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Noise abatement and traffic safety: The trade-off of quieter engines and pavements on vehicle detection

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ABSTRACT

Road traffic sounds are a major source of noise pollution in urban areas. But recent developments such as low noise pavements and hybrid/electric engine vehicles cast an optimistic outlook over such an environmental problem. However, it can be argued that engine, tire, and road noise could be relevant sources of information to avoid road traffic conflicts and accidents. In this paper, we analyze the potential trade-offs of traffic-noise abatement approaches in an experimental study, focusing for the first time on the impact and interaction of relevant factors such as pavement type, vehicle type, listener's age, and background noise, on vehicle detection levels. Results reveal that vehicle and pavement type significantly affect vehicle detection. Age is a significant factor, as both younger and older people exhibit lower detection levels of incoming vehicles. Low noise pavements combined with all-electric and hybrid vehicles might pose a severe threat to the safety of vulnerable road users. All factors interact simultaneously, and vehicle detection is best predicted by the loudness signal-to-noise ratio.

1. Introduction

Traffic related noise is nowadays the major source of environmental noise in most industrialized nations and developing regions. Its negative impact has been demonstrated at several instances, from health to school efficiency and overall emotional annoyance (e.g., Gorai and Pal, 2006; Passchier-Vermeer and Passchier, 2000; Sanz et al., 1993; Freitas et al., 2012). It is therefore a matter of active concern for traffic-related researchers, public authorities in health and traffic, as well as transportation and road industries, to find quieter alternatives to the major sources of transportation noise. In a near future, we might expect a reduction of road traffic noise both by pavements that are more efficient and because of the growing popularity of hybrid and all-electric vehicles. Therefore, there is an optimistic outlook on health improvement and annoyance reduction due to a quieter road traffic environment, specifically for populations living in urban areas.

However, in urban areas traffic noise could also be a key factor for the awareness of imminent conflicts by vulnerable road users. In other words, road, tire and engine noises might be used as meaningful signals by pedestrians and bicyclists: they can act as attentional triggers, allowing for a better perception of speed and proximity of incoming traffic and for timely reactions to avoid conflicts. Therefore, due to traffic noise abatement, we might face in the near future an increasing trade-off between the improvement of population's health and the rise of accidents involving vulnerable road users. Such trade-off analysis has never been approached from an experimental perspective.

When compared to internal combustion vehicles, electric/hybrid engine vehicles have higher incidence of crashes involving pedestrians and bicyclists (Garay-Vega et al., 2010; Hanna, 2009). On the one hand road users show substantial interest in driving quiet hybrid or all-electric cars; but on the other hand they are concerned with the reduced conspicuity of such vehicles (Wolgater et al., 2001). Some experimental studies have addressed this issue. Ashmead et al. (2012) analyzed the path identification of electric engine and internal combustion engine vehicles in quiet and noisy environments. They found that in quiet environments there were timely path identifications of the electrical vehicles, but not in noisy ones. They also found that these judgments were based on sound level, the main characteristic that is altered in electric/hybrid cars. Studies with visually impaired populations have also revealed lower vehicle detectability of hybrid and all-electric

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vehicles (Emerson et al., 2010). All these data have contributed to the official recognition by the U.S. National Highway Traffic Safety Administration that electric vehicles in low-speed operation may induce a safety issue for blind pedestrians (Garay-Vega et al., 2010).

Other factors might affect traffic-related noise and hence vehicle conspicuity. In a previous study (Freitas et al., 2012) we have demonstrated that pavement type largely affects the levels of environmental noise and related subjective annoyance. However, the way pavement type affects vehicle detection is still not clear. In addition, age might be regarded as a relevant variable. Young pedestrians are more often involved in accidents than older people are, but while being rare, accidents with older people are the most severe (Martin, 2006). In experimental studies with children, the number of correctly identified vehicle sounds was significantly improved with age (Pfeffer and Barnecutt, 1996). Despite the strong evidence of the role of several traffic noise factors on vehicle conspicuity, there has never been a comprehensive study analyzing the main relevant variables (Barton et al., 2012).

In this paper, we present for the first time such an integrated approach to traffic noise variables and related vehicle detection levels. We address the detection of approaching vehicles as a function of pavement, vehicle type, background noise and the age of the listener. Binaural pass-by noise samples were recorded using several combinations of pavement, vehicle and speed. These samples were then edited to create scenarios of approaching vehicles in noisy environments. Under controlled laboratory conditions, participants had to detect the approaching vehicles.

2. Materials and methods

2.1. Participants

Eighty-nine participants were recruited from educational and social institutions (7–86 years old, $M = 36.68$, $SD = 22.12$). Split into age groups, 26 participants were juvenile (19 years and below, $M = 12.93$, $SD = 2.31$), 27 were early adults (20–39 years old, $M = 27.98$, $SD = 5.33$), 19 were middle adults (40–59 years old, $M = 50.51$, $SD = 5.94$), and 17 late adults (60 years and above, $M = 71.35$, $SD = 6.96$). To exclude prior major hearing deficiency all participants underwent audiometric screening tests at 250, 1000 and 4000 Hz. As major hearing deficiency criterion, late adults all had the 1000 Hz and 4000 Hz thresholds under 40 dB HL. The remaining participants had those thresholds under 30 dB HL. On average, children had as thresholds 14, 10, and 4 dB HL at 250, 1000, and 4000 Hz respectively. At those frequencies, adolescents had 9, 5, and −1 dB HL thresholds; juvenile and early adults had 15, 10, and 9 dB HL; and late adults had 24, 19, and 21 dB HL respectively.

Participants were all volunteers. They were instructed about the general purpose of the study and provided their informed consent about the participation in the tests and the confidential data manipulation. Under-aged participants had the informed consent of their caregivers.

2.2. Stimuli and equipment

The pavement surfaces selected for the tire-noise recordings in this study were: cobble stones, dense asphalt, and open graded asphalt rubber. The vehicles were a small passenger car (petrol, Volkswagen Polo), a hybrid (Toyota Prius), and a pickup truck (diesel, Mitsubishi Strakar). Both the representative sections of the road surfaces and the recording techniques were selected according to the European ISO Standard 11819-1:1997. The controlled pass-by method (CPB) was used, with each single vehicle tire-road noise recorded with speeds of 30, 40 and, 50 km/h.

The tire-road noise was binaurally recorded with a Brüel & Kjaer Head and Torso Simulator (HATS) type 4128-C, a Brüel & Kjaer Pulse Analyzer type 3560-C and the Pulse CPB Analysis software. The noise samples were recorded with the HATS at 7.5 m from the road centre and at a height of 1.7 m (for methodological details see Freitas et al., 2012).

From each single vehicle recording, sound samples with the duration of 2 s were produced. Sound samples were edited according to a time-to-passage (TTP) criterion. As such, sounds were not presented only by vehicle speed or distance to the listener, but in a combined form that is relevant for the road user. The TTP for all stimuli was fixed to 3.5 s i.e., at the end of the stimulus presentation the vehicle would need 3.5 s to cross the line of sight of the observer. This TTP value is considered the amount of time in which a pedestrian of any age is able to perceive and make an informed decision about crossing a road in safety.

To mask the vehicle signal, five levels of white noise were generated with WaveLab 6: −40, −35, −30, −25, and −20 dBV, presented through the headphones at 62, 67, 72, 77, and 82 dB (A), respectively. A total of 135 stimuli with signal plus noise were generated with audio software (Ardour): 3 pavements × 3 vehicles × 3 speeds × 5 noise levels.

The stimuli were presented through a computer with a sound card Intel 82801BA-ICH2, a custom built C++ application, and AKG K 271 MKII closed headphones. The C++ application allowed the reproduction of different audio scenes: multiple audio files, stimuli with different number of audio files, configuration of reproduction time, configuration of the visual stimulus that appeared along sound reproduction, setting of the sound pressure for each ear and collecting the participants' answers. Using the Brüel & Kjaer HATS and the Pulse Analyzer referred before, this system was calibrated to achieve sound pressure levels identical to those recorded in the real scenarios. The values of loudness were assessed with the Psysound3 application (Cabrera et al., 2008).

2.3. Procedure

Within each trial, the participant was presented with two consecutive sound samples, with a fixed gap of 1 s, 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. The 135 trials were presented in a pseudo-random order (method of constant stimulus). Participants were requested to detect in which of the intervals, i.e., first or second sample, was the approaching vehicle (two-interval forced choice, 2IFC). To avoid biased answers from participants the left-right orientation of the approaching vehicle and the order of intervals were randomized across the 135 trials. Each trial started only after an answer was given to the previous trial, and no time limits were imposed. Therefore, experiments did not have a fixed duration.

3. Results

3.1. Pavement, vehicle and noise levels

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). These results did differ significantly in a one way ANOVA ($F_3 = 10.95$, $p < 0.001$). In a post-hoc Sheffé test, it was found that the early and middle adults did not differ significantly ($F = 0.05$, n.s.), and neither did the juvenile differ from the late