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Pedestrians' road crossing decisions and body parts' movements

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ABSTRACT

This study aims to examine pedestrians' crossing decision, body parts' movement and full body movement, just before and during road crossing in a simulated setup. To accomplish this, a novel experimental setup for analyzing pedestrians' crossing behavior and motion was developed where the simulated display was synchronized with a 3D motion capturing system. Twenty participants, divided into control and an experimental time pressure group, observed sixteen short (less than 30 s) and long road (70 s or more) crossing scenarios with varying crossing opportunities. Based on the crossing opportunities they were asked to cross a 3.6 m wide one-lane one way urban road. It was found that the crossing initiation process consists of four incremental movements of body parts: the head and the shoulder first; the hip, wrist and elbow second; the knee as a separate joint, and finally the ankle. Results showed that pedestrians' decision to cross and body parts movement are influenced by time pressure and wait time for a safe crossing opportunity. Specifically, pedestrians prepare their body parts earlier, initiate their crossing earlier, and adjust their speed to compensate for the risk taken in less safe or non-safe crossing opportunities. Within the control group, women tended to be more risk avoiding than men, however those differences disappeared in the time pressure group. Most importantly, the findings provide initial evidence that this novel simulation configuration can be used to gain precise knowledge of pedestrians' decision-making and movement processes.

1. Introduction

Pedestrians are the most vulnerable road users' category in traffic accidents, especially in urban areas. The World Health Organization (WHO, 2015) reported that more than 1.2 million people die every year in traffic accidents worldwide, and that 22% of these casualties are pedestrians. Learning about pedestrians' crossing decisions, movement, and body part movement prior to and while crossing the road may portray pedestrians intentions and behaviors. This knowledge can become useful for vehicular systems attempting to detect pedestrians' intent, with the aim to achieve the goal of reducing mortality rates.

Commonly used to analyze pedestrian behavior are methods based on questionnaires or interviews, where participants are asked to imagine themselves in different situations and answer questions about their preferences, attitudes and behaviors with regard to the situation (e.g., Cantillo, Arellana, & Rolong, 2015; Evans & Norman, 2003; Herrero-Fernández, Macía-Guerrero, Silvano-Chaparro, Merino, & Jenchura, 2016; Holland & Hill, 2007); and methods based on field observations, such as video recordings that take place outside of the laboratory, for example in busy or signalized intersections (e.g., Oudejans, Michaels, van Dort, & Frissen, 1996; Yang, Abdel-Aty, Huan, Peng, & Gao, 2015). Field observations are complicated to

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conduct and often require interpretation of the observed behavior by the researchers. They also lack control over several aspects of the road crossing situation such as vehicle speed, traffic density, or distractions (Papadimitriou, Lassarre, & Yannis, 2016; Simpson, Johnston, & Richardson, 2003).

Use of pedestrian simulators is also increasing. In simulators, one can incorporate various presentation and measurement methods. Typically, participants are asked to observe traffic scenarios from the perspective of a pedestrian aiming to cross the road, and indicate their crossing intentions without actual crossing, for example by pressing a button as a reaction to what happens in the scenario (e.g., Meir, Parmet, & Oron-Gilad, 2013; Tapiro, Oron-Gilad, & Parmet, 2016). To increase simulation validity and allow pedestrians to perform actual crossing movements, researchers have incorporated motion-capturing systems in pedestrian simulators like the French IFSTTR CAVE-like system (Dommes, Cavallo, Dubuisson, Tournier, & Vienne, 2014) or utilized head-mounted displays (HMDs) to project VR scenes in sync with a Movement Tracking System (Morrongiello & Corbett, 2015; Morrongiello, Corbett, Switzer, & Hall, 2015). These type of studies looked at crossing decisions and safety margins, and added elements of movement such as walking speed and acceleration. However, none of those studies had looked at pedestrians' body movement at the preparation phase prior to and during the crossing, which can lead to more precise results, give insights on how pedestrians perceive the crossing environment and how this perception influences their crossing behavior and most importantly, help in early detection of movement.

In the current study, the experimental configuration provides capabilities for studying pedestrians' crossing behavior and movement prior to and during crossing by combining the presentation of road crossing traffic scenes derived from the Ben-Gurion University (BGU) pedestrian simulator (Meir et al., 2013; Tapiro et al., 2016) with a motion capture system that enables tracking markers placed on the pedestrian's body.

Previous studies found that pedestrians' road crossing behavior is influenced by a variety of individual factors such as gender, age and sensation seeking. Males are more likely to take greater risks in road crossing than females (e.g., Herrero-Fernández et al., 2016), child pedestrians are less skilled, they demonstrate inferior visual search strategies compared to adult pedestrians (e.g., Meir et al., 2013) and inferior perception of dynamic affordances (O'neal et al., 2017). Lastly, sensation-seeking levels can predict reckless behavior in road crossing (e.g., Rosenbloom, Mandel, Rosner, & Eldror, 2015).

Environmental factors (e.g., Tapiro, Oron-Gilad, & Parmet, 2015), traffic volume and wait time influence pedestrians' behavior at signalized and non-signalized crossings. Signalized intersections may appear to be safer for pedestrians, yet studies show that pedestrians do not necessarily comply with the signal indication, low traffic volume (e.g., Sisiopiku & Akin, 2003) or long wait times on the curb, raise the level of traffic violations among pedestrians (e.g., wait time at signalized crosswalks; Guo, Gao, Yang, & Jiang, 2011; Yang & Sun, 2013). Guo et al. (2011) for example, specify that the longer the time that has elapsed since the start of the waiting duration, the more likely pedestrians will end the wait soon. Pointing out a wait period of 50 s as critical as only about half of all pedestrians whom they interviewed obeyed the traffic rules after waiting for 50 s, and only few pedestrians remained on the curb after 65 s. High traffic volume and fewer safe crossing opportunities affect pedestrians' behavior too. Guth, Ashmead, Long, Wall, and Ponchillia (2005) looked at blind and sighted pedestrians' judgments of gaps in traffic at roundabouts. While the focus of their study was on differences between sighted and blind road crossers, they reported that sighted participants sometimes initiated a crossing decision when a vehicle had cleared the area directly in front of them but had not cleared the entire width of the crosswalk. Hence, indicating that vehicular volume is affecting pedestrian accessibility to cross, and also implicating higher traffic volumes to more risky behavior of the pedestrian. Likewise, in the driving domain there are few observational studies that looked at driver gap acceptance as a function of wait time for a left turn (unsignalized; Adebisi & Sama, 1989; and signalized intersection; Kittleson & Vandehey, 1991). In these studies, it was found that for shorter expected delays (wait times) longer gaps were being accepted by the drivers while for longer delays (over 30 s in Adebisi & Sama, 1989) the acceptance gap was shorter. Hence, the critical gap chosen for maneuvering was affected by the amount of front-of queue delay that was incurred by individual drivers. Furthermore, pedestrians, who are time pressured to reach their destination at a given time, or as soon as possible, often prioritize convenience over safety, which results in riskier behavior (e.g., Kadali & Vedagiri, 2013; Morrongiello et al., 2015).

To evaluate the capability of the BGU experimental system to capture time based patterns in pedestrians movement as a function of crossing conditions, participants were asked to cross one-way non-signalized urban road while imposed time pressure and wait time were manipulated. The study was set therefore to fulfil two goals: (1) to examine whether participants were sensitive to the time pressure and wait conditions presented in the road crossing-scenes, and if so, (2) to examine how this was reflected in their whole body and body parts' movement, an examination, which to our knowledge, is introduced for the first time. It was hypothesized that under time pressure, and long wait times on the curb (70 s or more), pedestrians will demonstrate more risky crossings. Furthermore, it was hypothesized that participants will attempt to compensate for riskier crossing conditions by adopting higher crossing speeds. As for the body parts' movement analysis, no a priori hypotheses were made.

2. Method

2.1. Participants

Twenty participants, 10 males and 10 females aged 20–30 (mean age = 25.2, SD = 1.85 years; mean height = 168.35, SD = 9.67 cm; mean weight = 61.8, SD = 9.73 kg), were recruited from the Ben-Gurion University via the university on-line student forum. Half of the participant (five males and five females) were randomly assigned to the experimental time pressure group while the others were assigned to the control group. All participants declared that they had normal or corrected to normal vision and no other medical restrictions before they were requested to sign the consent form. To compensate for their time, they were given 30 NIS (~$8). To increase motivation, in addition to compensation, four meal coupons (~$24), were promised to the best two performers in each group.

2.2. Stimuli and design

Following the completion of the 40-item sensation seeking (Zuckerman, 1994) and the 44-item Big Five Inventory (BFI; see John & Srivastava, 1999) questionnaires in their native language, participants were instructed to observe one practice scenario and then 16 experimental traffic scenarios from a pedestrian's point of view, i.e., as if they were pedestrians standing on one side of the pavement in front of a 3.6 meters wide, one-way urban road with no parked vehicles. All participants were instructed to cross to the other side of the road whenever they felt it was safe to cross. In addition, participants in the time pressure group, were told to cross as fast as possible while maintaining their safety. The road scenarios were projected on a 42-in. screen placed parallel to the direction of the pedestrian's movement, one meter away to the side of the participant so that the viewing angle will resemble standing on the sidewalk (see Fig. 1). The viewpoint of the scenario was not linked to the subject's position while crossing.

The crossing-scenario database was formed from an existing custom-built three-dimensional generic model of a typical Israeli urban road. Using the VT-Mak applications (http://www.mak.com) VR-Vantage and VR-Forces, scenarios were designed varying in traffic density and in wait time till a crossing opportunity. One training scenario was used for practice and accommodation to the task and to the experimental system. Eight scenarios were generated as if the traffic came from the right (as shown in Fig. 1) and eight scenarios were generated as if the traffic came from the left, i.e., the screen was placed to the left of the participant. Changing the direction of the traffic (left to right or right to left) produced 'duplicate' scenarios with the same crossing opportunities and traffic density. To highlight the imposed time pressure for the experimental group, a visual alert in the form of a stopwatch appeared on the screen throughout the scenarios (see Fig. 2). All vehicles had the same dimensions and travelled at the same speed of 50 km/h. As a result, the 8 scenarios from each side, differed only in one aspect; the distances between every two passing vehicles. Thus generating dissimilar crossing opportunities as shown in Fig. 3.

Crossing opportunities were categorized into three: (i) unsafe crossing situations where participants had less than 2 s to cross the road safely, (ii) uncertain crossing situations where participants had more than 2 s but less than 4 s to cross, and (iii) safe crossing situations where participants had more than 4 s to cross (Oudejans et al., 1996). This categorization is well settled with the fact that participants were asked to cross a 3.6 m wide road, and the assumption that average crossing speed varies between 1.2 and 1.3 m/s (Demiroz, Onelcin, & Alver, 2015; Marisamynathan & Vedagiri, 2016). Scenarios 1–4 were relatively short (30–35 s) with at least two safe-crossing opportunities (of 5 s or above) and several uncertain crossing opportunities. Scenarios 5–8 were at least twice as long (70–160 s) with multiple unsafe-crossing opportunities and longer wait times until a safe or uncertain opportunity occurred. All scenarios had at least one safe-crossing opportunity. To avoid order effects, a Latin square balanced design was adopted such that each participant viewed the scenarios in a different order.

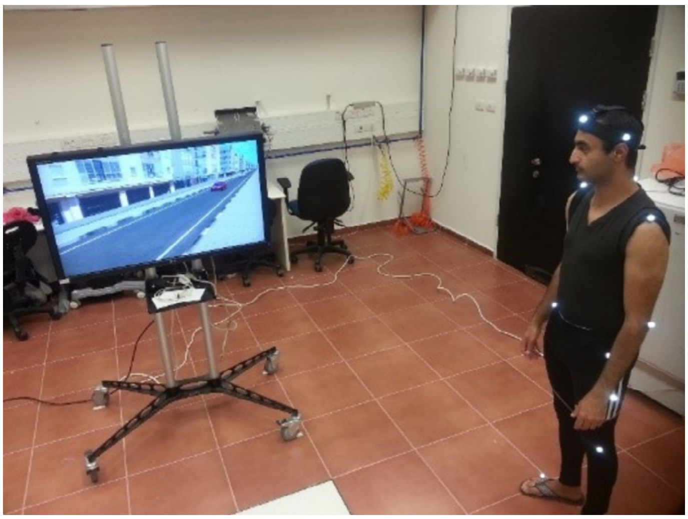

Fig. 1. The experimental setup. A participant looking at a simulated crossing scenario where traffic is approaching from the right.

Fig. 2. Illustration of the scenario for: (a) the experimental time pressure group with the stopwatch, (b) the control group.

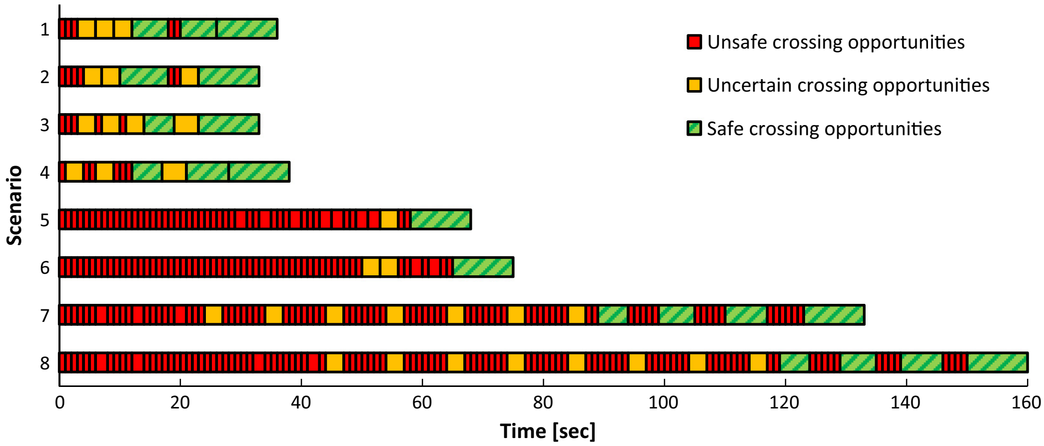

Fig. 3. Crossing scenarios (1–8). The X-axis marks the duration of the scenario and the color represent the crossing opportunity. Recall that each scenario appeared twice once from the left and once from the right. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.3. Data collection

Body locations (e.g. shoulder) were obtained using a motion capture system with ten cameras (Oqus 3 and 5, Qualisys, Inc. Göteborg, Sweden). Nineteen reflective markers (19 mm spheres) were placed on selected anatomical landmarks to track and calculate the motion of the body locations (see Fig. 4). Markers were attached to the body using double-sided adhesive tape and were tracked with an accuracy of sub 1mm at a sample frequency of 120 Hz. Prior to data collection, the capture volume was calibrated in accordance to guidelines provided by Qualisys.

2.4. Data analysis

The Qualisys Track Manager (QTM) software was used to record participants' crossings in three dimensions, where the X-axis represents forward motion (i.e., into the road), the Y-axis represents sideways movement, and the Z-axis represents the upward movement. A second-order two-phase-shift Butterworth digital low-pass (10 Hz) filter was applied to filter out high frequency noise. Data was exported to TSV files and then using our own custom-made MATLAB program the following parameters where calculated: recognition of beginning of movement for each body location, time for ankle lift (start of the step) and crossing speed. The description of the algorithm for calculating the above parameters are presented in Sections 2.4.2 and 2.4.3.

The analysis was divided into three stages of the crossing: (1) analysis of risk taking in the crossing decision, (2) analysis of the walk initiation and (3) analysis of the crossing phase.

2.4.1. Risk taking in the crossing decision

Risk taking was measured by the time gap, which is the interval between two vehicles measured in seconds and by the crossing opportunity (categorized into three levels: unsafe, uncertain and safe) in which the participant had decided to cross. As the time gap in which the participant had crossed is shorter, the risk taken is higher.

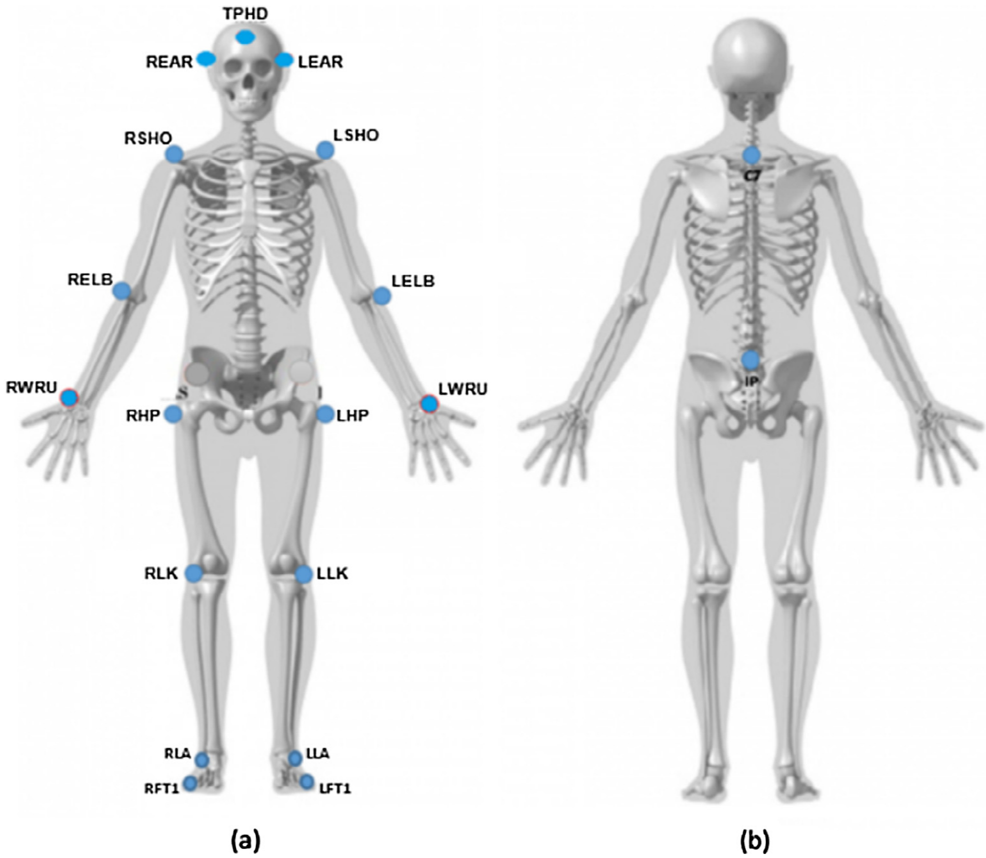

Fig. 4. Location of the reflective markers on participants. (a) Front view, (b) Back view.

2.4.2. Walk initiation

The beginning of the walk initiation process was defined as the point where participants began their movement forward (in the X-axis direction) with at least one of the following body locations: knee, hip, shoulder, elbow, wrist or head. The end of the walk initiation process was defined as the point where participants began lifting their ankle (as it was found to be the last body location that moves). To find the beginning of each body location movement, the mean forward velocity of the body locations (velocity in the X-axis direction) and the standard deviation during the wait time, i.e., before the crossing, were calculated. The beginning of the movement was determined as the first frame where the velocity was greater than the body location's mean velocity adding one standard deviation (mean ± SD) as shown in Fig. 5.

In order to be able to compare participants and to handle the fact that each participant started crossing at a different point in time or with a different foot, the time for the movement beginning of each body location was calculated relative to the participant's ankle movement beginning, which was defined as the zero point. All calculations were made on the side of the leg that initiated the movement, i.e., if the participant started crossing with his right foot, then his right knee, right side of the hip, right shoulder, right elbow, right wrist and the right side of the head were examined, and opposing if she started crossing with her left foot. An example of a first recognition of movement for the ankle, knee, hip, shoulder, elbow, wrist and head is shown in Fig. 6.

2.4.3. Crossing phase

The beginning of the crossing phase was defined as the point where participants began lifting their ankle from the ground, and the end of the crossing was defined as the point where the participant reached the opposite side of the 3.6 m road. The Analysis of the crossing phase was divided into three: (1) timing of crossing, (2) crossing speed, and (3) safety margin.

2.4.3.1. Timing of crossing. The time difference between the beginning of the time gap, i.e. when the rear bumper of the vehicle had passed through the crossing line and the start of the crossing (ankle lift), indicates the participants' 'timing of crossing'. A positive value specifies that the participant started the crossing after the vehicle had entirely passed, while a negative value specifies that the participant started the crossing while the vehicle was still on the crossing site and did not entirely pass (see Fig. 7). It is important to note that even when the timing of the crossing was negative pedestrians were not nec-

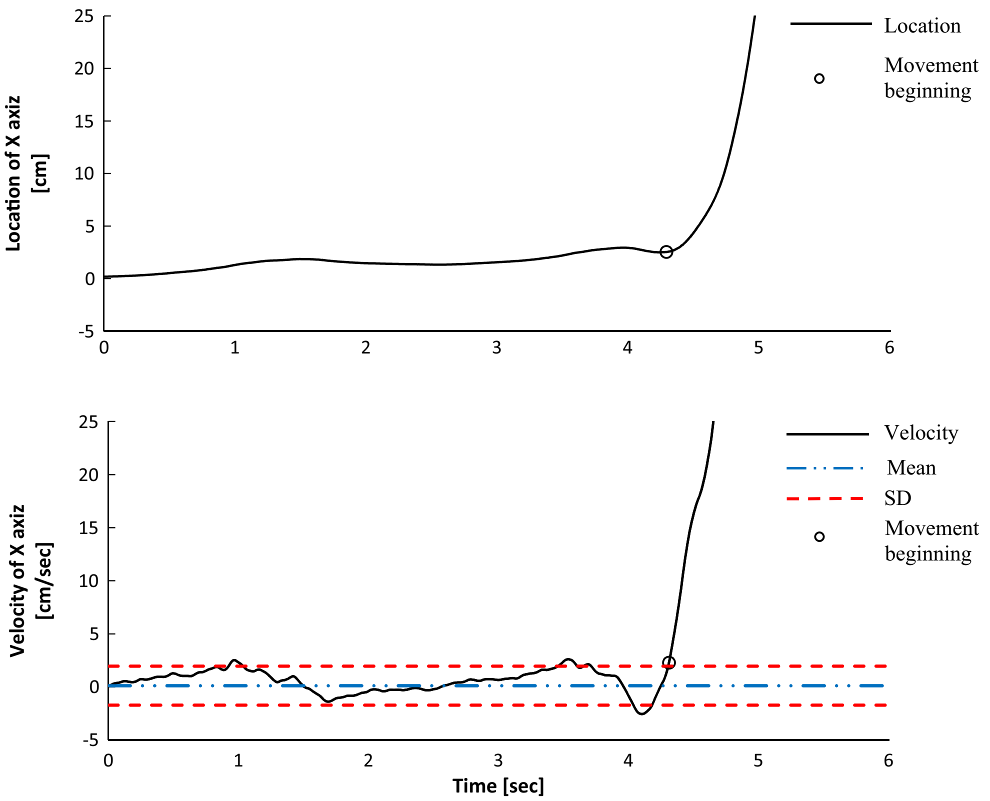

Fig. 5. An example for the automatic detection of the beginning of the body location movement. The upper chart shows the determination of the location of the movement beginning, as the lowest point before forward movement. The lower chart shows how the velocity was determined, by locating the first frame in which the velocity was greater than one standard deviation of the mean velocity till movement beginnig.

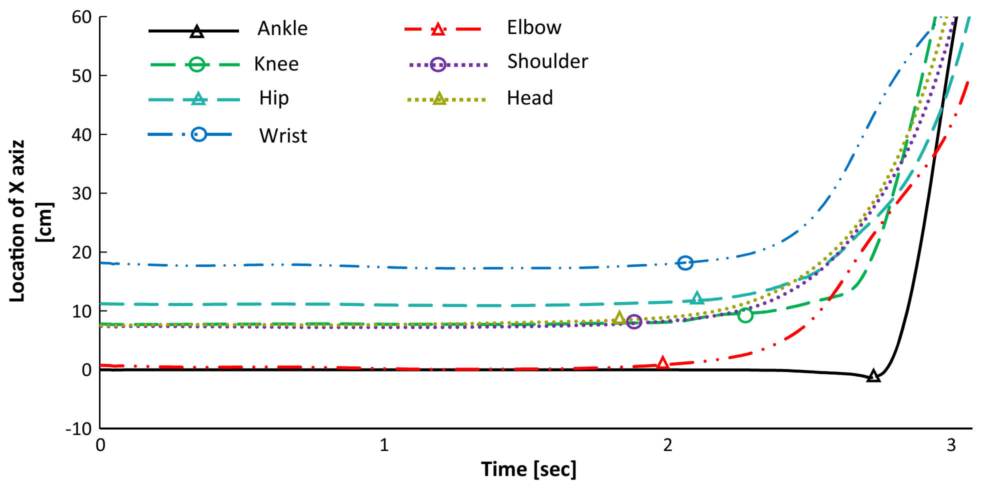

Fig. 6. An example of the recognition point of movement for the ankle, knee, hip, wrist, elbow, shoulder and head. The circles and the triangles represent the beginning of each body location movement. Participants' walk initiation process was defined as the phase from the moment the first body location began moving forward until the ankle began moving. For this example, the walk initiation process was determined as the phase between the beginning of the head movement until the beginning of the ankle movement.

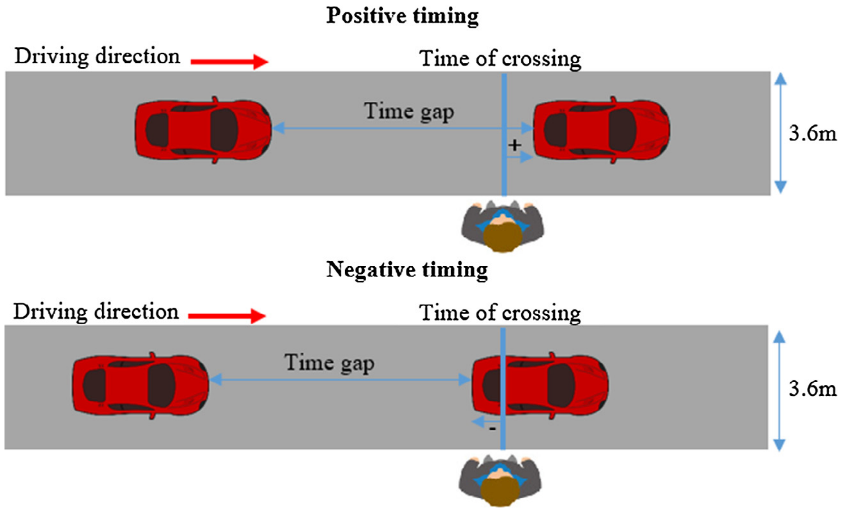

Fig. 7. An example of positive timing (top), where the participant inititates the crossing after the vehicle had passed, and negative timing (bottom) where the participant initiates the crossing before the vehicle had completely passed.

essarily hit by the vehicle, since there is a margin between the end of the sidewalk and the location of the side of the vehicle on the road. Hence, first they still had to pass the distance between the sidewalk and the vehicle on the road.

2.4.3.2. Crossing speed. Mean crossing speed was determined by calculating the mean center of mass (COM) velocity of the participant during the crossing (i.e., from the initiation of the first step till the end of the crossing), which in itself was calculated as the derivative of the COM location. To calculate the COM location, anthropometric data was used, including segment masses and segments lengths based on the data of De Leva (1996). The COM location vector representing a series of differences in position was calculated using the formulas:

$$X_{COM} = \frac{\sum_{i=1} m_i x_i}{\sum_{i=1} m_i}\,[\text{cm}] \quad (1)$$

$$Y_{COM} = \frac{\sum_{i=1} m_i y_i}{\sum_{i=1} m_i}\,[\text{cm}] \quad (2)$$

where m_i is the segment mass and x_i and y_i are the segment COM location.

2.4.3.3. Safety margin. Represents the elapsed time from the moment the participant safely crossed the 3.6-m road until the next vehicle arrived to the crossing line. Its value depends on the available time gap, pedestrians' timing of crossing, road width, and the crossing speed, described by the equation:

$$\text{Safety margin} = \text{Time gap} - (T_{\text{crossing start}} - T_{\text{gap start}}) - \frac{\text{Road width}}{\text{Crossing speed}} \quad (3)$$

where Time gap is the time available for crossing (the interval between two vehicles), $T_{\text{crossing start}}$ is the time when the first step was initiated (i.e., the ankle left the ground) and $T_{\text{gap start}}$ is the time when the rear bumper of the first car passed the crossing line. Safety margin was categorized into four levels of crossing performance: 'Hit' when the safety margin was less than 0 s, 'Close call' when the safety margin was less than 1 s, 'Risky cross' when the safety margin was between 1 and 2 s and 'Safe cross' when the safety margin was larger than 2 s (see Tapiro et al., 2016).

3. Results

There were twenty participants, each was presented with sixteen scenarios (a total of 320 observations). Due to missing data, six crossing trials were removed from the analysis making a total of 314 crossings (158 in the control group and 156 in the experimental time pressure group). Data analyses were divided into the three stages: risk taking, walk initiation process and crossing phase.

3.1. Risk taking

Chi square analysis found that participants under the time pressure condition crossed at risker crossing opportunities compared to participants in the control group ($\chi^2(2) = 66.82$, p = .000). Scenario type differences were also found in both groups, suggesting that in the short scenarios (30–35 s) participants were not willing to cross in unsafe crossing opportunities, yet, in the long scenarios (70–160 s) where wait times increased, some participants did cross in unsafe crossing opportunities ($\chi^2(2) = 37.90$, p = .000 for control group and $\chi^2(2) = 86.97$, p = .000 for the time pressure group). Finally, analysis also revealed that males within the control group tended to cross at risker opportunities compared to females ($\chi^2(2) = 33.78$, p = .000), however, no gender differences were found in the time pressure group ($\chi^2(2) = 2.25$, p = .324). Group (experimental/control), scenario type (short/long) and gender differences in the chosen crossing opportunities, which indicate upon the degree of risk taking, are presented in Table 1.

Next, Bivariate correlations (Pearson's r) between risky pedestrian behavior and the variables collected with the sensation seeking and the big five inventory questionnaires were calculated. For the control group, risky pedestrian behavior was statistically significant and positively associated with Boredom susceptibility (p = .000) and Neuroticism (p = .037), and negatively associated with Experience seeking (p = .000), Agreeableness (p = .000), Conscientiousness (p = .000) and Openness (p = .000). In the time pressure experimental group, there were no significant correlations with any of the above personality traits (Table 2).

3.2. Walk initiation

To test if there were differences between the time in which each body location began to move, the Kruskal–Wallis H test (for non-normally distributed variables) followed by Tukey post hoc tests were used in each group separately. It was found that in both groups the movement of the body parts could be divided into four increments ($\chi^2(6) = 506.97$; p = .000 in the control group; $\chi^2(6) = 543.08$; p = .000 in the time pressure group) as can be seen in Fig. 8. At first, the head and the shoulder start to move forward (-0.86 ± 0.46 s for the control group and -0.97 ± 0.52 s for the time pressure group), then the elbow, the wrist and the hip (-0.58 ± 0.40; -0.62 ± 0.41), following the knee (-0.35 ± 0.26; -0.33 ± 0.23) and finally, the ankle which was set as the reference (0.00 ± 0.00).

Analysis revealed that in the experimental time pressure group where participants were rushed, participants began their walk initiation movement earlier compared to the control group ($\chi^2(1) = 32.13$; p = .000) as can be seen in Fig. 9A. Wait times differences were found in both groups (Fig. 9B), such that in the long scenarios where participants tend to wait longer, the first movement began earlier compared to the short scenarios ($\chi^2(1) = 8.22$; p = .004 for the control group; $\chi^2(1) = 8.60$; p = .003 for the time pressure group). Gender differences (Fig. 9C) were found only within the time pressure group, identifying that males began their movement earlier compared to females ($\chi^2(1) = 4.38$; p = .036). Finally, crossing opportunity differences (Fig. 9D) were found only for the control group, indicating that the beginning of the movement during the unsafe crossings was identified earlier compared to the safe crossings ($\chi^2(2) = 6.78$; p = .034).

3.3. Crossing phase

3.3.1. Timing of crossing

The 'timing of crossing' was defined as the time difference between the ankle movement beginning (which specifies the beginning of the crossing) and the beginning of the time gap. Differences between the two experimental groups (Fig. 10A) revealed that in the experimental time pressure group participants' initiated their crossing more than 0.1 s before the begin-

Table 1
Participants' chosen crossing opportunities by gender, scenario type and experimental group. Unsafe: less than 2 s to cross the road, Uncertain: between 2 and 4 s, and Safe: more than 4 s.

Gender	Crossing opportunity	Control			Time Pressure		
		Short	Long	Total	Short	Long	Total
Male	Safe	11 (28%)	4 (10%)	15 (19%)	1 (3%)	0 (0%)	1 (1%)
	Uncertain	28 (72%)	15 (37%)	43 (54%)	36 (97%)	10 (26%)	46 (61%)
	Unsafe	0 (0%)	21 (53%)	21 (27%)	0 (0%)	29 (74%)	29 (38%)
	Total	39 (100%)	40 (100%)	79 (100%)	37 (100%)	39 (100%)	76 (100%)
Female	Safe	28 (72%)	23 (58%)	51 (64%)	0 (0%)	4 (10%)	4 (5%)
	Uncertain	11 (28%)	7 (18%)	18 (23%)	40 (100%)	11 (28%)	51 (64%)
	Unsafe	0 (0%)	10 (25%)	10 (13%)	0 (0%)	25 (62%)	25 (31%)
	Total	39 (100%)	40 (100%)	79 (100%)	40 (100%)	40 (100%)	80 (100%)
All	Safe	39 (50%)	27 (34%)	66 (42%)	1 (1%)	4 (5%)	5(3%)
	Uncertain	39 (50%)	22 (27%)	61 (38%)	76 (99%)	21 (27%)	97 (62%)
	Unsafe	0 (0%)	31 (39%)	31 (20%)	0 (0%)	54 (68%)	54 (35%)
	Total	78 (100%)	80 (100%)	158 (100%)	77 (100%)	79 (100%)	156 (100%)

Table 2
Correlation coefficients (Pearson's r) between the time gap and the questionnaires variables.

Group	1	2	3	4	5	6	7	8	9
Control	0.121	0.282**	−0.025	−0.408**	0.093	−0.166*	0.461**	0.300**	0.346**
Time pressure	−0.133	−0.136	−0.102	−0.051	−0.143	−0.073	−0.012	0.011	−0.121

Note: 1: Thrill and adventure; 2: Experience seeking; 3: Disinhibition; 4: Boredom susceptibility; 5: Extraversion; 6: Neuroticism; 7: Agreeableness; 8: Conscientiousness; 9: Openness.
* $p < .05$.
** $p < .01$.

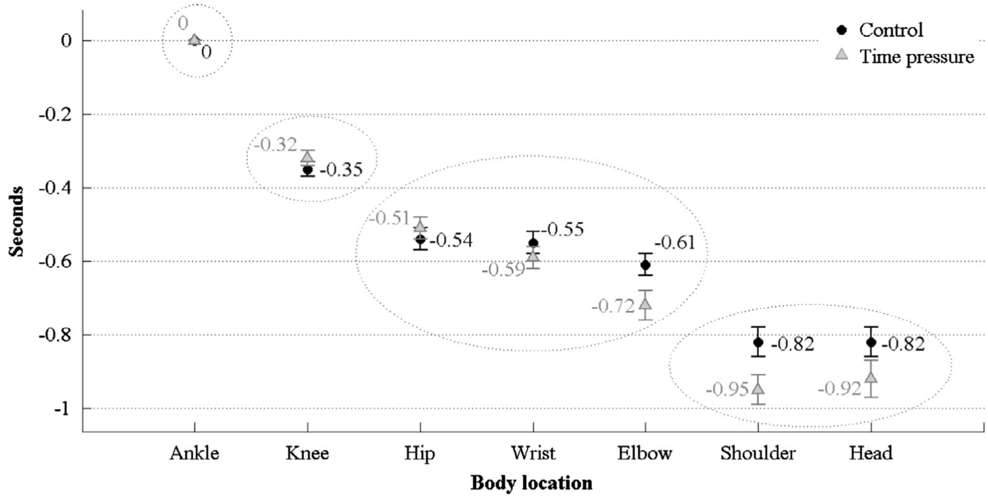

Fig. 8. Mean and Standard Error of the time in which the movement forward (in the X-axis) was recognized for each body part. Ellipses indicate non-significant differences.

ning of the time gap, i.e. while the vehicle was still at the crossing site, as opposed to the control group where the participants waited until the vehicle had entirely passed ($\chi^2(1) = 40.46$; $p = .000$). For the control group, it was found that in the long scenarios (Fig. 10B) participants initiated their crossing earlier compared to the short scenarios ($\chi^2(1) = 5.33$; $p = .021$). This finding is even stronger for the long scenarios in the time pressure group, where in general participants began their crossing before the vehicle had entirely passed ($\chi^2(1) = 13.74$; $p = .000$) but more so in long scenarios (Fig. 10B). Gender differences (Fig. 10C) were found only in the time pressure group, when both genders initiated their crossing before the beginning of the time gap, however, women initiated their crossing 0.2 s before men did ($\chi^2(1) = 8.56$; $p = .003$). Finally, crossing opportunities differences (Fig. 10D) found within the control group suggest that participants who crossed at uncertain or unsafe crossing opportunities had timed their crossing to start closer to the beginning of the time gap compared to participants who crossed at a safe crossing opportunity and timed their crossing to start after the vehicle had entirely passed the crossing site ($\chi^2(2) = 28.21$; $p = .000$).

3.3.2. Crossing speed

The effect of the experimental condition (time pressure versus control), scenario lengths (short vs long), gender, and crossing opportunities (safe, uncertain, unsafe), on crossing speed were analyzed using ANOVA and are presented in Fig. 11. It was found that the crossing speed for the experimental time pressure group was higher than the crossing speed for the control group ($F(1,312) = 30.67$; $p = .000$). Crossing speed during the short scenarios did not differ from the crossing speed during the long scenarios in neither one of the groups, implying that participants' wait time had no effect on their crossing speed ($F(1,156) = 2.27$; $p = .134$ for the control group and $F(1,154) = 0.04$; $p = .838$ for the time pressure group). Gender differences demonstrate that males tend to cross faster than females both in the control group and in the time pressure group ($F(1,156) = 10.90$; $p = .001$; $F(1,154) = 21.53$; $p = .000$). Crossing speed differences as a function of the crossing opportunity were also found, such that in both of experimental groups crossing speed during the safe crossing opportunities was the lowest while in the unsafe crossing opportunities it was the highest. ($F(2,155) = 28.68$; $p = .000$; $F(2,153) = 7.47$; $p = .001$). Tukey post hoc tests revealed that in the control group there were differences between all three crossing opportunities ($p = .000$) while in the time pressure group there were differences only between the safe and the unsafe crossing opportunities ($p = .028$).

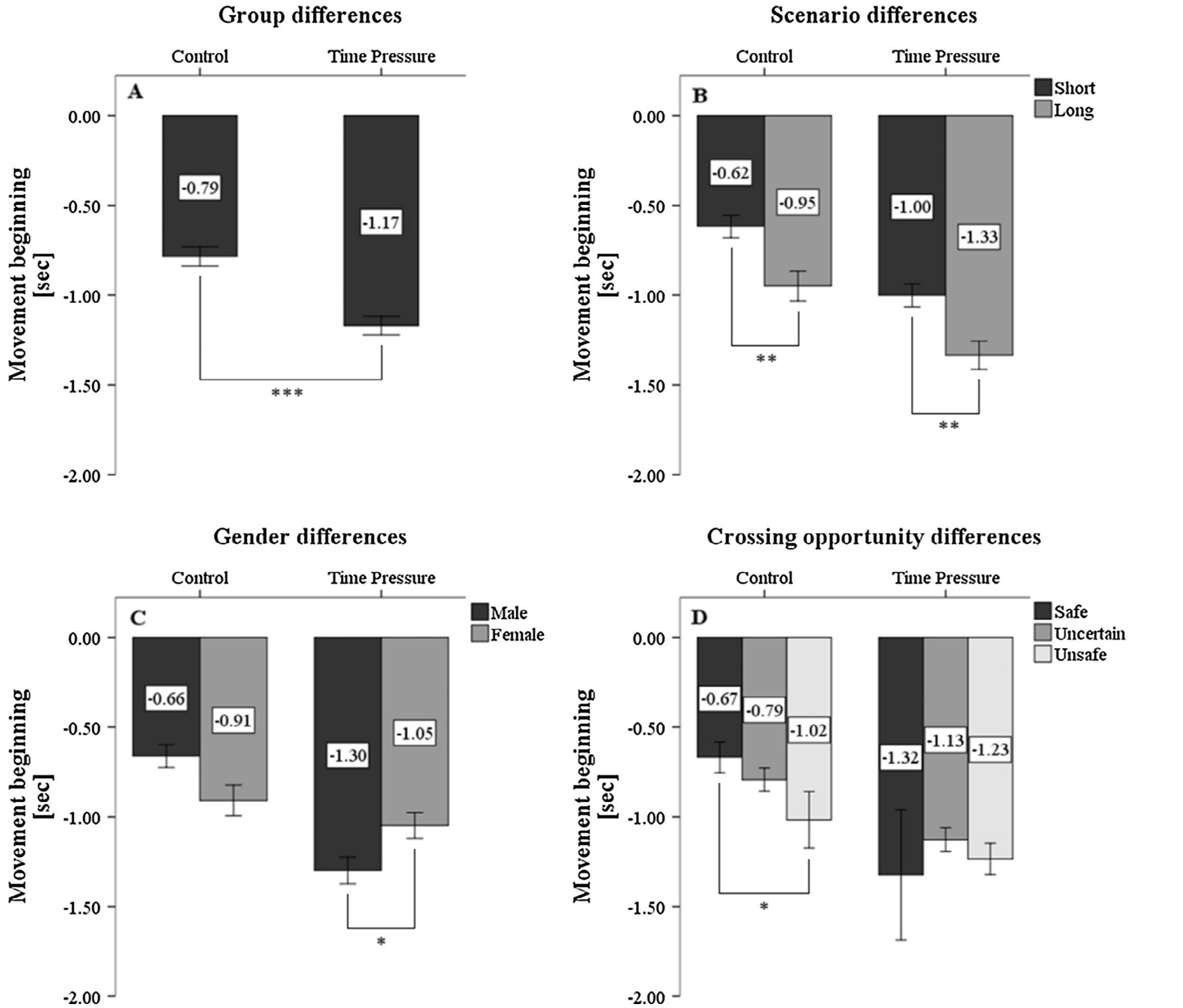

Fig. 9. Comparison of the movement beginning time between the experimental groups (A), scenario lengths (B), gender (C), and crossing opportunities (D). $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Fig. 12 shows the mean crossing speed for each one of the time gaps (measured in seconds) in which the participants had crossed. To describe the relation between the time gap and the crossing speed, a two-term exponential model in the form of equation 4 was fitted to the data using MATLAB.

$$F(x) = ae^{bx} + ce^{dx} \tag{4}$$

3.3.3. Safety margin

Comparing the safety margins between the two experimental groups, it was found that for the same time gap the safety margin increased in the time pressure condition. Further, comparison of the adaptation strategies taken by the participants to reduce the risk (i.e. timing the crossing to start earlier and increasing the crossing speed) between the two experimental conditions revealed that earlier timing of crossing under time pressure contributes on average 0.28 s to the safety margin, whereas higher crossing speed contributes on average 0.34 s. For an illustration of how the safety margins change considering the timing of initiation of the movement and the estimated crossing speed see Appendix A.

Next, to study the effect of time pressure, wait times and gender on participants crossing performance, a general linear mixed model (GLMM) was applied with the experimental group (control/time pressure), scenario type (short/long), gender and all second-order interactions as the predicting effects in the model. Participant and the scenario trial number were set as random effects to account for individual differences among participants and among scenarios. After applying a backward elimination procedure, the final model consisted of the following variables: the experimental group, scenario type, and gender as main effects, and the interaction between the experimental group and gender ($F(3,299) = 7.94$, $p = .000$; $F(3,299) = 15.42$, $p = .000$; $F(3,299) = 9.26$, $p = .000$; $F(3,299) = 4.5$, $p = .004$, respectively). Descriptive analysis of the results show that

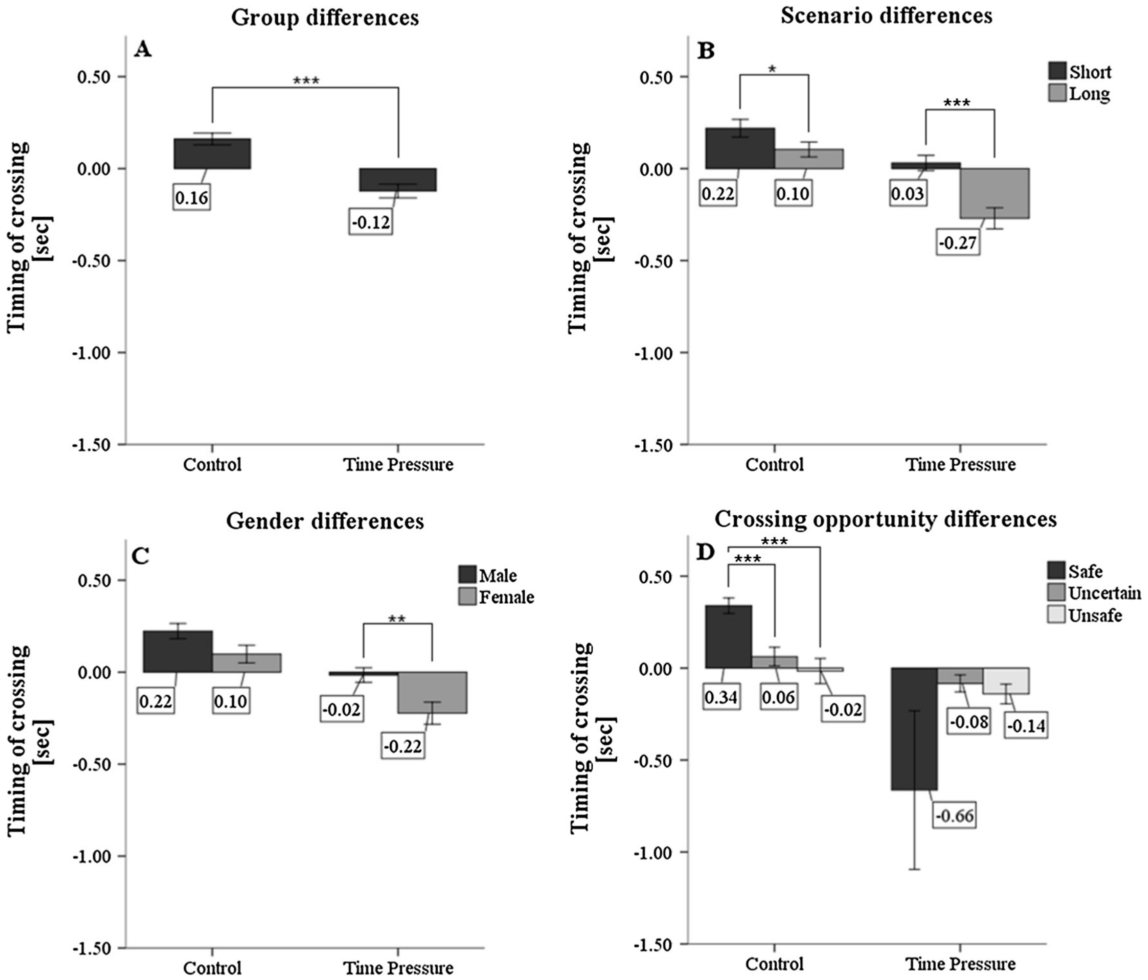

Fig. 10. Comparison of the timing of crossing between the experimental groups (A), scenario lengths (B), gender (C), and crossing opportunities (D). $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

participants in the control group demonstrated safer behavior than those in the time pressure group, where only 4% of the crossings ended with a 'safe cross' (Fig. 13A). During the short scenarios, participants performed better, with 96% successful crossings that ended without 'hit' events, compared to the long scenarios where only 65% of the crossings ended without 'hit' events (Fig. 13B). Gender differences (Fig. 13C) show that males were more likely to make crossing decisions that ended in a 'close call' (61%). Females were safer in the control group (49% of the crossings ended in 'safe cross') compared to the time pressure group, where only 5% of the crossings ended in a 'safe cross' (Fig. 13D).

4. Discussion

The aim of this study was to assess how long wait times and imposed time pressure affected pedestrians' behavior, i.e., decision to cross, readiness for crossing, and crossing speed in road-crossing scenes, and uniquely to examine how these changes in behavior were reflected in participants' body parts' movement as was measured with the motion capture system. This kind of examination, which is to our knowledge, introduced for the first time, can lead to better understanding of how pedestrians perceive the crossing environment under combined conditions of time pressure and long wait times and to new insights on how they adjust their movements in order to compensate for loss of time or risk taken.

The crossing behavior was divided into three stages: (i) risk taking in the crossing decision, (ii) the walk initiation process and (iii) the actual road-crossing phase. In each stage, the effect of three main factors was examined: (1) time pressure, using two levels, control and an experimental group (2) wait time, using scenarios with two levels of short wait (less than 30 s) and long wait (70 s or more) till a safe crossing opportunity; and (3) gender.

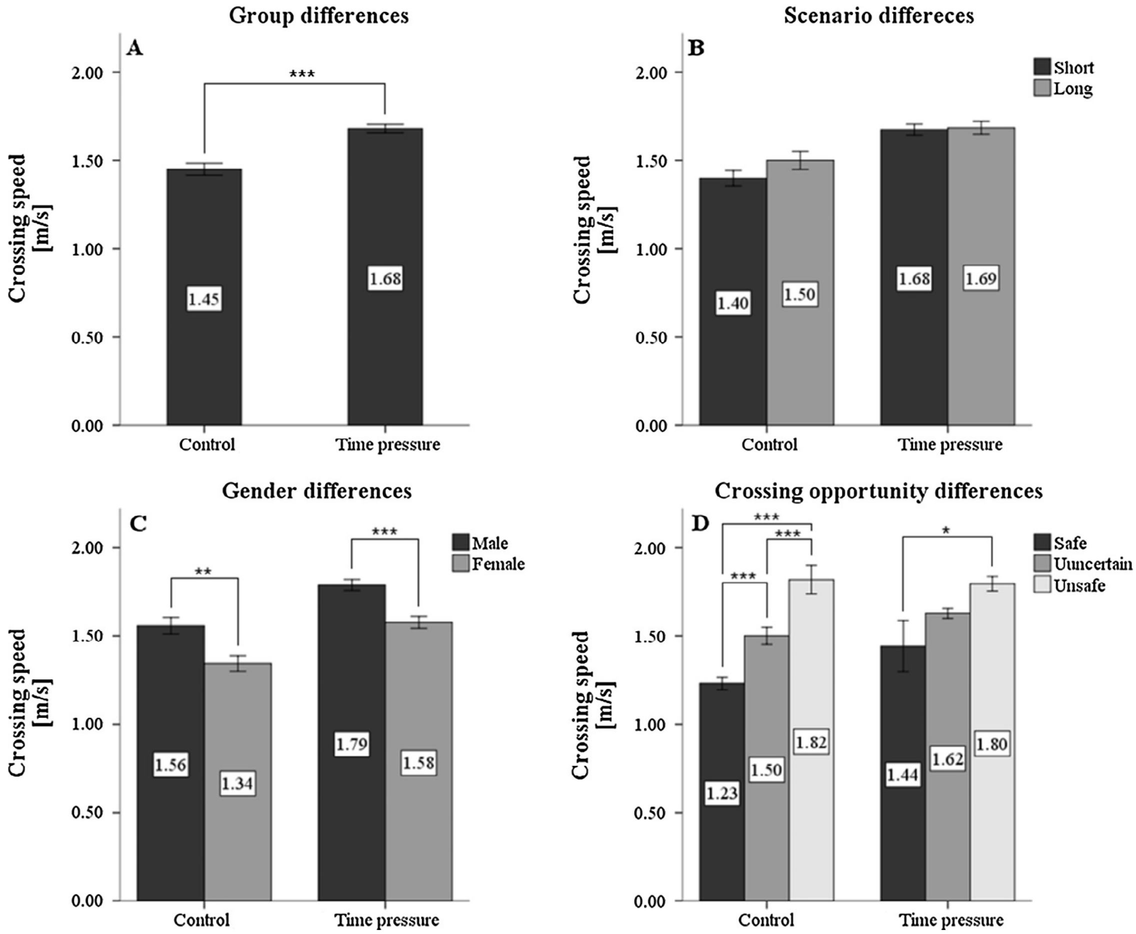

Fig. 11. Mean crossing speed differences between groups (A), scenario lengths (B), gender (C) and crossing opportunities (D), including error bars. *p < .05, **p < .01, ***p < .001.

4.1. Time pressure factor

Overall, it can be said that under time pressure pedestrians tend to make riskier choices when it comes to crossing the road. Looking at when participants chose to cross (Table 1), revealed that in the experimental time pressure group, pedestrians' likelihood to cross at risker crossing opportunities was higher compared to the control group (96.8% uncertain or unsafe crossings compared to 58.2%). These findings support our hypothesis about pedestrians' performance under time pressure and are consistent with previous studies that reported that time constraints led to risker pedestrian behavior (e.g., Morrongiello et al., 2015). Further considering the fact that participants were instructed to avoid being hit on all trials, it is important to note that the time pressure manipulation did not affect the percentage of 'hits' but rather the 'close call' and 'risky cross' behavior (Fig. 13A). Reinforcing findings of others (e.g., Plumert, Kearney, Cremer, Recker, & Strutt, 2011), it can be said that although the participants crossed at risker opportunities they were able to compensate by timing their crossing to the beginning of the time gap (thus, allowing longer crossing times), a behavior noted also by Guth et al. (2005), and by adjusting their crossing speed to the risk taken, such that higher risk resulted in higher pedestrians' crossing speed (Fig. 10D and 11D) as hypothesized.

As for the body parts' movement during the walk initiation process, it appears that the beginning of movement of pedestrians under time pressure is initiated earlier compared to the control group (Fig. 9A). It is plausible that under time constraints, pedestrians feel more anxious and therefore try to hasten their crossing (Li, Li, & Yuan, 2014). Thus, it is conceivable that earlier beginning of movement, which means slower movements of their body parts before the crossing, can help in synchronizing the beginning of the crossing with the beginning of the time gap, as can be seen in Fig. 10A.

Moreover, crossing under time pressure, was reflected in higher crossing speed (Fig. 11A). Although, this finding is in accordance with the study of Morrongiello et al. (2015), our results show higher crossing speeds (1.68 m/s in the experimental time pressure group and 1.45 m/s in the control group, compared to 1.38 m/s and 1.28 m/s). This may be because our study focused not only on safe crossings opportunities but also on uncertain and unsafe crossings, which resulted in higher

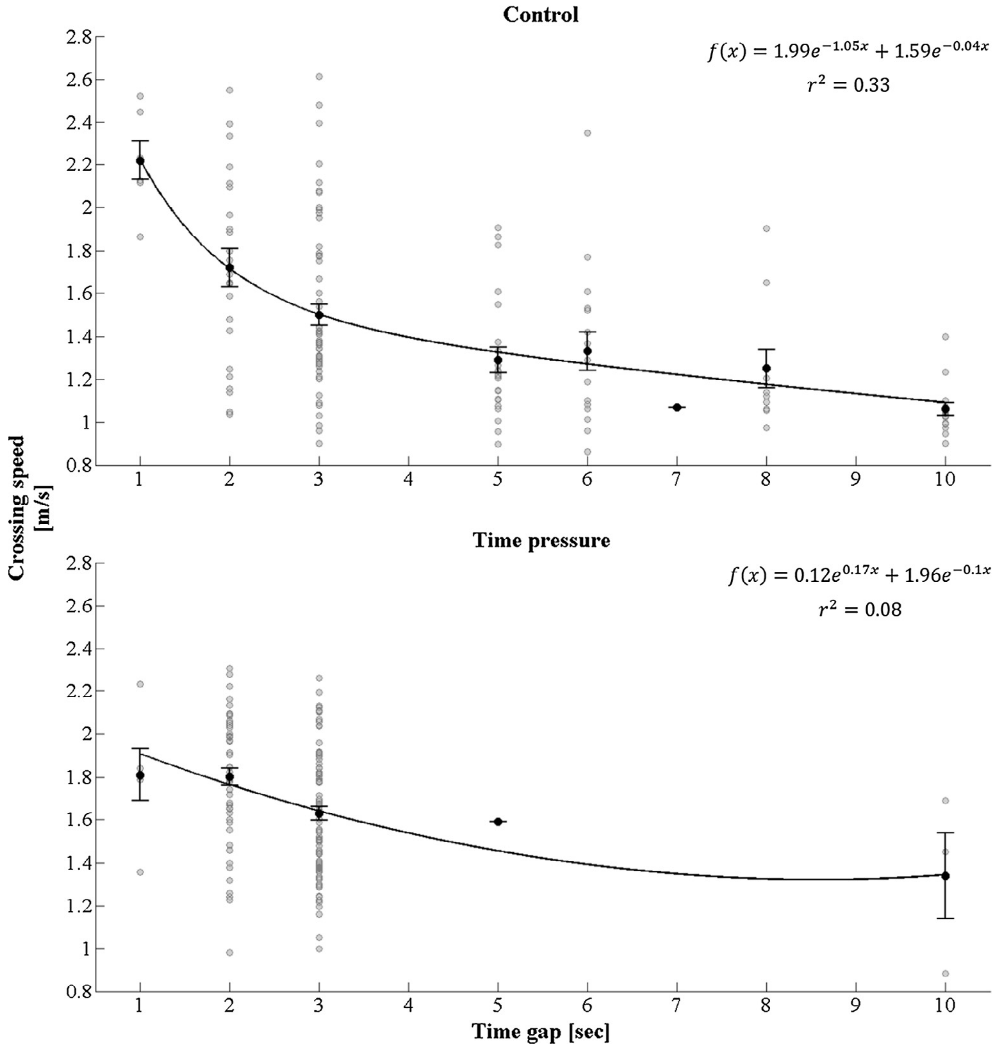

Fig. 12. Mean and Standard Error of the crossing speed as a function of the time gap, for the control (top) and the experimental group (bottom). The curve describes the two-term exponential fitted model and the grey dots represent the distribution of the participants.

crossing speeds. However, when analyzing only safe crossings opportunities (Fig. 11D) we obtained similar results (1.44 m/s and 1.23 m/s).

Another interesting finding is that while for the control group personality traits effected participants' choice of crossing opportunity (i.e. safe, uncertain, and unsafe) for the time pressure group these traits did not affect their choice (Table 2). It is possible that under time constraints, crossing decisions are based primarily on attaining to the most immediate available gap, making personality traits such as the big five inventory and sensation seeking less relevant. Correlations within the control group, verify the connection between the big five personality traits and risk taking and are in accordance with previous studies (Eensoo, Harro, Pullmann, Allik, & Harro, 2007; Herrero-Fernández et al., 2016). The correlation between neuroticism (the degree of emotional stability and impulse control) and the time gap was negative, meaning that higher levels of neuroticism lead to riskier behavior, and the correlations between agreeableness, conscientiousness and openness with the time gap were positive and lead to safer behavior. Other studies have reported upon positive correlations between thrill and adventure, and experience seeking traits, to risky behavior (e.g., Rosenbloom, 2003; Rosenbloom & Wolf, 2002), yet we did not find evidence for such behaviors in our study. Yet, we did find a negative correlation between the boredom susceptibility trait and the time gap, which can indicate that pedestrians with high levels of intolerance for repetition engage in more risky behavior compared to others.

4.2. Wait time factor

In this study, the wait time was manipulated by using two sets of scenarios: short scenarios (30–35 s), where the participants had several safe crossing opportunities relatively in the beginning of the scenarios, and long scenarios (70–160 s),

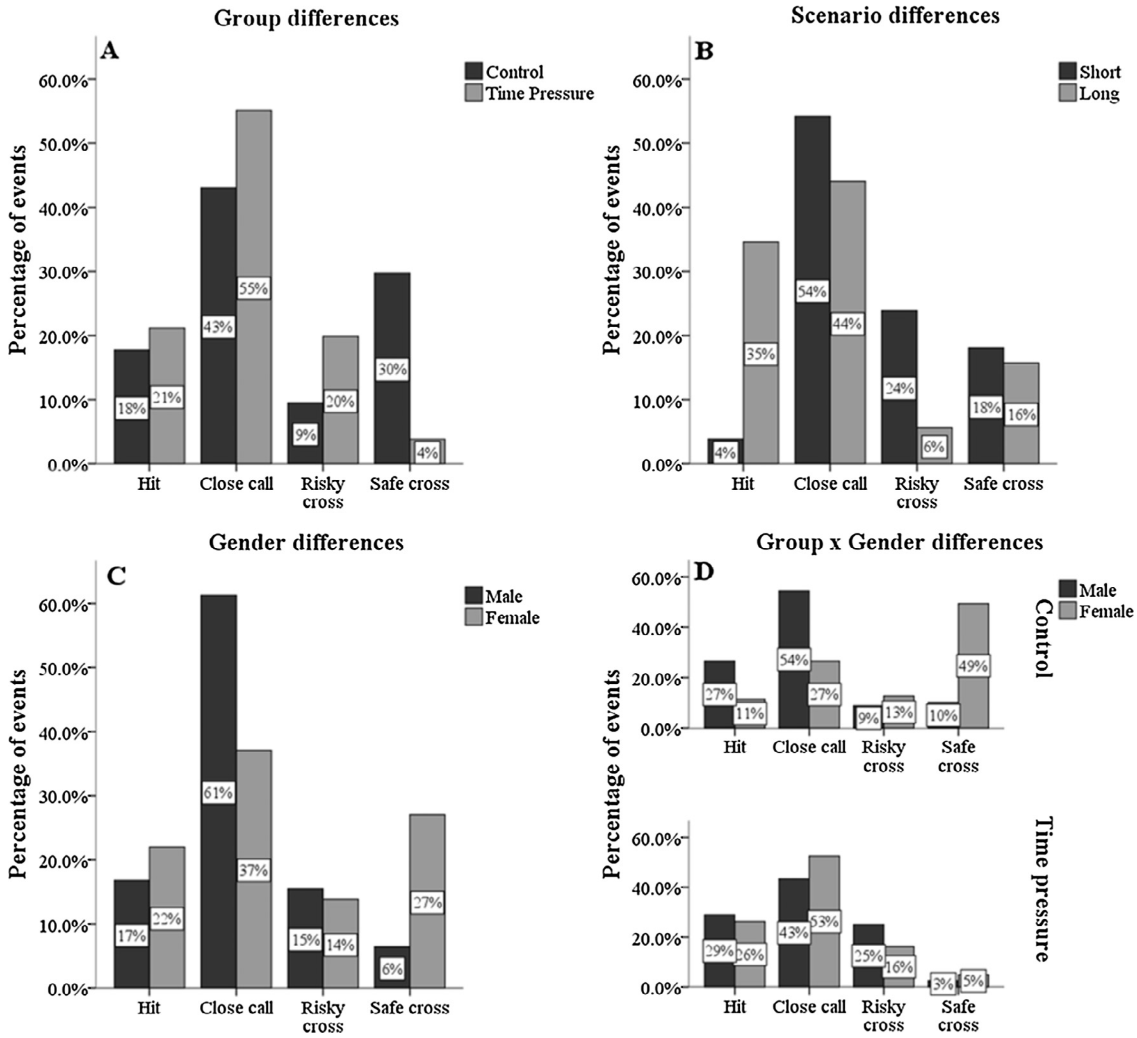

Fig. 13. Percentage of crossing performance event outcome ('hit', 'close call', 'risky cross' and 'safe cross') by group (A), scenario length (B), gender (C), and the interaction between group and gender (D).

where the safe crossing opportunities appeared after longer wait times. In line with previous studies on gap acceptance (e.g., Lobjois, Benguigui, & Cavallo, 2013; Plumert et al., 2011; Guo et al., 2011, Yang et al., 2015; Yannis, Papadimitriou, & Theofilatos, 2013), as well as older studies on drivers gap acceptance (e.g., Kittleson & Vandehey, 1991) our results confirmed that the chosen time gap decreased when the wait time increased (Table 1). Within the long scenarios, pedestrians demonstrated riskier crossing behavior, reflected by an increase in crossings preformed at unsafe crossing opportunities in contrast to short scenarios where only safe or uncertain crossings were carried out. The impact of this increase can be seen in crossing performance, which unlike the time pressure manipulation, yielded major increases in the percentage of 'hit' events in the long scenarios as opposed to the short ones (Fig. 13B). This increase can be associated with the fact that 'hit' events mostly occur when the pedestrians cross at unsafe crossing opportunities that do not leave them enough time to cross safely.

Similar to time pressure, long waiting also had an effect on pedestrians' body parts' movement, such that in the long scenarios pedestrians' beginning of movement was observed earlier in the scene (Fig. 9B). A possible explanation is that after long wait times on the curb, pedestrians' sense of impatience increases and they become more eager to cross the road. Therefore, similar to when under time pressure, pedestrians earlier beginning of movement when experiencing long waiting is meant to prepare the body to cross as close as possible to the beginning of the time gap. This can be well seen in Figs. 9B and 10B, where earlier movement beginning is reflected in earlier crossing relative to the beginning of the time gap.

4.3. Gender factor

Gender differences were found in the control group such that men were engaged in risker behavior compared to women. This result is similar to other studies on risk taking, which often show that women tend to be more risk avoiding than men (e.g., Herrero-Fernández et al., 2016; Rosenbloom et al., 2015). However, the findings revealed also that those differences disappear in the experimental time pressure group. Whereas men under time pressure show the same tendency to risky behavior as do men in the control group, women under time constraints performed more dangerous crossings compared to women in the control group. Although both women and men adjust their crossing speed relative to the experimental groups, men crossed faster within both groups (Fig. 11C).

Other differences between women and men can be found in the movement of their body parts. Although no differences were found within the control group, men under the experimental time pressure condition were found to start moving forward with their body earlier compared to women (Fig. 9C). However, in contrast to the time pressure and wait time factors in which earlier movement beginning was reflected in earlier crossing relative to the beginning of the time gap, in this case, women in the experimental time pressure group whose movement beginning was identified later compared to men (Fig. 9C), timed their crossing to start 0.2 s before men (Fig. 10C). It is possible that in this kind of configuration the ability of women to evaluate accurately when the vehicle had entirely passed the crossing site was less precise compared to men. Similar findings were reported using a fidelity real-time bicycling simulator, such that male participants timed their entry into the intersection more precisely than did female participants (Stevens, Plumert, Cremer, & Kearney, 2012).

5. Conclusions

Inside laboratory studies that aim to analyze pedestrians' road crossing behavior are often confronted with arguments about the generality of the judgments to real road crossing situations. It is therefore why the first goal of this study was to examine whether in our type of experimental configuration, participants would be sensitive to the road crossing conditions presented to them in the simulated scene. In this study, we focused on time pressure, wait time and gender factors, which are all contributing factors to road crossing traffic violations and risky behavior done by pedestrians. Our findings are consistent with previous laboratory studies (e.g., Dommes et al., 2014; Morrongiello et al., 2015; Plumert et al., 2011) as well with field observation studies (e.g., Yang et al., 2015; Yannis et al., 2013). The findings demonstrate that this novel simulation and measurement configuration is valid and resembles the necessary characteristics of the road-crossing environment. Therefore, it can be used to gain more precise knowledge of pedestrians' decision-making and action.

The second goal was to examine how the various conditions that participants faced were reflected in their movements prior to the crossing itself and during the crossing. We found that the walk initiation process has a pattern that can be divided into four increments, and each contains different body parts. The first body parts to move are the head and the shoulder, which are also the most distant from the ankle. The second group of body locations contains the elbow, the wrist and the hip, which are at the center of the body. The third group contains the knee, which is the closest joint to the ankle that completes the fourth group and is the last body part to move.

Findings also indicate that the time of movement initiation varies depending on the state of the pedestrian, i.e., under time pressure or after longer wait times. Better understanding of this behavior can help in recognizing pedestrians' intention to cross and further research needs to be done to explore how joint and body movements can translate into meaningful cues regarding the imminence of the pedestrian's intention to cross. This could be implemented in collision avoidance systems (e.g. Mobileye) that give warnings on pedestrians crossing. This understating could lead to earlier detection of pedestrians by drivers (i.e., detecting if the pedestrian is going to cross or is just standing).

To conclude, the current research had met its aims, however it has several limitations. First, the participant pool was fairly homogeneous and involved only participants aged 20–30 all students recruited from Ben-Gurion University. Second, participants in this study were faced with a relatively simple crossing decision in a one-way road, while their behavior was tested under two factors: time pressure and wait time. This research can be extended by recruiting participants that are more diverse in age and experience, and by expanding the range of crossing situations and crossing conditions.

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Appendix A

Here we provide an illustration of how the safety margins change considering the timing of the initiation of the movement and the estimated crossing speed. In order to calculate the expected safety margin for each one of the time gaps we used Eq. (3). The timing of crossing was determined using the mean values derived from Fig. 10D in accordance with the crossing opportunity. The crossing speed was calculated using the exponential models that were presented in Fig. 12.

Fig. A1 provides the calculated crossing time and consequent safety margins as a function of the time gap. Safety margins of more than 2 s are considered safe cross (Dagan, Mano, Stein, & Shashua, 2004). Hence, time gaps of 6 s or more generated safe crossing opportunities for both groups. Looking at gaps smaller than 5 s, it is important to note that although the safety margin increased for the time pressure experimental group; this had only a small effect on crossing performance. Crossing performance improved only in the 2 s time gap where it increased from 'Hit' (less than 0 s) in the control to 'Close call' in the

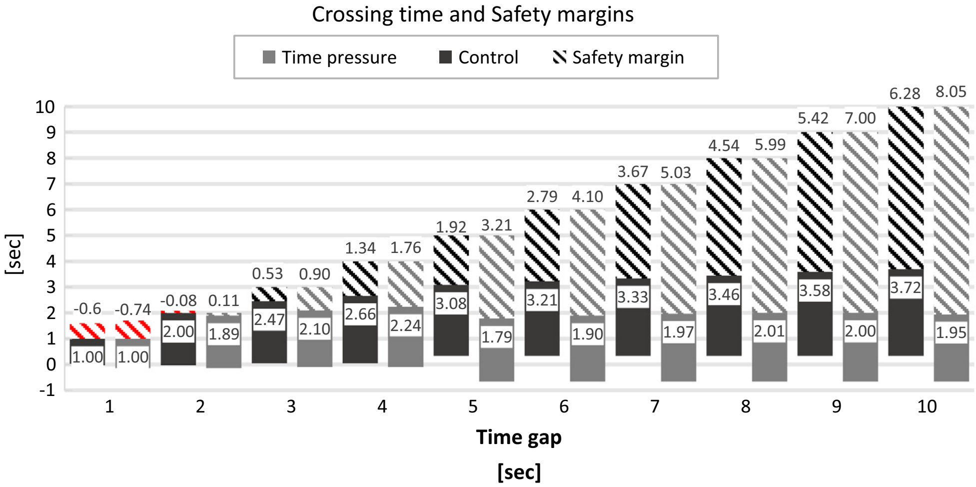

Fig. A1. Crossing time represented by the solid bars and the safety margin represented by the dashed bars. Red dashed bars (shown in time gaps 1–3 s) mean that the time gap was not enough to cross (i.e. hit). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

time pressure group (less than 1 s), and in the five second time gap where it increased from 'Risky cross' (less than 2 s) to 'Safe cross' (more than 2 s).

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