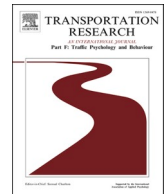




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To cross or not to cross: Impact of visual and auditory cues on pedestrians' crossing decision-making

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ABSTRACT

The controlled study of pedestrians' crossing decision-making is relevant to the search for better safety conditions for this class of vulnerable road users. Several risk factors have been identified in the literature related to the crosswalks' surrounding environment, the socio-demographic characteristics of the pedestrians crossing the road and the place where the crosswalks are inserted, as well as situational variables, such as speed and distance of the approaching vehicle during the crossing. In this work, the roles of visual and auditory cues in crossing decisions were analysed, comparing different speeds and distances, and taking into consideration different speed patterns of the approaching vehicle, aiming to identify what can affect pedestrians' crossing behaviour. Experiments were performed in a virtual environment. Participants were presented with 10 different stimuli featuring a vehicle approaching with different speeds and movement patterns, combined with 2 auditory conditions: one concerning a vehicle with a gasoline combustion engine and another one with no sound cues. Participants were tasked with indicating the moment they decided to cross the street when they thought it was safe to do so by pressing a response button. Percentage of crossings, response time (RT), and time-to-passage (TTP) were recorded and subsequently analysed. The results showed that lower speeds and higher distances lead to higher percentages of crossings and RTs. The auditory condition did not significantly affect participants' responses, leading to the conclusion that participants' crossing decision was especially based on their visual perception of the movement characteristics of the approaching vehicle, particularly its speed and distance. These results may have relevance for the development of communication strategies between the vehicles, especially the automated ones, and pedestrians.

1. Introduction

Over the past 20 years, the number of road traffic fatalities in Europe has been diminishing continuously due to new road safety policies and regulations. However, data from the Community database on Accidents on the Roads in Europe (CARE) shows that, since

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2013, the reduction trend has been slowing down. This appears to be driven by an increase in the number of car crashes involving young people and a slower than expected decrease in fatalities involving Vulnerable Road Users (VRUs) (European Commission, 2018a; Gicquel et al., 2017). Pedestrians, in particular, make up a large part of the number of road deaths and injuries (European Commission, 2018b; Hu & Cicchino, 2018; Olszewski, Szagała, Rabczenko, & Zielińska, 2019).

Unsurprisingly, most crashes involving pedestrians occur when they attempt to cross the road in the face of incoming traffic (Lassarre, Papadimitriou, Yannis, & Golias, 2007). Significant risk factors are well identified, namely, (1) environmental factors, *i.e.* those regarding all the physical environment surrounding the pedestrian when crossing the road at a given crosswalk, such as road design, traffic density, average traffic speed and visibility (Ewing & Dumbaugh, 2009; Ezziati Amini, Katrakazas, & Antoniou, 2019; Granié, Brenac, Montel, Millot, & Coquelet, 2014; Stoker et al., 2015; Sucha, Dostal, & Risser, 2017; Turner, Fitzpatrick, Brewer, & Park, 2006; Zegeer et al., 2006), (2) socio-demographic characteristics of the pedestrians crossing the road and of the place where the study section is inserted, such as pedestrians' age and gender, and population density, respectively (Bernhoft & Carstensen, 2008; Hamed, 2001; Holland & Hill, 2007; Johansson, Gårder, & Leden, 2004; LaScala, Gerber, & Gruenewald, 2000; Liu & Tung, 2014; Moyano Diaz, 2002; Papadimitriou, Lassarre, & Yannis, 2016; Rosenbloom, Ben-Eliyahu, & Nemrodov, 2008), and (3) situational factors relative to each crossing situation, such as speed and distance of the approaching vehicle during the crossing (Granié et al., 2014; Hine, 1996; Liu & Tung, 2014; Oxley, Ihsen, Fildes, Charlton, & Day, 2005; Papadimitriou et al., 2016; Papadimitriou, Yannis, & Golias, 2009; Simpson, Johnston, & Richardson, 2003; Sucha et al., 2017; Várhelyi, 1998; Yannis, Papadimitriou, & Theofilatos, 2013).

Regarding situational factors, a relevant part of the existing literature on pedestrian safety is devoted to identifying which variables influence the decision-making process of pedestrians crossing the roadway (Liu & Tung, 2014; Lobjois & Cavallo, 2007; Oxley et al., 2005) and the human behavioural factors that affect it (Hine, 1996; Papadimitriou et al., 2009, 2016). An ongoing discussion revolves around the question of whether pedestrians base their decision exclusively on an estimation of the available time to cross before the vehicle reaches the crosswalk or if they primarily consider the distance between them and the vehicle. In a seminal empirical work, Oxley et al. (2005) tested subjects of different ages in a crossing task in a virtual traffic environment. They observed that distance was a better predictor for crossing behaviour than time-to-arrival (TTA). Since then, numerous research works have been approaching the issue through both empirical and observational methods. An important observation is that this tendency to rely primarily on distance seems to be greater on the elderly (Liu & Tung, 2014; Lobjois & Cavallo, 2007; Oxley et al., 2005) and young people (Connelly, Conaglen, Parsonson, & Isler, 1998). A possible explanation for this is that people in these two age groups may have a reduced ability to perceive and integrate the distance and speed of the approaching vehicle to estimate the available time to cross the road before it reaches their position. A study by Feldstein and Peli (2020) seems to show that even young adults may rely on distance under less optimal conditions. They compared the crossing behaviour of young subjects in virtual (Head Mounted display - HMD) and real-world setups. They observed that participants based their decision primarily on distance in the virtual crossing task, while on the real-world they used time as main cue. They hypothesized that the low resolution of HMD may have prevented participants from properly assessing the speed of the vehicle, making them fall-back to a distance-based criterion. Taken together, these findings suggest that pedestrians may fall back from a time-based to a distance-based strategy when they have difficulties in estimating the vehicle's speed.

An important research gap in studies of pedestrian crossing behaviour and decision-making is the impact of the speed profile of the approaching vehicles. Most of the empirical studies conducted so far only consider vehicles with constant speeds (*e.g.* (Cavallo, Dommès, Dang, & Vienne, 2019; Dommès & Cavallo, 2011; Dommès, Cavallo, Vienne, & Aillerie, 2012; Feldstein, Dietrich, Milinkovic, & Bengler, 2016; Feldstein & Peli, 2020; Lobjois & Cavallo, 2007; Meir, Oron-Gilad, & Parmet, 2015; Simpson et al., 2003; Zito et al., 2015)). Nevertheless, it is known that crossing decisions often occur in the course of a driver-pedestrian interaction, with the pedestrians deciding to cross when they believe the driver will yield the passage (Ackermann, Beggiato, Bluhm, & Krems, 2018; Mahadevan, Somanath, & Sharlin, 2018; Schmidt & Färber, 2009). Misunderstandings are, however, common and often lead to crashes (Habibovic & Davidsson, 2012). Generally, it seems that pedestrians interpret speed reduction as an indication that the driver will yield (Dey, Martens, Eggen, & Terken, 2019; Schneemann & Gohl, 2016; Soares et al., 2020; Sucha et al., 2017). However, exactly how the vehicle speed before deceleration and particular kinematics affect crossing behaviour is still not fully understood.

Another factor often disregarded in the analysis of crossing decisions refers to the role of the auditory cues produced by the moving vehicle. Some attention has been given to the auditory stimuli, mostly considering blind pedestrians, which must solely rely on their audio perception to make crossing decisions (Ashmead Daniel, Guth, Wall Robert, Long Richard, & Ponchillia Paul, 2005; Emerson, Naghshineh, Hapeman, & Wiener, 2011; Guth, Ashmead, Long, Wall, & Ponchillia, 2005). Barton, Ulrich, and Lew (2012) analysed the detection and localization of approaching vehicles through auditory cues in sighted pedestrians. They concluded that higher speeds allow pedestrians to detect the vehicle approaching over greater distances, but lower speeds facilitate the judgment of when the vehicle is getting near them. Pugliese, Barton, Davis, and Lopez (2020) analysed TTA judgments based on visual, auditory, and combined cues. Their results point to a higher relevance of the visual cues. This is supported by Soares et al. (2020), who compared the crossing behaviours with visual and auditory input of gasoline and electric vehicles and found no significant effects of the sound.

Here, an extension of the previous research presented by Soares et al. (2020) is reported through a study that aims to clarify the role of the vehicle kinematics on pedestrians' crossing decision-making, mediated by the resulting visual and auditory cues. A more thorough analysis of the role of speed and distance, as well as the different speed profiles of the approaching vehicle, is also presented.

To do so, a virtual crossing simulator implemented through a CAVE-like, power wall setup was used. Participants were asked to visualize and hear an approaching vehicle in different conditions and decide if and when to cross by clicking on a computer mouse button. The use of simulators is becoming increasingly common for controlled pedestrian safety studies (Cavallo et al., 2019; Charron, Festoc, & Guéguen, 2012; de Clercq, Dietrich, Núñez Velasco, de Winter, & Happee, 2019; Deb, Carruth, Sween, Strawderman, & Garrison, 2017; Deb, Strawderman, & Carruth, 2018; Feldstein et al., 2016; Meir et al., 2015; Simpson et al., 2003; Zito et al., 2015). In

the experiment reported here, a congruent auditory input recorded from real vehicles is provided with the visual input. This was intended to increase the feeling of presence experienced by the participants and to address one of the topics of this study, namely the auditory perception of approaching vehicles.

2. Materials and methods

2.1. Participants

A sample of 30 adults (16 female and 14 male) with ages between 20 and 60 years old ($m = 39.70$ years old; $sd = 12.11$ years old) was recruited from the University of Minho community, Portugal. This age group corresponds to the segment of active population who is more likely to be found walking and crossing the road because of the daily commuting.

Prior to the experiment, all participants answered a questionnaire regarding their hearing, visual and mobility conditions. None of them reported any impairing condition that could interfere with participation in the experiment, such as some type of blindness, deafness, and problems impeding his/her movement. They also signed an informed consent form before participating in the experiments.

2.2. Virtual scenarios development

Two streets were chosen to be modelled in a virtual environment: the 25 de Abril Street, in the city of Braga; and the Teixeira de Pascoais Street, in the city of Guimarães, both located in Portugal. The main characteristics of each street are presented in Table 1. They were chosen because they have the same number of lanes, crosswalks with similar lengths, and no major differences in the environment involving the crosswalk (e.g. the sidewalks' dimensions and the existence of similar buildings). Two streets were used (instead of just one) to minimize the risk of biases created by uncontrolled visual elements.

The development process of the virtual scenario was similar for the two studied road sections. First, dimensions and distances of the different road elements in each road were taken, including dimensions of the crosswalks and respective ground marks, the surrounding streets' width, sidewalk width, width and height of the curbs, width and length of the parking spaces, and dimensions of the remaining road markings. The streets were modelled using Blender[™] 2.79a, an open-source 3D graphical computation software that uses Python as a scripting language. To provide participants with a realistic depiction of the roads, several pictorial details were also modelled, and textures from pavements and buildings were added (Fig. 1(a)(b) and Fig. 2(a)(b)).

These textures were obtained through photos and edited using Adobe® Photoshop CC 2015 before being included in the 3D model. Prior to the experiment, each scenario was previously tested on a CAVE projection system, opened in a Power-Wall configuration, to check for possible errors in the physical dimension of the virtual elements.

2.3. Stimuli

The development of the audio-visual stimuli relied on real-world information collected in a two-stage procedure. In the first stage, an observational study was conducted for characterizing the typical speed patterns for vehicles approaching crosswalks. In the second stage, a test vehicle was used to replicate the identified patterns in a controlled setting while the vehicle kinematic data and resulting sounds were recorded. Next, each of these stages is described.

2.3.1. Observational study

Firstly, video recordings of pedestrian crossings involving approaching vehicles were carried out in each of the selected streets. Videos were recorded at 30 fps, using a GOPRO 5 Black camera, with a resolution of 1920×1080 pixels. The camera was placed at the height of 5 m or more and between 15 and 25 m away from the crosswalk, depending on the conditions of each location. Each video had a duration of approximately 2 h.

Video analysis was performed using the Traffic Intelligence software (Jackson, Miranda-Moreno, St-Aubin, & Saunier, 2013; Saunier, Sayed, & Ismail, 2010). In short, for each recorded video, Traffic Intelligence identified and mapped the movement of each pixel, frame by frame, grouping them according to the similarity of their characteristics and classified each group as an object

Table 1

Main characteristics of the streets.

		Street	
		Teixeira de Pascoais	25 de Abril
Length of the crosswalk	(m)	7.13	7.85
Average width of the lanes	(m)	3.57	2.87
Width of the street to park	(m)	10.12	4.23
Average width of the sidewalk	(m)	4.11	4.17
Width of the crosswalk	(m)	5.12	3.4
Number of lanes		2	2
Road pavement		Asphalt concrete	Asphalt concrete



Fig. 1. Comparison between the virtual (a) and real (b) scenarios regarding the 25 de Abril Street.



Fig. 2. Comparison between the virtual (a) and real (b) scenarios regarding the Teixeira de Pascoais Street.

(pedestrian or vehicle). The software provides the trajectories and speed of both vehicles and pedestrians. A total of 126 observations were registered (68 on Teixeira de Pascoais street and 58 on 25 de Abril street).

From the video analysis, the three most observed vehicle speed patterns in pedestrian crossing situations were identified and characterized: i) the vehicle slows down and completely stops before reaching the crosswalk (Stop); ii) the vehicle slows down before reaching the crosswalk but continues its trajectory without stopping (Slow Down); iii) the vehicle maintains its trajectory without any, or with very subtle, speed changes (Constant Speed). Descriptive statistics are presented in Table 2.

For the Stop and Slow Down patterns, S_i and D_i represent respectively the speed and distance between vehicle and pedestrians at the beginning of the observation and S_f and D_f represent speed and distance at the end of the braking phase of the trajectory. For the Constant speed pattern, S represents the average speed. For each variable, mean (M), maximum (max), minimum (min), and standard deviation (SD) values are presented.

The characteristics of the vehicle movement for the simulation (Table 3) were defined, taking into account the descriptive statistics presented in Table 2. The goal was to have a limited set of experimental conditions while still having representative values of S_i , D_i , S_f , and D_f .

Table 2

Mean, maximum, minimum and standard deviation of vehicle speed and distance to pedestrian for each speed pattern.

	Stop				Slow Down				Constant Speed
	S_i (km/h)	D_i (m)	S_f (km/h)	D_f (m)	S_i (km/h)	D_i (m)	S_f (km/h)	D_f (m)	S (km/h)
M	17.30	15.80	0	5.71	21.34	16.72	7.24	7.01	25.91
SD	8.15	5.62	0	2.40	8.46	6.21	6.56	4.14	7.87
max	34.41	27.37	0	14.06	37.59	28.20	28.39	22.04	43.18
min	3.81	6.58	0	1.26	4.43	2.94	1.07	2.69	14.27

Perhaps because pedestrians found it unsafe to cross, almost no crossings were observed for the selected distances and speeds above 30 km/h during the observational study. So, the conditions of the study were limited to speeds equal to or lower than this value. To decrease the likelihood of participants memorizing the vehicle's motion profiles, and taking into account that in the Slow Down and Stop patterns the speed varied along the time of approaching, hampering some learning effect that could occur, the initial distance at which the vehicle appeared ($D_{i, \text{mov}}$) in the Constant speed stimuli also varied.

2.3.2. Auditory stimuli and trajectory acquisition

Controlled binaural sound recordings of real vehicles were carried out in a closed urban road. The vehicles' noise was recorded using a Brüel & Kjær Pulse Analyzer type 3560-C and a Brüel & Kjær Head and Torso Simulator (HATS) Type 4128-C equipped with Ear Simulators Type 4158-C and 4159-C. The Controlled Pass-By (CPB) movement of a Kia Ceed SW with a gasoline combustion engine and equipped with ContiEcoContact3 195/65-R15 tires was used for the recordings.

CPB measurements include all vehicle noise sources, the effect of propagation mechanisms, and noise from the surrounding environment (Freitas, Mendonça, Santos, Murteira, & Ferreira, 2012). For this reason, the recordings were performed during the night-time (20:00 h – 24:00 h) in a quiet zone to avoid traffic noise. To minimize the meteorological bias, all recording sessions were performed with dry pavement, wind speed below 5 m/s, atmospheric temperature between 5 °C and 30 °C, and pavement temperature between 5 °C and 50 °C as recommended in ISO 11819-1 (1997). Moreover, to represent the average conditions of the Portuguese urban roads, the sound recordings were performed in an asphalt mix (AC14) pavement with good maintenance conditions.

During the recordings, the HATS was placed with its head turned 35° from the road direction, on the side of the road, at 1.55 m from its centre, and 1.66 m height (Portuguese population average height). To generate the sound samples for each of the three types of vehicle motion pattern, a driver performed the trajectories defined by the parameters in Table 3. The real speed, time, and distance data from the vehicle were registered at 1/8 Hz rate simultaneously with the sound recordings.

The sound and vehicle position data were later synchronized, calibrated, and implemented in a virtual environment. The visual model of the vehicle used in the experiment was the same used in sound recordings.

2.4. Instruments

The experiment was conducted in a room where the CAVE type system is located in a Power-wall configuration. This system integrates a projection screen with a width of 9 m, of which 8 m are used for the projection, performed through three DLP Christie Mirage S + 4 K projectors, with a screen resolution of 1400 × 1050 pixels, located behind the screen. The stereoscopic projection was used with a frame rate of 60 fps (participants wore 3D shutter glasses). Four computers control the system (Dell Precision R7610 rack workstation, equipped with Nvidia Quadro K5000 graphics cards and Intel Xeon E5-2600 processors, three of which are used to render the projection itself while the 4th is used for motion-tracking, monitoring, and data gathering).

This system uses the BlenderVR software (Katz, Felinto, Touraine, Poirier-Quinot, & Bourdot, 2015), in conjunction with the VICON motion capture system, to provide participants with a three-dimensional realistic perspective of the virtual scene. VICON reflective tracking points were placed on a set of headphones worn by the participants. During the experiments, the only light available in the room was from the 3 projectors, the image projected on the screen, and the infrared lights of the VICON's cameras. The simulation was configured in such a way that the central point of the virtual world corresponded to the endpoint of the left curb of each street. A computer mouse was used to start the experiment. Participants indicated their answers with a click on either the right or the left button of the mouse.

CPB sounds were played, co-localized, and synchronous with the visual scene, through headphones following amplification through a Sony TA-AV570 Audio Video Amplifier. The sound was calibrated to ensure that its intensity level was the same as the one registered during the recording sessions.

2.5. Experimental procedure

Before the beginning of the experiment, each participant was placed in a predefined room point (2 m from the projection screen) where they had to stay throughout the experiment (Fig. 3). This point corresponded, in the virtual space, to the intersection of the

Table 3

Characteristics of vehicle movement in the different conditions presented in the experiment.

Condition	Speed Pattern	S_i (km/h)	S_f (km/h)	$D_{i, \text{mov}}$ (m)	D_i (m)	D_f (m)
1	Constant Speed	20	20	35	–	–
2		30	30	35	–	–
3		20	20	30	–	–
4		30	30	30	–	–
5		20	20	25	–	–
6	Slow Down	30	30	25	–	–
7		30	10	30	25	5
8		20	10	30	15	10
9	Stop	20	0	30	15	5.50
10		30	0	30	20	5.50

perpendicular to the direction of the vehicle movement and crosswalk's axis of symmetry and the curb.

Participants were asked to put on the headset and the 3D glasses while listening to the instructions. They were then tasked with indicating, in each trial, the moment they decide to cross the street, clicking on the buttons of the mouse. They were also told not to press any button if they decided not to cross. Fig. 4 shows a depiction of the experiment's performance.

Participants completed an experimental session composed of two main blocks, one in each street scenario. The experiment was preceded by a training block composed by four crossing trials. Each one of the ten speed patterns presented in Table 3 was repeated five times for each type of auditory condition (gasoline combustion engine – *audio-visual condition* and those without auditory cue – *no sound condition*). Participants went through 200 trials (10 movement conditions $\times$ 5 repetitions $\times$ 2 auditory conditions $\times$ 2 streets). The two main blocks were also split into two parts so that participants could rest between each part and block for as long as they needed. The experiment lasted 1 h.

2.6. Analysis

The influence of the variables addressed in this study on the participants' crossing decision-making was analysed in terms of the percentage of crossings, response time (RT), and time-to-passage (TTP). TTP is generally defined as the time it would take for a moving object (vehicle) to reach the frontal plane of a fixed observer (participant) (Hancock & Manser, 1998). This variable is also called time-to-arrival (TTA) in some studies on pedestrian safety (e.g. (Cavallo et al., 2019; Lobjois & Cavallo, 2007; Pugliese et al., 2020)). The TTP is measured in seconds and reports to the moment, during the stimulus presentation, when the participant indicated the intention to cross (Expression (1)).

$$TTP = D_{\text{vehicle-conflict point}} / S_{\text{vehicle}} \quad (1)$$

$D_{\text{vehicle-conflict point}}$ is the distance, in m, from the centre of the vehicle's license plate, assumed as the possible point of impact, and participant's frontal plane at the moment when he or she started to cross, and S_{vehicle} is the vehicle speed, in m/s, at the moment the participant began to cross.

The percentage of crossings was calculated, for each participant, by assuming there was a decision to cross in the trials in which the computer mouse was clicked before the vehicle stopped or passed in front of them. For those trials in which the participant did not click, it was assumed that he/she would cross after the vehicle had passed, with no conflict between vehicle and participant being considered. The RT, corresponding to the time from the beginning of the stimulus presentation to the moment the participant clicked the mouse, was also registered.

The influence of the variables *auditory condition*, *vehicle speed pattern*, *vehicle initial speed*, and *vehicle initial distance* on the percentage of crossings was assessed using three-way repeated-measures ANOVAs. The influence on RT and TTP was assessed by fitting mixed-effects regression models with random effects included for *participant* and fixed effects defined for the variables mentioned above. The use of Linear Mixed Models is justified by the existence of missing values in the data, corresponding to trials in which participants did not cross.

The data analysis was done in two distinct stages. In the first stage, the conditions characterized by constant speed patterns were analysed. In the second stage, a comparison was made between the different speed patterns.

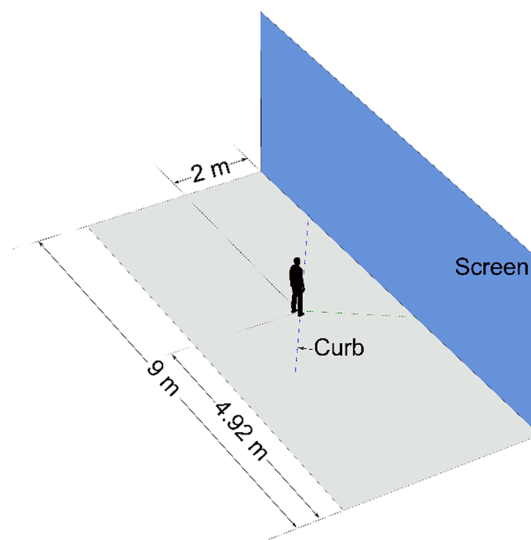


Fig. 3. Spatial layout of the room and participant position.

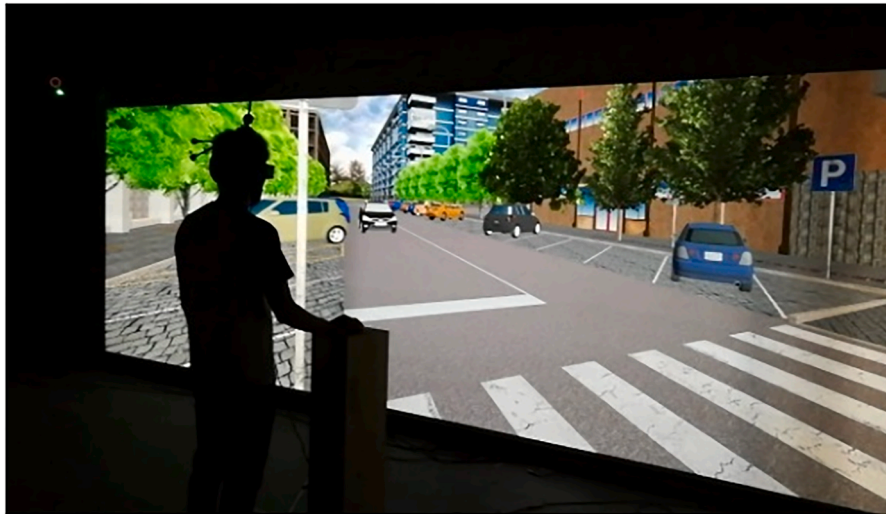


Fig. 4. Participants' view during the performance of the experiment.

3. Results

3.1. Constant speed pattern

Fig. 5 shows the crossings' data for each participant and condition (location of the circle along the axis represents the mean RT, the size of the circle represents the number of crossings and the line shows the standard error of the mean; participants are vertically ordered according to mean RT).

It is possible to note a group of participants that frequently decided to cross, irrespective of the condition. These participants also made consistently faster decisions. The summary of descriptive statistics in terms of percentage of crossings, RT and TTP, regarding the analysis of the Constant speed pattern is presented in the Appendix A.

3.1.1. Percentage of crossings

The percentage of crossings was examined using a three-way repeated-measures ANOVA with *vehicle initial distance* (3), *vehicle speed* (2) and the *auditory condition* (2) as factors. The auditory condition did not significantly influence the participants' percentage of crossings $F(1, 29) = 2.71$, $p = 0.11$, $\eta^2 = 0.09$. There was a main effect of vehicle speed, $F(1, 29) = 39.35$, $p < 0.01$, $\eta^2 = 0.58$, with higher values for the 20 km/h condition compared to when it was 30 km/h. There was also a main effect of vehicle initial distance, $F(2, 58) = 31.18$, $p < 0.01$, $\eta^2 = 0.52$, with Bonferroni post hoc tests showing that crossing percentages increased significantly with the initial distance. A significant speed $\times$ initial distance interaction was also found, $F(2, 58) = 9.66$, $p < 0.01$, $\eta^2 = 0.25$. Bonferroni post hoc tests were conducted comparing initial distances within each level of speed. At 20 km/h, there were significant differences between all levels of distance (25 m / 30 m: $p < 0.001$, 25 m / 35 m: $p < 0.001$, 30 m / 35 m: $p = 0.01$). At 30 km/h significant differences were only found between 25 and 35 m ($p < 0.001$).

In general, participants crossed more when vehicle speed was lower and its initial position was farther from the crosswalk. However, at 20 km/h, the distance increasing resulted in greater growth of the percentage of crossings (see Fig. 6).

3.1.2. Response time

Initial analysis of RT data showed a skewness pattern typical of response times. A linear mixed model of RT with random effects included for *participant* and fixed effects defined for the *initial speed*, *speed pattern*, and *auditory condition* was fitted. Visual inspection of the residual plots showed deviations from homoscedasticity and skewness, so the model was refitted applying a logarithmic transformation to RTs, which corrected the deviations. Satterthwaite's tests showed significant effects of vehicle initial speed, $F(1, 838.30) = 19.00$, $p < 0.001$, and interaction between vehicle initial speed and vehicle initial distance, $F(1, 837.22) = 6.01$, $p < 0.05$, and an interaction between initial speed and initial distance, $F(1, 837.38) = 3.10$, $p = 0.04$. There was no effect of the auditory condition.

The model was refitted after discarding the auditory condition, and contrasts were used to analyse the interaction between vehicle initial speed and initial distance. Differences were found, for the initial speed of 30 km/h, between initial distances of 25 and 35 m, $b = 0.20$, $t(842.84) = 2.45$, $p = 0.01$. No significant differences were found for the speed of 20 km/h.

Considering these results and Fig. 7 that shows RT as a function of vehicle initial distance, initial speed and auditory condition, it is apparent that participants' decisions to cross tended to be faster for higher speeds and when the vehicles were closer.

3.1.3. Time-to-passage

Fig. 8 shows the mean values of TTP at the crossing instant as a function of the TTP at the start of the trial. The observed TTP

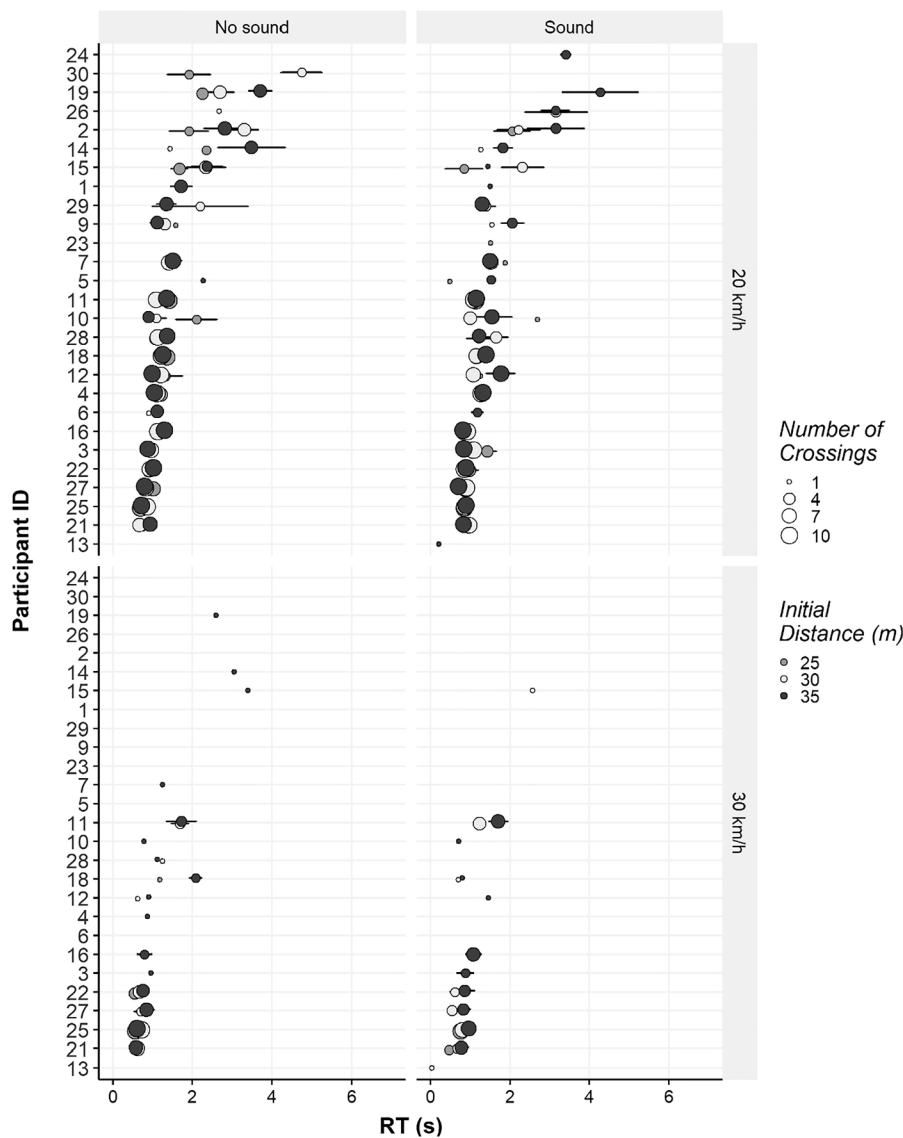


Fig. 5. Participants' responses along time of stimulus' presentation, per auditory condition and initial speed (Constant speed pattern).

appears to vary linearly with the initial TTP. This was expected given that RT variations were small compared with the variation of initial TTP. The RT analysis done in the previous subsection showed that for those participants that crossed with the approaching vehicle at 30 km/h there was an attempt to compensate for the shorter available time by initiating the crossing earlier. However, TTPs were still lower than the ones observed at 20 km/h, meaning that participants who crossed at higher speeds were, in effect, taking riskier decisions.

3.2. Different speed patterns

This section reports the analysis of participant's behaviour when confronted with different speed patterns. Fig. 9 and Fig. 10 show the crossings' data for each participant and condition (location of the circle along the axis represents the mean RT, the size of the circle represents the number of crossings, and the line shows the standard error of the mean; participants are vertically ordered according to mean RT). The line graphs show the actual speed profile observed by the participant (note that for the Constant speed profile, results are the same as in Section 3.1.1 for the initial distance of 30 m).

The number of crossings increases substantially for the Slow Down and Stop patterns, particularly for those participants who crossed less times in the constant speed. Nevertheless, these participants tended to cross later in the trial, when the vehicle was already slowing down.

The descriptive statistics of the results regarding the analysis of all speed patterns, in terms of percentage of crossings, RT, and TTP,

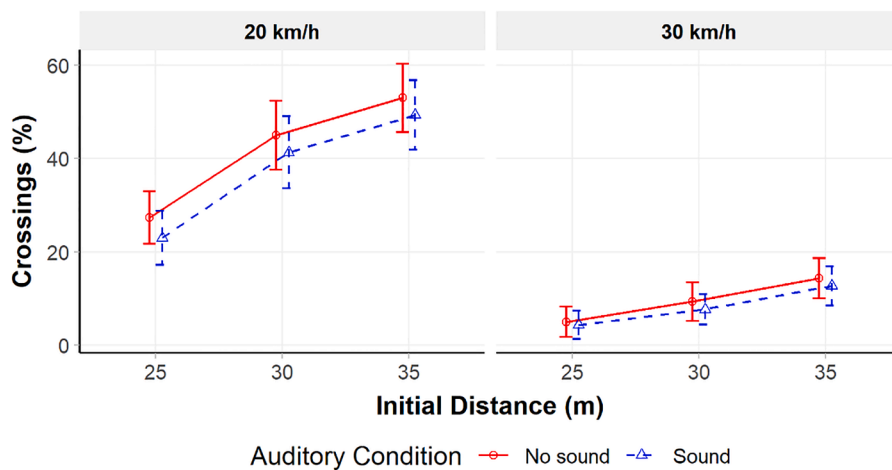


Fig. 6. Percentage of crossings and respective mean standard error as a function of auditory condition, per initial distance and initial speed (Constant speed pattern).

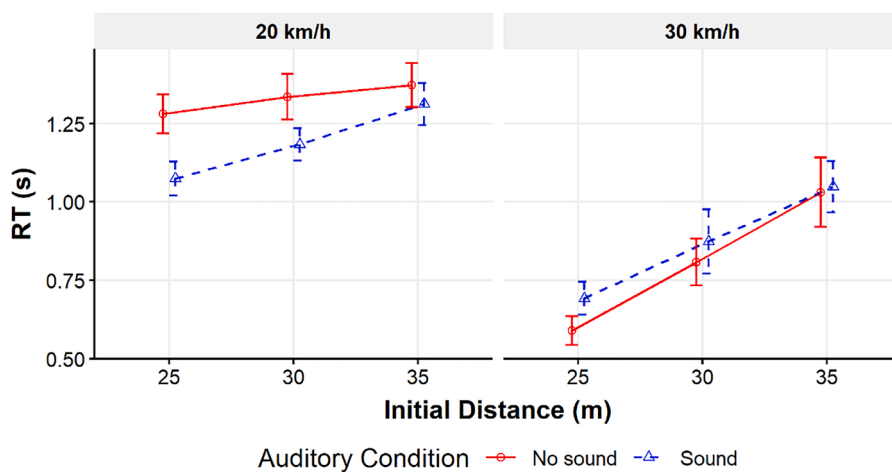


Fig. 7. Mean RT and respective standard error as a function of auditory condition, per initial distance and initial speed (Constant speed pattern).

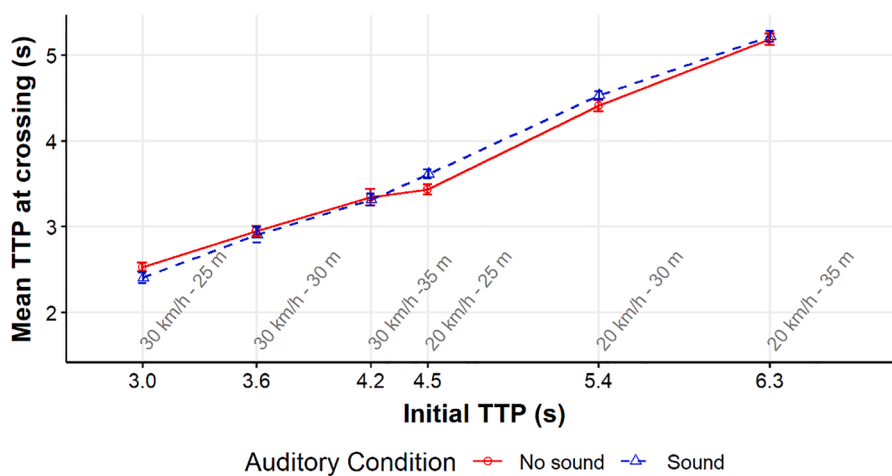


Fig. 8. Mean values of TTP at the crossing instant as a function of the TTP at the start of the trial (constant speed pattern).

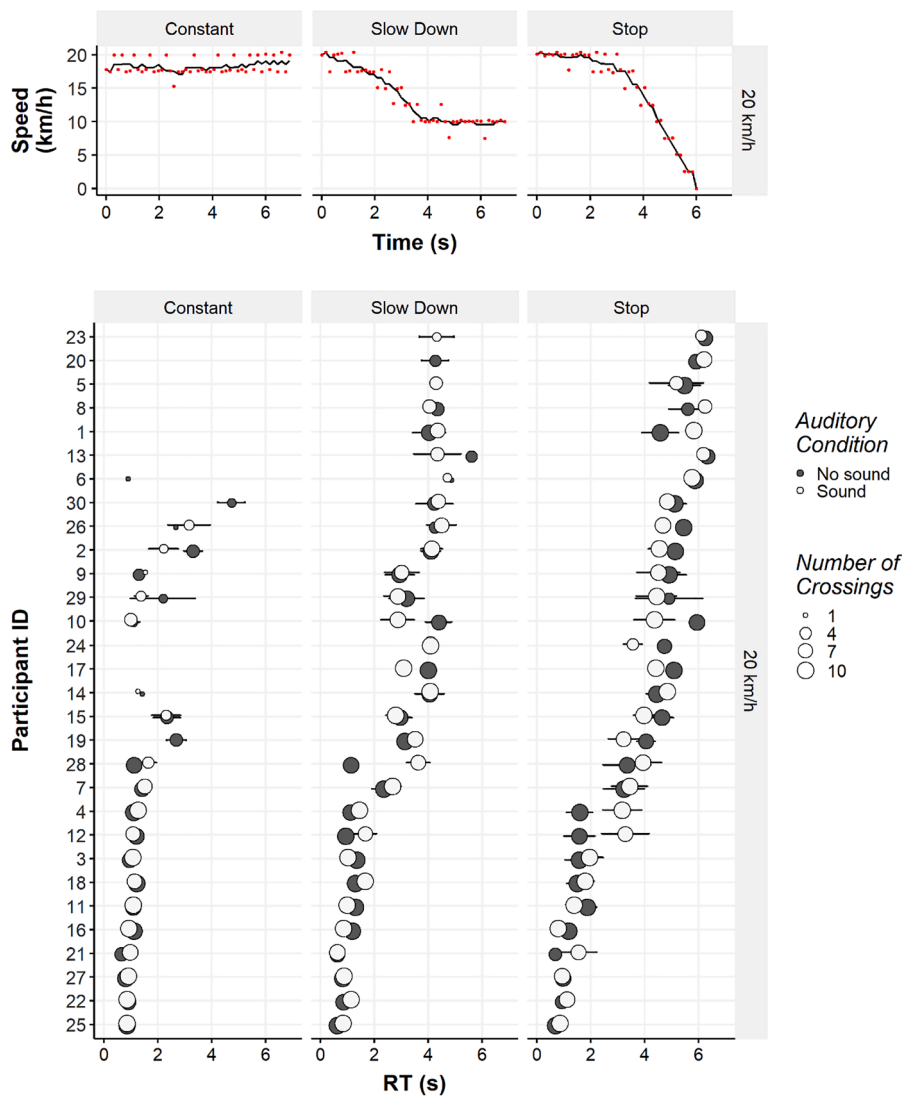


Fig. 9. Participants' responses and vehicle speed along time of stimulus' presentation, per speed pattern, for initial speed of 20 km/h.

are presented in the Appendix B.

3.2.1. Percentage of crossings

Such as in the previous section, the percentage of crossings was examined in a three-way repeated-measures ANOVA. In this case, the *vehicle speed pattern*, the *initial speed*, and the *auditory condition* were the considered factors. Main effects were found for initial speed, $F(1, 29) = 15.48$, $p < 0.001$, $\eta^2 = 0.35$ and speed pattern, $F(2, 58) = 68.16$, $p < 0.001$, $\eta^2 = 0.70$, but not for the auditory condition $F(1, 29) = 0.70$, $p = 0.41$. A significant initial speed $\times$ speed pattern interaction was also found $F(2, 58) = 14.72$, $p < 0.001$. Bonferroni post hoc tests were conducted comparing the different speed profiles and initial speed within speed profiles. Generally, there was a significant increase in the percentage of crossings from Constant to Slow Down ($p < 0.001$) and from Constant to Stop ($p < 0.001$), but not from Slow Down to Stop ($p = 0.09$). Contrasts within each speed profile show differences between 20 km/h and 30 km/h for the Constant speed, $t(60.50) = 6.38$, $p < 0.001$, but not for the Slow Down, $t(60.5) = 1.78$, $p = 0.08$, nor the Stop, $t(60.50) = 1.31$, $p = 0.19$.

The results show that the participants crossed significantly more when the vehicle slowed down or stopped. They also show that the participants crossed more when the car was approaching at 20 km/h than at 30 km/h, but this difference was only significant when the car was approaching at constant speed. When the vehicle was slowing down, the speed played a substantially less important role in the participant's behaviour (see Fig. 11 and Appendix B).

These results indicate that for those conditions in which the vehicle speed varied, the participants had a greater tendency to cross after the speed began to decrease.

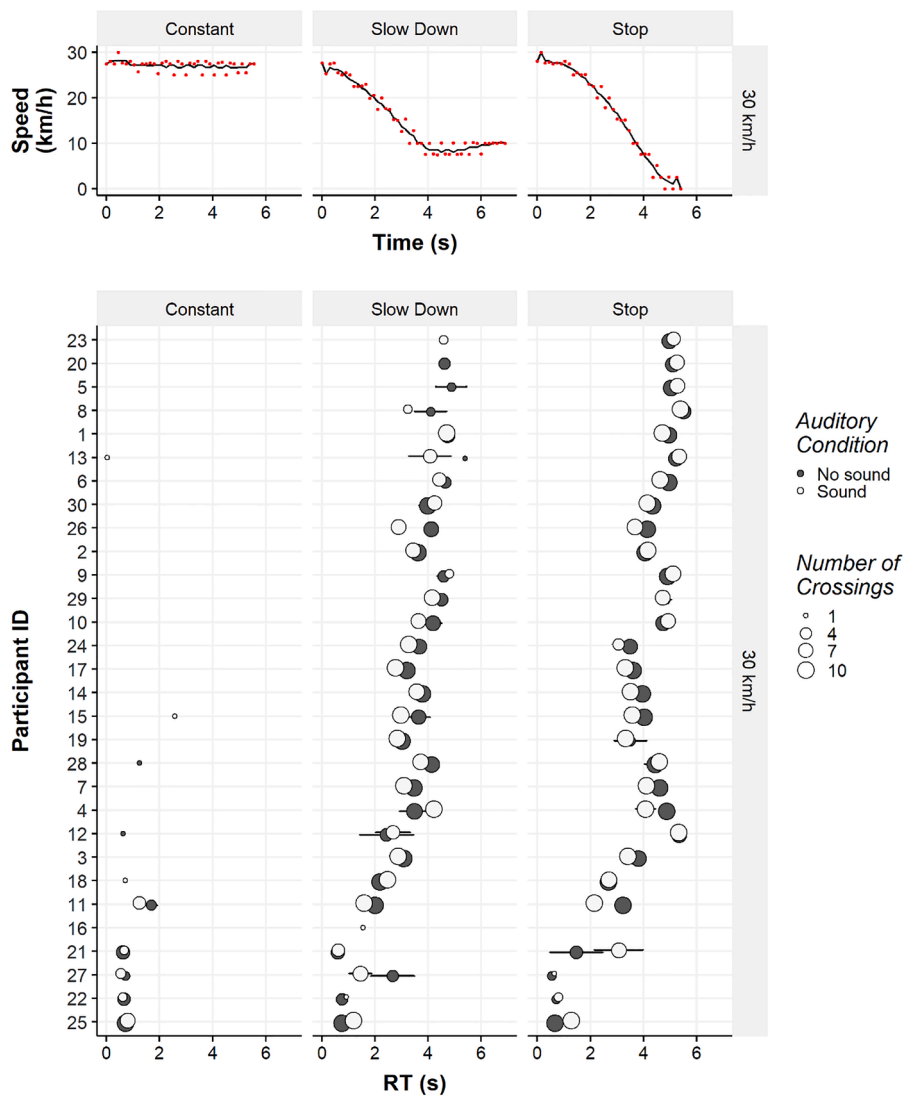


Fig. 10. Participants' responses and vehicle speed along time of stimulus' presentation, per speed pattern, for initial speed of 30 km/h.

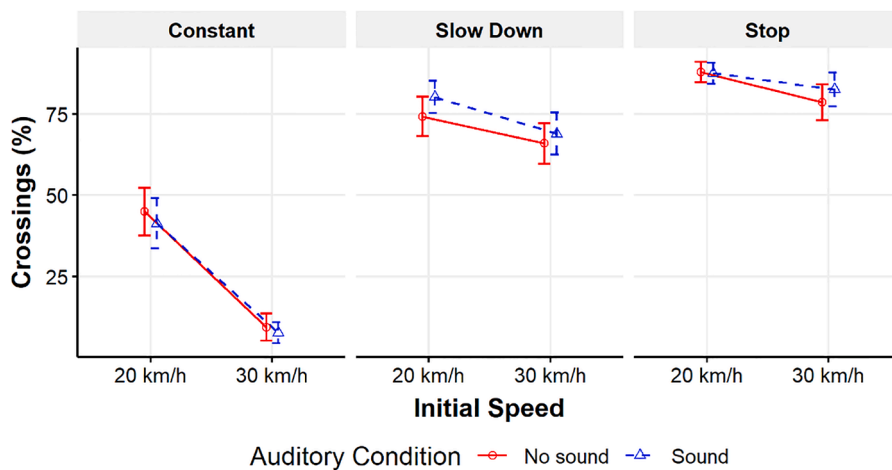


Fig. 11. Percentage of crossings and respective mean standard error as a function of auditory condition, per initial speed and speed pattern.

3.2.2. Response time

As in the previous section, a linear mixed model of $\log(RT)$ with random effects included for *participant* and fixed effects defined for the *initial speed*, *speed pattern* and *auditory condition* was fitted. Visual inspection of the residual plots showed no deviations from homoscedasticity or skewness. Satterthwaite's tests showed significant effects of vehicle initial speed, $F(1, 2151.10) = 25.72$, $p < 0.001$, speed pattern, $F(1, 2151.10) = 25.72$, $p < 0.001$, and an interaction between initial speed and speed pattern, $F(1, 2150.30) = 4.24$, $p = 0.01$. There was no effect of the auditory condition.

The model was refitted after discarding the auditory factor, and contrasts were used to compare the different speed patterns. Differences were found between Constant and Slow Down patterns, $b = -0.24$, $t(2157.36) = -5.94$, $p < 0.001$, and between Slow down and Stop, $b = 0.24$, $t(2156.36) = 7.15$, $p < 0.001$, indicating a significant increase in RT from Constant to Slow Down and also from Slow Down to Stop. A third contrast was used to compare the initial speeds of 20 km/h and 30 km/h for the Constant speed pattern compared to Slow Down. This contrast was significant, $b = -0.24$, $t(2157.08) = -2.78$, $p < 0.01$, meaning that for the Constant speed pattern, the value of RT decreased with speed, contrarily to Slow Down and Stop, in which RT increased with speed.

In the Constant speed profile, the crossing decisions were given at most until about 2.20 s after the stimulus started, for the stimuli characterized by a constant speed of 20 km/h, and up to about 1.20 s, for the ones with a constant speed of 30 km/h (Fig. 12).

Regarding the speed patterns in which the vehicle speed varied, the RT did not vary significantly between the different initial speeds, either in the Slow Down or in the Stop pattern. However, the values were considerably higher than those observed for the Constant speed stimuli. Nevertheless, a slight increase in the mean values of the RT is visible in the stimuli in which the movement of the vehicle started at a speed of 30 km/h.

Overall, the analysis of the percentage of crossings and RT, shows that the participants crossed more often when confronted with the stopping and slowing down patterns. However, while some crossings happened during the initial moments of the stimulus presentation, as in the constant speed pattern stimuli, the others only took place after the vehicle began to slow down. Fig. 13(a) shows the histogram of the number of crossings as a function of RT. One can see that most crossings concentrated around these two moments.

To verify if participants were individually consistent in the moments they choose to cross, the sample of thirty participants was split into two groups, according with the individual mean RTs (Fig. 13(b)).

The value of 2.20 s was used as a threshold, since it corresponds to the local minima of the complete histogram that separates the early from the late crossings. One can see that RTs above this threshold generally belong to the same participants, the ones who consistently crossed in the Slow Down and Stop conditions when the vehicle speed was decreasing (Group A). RTs below threshold belong to the other group (Group B) which includes those who tended to cross in the initial moments of the presentation of the stimuli, both at constant speed (especially at 20 km/h) and in the other conditions. The first group includes the major part of participants. A Mann-Whitney confirms the observation, showing that the mean values of RT of the two groups are statistically different ($W = 945808$, $p\text{-value} < 0.001$).

3.2.3. Time-to-passage

A model was also fitted for TTP with random effect included for *participant* and fixed effects defined for the *vehicle initial speed*, *speed pattern*, and *auditory condition*. Visual inspection of the residual plots showed deviations from homoscedasticity and skewness. So, the model was refitted after applying a log transformation to TTP values, which minimized the deviations. As TTP is directly dependent on the RT, similar effects to the ones found on the RT model were expected to exist. Satterthwaite's tests showed significant effects of initial speed, $F(1, 2152.80) = 61.11$, $p < 0.001$, speed pattern, $F(2, 2157.30) = 3.05$, $p = 0.04$, and an interaction effect between initial speed and speed pattern, $F(2, 2151.20) = 39.27$, $p < 0.001$. There was no effect of the auditory condition.

The model was refitted discarding the auditory factor and contrasts were used to compare the different speed patterns. A first contrast compared the Constant and Slow Down speed patterns, and non-significant differences were found between them. A second

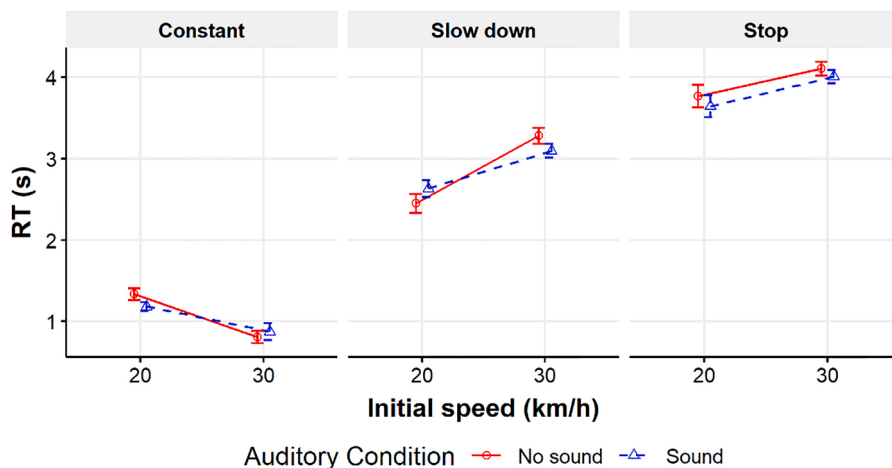


Fig. 12. Mean RT and respective standard error as a function of auditory condition, per initial speed and speed pattern.

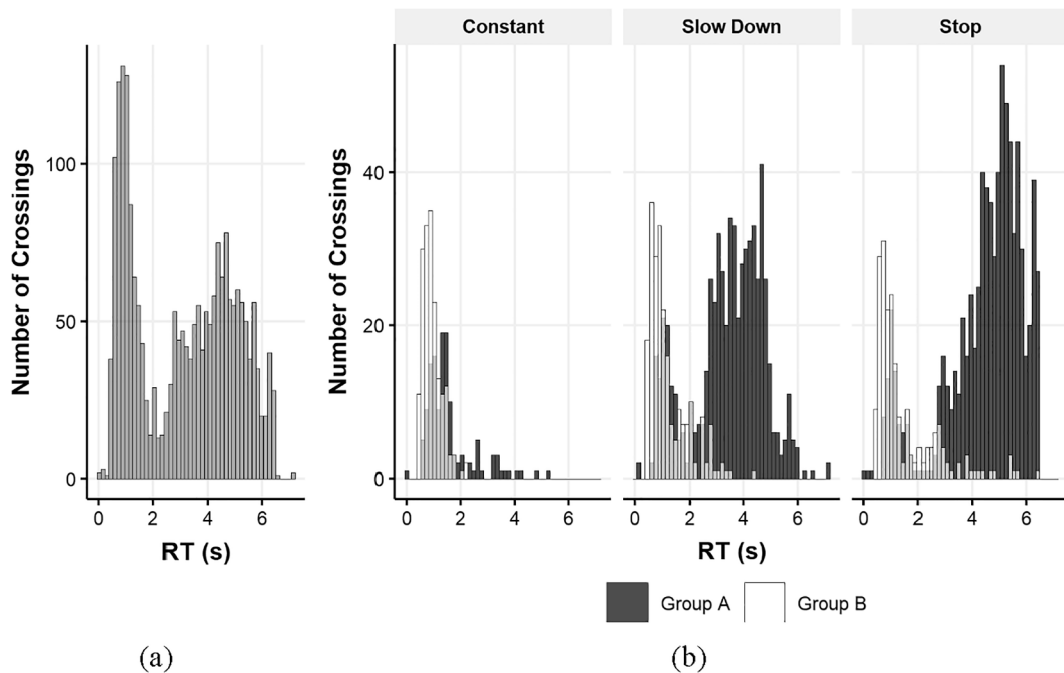


Fig. 13. Histogram of number of crossings by RT: (a) for the general data; and (b) by speed pattern and group of participants.

contrast compared the Constant and Stop patterns, and it showed a significant difference between them, $b = -0.18$, $t(2163.03) = -5.07$, $p < 0.001$. A third contrast compared the Constant and Slow Down patterns for each initial speed. Significant differences were found, $b = 0.22$, $t(2158.82) = 2.91$, $p < 0.01$, showing that, for 20 km/h, the TTPs on the Slow Down pattern are significantly lower than in the Constant one, but for 30 km/h, the opposite is true. A fourth contrast showed the same tendency when comparing the Constant and Stop patterns for each initial speed. A significant difference was found, $b = 0.52$, $t(2158.61) = 6.86$, $p < 0.001$, showing that, at 20 km/h, the TTP was lower for the Stop compared with the Slow Down, but the opposite was true for the 30 km/h.

It is worth noting that, although the differences are significant, the TTPs for the Slow Down patterns are close to the ones for the Constant. Nevertheless, the percentage of crossing was remarkably higher in this condition, showing that participants have either made a substantially different risk assessment or were in the belief that, as the vehicle was slowing down it would eventually stop, which in fact did not happen. The large increase in TTP for the 30 km/h is shown in Fig. 14. At 30 km/h, most crossings happened later in the trial, when the vehicle was already at a lower speed, making the TTP higher.

No significant differences were found for the auditory condition. However, Fig. 14 shows that participants accepted higher TTPs when no sound was presented, particularly for the Stop pattern.

4. Discussion

For a vehicle approaching at constant speed, the results suggest that both speed and distance affect the crossing decisions. Crossing percentages increased with distance but were also substantially lower at the highest speed. While the experimental design used in this study does not allow a direct comparison of crossing decisions as a function of TTP with different speeds, the results do hint to an important role of speed in crossing decisions instead of a decision criterion based mostly on distance. Considering that the study population was composed of young adults, with ages between 20 and 40 years old, this agrees with past research (e.g. (Liu & Tung, 2014; Lobjois & Cavallo, 2007, 2009; Oxley et al., 2005)) which indicates that young people are better at estimating the available time to cross and thus more apt to balance the risk of increased speed. However, these results contrast with the study of Feldstein and Dyszak (2020). In their experiment, a group of young participants seemed to use distance-based criteria in a virtual environment in contrast to a time-based criteria in real environment. The difference might be attributed to different experimental speeds. It is known that lower speeds are easier to distinguish. The virtual vehicle used by Feldstein and Dyszak (2020) moved at speeds ranging from 30 to 40 km/h. In this study, speeds between 20 and 30 km/h were used, which may have made the lower speed more salient in comparison to the higher, fostering a weighted crossing decision.

RTs also showed dependency on both speed and distance. Higher speeds and shorter distances seem to have prompted faster decisions, although this result was only significant for the higher speed. This observation was not entirely unexpected. Lobjois and Cavallo (2009) compared RTs for crossing decisions in a simulated environment, with and without a time constraint. They verified that participants were faster to respond under the time-constrained condition, which also favoured a distance-based decision. It is possible that, in this study, the higher speeds and close distances have prompted a similar sense of urgency, which is known to accelerate decision processes, although at the cost of accuracy in judgments (Soares et al., 2020). This agrees with Beggiato, Witzlack, Springer,

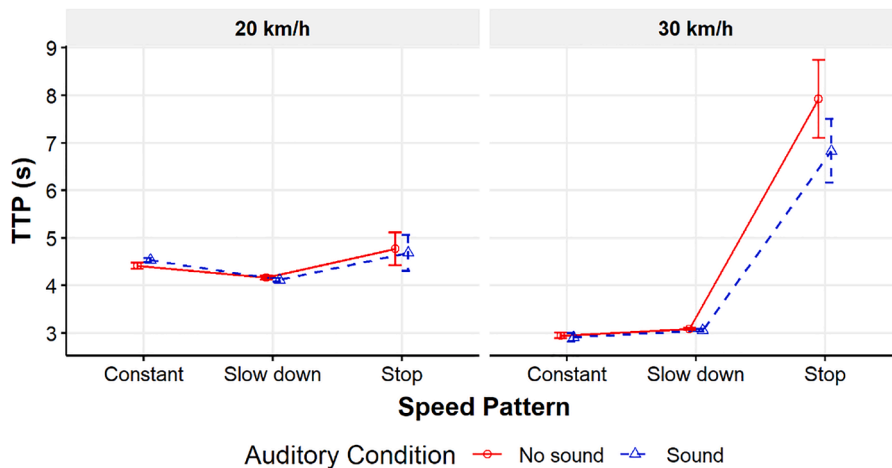


Fig. 14. Mean TTP and respective standard error as a function of auditory condition, per initial speed and speed pattern.

and Krems (2018), who analysed the effect of daytime, approaching vehicle speed and pedestrian's age on the time gaps accepted to cross the road, and found that the participants took more risky crossing decisions, accepting lower time gaps with the increasing vehicle speed.

An important consideration can be made regarding the individual subjects' behaviour. It is noticeable that most participants were consistent in terms of RT and crossings percentages but differed substantially among themselves. Participants with higher crossing percentages were also the ones with shorter RTs. Fig. 5 shows that participants who decided not to cross at 30 km/h crossed fewer times and did so later at 20 km/h. In contrast, participants who decided to cross often at 30 km/h also decided to cross early for both approaching speeds, pointing to a more impulsive behaviour. However, the faster responses were not enough to substantially increase the TTP, which means that in a real situation, these participants would have put themselves at greater risk.

Concerning the influence of the auditory condition on participants' crossing decision, despite a slight superiority in the crossing percentages obtained in the presentation of the merely visual stimuli, mainly for the speed of 20 km/h, the applied statistical tests showed that differences were not significant. The analysis of RT and, consequently, TTP made it even more evident that the auditory condition had no effect on the participants' crossing decision-making.

Regarding the comparison between different types of speed pattern, results also showed a significant influence of the vehicle's initial speed on the percentage of crossings. In this case, the participants crossed more often when the initial speed of the vehicle was 20 km/h. The analysis of the results showed even more clearly a division between those participants who crossed shortly after the start of the stimulus and those who took more time to decide. As previously referred, participants with shorter reaction times tended to cross more often, showing that they are more likely to make dangerous decisions consistently. Most of the participants took a more cautious approach, with few crossings when the vehicle was approaching at a constant speed, particularly at 30 km/h. When the vehicle slowed down, they started to cross when the speed started decreasing. The longest RTs in the Stop and Slow Down conditions confirm this behaviour.

For both conditions, participants seem to have assumed that the deceleration meant the vehicle would stop, or at least provide them enough time to cross, irrespective of the initial speed. An indication of this can be found in the differences in the percentage of crossings between initial speeds. In the Constant speed condition, this difference is substantial with more crossings at 20 km/h. In the Slow Down and Stop conditions there is no significant difference between initial speeds. Also, crossing percentages are overall higher than in the Constant condition. The TTP analysis also seems to support this. At the initial speed of 30 km/h in the slow down condition, the TTP was remarkably lower than in the stop condition, although neither RT nor crossing percentages differed significantly. This again seems to indicate that participants made their decisions based on the perceived deceleration and not on a TTP estimation.

The results highlight the role of perceived vehicle kinematics as a communication tool between vehicle and pedestrian. The early deceleration seems to have been taken by the participants as an indication that they could cross, with the initial speed and actual driver intention (stop or simply slow down) playing a less important role in the decision. This conclusion is in line with the results of recent studies that explore the role of vehicle movement as a mean of communication and coordination between drivers and pedestrians. Deceleration is normally interpreted by pedestrians as an indication that the driver has seen them and will yield the passage (Ackermann et al., 2018; Dey et al., 2019; Mahadevan et al., 2018; Schmidt & Färber, 2009; Várhelyi, 1998). Drivers, in turn, may deliberately use anticipated braking as a way to signal their yielding intention, encouraging the pedestrian to cross with the vehicle still moving, speeding up the encounter and eventually preventing the need for a full stop (Risto, Emmenegger, Vinkhuyzen, Cefkin, & Hollan, 2017).

This result has implications in the development of communication strategies between automated vehicles and pedestrians, a topic that has been receiving growing attention as the presence of driverless vehicles in our roads seems to be an approaching reality (Schneemann & Gohl, 2016; Sucha et al., 2017). On the one hand, vehicle developers should keep in mind that speed adjustments may convey false cues regarding vehicle behaviour. On the other hand, kinematics may be a simple way to convey intention to pedestrians,

although it should also be considered that judgements of available crossing time may be inaccurate and lead to risky situations (Dietrich, Maruhn, Schwarze, & Bengler, 2020).

At last, regarding the audio-visual and the merely visual stimuli, participants relied mostly on the visual information they received from the approaching vehicle to estimate the available crossing time, contradicting Barton et al. (2012) and agreeing with the conclusions of Pugliese et al. (2020) and Soares et al. (2020). These results prove that the absence of the audio component regarding the road traffic does not compromise the results obtained in pedestrian safety studies performed in a virtual environment. Table 4 summarizes the main findings of the present work.

As a limitation, it should be underlined that this study only considers the particular situation in which the vehicle approached the pedestrian from a clearly visible position and maintaining a straight trajectory without obstacles to the participants' view, such as in other studies developed in this research area (e.g. (Cavallo et al., 2019; Cavallo, Lobjois, Dommes, & Vienne, 2009; Charron et al., 2012; de Clercq et al., 2019; Dommes et al., 2012; Feldstein et al., 2016; Simpson et al., 2003; Zito et al., 2015)). In cases in which the visibility of participants could be impaired, greater importance of the auditory cues in their decision would be expected, as shown by Barton et al. (2012).

Another limitation of this study was the participants' experimental task. In the experiments, participants signalled their decision by clicking on a button of a computer mouse while remaining still in a predetermined position. This approach has been used in most pedestrian simulator studies (Charron et al., 2012; Meir et al., 2015; Schwebel, Gaines, & Severson, 2008; Thomson et al., 2005; Zito et al., 2015). Some of the most recently developed simulators already allow participants to freely walk the virtual crossroad (Cavallo et al., 2019; Deb et al., 2018; Feldstein et al., 2016; Morrongiello, Corbett, Milanovic, Pyne, & Vierich, 2015; Schneider et al., 2021; Simpson et al., 2003; Sween, Deb, Carruth, Waddell, & Furuichi, 2017). Being able to move freely turns the simulator and the experimental task more realistic and immersive. It provides participants with a complete sense of the space and their own speed and, consequently, of the time they need to initiate movement and cross the road. However, one of the objectives of this study was to analyse the role of auditory cues in the pedestrians' crossing decision, and modelling vehicular sound in a spatially congruent manner for a moving listener is far from trivial. For the sake of simplicity, it was decided to consider an experimental task where the participant chose between go/no go options by clicking on a simple button. This also allowed for lighter and less time-consuming trials for the participants.

Future work may pass by the analysis of other types of trajectories (such as turning movements at intersections) and obstacles to the participants' vision (such as parked vehicles, trees, and urban furniture), to assess the general effect of the auditory cues on the pedestrian crossing decision-making in a more comprehensive way.

5. Conclusions

The main goal of this research was to analyse the role of visual and auditory cues in crossing decisions, considering different initial speeds and distances of the vehicle as well as deceleration profiles. The results support the general conclusion that the speed and initial distance of the vehicle and its speed profile impact the crossing behaviour. Contrarily, the auditory input has no major role in modulating decisions, at least when pedestrians are crossing a virtual road having perfect visibility conditions of the approaching vehicle.

Regarding the vehicle motion, most participants made a decision based on the vehicle's perceived kinematics, with the deceleration being interpreted as an indication that the vehicle would yield the passage. However, a small group of participants seems to have responded more hastily, taking less time to decide, crossing more often, including when the vehicle approached at the highest speed and from closer distances and irrespective of whether it would yield or not.

These conclusions highlight the role of vehicle kinematics as an important mean of communication between vehicles and pedestrians, which should be considered in the development of new strategies to mitigate the severity of conflicts between vulnerable road users and motorized traffic. The results are also relevant for autonomous driving developers, showing that vehicle movement can be explicitly used to communicate with pedestrians and that care should be taken to prevent unintentional, misleading signals.

CRedit authorship contribution statement

Francisco Soares: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft,

Table 4
Summary of the main findings.

Main Findings	Agreeing with	Disagreeing with
When a vehicle is approaching the crosswalk at constant speed, both speed and distance affect the pedestrian crossing decisions.	Oxley et al. (2005); Lobjois and Cavallo (2007); Lobjois and Cavallo (2009); Liu and Tung (2014)	Feldstein and Dyszak (2020)
Vehicle's higher speeds and shorter distances lead to faster and unsafe crossing decisions.	Lobjois and Cavallo (2009); Beggiato, Witzlack, Springer, and Krems (2018); Soares et al. (2020)	–
Assuming full visibility of the approaching vehicle, the auditory condition does not influence the pedestrians' crossing decision-making.	Pugliese et al. (2020); Soares et al. (2020)	Barton et al. (2012)
Vehicle kinematics is a relevant communication tool between vehicle and pedestrian. Vehicle deceleration is interpreted by pedestrians as an indication of the intention to yield the passage.	Várhelyi (1998); Schmidt and Färber (2009); Ackermann et al. (2018); Mahadevan et al. (2018); Dey et al. (2019)	–

Visualization. **Emanuel Silva:** Methodology, Software, Investigation, Data curation. **Frederico Pereira:** Methodology, Software, Validation, Investigation, Data curation. **Carlos Silva:** Conceptualization, Resources, Project administration, Funding acquisition, Writing – review & editing. **Emanuel Sousa:** Conceptualization, Formal analysis, Resources, Supervision, Project administration, Funding acquisition, Writing – review & editing. **Elisabete Freitas:** Conceptualization, Supervision, Resources, Project administration, Funding acquisition, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Descriptive statistics of the results regarding Constant speed pattern

Audio Cond.	V_i (km/h)	$D_{i,mov}$ (m)	Crossings			RT			TTP		
			Mean (%)	SD (%)	SE (%)	Mean (s)	SD (s)	SE (s)	Mean (s)	SD (s)	SE (s)
No sound	20	25	27.30	30.80	5.63	1.28	0.56	0.06	3.43	0.54	0.06
		30	45.00	40.20	7.35	1.33	0.85	0.07	4.41	0.77	0.07
		35	53.00	40.40	7.37	1.37	0.89	0.07	5.19	0.81	0.06
	30	25	5.00	17.80	3.24	0.59	0.18	0.05	2.53	0.19	0.05
		30	9.33	22.70	4.15	0.81	0.39	0.07	2.95	0.31	0.06
		35	14.30	23.60	4.31	1.03	0.73	0.11	3.34	0.62	0.10
Sound	20	25	23.00	31.90	5.82	1.07	0.45	0.05	3.62	0.41	0.05
		30	41.30	42.30	7.73	1.18	0.58	0.05	4.53	0.52	0.05
		35	49.30	40.70	7.43	1.31	0.82	0.07	5.22	0.75	0.06
	30	25	4.33	16.80	3.06	0.69	0.19	0.05	2.41	0.23	0.06
		30	7.67	17.70	3.24	0.87	0.49	0.10	2.91	0.43	0.09
		35	12.70	22.90	4.18	1.05	0.50	0.08	3.32	0.43	0.07

Appendix B. Descriptive statistics of the results regarding all vehicle speed patterns

Audio Cond.	V_i (km/h)	Speed Pattern	Crossings			RT			TTP		
			Mean (%)	SD (%)	SE (%)	Mean (s)	SD (s)	SE (s)	Mean (s)	SD (s)	SE (s)
No sound	20	Constant	45.00	40.20	7.35	1.33	0.85	0.07	4.41	0.77	0.07
		Slow Down	74.30	33.30	6.08	2.45	1.73	0.12	4.17	0.67	0.04
		Stop	88.00	17.50	3.19	3.76	2.27	0.14	4.77	5.56	0.34
	30	Constant	9.33	22.70	4.15	0.81	0.39	0.07	2.95	0.31	0.06
		Slow Down	66.00	34.00	6.21	3.28	1.37	0.10	3.08	0.33	0.02
		Stop	78.70	30.30	5.52	4.10	1.31	0.09	7.92	12.60	0.82

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Audio Cond.	V _i (km/h)	Speed Pattern	Crossings			RT			TTP		
			Mean (%)	SD (%)	SE (%)	Mean (s)	SD (s)	SE (s)	Mean (s)	SD (s)	SE (s)
Sound	20	Constant	41.30	42.30	7.73	1.18	0.58	0.05	4.53	0.52	0.05
		Slow Down	80.30	27.10	4.95	2.63	1.63	0.11	4.12	0.58	0.04
		Stop	87.70	17.90	3.28	3.64	2.19	0.14	4.68	6.07	0.37
	30	Constant	7.67	17.70	3.24	0.87	0.49	0.10	2.91	0.43	0.09
		Slow Down	69.00	35.60	6.49	3.10	1.24	0.09	3.06	0.33	0.02
		Stop	82.70	28.40	5.18	4.01	1.30	0.08	6.83	10.50	0.67

Appendix C. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.trf.2021.08.014>.

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