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Influence of speed-related auditory feedback on braking in a 3D-driving simulator

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ABSTRACT

Although discrete auditory stimuli have been found useful for emergency braking, the role of continuous speed-related auditory feedback has not been investigated yet. This point may though be of importance in electric vehicles in which acoustic cues are drastically changed. The present study addressed this question through two experiments. In experiment 1, 12 usual drivers were exposed to naturalistic auditory feedback mimicking those issued from electric cars, while facing dynamic visual scenes in a 3D driving simulator. After being passively travelled up to a sustained constant speed, subjects had to stop their car in front of a traffic light that unexpectedly turned to red. Modifications of the speed-related auditory feedback did not impact braking initiation and regulation. In experiment 2, synthesized auditory feedback based on the Shepard-Risset glissando was provided to a new sample of 15 usual drivers in the same task. Pitch variations of this acoustic stimulus, although not scaled to an absolute speed, were manipulated as a function of visual speed changes. Changing the mapping between pitch variations of the synthesized auditory feedback and visual speed changes induced adjustments on braking which depended on acceleration/deceleration feedback. These findings stressed the importance of the acoustic content and its dynamics for car speed control.

1. Introduction

With the commercialization of electric vehicles at a larger scale, there is a growing interest regarding the impact of sound on driving. Indeed, electric vehicles produce little sound, due to the lack of internal combustion engine noise. This improves comfort for drivers and their environment. However, it also results in the drastic reduction of source of information regarding car displacement. While this can obviously impact the safety of pedestrians and other road users such as cyclists, it also raises the question of how this reduced auditory feedback could directly affect driving. Since driving safety has mostly been associated with drivers perception and control of their actual speed (Aarts & van Schagen, 2006; Brooks et al., 2011; Horswill

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& McKenna, 1999; Joksch, 1993), it appears crucial to investigate how acoustic content during driving may influence drivers speed perception and its effective regulation.

Actually, both presence and level of internal noise have been found critical for visual speed judgments. In the absence of acoustic feedback, or when this feedback is reduced, drivers tend to underestimate their speed to a greater extent (Evans, 1970; Horswill & Plooy, 2008; Matthews & Cousins, 1980; Merat & Jamson, 2011). For instance, based on psychometric estimates, Horswill and Plooy (2008) showed that a 5 dB attenuation of the ambient sound led to a decrease in perceived visual speed of about 5 $km{\cdot}h^{-1}$ (for a 60 $km{\cdot}h^{-1}$ reference visual speed). However, a critical question remains to be solved before the auditory influence on road safety can be assessed: While the level of ambient sound may affect subjective speed estimates, does this necessarily impact driving behavior? Although recent findings supported a direct link between motion perception scores and driving performance, including braking responses (Wilkins, Gray, Gaska, & Winterbottom, 2013), the specific consequences of sound manipulation on driving control (and not only on speed estimates) has not yet been investigated.

Currently, auditory-based Advanced Driving Assistance Systems (ADAS) provided in modern vehicles are mostly focused on discrete alerting stimuli which may help drivers to trigger earlier braking reactions (Chang, Lin, Fung, Hwang, & Doong, 2008; Mckeown, Isherwood, & Conway, 2010). This appears all the more effective when the intensity of such alerting stimuli is directly referred to the time to collision as for looming auditory warnings (Gray, 2011).

The question arises as to whether continuous speed-related auditory feedback could provide more subtle and smoother speed regulation than discrete or collision-related signals provided to the drivers. In other words, whether different types of online auditory feedback directly referred to car speed changes may impact braking is a relevant issue which has remained unexplored to our knowledge.

The present study therefore aims at investigating the direct influence of continuous auditory feedback on visual speed regulation through a braking task presented in a 3D-driving simulator. Specifically, the question was addressed via two experiments, in which the content of the acoustic information was manipulated, either using naturalistic sound recordings resembling those which would be emitted by an electric vehicle, or using synthesized sounds evoking motion dynamics through pitch variations. Overall, we hypothesized that sound content and its inherent dynamics conveyed by acoustic variations could be decisive for influencing driving in terms of speed regulation and braking.

2. General methods

The main device was composed of a fixed-based driving simulator inserted into a 3D immersive environment (Fig. 1). The virtual reality display (CAVE for Cave Automatic Virtual Environment) corresponded to a 3 m wide, 4 m high box space with three vertical screens constituting walls and a horizontal screen for the floor. The three vertical surfaces were back-projected, and the ground received direct projection with a 1400 × 1050 pixel resolution and a 60 Hz frame rate (more details about this setup can be found in Bringoux et al., 2009). In-house software (Ice©) was used to build and control virtual scenarios. It enabled projection of a virtual scene composed of a dynamic driver's perspective observed from a car travelling along a straight two-lane road. The driving simulator included a brake pedal with a mechanical gauge to control online the deceleration of the virtual car, from which visual and auditory cues were displayed and adjusted in real-time. Drivers' actions and simulator responses were linked directly without transformation (e.g.., no simulated inertia, no skid, straight handling). Maximal deceleration capabilities were standardized in both experiments at 16 $m{\cdot}s^{-2}$.

In both following experiments, the virtual car was first passively accelerated up to a 90 $km{\cdot}h^{-1}$ (i.e., 25 $m{\cdot}s^{-1}$) constant visual speed (Fig. 2). For all trials and conditions, the level of the initial passive acceleration was set at 3.25 $m{\cdot}s^{-2}$. In the

Fig. 1. Illustration of the main setup. A driving simulator was placed in a CAVE-like environment to provide realistic 3D visual stimuli to which different auditory stimuli were scaled and displayed to the drivers via earphones.