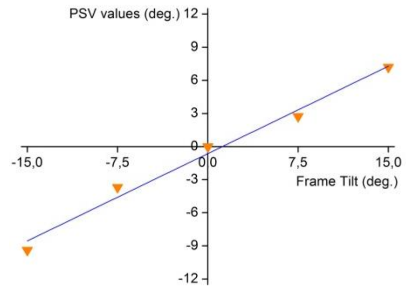
$y = 0{,}43155x + 2{,}08924$
R^2: 0,98578

p4



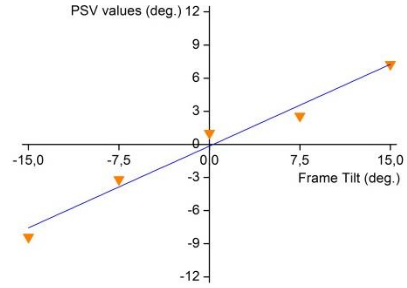
$y = 0{,}30272x + 0{,}54856$
R^2: 0,96889

p6



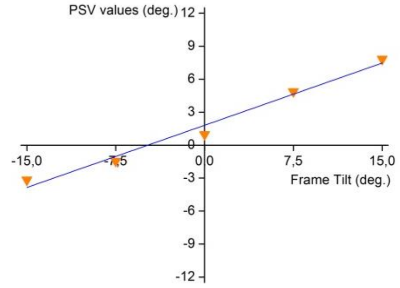
$y = 0{,}52787x - 0{,}63584$
R^2: 0,98102

p8



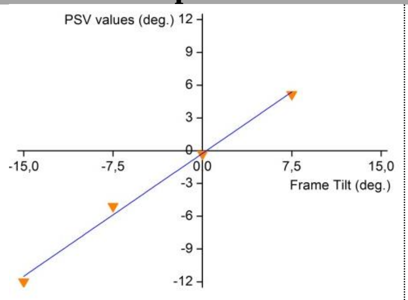
$y = 0{,}49396x - 0{,}15475$
R^2: 0,96689

p9



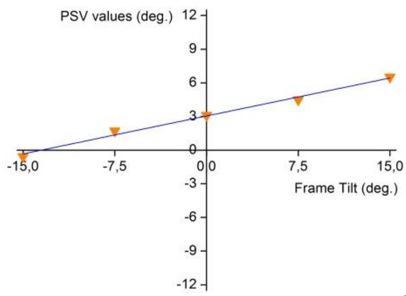
$y = 0{,}37755x + 1{,}80901$
R^2: 0,97472

p10



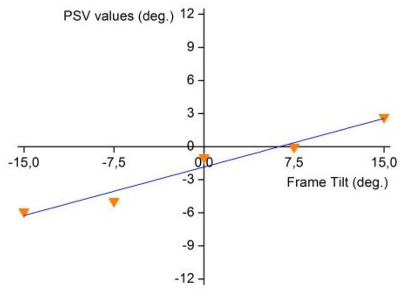
$y = 0{,}75019x - 0{,}24885$
R^2: 0,99142

p11



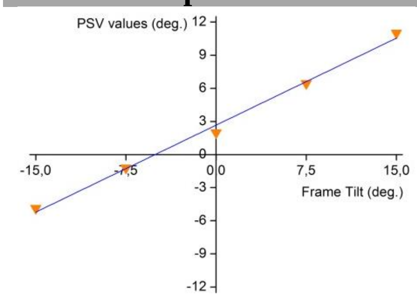
$y = 0{,}22559x + 3{,}04925$
R^2: 0,98855

p12



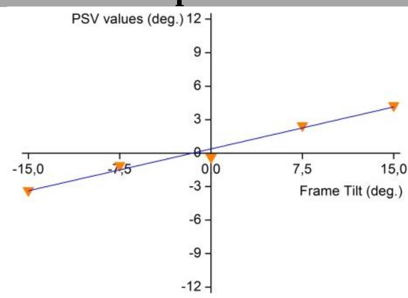
$y = 0{,}29378x - 1{,}84446$
R^2: 0,98855

p14



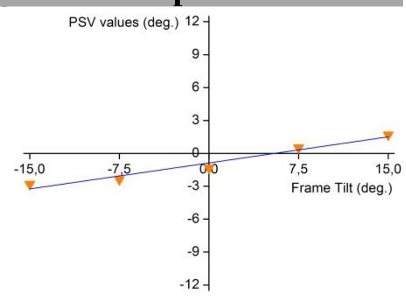
$y = 0{,}52557x + 2{,}66507$
R^2: 0,99304

p15



$y = 0{,}25049x + 0{,}38118$
R^2: 0,97232

p16



$y = 0{,}15861x - 0{,}86947$
R^2: 0,94708

▼ PSV values (deg.)
— Linear Fit of PSV values (deg.)

*Figure 8.*Linear fit of individual PSV values.

Correlations analyzes were conducted. Because we used a small sample (n<30), non-parametric tests were administered. Slopes, as a representation of visual field dependence, were correlated with fear of heights and motion sickness indicators. Spearman correlations were made between slopes and BAT, AQ, MSQ and RFT measures.

Table 4

Correlations between measures

Measure	AQ	BAT	RFT
MSQ	0,80351**	0,67838*	0,02456
AQ		0,85114***	0,13287
BAT			-0,09107

Note. *p<.05, **p<.01, ***p<.001

As displayed in table 4, correlation analyzes indicate that AQ is highly correlated with MSQ (r=0.8, p<.01) and BAT (r=0.85, p<.001) and that BAT and MSQ are moderately correlated (r=0.67, p<.05). No significant correlations were found between RFT results and MSQ (r=0.02, n.s.), AQ (r=0.13, n.s.) and BAT (r=-0.09, n.s.).

Discussion

As expected, BAT and AQ, both measures of fear of heights, were highly correlated (r=0.85, p<.001), showing the consistency of participants answers. Because motion sickness and fear of heights seems to share a common visual-vestibular etiology, we were expecting that measures related to both were associated. Correlation analyzes supported this hypothesis, once MSQ is highly correlated with AQ (r=0.8, p<.01) and moderately correlated with BAT (r=0.67, p<.05). This was an interesting result, once we could observe that individuals with fear of heights are more susceptible to experience motion sickness symptoms.

Even, more than understanding if these two phenomena co-occur and are etiologically related, we were interested in understanding the associations they keep with visual field dependence. We were expecting to find some association between visual field dependence and acrophobia and motion sickness, what would able us to give some light about the previous controversial findings. Unfortunately, we fail to show any association, no significantly results were found.

Although we have not found any significant correlation, we may believe that the scoring method developed in this dissertation one has the potential to be a good representation of visual field dependence. As can be seen on table 4, slopes adjustments were even better than those found on study 1 and uncertainties were smaller maybe because we used frames with a bigger range, which give us more information about the phenomena that we were trying to estimate.

General Discussion

This dissertation project was focused on motion sickness and acrophobia as visual-vestibular phenomena, aiming develop a new valid scoring method for RFT (study 1), which would result in a continuous representation of visual field dependence, and to explore the associations between this variable, motion sickness and acrophobia (study 2).

In Study 1, we surprisingly found that the relationship between individual PSV values and frame tilt is extraordinarily well represented by a linear function and that slopes can be a good representation of visual field dependence. It was also noticed that statistical uncertainty is an important factor when evaluating the potential that scoring methods have to compare and distinguish individuals concerning visual field dependence. However, because we have not access to individual means and standard deviations used in previous studies, we can't state that previous scoring methods are worse than ours. Nonetheless, previous studies used less frame tilt conditions and RFT formats that are less controlled experimentally (e.g., method of adjustment, manual measurements) and this make us believe that resulting individual judgments of subjective vertical for each frame tilt must be very disparate, turning the result means an indicator that includes large standard deviance. Even, comparing to previous scoring methods, our method has a huge advantage of predicting individual behavior. Although we have good reasons to believe that this scoring method has a large potential, we suggest that future studies to objectively compare scoring methods in terms of statistical uncertainty of estimates determination.

Results of study 2 were very interesting, once we found that individuals that fear heights are more susceptible to experience motion sickness. Although the scientific community's suspicion that motion sickness and acrophobia could share a common etiology, at our knowledge, this association was never reported. However, our results do not allow us to go further on interpretations and future studies will be needed to clarify if this etiology is in fact visual-vestibular.

Even related with study 2, we fail to show any association between visual field dependence and motion sickness and acrophobia. However, this is not a surprising result. First, because we were testing for the first time the slopes as indicators of visual field dependence. These slopes reflect PSV values vs frame tilt. This represents just one of many other relations that may be found in our variables system and maybe in future studies we'll found other that correlates better with visual field dependence; second, because the association between visual field dependence and phenomena like motion sickness and acrophobia is not that clear as observed in previous studies; and third, because we used only 12 participants in this study, maybe not enough to find a solid relationship between these variables and attenuate individual differences related to visual field dependence.

Although has been reported that an accurate perception of verticality to make judgments about the orientation of an object in the gravitational field depends on visual and vestibular information (e.g., Anastasopoulos, Bronstein, Haslwanter, Fetter, & Dichgans, 1999; Vingerhoets, De Vrijer, Van Gisbergen, & Medendorp, 2008), we consider that RFT may not the most appropriate measure of VV integration. RFT has been considered a spatial ability test, which evaluated individuals perceive special relationships relative to their bodies (Linn & Petersen, 1985 as cited in Reger et al., 2003), turning RFT an "exocentric" test, not evaluating "egocentric" factors, like postural control, relevant for motion sickness and acrophobia. Also, Isableu et al. (1997) found that VFD use mainly dynamic visual cues, while VFI rely on gravitational or/and egocentric cues and use preferentially static visual cues. Once, RFT evaluates only the sensitivity to static visual field. These may suggest that RFT may not be an appropriate method, at least for VFD. Future studies may be taking in account dynamic cues using, for instance, Rod and Disc Test (RDT) (Guerraz et al., 1998). We also suggest that future studies consider body manipulations, like head or body tilt, which could give additional information regarding on how one system is influencing the other. That is the next step of this research, currently taking place.

Conclusion

This dissertation project raised fundamental questions about the hypothetical visual-vestibular etiology of two well-known phenomena, motion sickness and acrophobia. Although some limitations, the results found in this project brings new evidences about a common etiology, raises the improvement of RFT scoring methods and brings new challenges and perspectives about VV integration.

We believe that a deep understanding of the perceptual processes and mechanisms underlying VV integration may give us important lights about the origin, development and the factors than maintain these clinical conditions and contribute to the development of innovative and efficient clinical treatments.

The implications of the present work do not stop on motion sickness and acrophobia, but may be extensible for a huge variety of daily-required occurrences that depend on a congruent VV integration, like motion and balance, keep stability and control of body and head posture and perceive and control *self-motion*, orientation and navigation.

References

Abelson, J. L., & Curtis, G. C. (1989). Cardiac and neuroendocrine responses to exposure therapy in heights phobias: desynchrony within the "physiological response system. *Behaviour Research and Therapy, 27(5),* 561-567. doi: 10.1016/0005-7967(89)90091-0

Anastasopoulos, D., Bronstein, A., Haslwanter, T., Fetter, M., & Dichgans, J. (1999). The role of somatosensory input for the perception of verticality. *Annals of the New York Academy of Sciences*, *871*, 379–383. doi: 10.1111/j.1749-6632

Arntz, A., Rauner, M., & van der Hout, M. (1995). "If I feel anxious, there must be danger": ex-consequential reasoning in inferring danger in anxiety disorders. *Behaviour Research and Therapy*, *33*, 917-925. doi: 10.1016/j.brat.2003.10.009

Asch, S. E., & Witkin, H. A. (1948a). Studies in space orientation: I. Perception of the upright with displaced visual fields. *Journal of experimental psychology*, *38*(3), 325. doi:10.1037/h0057855

Asch, S. E., & Witkin, H. A. (1948b). Studies in space orientation. II. Perception of the upright with displaced visual fields and with body tilted. *Journal of experimental psychology*, *38*(4), 455. doi: 10.1037/h0055372

Baker, B. L., Cohen, D. C., & Saunders, J. T. (1973). Self-directed desensitization for acrophobia. *Behaviour Research and Therapy, 11(1),* 79-89. doi: 10.1016/0005-7967(73)90071-5

Balaban, C. D., & Yates, B. J. (2004). *Vestibulo-autonomic interactions: a teleologic* *perspective*. In S. N. Highstein, R. R. Fay & A. N. Popper (Eds.), *Springer Handbook of Auditory Research: The Vestibular System* (pp. 286-342). New York, NY: Springer-Verlag.

Barrett, G. V., & Thornton, C. L. (1968). Relationship between perceptual style and simulator sickness. *J. Appl. Physiol., 52*, 304-308. http://dx.doi.org/10.1037/h0026013

Benson, A. (1984). Vertigo. In M. R. Dix and J. D. Hood (Ed.), *Motion Sickness* (pp. 391-425). Hants, UK: John Wiley & Sons Ldt. doi: 10.1037/h0026013

Bles, W., Kapteyn, T. S., Brandt, T., & Arnold, F. (1980). The mechanism of physiological height vertigo. II. Posturography. *Acta Oto-Laryngologica, 89*, 534-540. doi: 10.3109/00016488009127171

Brandt, Th., Glasauer, S., Stephan, T., Bense, Yousry, T. A., Deutschländer, & Dieterich, M. (2002). Visual-vestibular and visuovisual cortical interaction. *Annals of Neurology*, *956*, 230-241. doi: 10.1111/j.1749-6632.2002.tb02822.x

Butler, S. J., Smith, S. T., Campos, J. L., & Bülthoff, H. H. (2010). Bayesian integration of visual and vestibular signals for heading. *Journal of Vision*, *10(11),* 1-13. doi: 10.1167/10.11.23

Claremont, C. A. (1931). The psychology of sea sickness. *Psyche., 11,* 86-90.

Coelho, C. M., & Wallis, G. (2010). Deconstructing acrophobia: physiological and psychological precursors to developing a fear of heights. *Depression and Anxiety, 27,* 864-870. doi: 10.1002/da.20698

Coelho, C. M., Santos, J. A., Silva, C., Wallis, G., Tichon, J., & Hine, T. J. (2008). The role of self-motion in acrophobia treatment. *Cyberpsychology & Behavior, 11(6),* 723-725. doi:10.1089/cpb.2008.0023

Corbett, J. E., & Enns, J. T. (2006). Observer pitch and roll influence: the rod and frame illusion. Psychonomic Bulletin & Review, 13(1), 160-165). doi: 10.3758/BF03193828

Depla, M., ten Have, M. L., van Balkom, A., & de Graaf, R. (2008). Specific fears and phobias in the general population. Results from the Netherlands Mental Health Survey and Incidence Study (NEM-ESIS). *Soc Psychiatr Epidmiol, 43*, 200-208. doi: 10.1007/s00127-007-0291-z

DiLorenzo, J. R., & Rock, I. (1982). The rod-and-frame effect as a function of the righting of the frame. *Journal of Experimental Psychology: Human Perception and Performance, 8(4),* 536. doi: 10.1037/0096-1523.8.4.536

Gascuel, J. D., Payno, H., Schmerber, S., & Martin, O. (2012). Immersive virtual environment for visuo-vestibular therapy: preliminary results. *Stud Health Technol Inform*, *181*, 187-191. doi: 10.3233/978-1-61499-121-2-187

Gescheider, G. A. (1997). *Psychophysics: The Fundamentals*. Lawrence Erlbaum Associates: Mahwah.

Gianaros, P. J., Muth, E. R., Mordkoff, J. T, Levine, M. E., & Stern, R. M. (2010). A questionnaire for the assessment of the multiple dimensions of motion sickness. *Aviation Space Environmental Medicine, 72 (2),* 115-119.

Isableu, B., Gueguen, M., Fourré, B., Giraidet, G., & Amorim, M. (2008). Assessment of visual field dependence: Comparing between the mechanical 3D rod-and-frame test developed by Oltman in 1968 with a 2D computer-based version. *Journal of Vestibular Research*, *18,* 239-247.

Isableu, B., Ohlmann, T., Crémieux, J., & Amblard, B. (1997). Selection of special frame of reference and postural control variability. *Experimental Brain Research, 114,* 584-589. doi: 10.1007/pl00005667

Isableu, B., Ohlmann, T., Crémieux, J., & Amblard, B. (1998). How dynamic visual field dependence-independence interacts with the visual contribution to postural control. *Human Movement Science, 17,* 367-391. doi: 10.1016/S0167-9457(98)00005-0

Keetels, M., & Vroomen, J. (2007). No effect of auditory–visual spatial disparity on temporal recalibration. *Experimental Brain Research, 182,* 559-565. doi: 10.1007/s00221-007-1012-2

Kennedy, R. S. (1975). Motion sickness questionnaire and field dependence scores as predictors of success in naval aviation training. *Aviation Space Environmental Medicine, 46,* 1349-1352.

Kennedy, R. S., & Fowlkes, J. E. (1992). Simulator sickness is polygenic and polysymptomatic: implications for research. The International Journal of Aviation Psychology, 2 (1), 23-38. doi:10.1207/s15327108ijap0201_2

Lackner, J. R., & DiZio, P. (2009). Angular displacement perception modulated by force background. *Experimental Brain Research*, *195*, 335-343. doi: 10.1007/s00221-009-1785-6

Lester, G. (1968). The rod-and-frame test: some comments on methodology. *Perceptual and Motor Skills, 26,* 1307-1314. doi: 10.2466/pms.1968.26.3c.1307

Long, G. M., Ambler, R. K., & Guedry, F. E. (1975). Relationship between perceptual style and reactivity to motion. *Journal of Applied Psychology, 60(5),* 599-605.

Mahoney, J. R., Li, P. C., Oh-Park, M., Verghese, J., & Holtzer, R. (2011). Multisensory integration across the senses in young and old adults. *Brain Research, 14,* 43-53. doi: 10.1016/j.brainres.2011.09.017

Oltman, P. K. (1968). A portable rod-and-frame apparatus. *Perceptual and Motor Skills, 26,* 503-506. doi: 10.2466/pms.1968.26.2.503

Reason, J. T. (1970). Motion Sickness: a special case of sensory rearrangement. *Advancement of Science, 26,* 386-393.

Reger, G. M., McGee, J. S, Zaag, C., Thiebaux, M., Buckwalter, J. G., & Rizzo, A. A. (2003). A 3D virtual environment rod and frame test: the reliability and Validity of four traditional scoring methods for older adults. *Journal of Clinical and Experimental Neuropsychology, 25(8),* 1169-1177. doi: 10.1076/jcen.25.8.1169.16733

Spence, C., & Squire, S. (2003). Multisensory integration: maintaining the perception of synchrony. *Current Biology, 13,* 519–521. doi: 10.1016/s0960-9822(03)00445-7

Stanney, K., & Salvendy, G. (1998). Aftereffects and sense of presence in virtual environments: formulation of a research and development agenda. *International Journal of Human-Computer Interaction, 10(2),* 135-187. doi:10.1207/s15327590ijhc1002_3

Tam, W. J., Speranza, F., Yano, S., Shimono, K., & Ono, H. (2011). Stereoscopic 3D-TV: visual comfort. *Broadcasting, IEEE Transactions on, 57*(2), 335-346. doi: 10.1109/tbc.2011.2125070

Taylor, J. R. (1982). *An introduction to error analysis: The study of uncertainties in physical measurements.* University Science Books. Mill Valley: California.

Thorpe, A. J., & Fabre-Thorpe, M. (2001). Seeking categories in the brain. *Science, 219,* 260-263. doi: 10.1126/science.1058249

Vingerhoets, R.A.A., De Vrijer, M., Van Gisbergen, J. A. M., & Medendorp, W. P. (2008). Fusion of visual and vestibular tilt cues in the perception of visual vertical. *Journal of neurophysiology, 101(3),* 1321-1333. doi:10.1152/jn.90725.2008.

Vroomen, J., & Keetels, M. (2010). Perception of intersensory synchrony: a tutorial review. *Attention, Perception, & Psychophysics, 72 (4),* 871-884. doi: 10.3758/app.72.4.871

Wilkie, R. M., & Wann, J. P. (2005). The role of visual and nonvisual information in the control of locomotion. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 901-911. doi: 10.1037/0096-1523.31.5.901

Willey, C. R., & Jackson, R. E. (2014). Visual field dependence as a navigational strategy. *Attention, Perception, & Psychophysics, 76*(4), 1036-1044. doi: 10.3758/s13414-014-0639-x

Young, L. R. (1982). Perception of the body in space: mechanisms. *Comprehensive Physiology*. doi: 10.1002/cphy.cp010322

Zoccolotti, P., Antonucci, G., & Spinelli, D. (1993). The gap between rod and frame influences the rod and frame effect with small and large inducing displays. *Perception and Psychophysics, 54 (1)*, 14-19. doi: 10.3758/bf03206933