TYRE-ROAD NOISE: ANNOYANCE AND DETECTION OF INCOMING TRAFFIC

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ABSTRACT

In this paper, annoyance ratings and detection thresholds of incoming traffic are discussed as a function of road-tyre noise. Empirical data on annoyance, from the Noiseless project, can be interpreted as follows: (1) cobble stones pavements were significantly the most annoying; (2) the open asphalt rubber pavement had lower annoyance ratings but it did not differ significantly from the dense asphalt; (3) increasing speeds and traffic densities always led to higher annoyance ratings. On the other hand, as far as safety and detection of incoming traffic is concerned: (1) the hybrid vehicle was the least detected whereas the pickup truck was the most detected; (2) a clear effect of pavement type was found, with less detections for the asphalt rubber pavement while the cobble stones pavement always provided good detection.

Practical implications for traffic noise abatement and the possible trade-off for road safety (vulnerable road users) will be outlined.

INTRODUCTION

Traffic related noise is nowadays the major source of environmental noise in most industrialized nations and developing regions. The negative impact of such noise has been demonstrated in work, educational, social and private contexts.

In a foreseeable future we might expect a significant reduction of road traffic noise both through the use of more efficient pavements and because of the growing popularity of hybrid and full electric vehicles.

However, in urban areas traffic noise could also be a key factor for the awareness of imminent conflicts by vulnerable road users. Therefore, due to traffic noise abatement, we might face in the near future an increasing trade-off between the general improvement of population's health and the increase of accidents involving vulnerable road users.

This paper focuses on two main practical questions:

1) is there a clear improvement of urban road networks (i.e., lower annoyance rates) with new pavements, as the open graded asphalt rubber over traditional ones? And could we find further practical implications from the study of other variables such as population age groups, traffic speed or traffic density composition?

2) might we face in the near future an unexpected and unwanted outcome of traffic noise abatement, with increasing traffic conflicts and accidents involving vulnerable road users? And what might be the negative outcome as a function of pavements, type of vehicles and population age groups?

For more detailed analyses of these issues please refer to Freitas & al. (2012) and Mendonça et al. (in preparation). For methodological aspects of noise recording, sample noise compositions and psychoacoustic variables, please check previous presentations from Elisabete Freitas and Catarina Mendonça.

MATERIALS AND METHODS

Experiment 1: Annoyance

Ninety-six listeners participated in the experiment (7-86 years old, average of 37 years old). Considering age span, 26 participants were juvenile (19 years and below), 32 early adults (20-39 years), 18 middle adults (40-59) and 20 late adults (60 years and above).

The single vehicle recordings were factorially paired by audio software (Ardour) to produce the stimuli for the annoyance assessment. For each pavement type (cobble stones, dense asphalt, and open graded asphalt rubber) and vehicle speed, from 30 to 70 Km/h with 10 Km/h increments, two traffic density compositions were defined (simulating a 2X1 road). Traffic composition 1 (TC1) had a total of 5 vehicles (3 small passenger cars, 1 hybrid and 1 pickup truck) spaced 2.5 seconds from each other. Traffic composition 2 (TC2) had a total of 15 vehicles (9 small passenger cars, 3 hybrids, 3 pickup trucks) spaced 1 second from each other. Therefore there were a total of 30 stimuli (3 pavements x 5 speeds x 2 traffic compositions). Each stimulus had the duration of 5 seconds.

The stimuli were presented through a custom built C++ application, running in a computer with a sound card Intel 82801BA-ICH2, and AKG K 271 MKII closed headphones.

Each participant listened to a total of 120 noise trials. Participants were requested to assess the annoyance of each noise trial with a 10-graded interval scale from 1 (less annoying) to 10 (very annoying).

Experiment 2: Detection

Eighty-nine participants were tested in this experiment (7-86 years old, average of 37 years old). Split into age groups, 26 participants were juvenile (19 years and below), 27 were early adults (20-39 years), 19 were middle adults (40-59) and 17 late adults (60 years and above). While not entirely overlapping, this sample was composed by participants who were also tested in experiment 1.

From each single vehicle recording, sound samples with a duration of 2 seconds were produced. For all sound samples the final Time-to-Passage (TTP) of the approaching vehicle was fixed to 3.5 seconds; i.e. at the end of the stimulus presentation the vehicle would need 3.5 seconds to cross the line of sight of the observer. To mask the signal (tyre-road sound) five levels of white noise were generated with WaveLab 6: corresponding to the LAeq (dBA) values, as listened by the participants, of 62, 67, 72, 77 and 82, respectively. A total of 135 stimuli with signal plus noise were generated with audio software (Ardour): 3 pavements x 3 vehicles x 3 speeds (30, 40 and 50 Km/h) x 5 noise levels.

The general experimental setup and equipment were the same as the experiment 1.

Within each trial the participant was presented with two consecutive sound samples, with a fixed gap of 1 second, one with the signal plus noise and the other with only noise. Both noise backgrounds of each trial had the same level of white noise. Participants were requested to detect in which of the intervals, i.e., first or second sample, was the approaching vehicle.

RESULTS

Experiment 1: Annoyance

A preliminary analysis of the data, intra and inter-participants, revealed a high consistency of annoyance rates as a function of the main variables (pavement, speed and traffic composition). The results were also similar across all age groups: the juvenile had a mean annoyance of 5.59 (SD 0.70); the early adults had a mean of 5.79 (SD 0.84); middle adults had 5.47 (SD 0.84); and late adults had 5.60 (SD 0.80).

The pooled data per pavement (n=3840 trials) points to a small difference of mean annoyance between the dense asphalt (mean 4.8, SD 2.1) and open asphalt rubber (mean 4.4 ,SD 2.1) pavements. The cobble stones pavement induces the highest rate of annoyance (mean 7.7, SD 2.1). Percentile 85 indicates the same trend with annoyance values of 7 for both dense asphalt and open asphalt rubber, and 10 for the cobble stones pavement.

Cumulative frequencies analysis also suggests that annoyance accumulates with a steep slope for the cobble stone pavement, while both the dense asphalt and the open asphalt rubber pavements follow a smoother and similar path (see Figure 1).

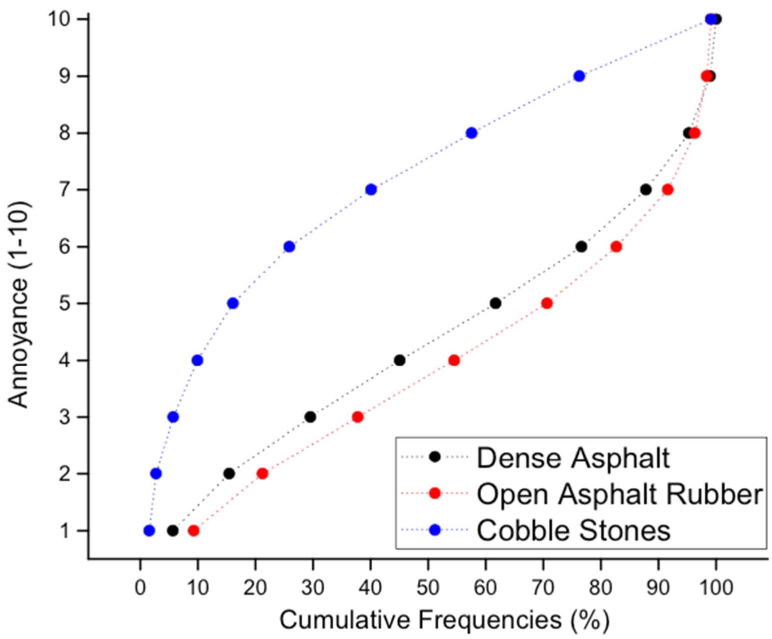

Fig.1. Cumulative frequencies for the dense asphalt, open asphalt rubber, and cobble stones (pooled data n= 3840 per pavement) and annoyance assessment.

The analysis of the speed-pavement interactions reveals a linear increase of the mean annoyance as a function of speed (see Figure 2) with similar slopes for all pavements (cobble stones=0.07, dense asphalt=0.06, open asphalt rubber=0.05). Again, as found in the previous global analysis, the cobble stones pavement shows the highest rates of annoyance. The dense asphalt and open asphalt rubber pavements have similar rates (mean differences not exceeding 0.5); but with a consistent lower level of annoyance for the open asphalt rubber pavement.

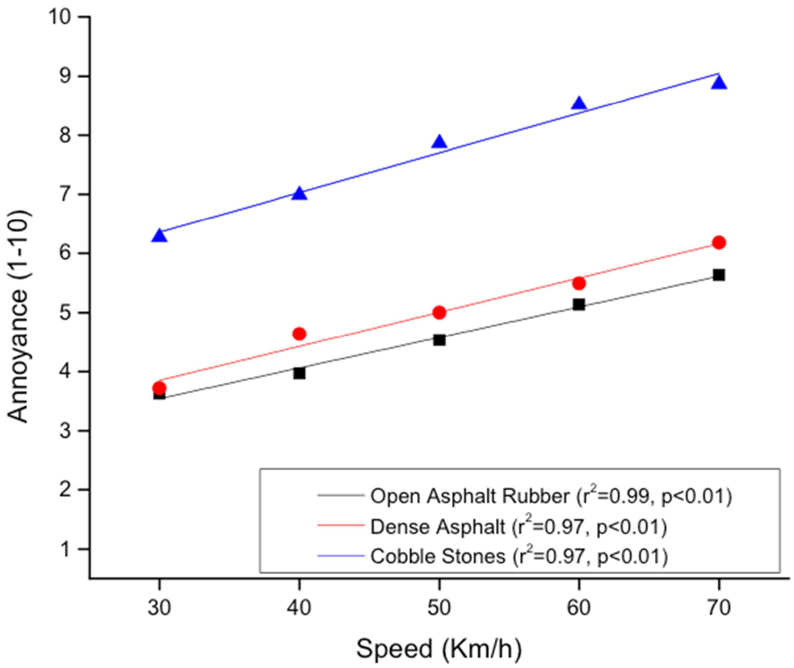

Fig. 2. Annoyance results per speed and pavement: mean values and linear regressions (pooled data n= 768 per dot).

In a similar way as found for the traffic speed, the traffic density composition also had an effect over annoyance rates for all pavements, with an increase of the mean annoyance as a function of the density. In line with both the global analysis per pavement and the speed-pavement results, the cobble stones pavement shows the highest rates of annoyance with mean values of 6.8 and 8.5 for the first (TC1) and second (TC2) traffic compositions, respectively. The dense asphalt and open asphalt rubber pavements have again very close mean rates with mean differences not exceeding 0.6 for TC1 (4.0 and 3.4 respectively) nor for TC2 (5.7 and 5.3 respectively). The analysis of percentile 85 reveals identical patterns of annoyance variation and magnitude. For the cobble stones pavement, the values are of 9 and 10 for TC1 and TC2, respectively. For the other pavements, the percentile values are of 6 and 8 for the dense asphalt, and of 5 and 7 for the opens asphalt rubber.

Summarizing, all age groups rate traffic noises according to the same standards. Cobble stones pavement lead to more annoying traffic noises than dense asphalt and open asphalt rubber. Open asphalt rubber noise is consistently less annoying than dense asphalt, but these differences are of low magnitude and are not significant (Freitas & al., 2012).

Vehicle speed has a strong relation with annoyance for all pavement types. Traffic composition also has a clear effect over results, with higher density traffic scenes consistently leading to higher annoyance rates.

Experiment 2: Detection

Unlike was found in experiment 1, here a preliminary analysis of the data, after computing detection thresholds per participant, revealed clear differences as a function of age. The global mean detection was of 80.51 % and the standard error (SE) of 1.09. The results across age groups were: for juvenile a mean of 78.27% (SE 2.07); for early adults 87.93% (SE 1.34); for middle adults 79.84% (SE 1.90); and late adults 72.88% (SE 2.33).

Here will focus on selected case scenarios: comparing a foreseeable combination of noiseless pavements with hybrid cars to traditional pavements with conventional passenger cars. In the first case, the impairment of vehicle detection is quit clear (Figure 3). The overall mean detection in the sample is of 69.60 (SE 1.64) for the hybrid / open asphalt rubber condition with only the age group of 20-39 years old being able to reach a suprathreshold of 79.48 (SE 2.36). Older participants reached the lowest mean detection percentage of 58.41 (SE 3.17) in that condition and they were still below threshold for the ordinary vehicles – dense asphalt scenario with a percentage of only 70.76 (SE 2.55) of correct detections.

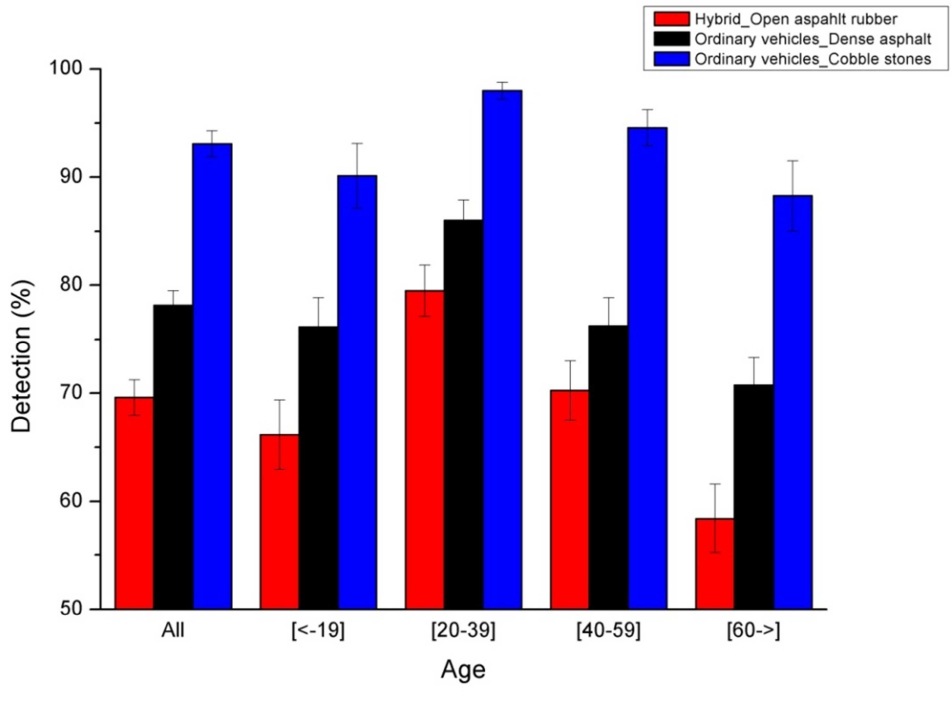

Fig. 3. Overall and age groups mean detection percentages and SE for selected scenarios.

The combination of pavement and vehicle types seems to have an interactive effect on detection performance, which is consistent across age groups. Considering the overall data from the sample, the detection decreases 4.95% and 21.15% from dense asphalt and cobble stones to the open asphalt rubber pavement, respectively. The mean decrease is of 2.67% from the internal combustion engine vehicles to the hybrid. In the extreme scenarios the detection of the approaching vehicle is decreased respectively in 8.55 % and 23.5 %, from the conditions with ordinary vehicles - dense asphalt and cobble stones to the condition with hybrid - open asphalt rubber.

Older adults of 60 years old and above are the most impaired in these extreme scenarios with detection differences of 12.35% and 29.88%. These results point to a somehow additive effect where noisier sounds add up to noisier pavements and interact with the listeners' auditory accuracy.

CONCLUSION

Approaching our findings from a practical point of view, two key factors on noise abatement should be considered.

First, the relation between pavement type and traffic noise abatement should be taken cautiously. A substantial investment has been made in new asphalt rubber mixtures under the argument that they should reduce traffic noise. Although the noise reduction cannot be contested, it should be stressed that the perceived differences by users might not be as significant as expected.

Second, a cost-effective approach to reduce noise-related discomfort should also consider traffic management approaches as traffic calming, including the control of traffic speed and density, two factors that in this study revealed a consistent effect on annoyance ratings.

Considering traffic safety and the possibility of a trade-off, our results clearly point to a negative impact of traffic noise abatement on the detection of approaching vehicles.

The following concerns should be stressed.

1. Detection is significantly lowered by noiseless pavements and quieter vehicles.

2. Younger and particularly older participants are the most impaired.

3. Not only all variables revealed direct effects over the vehicle detectability, but moreover they all showed interactive effects. Therefore, comprehensive approaches that account for subject's age (or listening abilities), vehicle and pavement type, as well as background noise are needed.

4. In the real world the detection performance should be even worst. First, we used a standard white noise background, while in everyday situations road traffic contributes heavily to the noise environment, thus reducing the conspicuity of the sound envelope of each vehicle. Secondly, in our experiments participants had to detect only one approaching vehicle at a time instead of facing simultaneously several targets.

5. Moreover, transition periods as we are already living nowadays, are potentially very difficult and risky. Vulnerable road users will inevitably have to cope with a growing mix of vehicles and pavements, with varying degrees of conspicuity. In such a transition scenario, hybrid and full electric vehicles, circulating on noiseless pavements, might prove quite difficult to detect.

6. In short, with noise abatement a trade-off between a more pleasant and healthy urban road environment and an increase of traffic conflicts and accidents involving pedestrians and bicyclists should be a matter of concern.

ACKNOWLEDGEMENTS

This study was financed by the Portuguese Foundation for Science and Technology and FEDER, projects FCOMP-01-0124-FEDER-007560, FCOMP-01-0124-FEDER-022674 and PEst-OE/ECI/UI4047/2011.

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