Simulated traffic and auditory information: The impact on street crossing in young and old adults.

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Abstract

This study aimed at investigating the influence of auditory information and ageing on street-crossing decisions, using a virtual environment. Four auditory contexts were tested: (1) no sounds at all; (2) only the sounds from the simulated vehicles; (3) only an ambient auditory context composed of traffic sounds; and (4) the sounds from the simulated vehicles + the ambient context. Young and older participants were evaluated on their performance regarding the safety margins during the simulated street-crossing task. The results indicated that a full privation of auditory information significantly increased the participants' unsafe behaviour. They also point to a global benefit from auditory information on the participants' decisions, irrespective of its type. Finally, no age-related differences were observed. The findings support the idea that auditory information is an important experimental factor when simulating traffic and investigating street crossing in virtual environments. The results are discussed regarding the psychological notion of *presence*.

Key words: *Simulated traffic, auditory information, street crossing, ageing, presence.*

Introduction

To cross a road safely, pedestrians have to select appropriate gaps in traffic. To do so, they have to estimate the *time to arrival* (TA) of oncoming vehicles [Hec15]. TA judgments have been shown to depend on both visual [DeL6] and auditory [But4] information. For example, It has been demonstrated that multiple visual sources of information, such as pictorial [DeL7] or motion-based [Kai19] cues, can help TA judgements. Similarly, multiple auditory indicators can be used to estimate the TA of oncoming vehicles [But4]. Jenison argued that TA judgments are dependent on the observer's motion, and that interaural time delays, Doppler shift, and average sound intensity are relevant variables used to specify TA information [Jen18]. In the same way, papers reported that the listener-to-source distance can be estimated using spectral changes in the emitted sounds [Ros29], as well as the rate of change in sound pressure [Ash1]. Among the multiple auditory indicators, it seems that rising sound intensity is one of the most used and important auditory cues in TA judgments [Neu25, Sei31].

In most ecological situations, vision and audition are simultaneously used in TA judgments, and the multimodal integration generally helps the coupling of perceptions and actions. Auditory information seems therefore important to estimate the TA of oncoming vehicles, especially because it allows compensating for deficits in visual processing [Gus14, Sch30]. Regarding street crossing, auditory information could then be especially beneficial to vulnerable pedestrians, such as the elderly.

Regarding transport activities, the global decline with age creates safety problems for both older drivers [Cla5, Dob8, Sha32], and older pedestrians [Dom9, Fra13, Lob20, Lob21, Oxl27, Oxl28, Spa36]. Street-crossing studies have shown that the elderly tend to adopt more unsafe behaviours compared to young adults [Lob20, Lob21, Oxl28]. These unsafe behaviours were particularly observed in constraining circumstances, such as complex road traffic [Oxl27] or high vehicle speeds [Lob20, Lob21, Oxl28]. Increased unsafe behaviours in older individuals compared to younger pedestrians can be explained by the tendency to rely on simplified distance-based heuristics, leading to a less efficient use of the visual information, and, thus, to more unsafe decisions [Lob20, Lob21, Oxl28]. In this context, it can be assumed that, similarly to visually impaired individuals [Sch30], older pedestrians could benefit from the presence of auditory information to compensate their deficient use of visual cues in TA judgments.

Virtual environments are more and more often used as experimental tools to conduct street-crossing studies [Dom9, Lob20, Lob21, Nei23, Nei24, Oxl28, Sim35]. Although auditory information seems important in TA judgments, this factor was not really considered in previous studies which used virtual environments. Some studies provided their participants with auditory information, but this factor was not manipulated and not analyzed regarding its potential influence on street-crossing performance [Dom9, Lob20, Lob21, Oxl28]. In other studies, audition was neglected by the authors, as no acoustic information was given to the participants during the experiments [Nei24, Nei25]. In few papers, no information about this parameter was even presented to the readers [Hol17, Sim35]. In simulated tasks, as well as in real situations, auditory information can be assumed to contribute to TA judgments, and, more generally, to performance. This assumption is supported by the TA literature but also by many papers dealing with virtual reality, and showing the importance of auditory information in simulated activities [Bor2, Hen16, Nam22]. Actually, several studies indicate that auditory information generally increases task performance in virtual environments [Nam22], and that behaviours can be modified by both relevant and irrelevant auditory sources [Bor2].

In this context, the aim of the present study was to investigate the influence of auditory information on TA judgments and street-crossing performance, but also to determine whether a potential effect of auditory information depends on the participants' age. Three hypothesises were made: (1) a full privation of auditory information is detrimental to street-crossing safety; (2) the type of auditory context influences the participants' performance differently; and (3) auditory information is particularly beneficial in older pedestrians.

Material & Methods

Participants

Forty participants took part in the study: 20 young people (20-35 years old; M = 28.5, SD = 5.1) and 20 older individuals (60-80 years old; M = 68.0, SD = 4.7). Each age group was composed of 13 men and 7 women. All the older participants were living on their own at the time of the experiment, without any medical assistance. All the participants went through a series of control tests aimed at eliminating subjects with visual, auditory, or motor deficient skills. Moreover, the older participants were tested using the Mini Mental State Evaluation (MMSE) [Fol11] to be sure that none of them were suffering from pathological ageing. Finally, an informed consent form was signed by the participants before starting the experiment.

Experimental set up

The street-crossing simulation device used in the experiment was based on the INRETS Sim^2 driving simulator [Esp10]. The device included a portion of experimental street (4.2-m wide, materialized on the ground), 3 large screens (2.70m x 1.90m each), an image-generation system including 3 video projectors, and a computer connected to a spatial sound-rendition system and a movement-tracking apparatus (Fig. 1, bottom). This computer was dedicated to the emission of the auditory contexts and data recording. The sound-rendition system was composed of five speakers: 2 in front of the participants, 2 in the back, and one subwoofer which was placed aside. This configuration allowed emitting the auditory contexts stereophonically, and, therefore, with spatial variations. Regarding the movement-tracking apparatus, it was composed of a locometer linked to the participants by the mean of a cable attached to their waist. Each time the participants moved forward to cross the experimental street, distance and time were recorded.

The setup provided the participants with a horizontal visual field between 90° (at the departure sidewalk) and 140° (in the middle of the experimental road), and a vertical visual field of 40°. The images were calculated at a refresh rate of 30 Hz. Image generation and projection took the participants' eye height into account; the simulated viewing angle was aimed the vanishing point of the modeled street. By way of a cable attached to the participants' waist, the movement-tracking system interactively updated the visual scenes according to their motion, and all their movements were simultaneously recorded.

The visual scenes represented a one-way street, 4.2-m wide sidewalk-to-sidewalk (Fig. 1, top). Traffic consisted of three vehicles: a motorcycle followed by two identical cars. All vehicles were moving at a constant speed from left to right in reference to the participants' position on the departure sidewalk. At the beginning of each scene, the motorcycle was 1.5 seconds away from the participants, and the first car was 1 second away from the motorcycle. Given that the visual scenes were updated according to the participants' position, oncoming vehicles were displayed on the central screen when crossing was accepted, but the vehicle approach ended on the right screen when the participants rejected crossing.

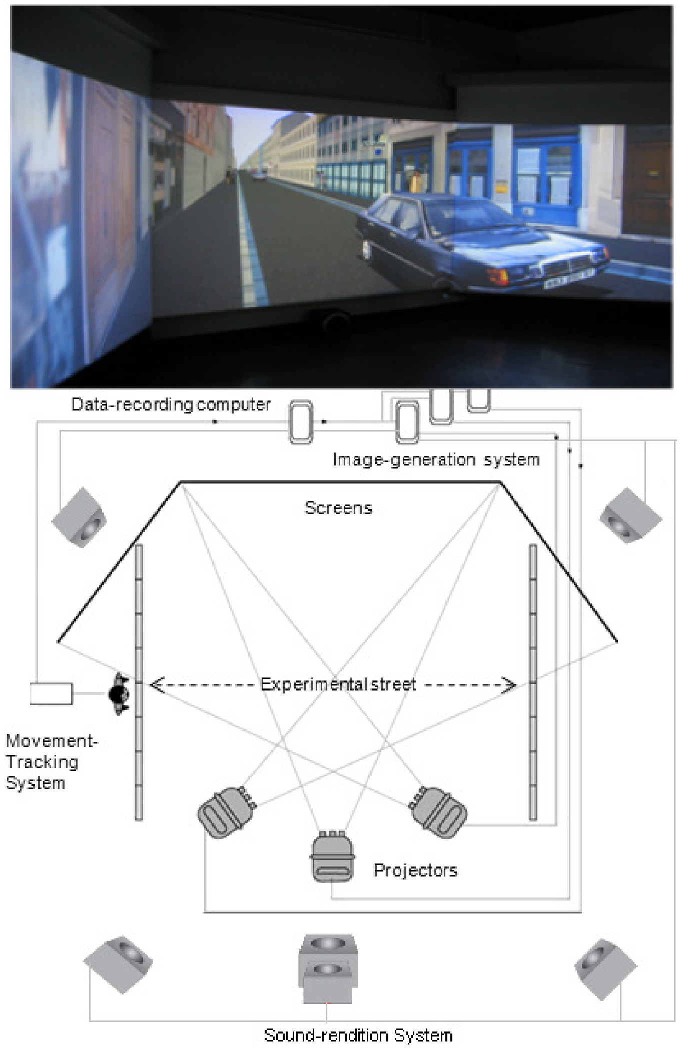

Fig. 1. Picture representing a scene from the participant's point of view at the departure sidewalk (Top). Top-down schematic view of the experimental setup (Bottom). **(© IFSTTAR, 2010)**

Experimental design

Four auditory conditions were used to investigate the role of auditory information in street-crossing: (1) no sounds at all (i.e., "no-sound" condition); (2) only the sounds from the simulated vehicles, that is to say engine, tires, and air displacement (i.e., "vehicle-sound" condition); (3) only an ambient auditory context composed of traffic sounds with no relations with the simulated vehicles (i.e., "ambient-sound" condition); and (4) sounds from the simulated vehicles to which was added the ambient context (i.e., "full-sound" condition). Considering conditions 2 and 4, the sound level from the vehicles was proportionally decreasing as a function of the distance between the considered position of the vehicle in the virtual environment and the crossing line, where was standing the participants and crossing the experimental street. The maximum sound level was therefore reached when the vehicle passed the crossing line, and the minimum vehicle-sound level (actually inaudible by the participants) corresponded to the vanishing point of the modeled street.

Four experimental blocks were distinguished, corresponding to the four possible auditory contexts. In each experimental block, 2 vehicle speeds were used (i.e., 40 and 60 km/h), and the time gap between the two cars varied from 1 to 7 s. The speeds were chosen to be representative of urban areas in France (i.e., speed limit = 50 km/h). Time gaps were chosen so that all of the participants, regardless of their age, would be confronted with both favorable (i.e., gap ≥ 4 s) and unfavorable (i.e., gap < 4 s) street-crossing situations. The number of repetitions per time gap differed according to their probability of being accepted for crossing. In fact, as it has been shown in previous studies, the shortest gaps are systematically refused and the longest gaps systematically accepted (e.g., Lobjois & Cavallo, 2007). Therefore, time gaps of 1 and 7 s were presented once, time gaps of 2 and 6 s twice, and the "critical" time gaps of 3, 4, and 5 s three times, making 15 trials in all. Using 15 trials for each vehicle speed leads to 30 trials per experimental bloc, that is to say 120 trials considering the whole experiment.

Procedure

Participants were tested individually on the street-crossing simulator. They were positioned at the edge of the sidewalk facing the experimental road and had to look to the left at the virtual environment and the approaching simulated vehicles. For each trial, participants were instructed to cross the street between the two cars when they thought it was safe to do so, by walking at any pace but not running. They were also told that they did not have time to cross in front of the approaching motorcycle, or between the motorcycle and the first car.

Before beginning the experiment, the participants performed some practice trials until they told the experimenter they fully understood the task. Thereafter, they performed the 120 experimental trials divided, as indicated above, in 4 experimental blocks of 30 trials each. Presentation order of the blocks was counterbalanced between the participants for each age group, and, in each experimental bloc, the presentation order of the trials was randomized. The participants' decisions to cross or not to cross and their motion until the end of the visual sequence were recorded on each trial. The complete session lasted approximately 45 minutes, and a 5-minute break was proposed in the inter-bloc intervals to the participants (especially for the older ones) to prevent fatigability.

Data Analysis

All trials were marked according to the participants' decision to accept or reject gaps to cross the street. For each accepted trial, the safety margin (SM) was computed. The SM corresponds to the time between the moment when the participants were completely over the edge of the arrival sidewalk and when the second car passed through the crossing line. Therefore, SM was negative if the participant was still on the road when the front of the second car passed the crossing line. For each participant, mean SM was computed for each auditory condition and each vehicle speed. Thereafter, the mean SM were input into a 4 (auditory contexts) x 2 (vehicle speeds) x 2 (age groups) mixed analysis of variance (ANOVA) with the significant level set at .05. The effect size (η^2) was also computed, and significant effects were further examined using Fisher's PLSD post hoc test.

Results

The participants' performance is presented in Table 1. The ANOVA on mean SM first revealed a significant effect of the auditory context, $F(3,114) = 3.09$, $p < .05$, $\eta^2 = .08$. The post hoc test indicated that the "no-sound" condition (M = 1.59s) induced a significant decrease of the SM, compared to all of the other auditory conditions ("vehicle-sound": M = 1.65s; "ambient-sound": M = 1.72s; "full-sound": M = 1.70s).

Similarly, the ANOVA revealed a major effect of the vehicle speed, $F(1,38) = 38.78$, $p < .0001$, $\eta^2 = .51$, yielding to greatly decreased SM while simulating cars moving at 60 km/h (M = 1.44s) compared to 40 km/h (M = 1.88s). In contrast, no significant effects of the age factor were observed, $F(1,38) = 2.22$, $p = .14$, $\eta^2 = .05$, indicating no overall differences on SM between the young (M = 1.76s) and the elderly (M = 1.56s) participants.

Regarding interactions, the *Speed×Age* interaction was close to significance, $F(3,114) = 2.79$, $p = .08$, $\eta^2 = .07$. Examination of the means and the post hoc test showed that the SM of each group were significantly decreased while increasing the vehicle speed, but that the decrease tended to be higher in the elderly (M = -0.57s) than in the young (M = -0.32 s) participants. No other interactions were significant.

Table 1. Mean safety margins (expressed in seconds) depending on the age group, the auditory context, and the vehicle speed. Standard deviations are indicated in parentheses.

Auditory context	Vehicle speed	Young participants	Old participants
« No-sound » condition	*40 Km/h*	1.8 (0.6)	1.9 (0.7)
	60 Km/h	1.5 (0.7)	1.2 (0.5)
« Vehicule-sound » condition	*40 Km/h*	1.9 (0.7)	1.7 (0.6)
	60 Km/h	1.6 (0.5)	1.3 (0.4)
« Ambient-sound » condition	*40 Km/h*	2.0 (0.5)	2.0 (0.5)
	60 Km/h	1.6 (0.4)	1.3 (0.5)
« Full-sound » condition	*40 Km/h*	2.0 (0.7)	1.9 (0.5)
	60 Km/h	1.7 (0.6)	1.3 (0.4)

Discussion

In the context of a simulated street-crossing task using a virtual environment, the present study indicates that full privation of auditory information tends to decrease the safety of the participants' decisions. SM were actually increased when auditory information was added to the visual scenes, compared to the conditions in which auditory information was not present. From this result, it can be concluded that auditory information was useful to the simulated street-crossing task and that auditory-visual information seemed to help the increase of the participants' performance. This conclusion is in accordance with previous papers reporting the benefit from auditory-visual information on TA judgments [But3, But4, Gus14, Sha33]. One observation moderates however the conclusion.

Analyzing the SM variations in the different auditory conditions, it was observed that, although they were statistically significant, these variations ranged only between 0.06 and 0.13 s. The variation range being relatively small, it is therefore difficult to estimate the impact of such variations in real conditions. Although auditory-visual information seemed to help the participants in the simulated street-crossing task, compared to the visual condition only, the results have however to be taken with careful considerations before generalizing the findings to reality. Transposition to a real street-crossing task seems even more premature as the explanation of the results needs to be clarified.

In the present experiment, the results do not seem to indicate that the benefit from auditory-visual information on the participants' performance can be explained by the use of relevant auditory cues (i.e., the specific sounds of the oncoming simulated vehicles) helping the participants to estimate the TA of the vehicles during the task. Actually, If this had been the case, a significant difference would have been observed between the auditory conditions where only the vehicles sounds or only the ambient context were available. The absence of such a difference tends to indicate that the improved performance when auditory information was available cannot be explained by the auditory cues specifically involved in TA estimation.

The present results could be explained instead by referring to the field of virtual reality (VR). Many studies reported that auditory information is an important experimental factor in simulated tasks as it increases the participants' *sense of presence* [Bor2, Hen16]. Applied to virtual environments, presence refers to experiencing the computer-generated environment rather than the actual physical location [Wit38]. Studies in the field of VR have demonstrated that the extent of sensory information transmitted to the participants in virtual environments determines the strength of the sense of presence [She34]. Concerning auditory information, Hendrix and Bartfield have shown in a free-navigation task that auditory-visual conditions increase the sense of presence, compared to visual conditions alone [Hen16]. According to Bormann's work, this observation seems true even when the auditory information is not relevant for the to-be-performed task [Bor2]. Increasing the sense of presence generally leads to increased performance in a simulated task [Nam22]. Actually, presence and attention are intimately linked [Fon12]: increased presence is related to increased attentional focus, and, thus, to greater performance.

In line with the VR literature, it can be assumed that the auditory information available in the present experiment increased the sense of presence in the participants, compared to the "no-sound" condition, leading to an increased attentional focus and, thus, to better performance in the simulated street-crossing task. Our results seem then to confirm Bormann's findings [Bor2], as an ambient auditory context (i.e., irrelevant information) had as much impact on the participants as the specific sounds of the simulated vehicles (i.e., relevant information). Further investigations should address the influence of presence in simulated street-crossing tasks, using dedicated questionnaires [Nic26, Tro37, Wit38].

Regarding ageing, no age differences were observed in this experiment when comparing the two groups of participants on the simulated street-crossing task. In our previous studies, the results showed that, considering normal ageing, some cognitive differences appeared when comparing the data of young and older participants. Precisely, regarding visual cues, it was showed that older individuals seem to rely more on distance-based heuristics than young subjects to estimate the time-to-arrival of oncoming vehicles. Similarly to visual cues, we expected that age-related differences could be revealed regarding the utilization of auditory information by young and older pedestrians in a street-crossing task. This hypothesis was obviously not confirmed. One explanation of this unexpected result could be that our old participants may actually have been too "young". In the street-crossing literature, it was demonstrated that ageing effects on performance tend to appear particularly in "old-old" participants (i.e., > 75 years old), but in a less important manner in "young-old" participants (i.e., 60-70 years old) [Lob20, Lob21, Oxl28]. In our study, the average age of the older participants was 68 years old, and only three of them were over 75 years old. It can therefore be assumed that the older group did not exhibit important age-related declines, and that the consequences on street-crossing safety remained limited. The present results therefore support the idea that the effects of age on street-crossing safety seem to especially concern pedestrians aged above 75 years old. Further investigations should be done to test the effect of auditory information in a simulated street-crossing task in "old-old" pedestrians.

In conclusion, the present study indicates that auditory information influences behaviours and contributes to increase the safety of decisions in the context of a simulated street-crossing task. Despite the limits of our experiment, the findings underline the fact that auditory information is an important factor when simulating traffic and investigating street crossing in virtual environments. Consequently, the studies which neglected this experimental parameter may appear questionable [Hol17, Nei24, Nei25, Sim35].

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