Accepted Manuscript

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PII:	S0966-6362(16)30122-9
DOI:	http://dx.doi.org/doi:10.1016/j.gaitpost.2016.07.003
Reference:	GAIPOS 4830

To appear in: *Gait & Posture*

Received date:	28-10-2015
Revised date:	30-6-2016
Accepted date:	1-7-2016

Please cite this article as: Dicks Matt, Clashing Christal, O'Reilly Liam, Mills Chris.Perceptual-Motor Behaviour During a Simulated Pedestrian Crossing.*Gait and Posture* http://dx.doi.org/10.1016/j.gaitpost.2016.07.003

Running Head: Pedestrian Crossing Behaviour

Perceptual-Motor Behaviour During a Simulated Pedestrian Crossing

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Research Highlights

- Avoiding collision with two oncoming pedestrians significantly decreases gait velocity
- When two oncoming pedestrians are not looking at a mobile phone, participants adopt a ‘stop-start’ adaptive control strategy to avoid collision
- When two oncoming pedestrians are looking at a mobile phone, participants wait later before taking a medio-lateral deviation to avoid collision
- Attentional load as a consequence of social interactions affects gait control

Abstract

This study used a novel research paradigm to examine gait control during real-time between-person collision avoidance. Ten young adults (*M* = 20.1 ± 1.52 years) were required to walk across a six metre simulated pedestrian crossing, while avoiding a collision with one or two oncoming pedestrians. The potential for social interaction was manipulated by having the oncoming pedestrians walk with (2MP) or without (2P) looking at a mobile phone. Participants took longer to complete the crossing when avoiding a collision with two oncoming pedestrians (2MP: *M* = 5.68s; 2P: *M* = 5.74s) in comparison with baseline (*M* = 4.96s). Gait velocity decreased and was more variable when avoiding a collision during the 2P condition, whilst the anterior-posterior separation distance between pedestrians and the participants at the initiation of peak mediolateral deviation was significantly smaller in 2MP compared to 2P. These findings offer preliminary understanding on how gait control may be adapted to changes in the availability of other persons' gaze orientation information. Future work is needed to further understand how different adaptive behaviours emerge relative to other persons during pedestrian crossings.

Keywords: Collision Avoidance; Gait; Kinematics; Social Attention

Abstract word count: 181

Article word Count: 2,996

1. Introduction

The ability to walk through cluttered environments requires the navigation of a safe walking path. To ensure the avoidance of any potential static (e.g., uneven pavement) and moving hazards (e.g., other persons) in the environment, skilful walking is predicated on the adaptation of gait trajectory. The avoidance of moving obstacles requires accurate perceptual-motor control regulated by an array of information, including time-to-contact (Higuchi, 2013) and biological motion variables (Olivier, Marin, Crétual, & Pettré, 2012). For example, research has shown that there is a decrease in walking speed and a mediolateral deviation in gait trajectory during both the avoidance of a moving mannequin (Cinelli & Patla, 2008) and another person (Basili et al., 2013; Huber et al., 2014).

Decreases in walking speeds during collision avoidance hold implications for a range of daily contexts. Pedestrian crossing studies indicate that the time available for older adults to cross is insufficient (Asher, Aresu, Falaschetti, & Mindell, 2012). However, understanding is limited, as experimental approaches have not fully considered the influence that other people have on crossing behaviours. Between-person avoidance may present significant challenges given that this skill requires anticipation of another person's walking path based on gait (Basili et al., 2013) and gaze behaviour (Nummenmaa, Hyönä, & Hietanen, 2009) information. Indeed, it is unknown whether social attention further adds to the complexity of collision avoidance. Specific to the context of pedestrian crossings, it is of essence to understand the affect that social attention processes have on gait control and time to cross the road.

Recent research has identified that the processes underpinning social attention are best captured through the analysis of real-time interpersonal interactions (Dicks, Button, & Davids, 2010b; Laidlaw, Foulsham, Kuhn & Kingstone, 2011). As a consequence, there has been a concerted effort to enhance understanding on the processes that underpin interpersonal perceptual-motor actions (Risko, Richardson, & Kingstone, 2016). Such empirical emphasis is particularly pertinent for the study of gait control during interpersonal interactions as current understanding is partly based on passive (non-interaction) experimental paradigms (e.g., Cinelli & Patla, 2008). Nummenmaa and colleagues (2009) reported that people use information based on an avatar's gaze orientation to make judgements about the intended walking direction of the avatar in a virtual reality environment. However, it is currently unknown how the availability of gaze orientation information impacts upon gait control during real-time interactions. This gap in current understanding is particularly pertinent given that where one looks does not necessarily define one's walking direction (Cinelli & Warren, 2012). The use of mobile phones when walking reflect this layer of complexity during interpersonal interactions as this mode of technology affects the potential for social attention (Licence, Smith, McGuigan, & Earnest, 2015). Changes in gait patterns associated with walking while using a mobile phone (Lamberg & Muratori, 2012) may lead to changes in the availability of different informational variables (e.g., minimal predicted distance: Olivier et al., 2012) that are exploited during the regulation of interpersonal collision avoidance (Basili et al., 2013; Huber et al., 2014).

The aims of the current study were to: (i) determine if the presence of oncoming pedestrians influences crossing behaviour, and: (ii) examine the extent to which potential social interactions influence crossing behaviour. We manipulated the number of oncoming pedestrians and their looking behaviour by having them walk with or without looking at a mobile phone. It was hypothesized that there would be a significant increase in crossing time and a significant decrease in crossing speed in the presence of oncoming pedestrians (Cinelli & Patla, 2008). Furthermore, it was hypothesized that there would be a difference in collision avoidance gait patterns, including a change in the regulation of mediolateral trajectory deviations, between social attention (no mobile phone) and no social attention (mobile phone) conditions.

2. Methods

2.1 Participants

Five male and five female participants (*M* = 20.1 ± 1.52 years) and six oncoming confederates (pedestrians), four female and two male (*M* = 27.2 ± 5.95 years), were recruited to take part in the study. One confederate acted as pedestrian one in all trials (Male: 24 years), while the remaining confederates were randomly allocated to act as pedestrian two (see Experimental protocol and apparatus) on two different occasions. The local institution's ethics committee provided ethical approval, whilst participants and confederates provided informed consent prior to taking part in the experiment.

2.2 Experimental Protocol and Apparatus

Participants were required to cross a simulated pedestrian crossing, measuring 6m x 2.5m (Figure 1). Each trial began when participants pressed a button, which triggered a red signal. Immediately after the signal appeared, the participant positioned themselves at the same location, directly in the middle of one side of the crossing. This position reflected the origin of the mediolateral axis, 0m (see Figure 2). Participants waited until the signal turned green before crossing along a self-regulated path.

Insert Figure 1 Here

In order to capture instances of naturally occurring interpersonal interactions, we measured participant behaviour across five conditions, with one trial per condition (see Laidlaw et al., 2011): (i) baseline – no pedestrians; (ii) one oncoming pedestrian (P); (iii) one oncoming pedestrian, using a mobile phone (MP); (iv) two oncoming pedestrians (2P); and (v) two oncoming pedestrians, looking at the same mobile phone (2MP). The order of experimental conditions was counterbalanced between participants. Two confederates fulfilled the role of the pedestrians: pedestrian one was the same for every participant, and pedestrian two was randomly assigned to each participant. Pedestrians adopted the same start positions prior to each trial and were instructed to begin crossing once the participant had begun to walk. Pedestrian one always started crossing from the origin of the mediolateral axis, 0m (*SD* = 0.07) – that is, directly opposite the participant – and pedestrian two always started alongside pedestrian one at an average location of -0.70m (*SD* = 0.13) on the mediolateral axis (see Figure 1 and 2). During the mobile phone conditions, pedestrians were instructed to look at the phone although they were not required to write a text message. In all cases, pedestrians and participants were instructed to walk, as they would do when normally crossing the road and to avoid collision with each other.

Kinematic data was measured via thirteen optoelectronic cameras (Qualisys Oqus 300/310, Sweden) set at a sampling frequency of 60Hz, with six retro-reflective markers placed on the participant’s pelvis. Markers were identified using Qualisys Track Manager/QTM (2.6, Qualisys Track Manager, Sweden) and exported to Visual 3D Professional (Visual3D, C-motion, Inc, 2010).

Insert Figure 2 Here

2.3 Verification of Pedestrian Behaviour

In order to quantify any possible changes in pedestrian crossing behaviours between conditions, crossing speeds were calculated using pelvic centre of mass (COM) and compared across the P, MP, 2P and 2MP conditions. For pedestrian one, an analysis of variance (ANOVA) with repeated measures on experimental condition revealed no significant difference in crossing speed between P (M = 1.25, SD = 0.11), MP (M = 1.29, SD = 0.24), 2P (M = 1.19, SD = 0.19) and 2MP (M = 1.08, SD = 0.18), $F(3, 21) = 2.72$, $p = .07$. However, analysis of pedestrian two crossing speeds revealed a significantly slower crossing speed in the 2MP condition (M = 1.08m/s, SD = 0.20) in comparison with 2P (M = 1.18m/s, SD = 0.15), $t(8) = 2.425$, $p = .042$, $d = .96$. Together, data indicated that pedestrian speeds differed between conditions. Specifically, when looking at a mobile phone, pedestrian walking speeds were significantly slower than when walking without looking at a mobile phone (Lamberg & Muratori, 2012; Licence et al., 2015).

2.4 Analysis of Crossing Behaviour

Crossing time (s), distance-travelled (m), steady-state crossing speed (m/s) and variability of steady-state crossing speed (m/s) were calculated using pelvic COM. Crossing time was defined as the time taken to walk the 6m crossing, distance-travelled was calculated using the path of the pelvic COM, steady-state crossing speed was the mean walking velocity following the initial acceleration phase (Basili et al., 2013), and variability of steady-state crossing speed was calculated as the coefficient of variation of steady-state crossing speed. The percentage of total trial time that participants spent at steady-state crossing speed equated to 75.1% (SD = 5.59) of the trial at baseline, 79.2% (SD = 6.48) during P, 77.3% (SD = 6.48) during MP, 80.2% (SD = 4.08) during 2P, and 78.8% (SD = 4.82) during 2MP.

2.5 Analysis of Collision Avoidance

A deviation was defined as a mediolateral (M/L) displacement of pelvic COM outside of 3 standard deviations of the mean baseline trajectory (Cinelli & Patla, 2008). The mean and standard deviation were calculated using the baseline trajectory data from all participants. As the crossing speeds of pedestrians differed between experimental conditions (see 2.3 Verification of Pedestrian Behaviour), collision avoidance was calculated using the following dependent measures: (i) the anterior-posterior (A/P) separation distance between the participant and pedestrian one at the point where peak M/L deviation began (m); (ii) the A/P separation distance between the participant and pedestrian two at the point where peak M/L deviation began (m); (iii) the magnitude of the peak M/L deviation (m); and (iv) velocity of the peak M/L deviation (m/s) (Figures 1 and 2).

3. Statistics

Normality distribution was assessed using Shaprio-Wilk test. For normally distributed dependent measures (p >.05), one-way repeated measures ANOVA with condition as a within-subject factor were performed to assess the affect of condition on crossing and collision avoidance behaviours. Main effects were analysed using Bonferroni corrected post hoc tests. If dependent measures were not normally distributed (p <.05), Friedman's ANOVA with condition as a within-subject factor were performed. Main effects were analysed using Bonferroni corrected Wilcoxon signed-rank tests.

4. Results

Steady-state crossing time and speed were significantly affected by experimental condition ($F(4, 32) = 5.121$, $p = .002$, $\eta^2 = .363$ and $F(4, 32) = 3.041$, $p = .008$, $\eta^2 = .343$, respectively) (Table 1). Post-hoc tests with Bonferroni corrected values for multiple comparisons (p <.005) revealed that steady-state crossing speeds during 2MP were slower than baseline and P. Moreover, crossing times were longer in 2P and 2MP conditions compared to baseline. There was a main effect for condition on variability of steady-state crossing speeds, $\chi^2(4) = 19.65$, $p = .001$. Wilcoxon signed-rank test revealed that variability in steady-state crossing speed was greater during 2P ($M = 0.22$, $SD = 0.05$) compared to baseline ($M = 0.11$, $SD = 0.01$) condition $z = -2.80$, $p < .005$, $r = 0.89$ (see Figure 3). There were no significant differences for actual distance walked $F(4, 32) = 1.592$, $p = .238$.

Insert Table 1 Here

Insert Figure 3 Here

There was a main effect for condition on the A/P separation distance between the participant and pedestrian one at the initiation of the peak M/L deviation, $F(3, 18) = 3.706$, $p = .031$, $\eta^2 = .382$ (Table 2). The initiation of the peak M/L deviation occurred at a shorter A/P separation distance from pedestrian one in the 2MP condition ($M = 1.46$m, $SD = 0.86$) in comparison with all other conditions. However, post-hoc tests with Bonferroni corrected values for multiple comparisons ($p = .008$) revealed no significant differences between conditions. Analysis of the A/P separation distance between the participant and pedestrian two revealed that the initiation of the peak M/L deviation occurred at a significantly smaller separation distance in the 2MP ($M = 1.54$m, $SD = .88$) condition in comparison with 2P ($M = 2.38$m, $SD = .87$), $t(6) = 2.963$, $p = .025$, $d = .96$. There were no differences between conditions for the magnitude or the velocity of the peak M/L deviation, $F(3,24) = 0.460$, $p = .525$, $\eta^2 = .054$ and $F(3, 24) = 0.115$, $p = .950$, $\eta^2 = .016$, respectively.

Insert Table 2 Here

5. Discussion

Research has begun to reveal how gait control is adapted to avoid between-person collisions during interpersonal interactions (Basili et al., 2013; Huber et al., 2014). Moreover, there is a suggestion that social attention processes affect the accuracy of collision avoidance (Nummenmaa et al., 2009). The increased use of mobile phones may therefore add a layer of complexity to gait control as this mode of technology affects the potential for social attention (Licence et al., 2015). The current study examined how the presence of other people and social attention affected collision avoidance during a simulated pedestrian crossing. The number of oncoming pedestrians and their looking behaviour were manipulated, by having the pedestrians walk with or without looking at a mobile phone.

Crossing speeds significantly decreased in the two oncoming pedestrian conditions (i.e., 2P and 2MP), leading to participants taking more time to cross in comparison with baseline. No differences were found for the one pedestrian conditions compared to baseline. These results indicate that in the presence of more than one oncoming person, the complexity of collision avoidance is increased, leading to a longer crossing time. M/L trajectory deviations to avoid collision did not change the total distance walked. However, there was greater variation in crossing speed in the 2P condition compared to baseline. Together, these results indicate that participants did not walk further to avoid a collision in the 2P condition; rather, they adopted a ‘stop-start’ adaptive control behaviour. The adaptations in gait reflected a combination of changes in M/L trajectory and A/P velocity that underpinned collision avoidance (Figures 2 and 3).

For the initiation of peak M/L trajectory deviations, there was a main effect for condition on the A/P separation distance between participants and pedestrian one, although further analysis revealed that there were no significant post hoc differences. Descriptive statistics (Table 2) indicated that the A/P separation distance was smaller in 2MP in comparison with all other conditions. Moreover, the A/P separation distance between participants and pedestrian two was significantly smaller in the 2MP condition compared to the 2P condition. These results suggest that the 2MP condition led to apparent uncertainty, potentially as a consequence of the removal of social attention (gaze orientation) information when the pedestrians looked at the mobile phone (Lamberg & Muratori, 2012).

The results highlighted above indicate that two different gait control behaviours emerged during the two pedestrian crossing conditions. First, in the 2P condition, changes in M/L trajectory and A/P velocity led to collision avoidance adaptations, that resulted in a ‘stop-start’ gait pattern (Figures 2 and 3). Second, in the 2MP condition, the initiation of peak M/L deviations occurred at a significantly smaller distance between the participant and pedestrians, which appears to be a consequence of the partial removal of social attention (gaze orientation) information (Table 2). These findings suggest that during collision avoidance, people utilise gaze orientation information from another person in order to prospectively control their own walking behaviours (Nummenmaa et al., 2009). However, anticipating another person’s behaviour on the basis of gaze orientation may lead to more adaptations (i.e., stop-start behaviour) in gait control (Dicks, Button, & Davids, 2010a) as gaze information does not specify one’s walking direction (Cinelli & Warren, 2012). In contrast, when gaze orientation information is concealed, there is apparent uncertainty in the anticipation of another’s walking trajectory, which results in a later change in gait trajectory. However, despite such uncertainty, changes in M/L trajectory led to accurate collision avoidance (i.e., there was an absence of ‘stop-start’ behaviour). Moreover, it is possible that the later change in M/L trajectory in the 2MP condition was a consequence of changes in the oncoming pedestrians' gait patterns that occur when attending to the mobile phone (Lamberg & Muratori, 2012).

In order to capture instances of naturally occurring social attention during interpersonal interactions, we measured participant behaviour in one trial per condition (Gallup, Chong & Couzin, 2012; Laidlaw et al., 2011), which may limit the generalisation of the findings in the current study. Moreover, in 2MP, both pedestrians were instructed to view the same mobile phone, rather than each pedestrian looking at a separate phone. A long-established body of literature on affordance perception of apertures (e.g., Warren & Whang, 1987) demonstrates that people scale decisions of whether they can or cannot pass through a gap relative to their own shoulder-width (Higuchi et al., 2011). As such, it is plausible that the affordance (i.e., the animal-environment relation between participant shoulder width and the gap between pedestrians) differed between the 2P and 2MP conditions, meaning that this manipulation may have inadvertently led to the observed differences in perceptual-motor behaviour between 2P and 2MP. Future work is required to build on the current efforts to better understand how gait control is adapted to changes in the complexity of interpersonal interactions encountered on a daily basis (Gallup, et al., 2012). A particularly fruitful approach in this respect may entail the integration of gaze behaviour measures alongside gait kinematics in order to understand how information is utilised to support accurate (and inaccurate) social attention during gait control (Chapman & Hollands, 2006).

Pedestrian crossing operational cycles assume that people are able to walk at a speed of 1.2 m/s (Asher et al., 2012), which was not achieved by healthy young-adults in the current study when faced with two oncoming pedestrians. Signalled crossing cycles might overestimate gait velocities, as they do not adequately account for the complexity of navigating other pedestrians. Research is needed to understand how between-person collision avoidance impacts upon populations with complications in gait control. Older adult cohorts who are known to have insufficient time to cross (Asher et al., 2012) may prove to be a particular important sub-population for future work (Young, Ferguson, Brault, & Craig, 2011).

In conclusion, this study used a novel simulated pedestrian crossing paradigm in order to examine gait control during real-time between-person collision avoidance. Gait velocity decreased and was more variable when avoiding a collision during the 2P condition, whilst the A/P separation distance between pedestrians and the participant at the initiation of peak M/L deviation was significantly smaller in 2MP compared to 2P. These changes in gait control reflect different adaptive behaviours, which underpinned collision avoidance in the respective conditions (Basili et al., 2013; Huber et al., 2014). The results offer preliminary understanding on how gait control may be adapted to changes in the availability of other persons' gaze orientation information during complex interpersonal interactions (Gallup et al., 2012; Nummenmaa et al., 2009).

Conflict of interest statement

The authors have no conflict of interest to declare.

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Figure Caption

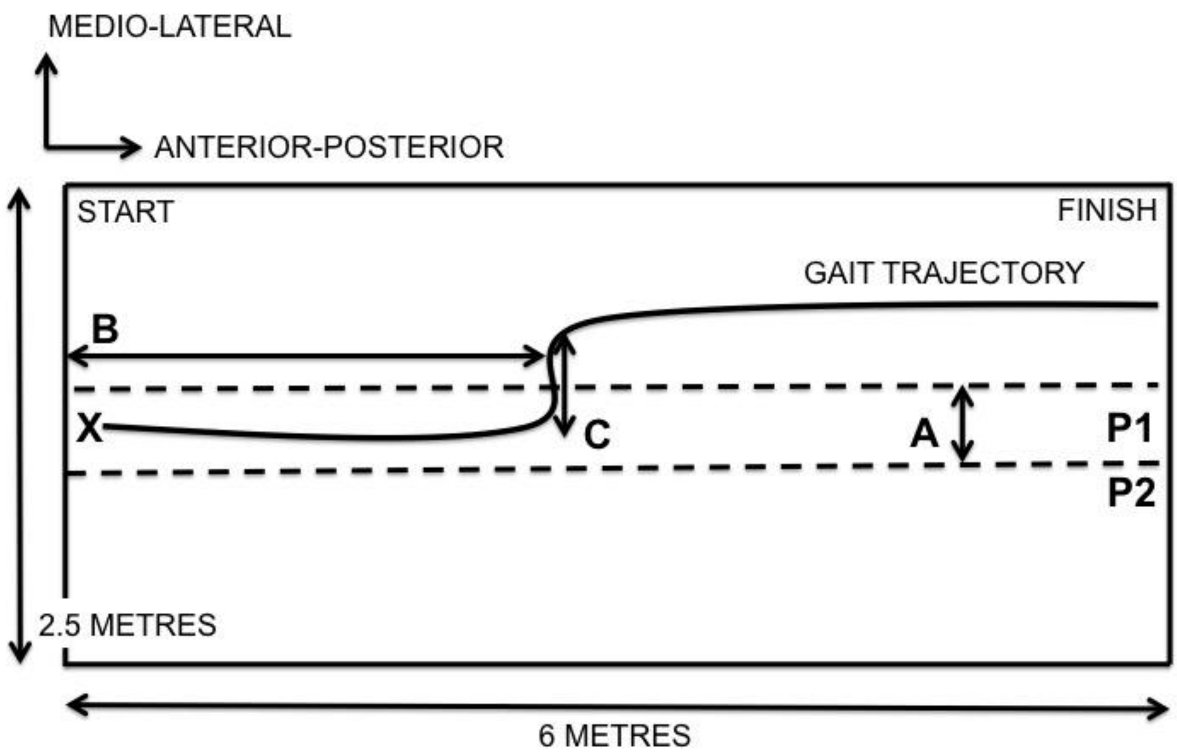

Figure 1: Illustration of the experimental setup and a hypothetical example of how collision avoidance measures were obtained. A = 3 standard deviations of the mean baseline trajectory; B = the distance from the start of the crossing that the peak mediolateral deviation began; C = the magnitude of the peak mediolateral deviation; P1 = Pedestrian 1 start position; P2 = Pedestrian 2 start position; X = Participant start position.

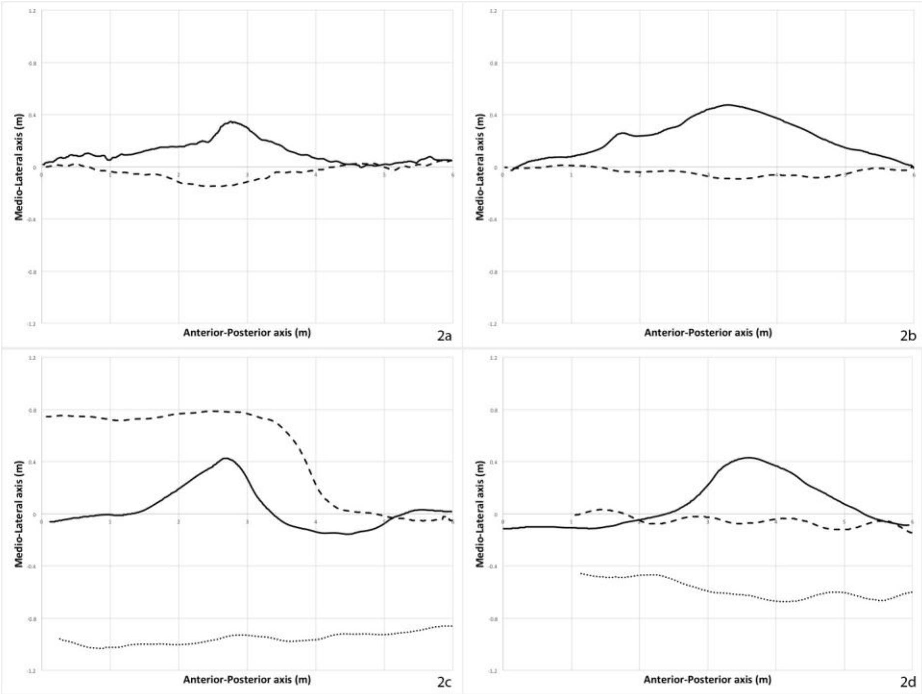

Figure 2: Data from one representative participant and pedestrian trajectories for each experimental condition. In all plots, the participant's trajectory is denoted as a complete line, pedestrian one's trajectory is a dashed line and the trajectory of pedestrian two is denoted as a dotted line. 2A: P condition – participant avoids collision while pedestrian one maintains trajectory. 2B: MP condition – participant avoids collision while pedestrian one maintains trajectory (looking at the phone). 2C: 2P condition – participant and pedestrian one both adopt the same collision avoidance trajectory, and subsequently, the participant changes direction a second time to avoid collision (stop-start behaviour). 2D: 2MP condition – the participant avoids collision while the two pedestrians maintain trajectory (looking at the phone).

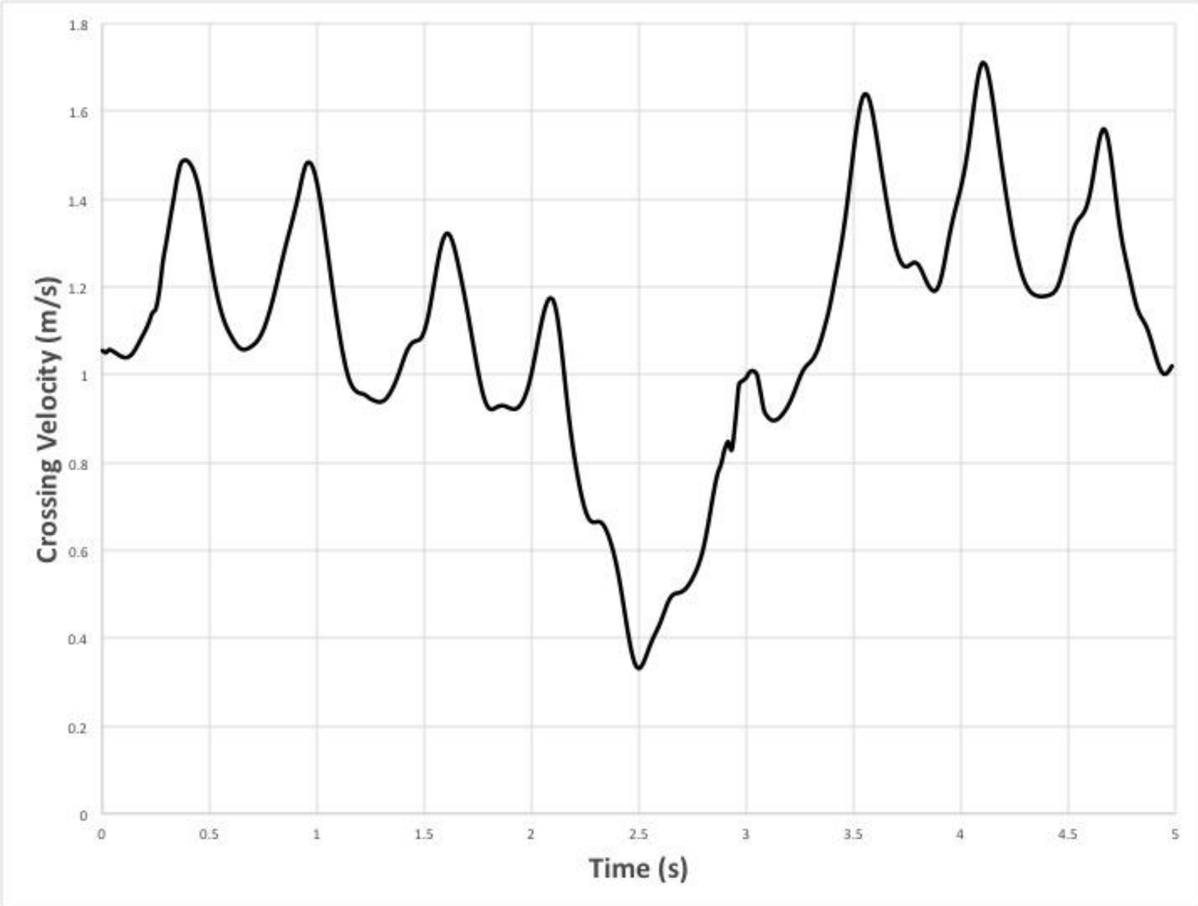

Figure 3: A plot of the anterior-posterior velocity from one representative participant during the 2P condition.

Table 1: Mean participant crossing behaviours (and SD) for each experimental condition.

	Crossing Time (s)	Total Distance Walked (m)	Steady-State Crossing Speed (m/s)	Variability of Steady-State Crossing Speed (m)
Baseline	4.96 (0.47)	6.08 (0.15)	1.31 (0.11)	0.11 (0.01)
P	5.30 (0.63)	6.36 (0.35)	1.26 (0.15)	0.16 (0.07)
MP	5.27 (0.59)	6.46 (0.69)	1.23 (0.13)	0.16 (0.07)
2P	5.74 (0.78)	6.22 (0.12)	1.15 (0.15)	0.22 (0.05)
2MP	5.68 (0.69)	6.28 (0.83)	1.14 (0.16)	0.15 (0.05)

Table 2. Mean participant collision avoidance behaviours (and SD) for each experimental condition.

	A/P separation distance between pedestrian one and participant at the initiation of peak M/L deviation (m)	A/P separation distance between pedestrian two and participant at the initiation of peak M/L deviation (m)	Magnitude of Peak M/L Deviation (m)	Velocity of Peak M/L Deviation (m/s)
P	2.78 (1.50)		0.50 (0.21)	1.01 (0.46)
MP	2.61 (1.54)		0.62 (0.22)	1.08 (0.30)
2P	2.23 (1.00)	2.38 (0.87)	0.80 (1.57)	1.01 (0.25)
2MP	1.46 (0.86)	1.54 (0.88)	0.46 (0.12)	1.03 (0.18)