Gaze behavior during pedestrian interactions in a community environment: a real-world perspective

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Keywords: Gaze behavior, locomotion, community ambulation, obstacle avoidance, pedestrian

Acknowledgements: The authors would like to thank all individuals who participated in this study, as well as Cominar REIT, owner of the Alexis Nihon Mall, for granting our research team access to their shopping mall. This study was funded by the Fonds de la recherche en santé du Québec (FRQS) and The Natural Sciences and Engineering Research Council of Canada (NSERC) - RGPIN-2016-04471. HJ was the recipient of scholarship from the McGill Faculty of Medicine and CRIR.

ABSTRACT

Locomotor adaptations, as required for community walking, relies heavily on the sense of vision. Little is known, however, about gaze behavior during pedestrian interactions while ambulating in the community. Our objective was to characterize gaze behavior while walking in a community environment and interacting with pedestrians of different locations and directions. Twelve healthy young individuals were assessed as they walked in a shopping mall from a pre-set location to a goal located 20m ahead. Eye movements were recorded with a binocular eye-tracker and temporal distance factors were assessed using wearable sensors from a full body motion capture system.

Participants exhibited more numerous and longer gaze episodes on pedestrians (GEP) that were walking in the same direction as themselves vs. those that were in the opposite direction. The relative durations of GEPs, however, showed no significant differences between pedestrians walking in the same vs. opposite direction. Longer durations of GEPs were also observed for centrally located pedestrians compared to those located on either side, but this was the case only for pedestrians that were walking in the same direction as participants. In addition, pedestrians in the centre, and even more so those on the right, were fixated at farther distances compared to those on the left.

Results indicate that healthy young individuals modulate their gaze behavior as a function of the location and direction of pedestrians when ambulating in a community environment. The observed modulation is interpreted as being caused by an interplay between collision risk, pedestrian visibility, presence of leaders and social conventions (right-sided circulation). Present results also establish a benchmark for the quantification of defective visuomotor strategies in individuals with mobility disorders.

INTRODUCTION

In everyday life, mobility activities are generally carried out in complex environments such as a community setting (e.g. street, shopping mall, etc.), and many environmental features influence the intricacy and difficulty of mobility (Patla and Shumway-Cook 1999). This study tackles the requirement related to traffic negotiation, in particular pedestrian circumvention, which is crucial to safely ambulate in a community environment (Patla 2001; Shumway-Cook et al. 2002). The ability to successfully avoid collisions with moving obstacles or pedestrians can be challenging for older adults (Shumway-Cook et al. 2002), and has been shown to be compromised in people with physical disabilities (Darekar et al. 2015; Aravind and Lamontagne 2017; Darekar et al. 2017). This emphasizes the need to further elucidate the underlying control mechanisms.

Locomotor adaptations, as required for community walking, heavily relies on the sense of vision. In fact, other than sound through which some spatial information about the environment can be acquired (Thomas and Shiffrar 2010; Kolarik et al. 2014), vision is the only human sensory modality capable of providing information about distal environmental features (Hollands et al. 2002). Complete visual scanning of the environment requires constant, coordinated head and eye movements in space. The coordination of gaze and body movements has been extensively studied in tasks such as locomotor steering or circumvention of static obstacles. Common across all studies is the observation of a reorientation of gaze in the new travel direction, which precedes the change in walking trajectory (Grasso et al. 1998; Imai et al. 2001; Hollands et al. 2002; Stephenson et al. 2009; Matthis et al. 2018). Analysis of gaze behavior has provided additional insight into the nature of visual information that is used to adapt locomotion, as well as the timing at which such information is gathered. When changing direction while walking, for instance, gaze is consistently reoriented in a feedforward manner towards the final goal (Hollands et al. 2002), a behavior that is consistent with the notion that one uses information about one's position and motion in space in relation to goal location to control locomotor heading (Rushton et al. 1998; Warren et al. 2001). When walking in presence of obstacles as well as during precision stepping tasks, gaze is drawn towards task-relevant features of the environment (e.g., obstacle, targeted foot placement location) (Marigold and Patla 2007; Jovancevic-Misic and Hayhoe 2009; Dominguez-Zamora et al. 2020) while remaining primarily allocated to route planning areas (Dominguez-Zamora et al. 2020). This allocation of gaze, however, was also shown to vary according to task demands to acquire the necessary visual information, for instance when walking on rough vs. flat terrains (Matthis et al. 2018).

While the above-mentioned studies provided insight into the control of gaze behavior and the visual information guiding locomotion, there is a paucity of literature on gaze behavior related to the circumvention of moving obstacles and even more so for pedestrian interactions. Different control parameters have been proposed to specifically explain how obstacle circumvention can be achieved in a variety of contexts. It is hypothesized that such control parameters are appraised by the nervous system through visual information and help establish the spatial or temporal relationship between the participant and a potential obstacle. Commonly investigated parameters include personal space (Gerin-Lajoie et al. 2005) (and variations such as obstacle clearance (Darekar et al. 2015) or minimum distance (Souza Silva et al. 2018)), obstacle bearing angle (Fajen 2013), time to collision (TCC) (Cinelli and Patla 2007; Pfaff and Cinelli 2018) and minimum predicted distance (MPD) or minimum distance at closest approach (Olivier et al. 2012; Lynch et al. 2020). For instance, in a context of mutual interaction, pedestrians would adapt their motions only when the estimated value of MPD is low (<1m), implying a risk of collision (Olivier et al. 2012). In a preliminary study on eye and body movement coordination during pedestrian interactions while walking in a virtual environment, our group showed that eye and gaze horizontal reorientation precedes changes in walking trajectory, possibly to assist with the localization of the approaching pedestrian and planning of future walking trajectory (Boulanger and Lamontagne 2017). As for studies that have actually examined the distribution of gaze behavior during pedestrian interactions, they indicate that individuals generally look more frequently and/or for longer durations at the environment (e.g. wall, ground surface, etc.) than at pedestrians (Jovancevic et al. 2006; Kitazawa and Fujiyama 2010; Berton et al. 2019; Hessels et al. 2020), although such a pattern could depend on characteristics of the environment (e.g. presence of hazards (Kitazawa and Fujiyama 2010)) and the number of pedestrians present in the environment (Hessels et al. 2020). Fixation on pedestrians would be primarily located in a visual field of 45°, with more fixation on centrally located pedestrians (Kitazawa and Fujiyama 2010). In addition, gaze behavior was found to change depending on the risk of collision, where interferers posing a risk of collision are looked at more frequently as compared to the non-risky interferers (Jovancevic-Misic and Hayhoe 2009; Meerhoff et al. 2018).

There also exists evidence in the literature that collision avoidance strategies are modulated as a function of the location/direction of approach of obstacles or pedestrians present in the environment (Huber et al. 2014; Buhler and Lamontagne 2018; Meerhoff et al. 2018; Souza Silva et al. 2018). The extent to which gaze behavior is modified accordingly, however, remains unclear. Furthermore, existing studies have described gaze behavior and various gait adaptions in a controlled laboratory or a virtual setting by regulating the density and motion (direction, speed) of the obstacles. In a community setting, however, the density and direction of the dynamic obstacles is constantly changing, with pedestrians coming and going from and towards different locations. Therefore, results collected in a controlled setting may fail to represent everyday life demands, leaving us with a gap in knowledge on actual visuomotor control requirements for successful pedestrian interactions in the community setting. Current research is also yet to come up with metrics for quantifying gaze behavior in a constantly changing environment, as experienced in the community.

In this study, we used a real-world perspective to examine gaze behavior as healthy participants ambulated in a community environment (shopping mall). This real-world perspective had the advantage of replicating a real-world scenario and providing the participants with sensory stimulation, comfort, convenience, and social interactions just as one would normally have in everyday life. The shopping mall as a location incorporates the specificity and diversity of contextual demands typical of a community environment, including pedestrians of different characteristic in different directions and at different speeds, while paying different levels of attention to their environment. The mall also offers multiple and changing sensory stimuli (e.g., visual, auditory) and a natural setting where participants and other mall users interact in real time, all this being difficult to replicate in a laboratory setting.

As this study represents a first attempt, to our knowledge, to measure participants' gaze behavior while walking and interacting with pedestrians in a shopping mall as a representation of a community setting, it focused on the evaluation and development of metrics to quantify gaze behavior during community ambulation. Therefore, our specific objective was to characterize gaze behavior of healthy young adults during obstacle circumvention in a community environment. We hypothesized that despite the complexity of a community environment, healthy young adults would exhibit gaze behaviors that are modulated as a function of obstacle characteristics such as their location in space (left, center, right) and direction of progression (same or opposite) in relation to the participants. This modulation would translate by increased durations and possibly more frequent gaze episodes for pedestrians that are walking in the opposite direction and that are located along the midline of participants' field of view, as these may be perceived by the observer at a higher risk of causing a collision.

METHODS

Study design

This is a descriptive cross-sectional, exploratory study where the participants' ability to walk towards a pre-determined location in the mall was examined in one session, lasting an hour.

Participants

A convenience sample of twelve right-handed healthy young adults between the ages of 18 to 29 years were recruited from McGill University, Montreal (Canada) while maintaining a male to female ratio of 1. On average, participants were aged 27 ± 2.6 years (mean ± 1SD) and presented a weight of 65.6 ± 6.8 kg and height of 165 ± 7 cm. Right-handed participants with scores equal to +40 or more were recruited as per the Edinburgh Handedness Inventory (Oldfield 1971), since handedness was shown to have an influence on visual-spatial and navigational abilities (Reio et al. 2004; Voyer and Voyer 2015), and since right handers represent 80% to 90% of the population (Bhushan and Khan 2006; Voyer and Voyer 2015). Participants presented normal or corrected-to-normal visual acuity, with scores equal or above 20/20 (LogMAR of 0) as measured by the EDTRS visual acuity chart (Kaiser 2009). Also, to control for the impact of cultural factors, we only recruited participants from countries with a right-side traffic rule. Participants were excluded if they presented any condition interfering with locomotion (e.g., orthopedic, rheumatologic or neurological), lower limb or back pain, as well as any visual condition interfering with visual perception (e.g., strabismus, color blindness, etc.). The study was approved by the Ethics Committee of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR) and all participants provided their informed written consent.

Experimental set-up and procedure

Data collection took place at the Alexis Nihon Mall located in downtown Montreal. Participants were assessed while walking and wearing a portable eye tracking system and wearable movement sensors. More specifically, the Tobii system (Tobii Pro Glasses 2) was used to record participants' eye in head movements. The Tobii system is a lightweight discrete glasses-mounted eye tracker with 90° viewing angle, wirelessly connected to a recording tablet. The head unit also comprised of a forward-mounted (scene) camera allowing the recording of point of gaze on the environment. Gaze was measured from both eyes at a sampling frequency of 25 Hz and resolution of 1920 x 1080 pixels, for each eye.

An APDM motion capture system (Ambulatory Parkinson's Disease Monitoring) that comprised of fifteen lightweight inertial sensors (gyroscope, magnetometer and accelerometer) positioned on the head, trunk, pelvis and bilaterally on the arms, hands, legs and feet, was used to measure body kinematics. The APDM system was developed and validated for the measurement of locomotion and various gait parameters (Washabaugh et al. 2017). It also has a wireless range from 20-50 meters and allows recording at a sampling rate at 128 Hz (APDM). Brief audio signals were emitted by the APDM system at the beginning and end of the recording. These signals were recorded by the Tobii eye tracking system and later used for an offline synchronization of data recorded with the two systems.

Participants were assessed in a straight-line corridor (30 m in length and 8 meters in width) in the mall, leading to a subway entrance so as to ensure a continuous flow of pedestrians

(Figure 1). They were assessed from a pre-set starting point (located in the middle of the hallway, at 10 m) to a final goal which was the sign for the subway entrance. These two pre-set locations were 20 m apart and ensured a clear visibility of the end goal from the starting position. Participants were instructed to walk at their comfortable speed for a community environment. A member of the team helped them locate and visit the area prior to data collection. Participants performed 5 trials and were allowed to rest as often as needed throughout the evaluation.

Data analysis

The combination of scene camera and eye-tracking sensor allowed to record the point where the eyes were directed along the horizontal and vertical planes with respect to the environment, as viewed on the video file. Further analyses of gaze behavior were carried out using a custom-made software developed by co-author WC (Cybis 2019).

The primary outcome measure was the relative (%) duration of gaze episode on pedestrian (GEP). Secondary outcomes included the number of GEPs as well as the total duration of all GEPs and mean distance at onset of all GEPs. In addition, the absolute duration and distance at onset were quantified for the first GEP on a given pedestrian. Instantaneous walking speed, as well as temporal distance parameters such as step length, step width, and cadence were also examined.

The procedure to identify the GEPs and derived outcomes goes as follow. Pedestrians present in the camera's field of view were first identified and manually marked with a rectangle for each video frame, as indicated in Figure 2A. *Pedestrian visibility duration* was defined as the time during which a given pedestrian was visible to the participant during the trial. As soon as the point of gaze moved over any pedestrian (rectangle), it would commence a GEP, which lasted as long as the point of gaze was located within that box. The *absolute duration of GEP* was defined as the length of time during which a pedestrian was looked at by a participant. A GEP could have a minimum duration of one time frame (40 ms) to several time frames. Presence of a blink would result in two successive GEPs. Hence, pedestrians in a particular trial could have one or many recorded GEPs of varying lengths as shown in Figure 2B. For each pedestrian looked at, the *number of GEPs* was noted, and the *total absolute duration of GEP* was calculated by adding the absolute duration of all GEPs for that pedestrian. The *total relative duration of GEPs* was then obtained by dividing the total absolute duration of all GEPs for a given pedestrian by its total visibility duration in the walking trial, expressed as a percentage. The latter approach allowed to control for differences in the time taken by each participant to walk the pre-set distance and also for the duration for which pedestrians were present in the visual field during the trial.

The distance (m) at onset of GEP, which corresponds to the horizontal distance between the participant and the bottom of the marking rectangle surrounding the pedestrian being looked at, was determined by graphics processing and computational analysis of the image in the video recorded by the eye-tracking scene camera. The computing strategy is based on projective transformation of bi-dimensional images, as well as on Pythagorean laws (Figure 2C). The projective transformation depends on the image vanishing point, which can be determined based on two or more edges in the environment in front of the participant that are parallel (Andersen 2008). In the image recorded by the scene camera, these parallel edges appear as converging lines and their intersection give the image vanishing point. The measured error for distances up to 12m is estimated at 11.4% (Cybis 2019). The *mean distance at onset of GEPs* for a given pedestrian was then calculated by averaging the distance at onset of all its GEPs. Both the *absolute duration* and *distance at onset for the first GEP* were also noted for each pedestrian being looked at in order to gain insight into the participant's initial visual scanning of the environment to locate pedestrians with possible risks of collision.

Gaze behavior outcomes described above were further examined in relation to the direction of walking and relative position of pedestrians with respect to the participant. More specifically, direction of pedestrian approach was categorized as being either in same or opposite direction in relation to the walking displacement of the participant. This classification was done with the prospect of associating risk to the direction of pedestrian progression (e.g., a greater risk of collision is assumed for pedestrians coming from the opposite direction). The pedestrians' position with respect to the participant was also estimated using gaze orientation at GEP. The latter was obtained by adding the horizontal eye angle recorded with the Tobii system to the head on trunk angles computed with the APDM system during the GEP, after down-sampling APDM's data at 25Hz to match the sampling frequency of the Tobii system. Based on gaze orientation, obstacles were classified as being located on the left (<-5 deg), center (-5 to 5 deg) and right (>5 deg) visual field of the participant. A central visual field of 10 deg was chosen based on previous literature, as this range is assumed to include foveal and para foveal vision (Wandell 1995; Strasburger et al. 2011). Video images from the scene camera were also scrutinized to identify whether strollers, wheelchairs users, carts, any pedestrian with a walking aid or any pedestrian running were present in the field of view of the participants, as this could potentially influence outcomes measures of gaze behavior.

Statistical analysis

Generalized estimation equations (GEEs) were used to analyze the outcomes characterizing participants' gaze behavior, including the number of GEPs, total relative duration GEPs, total absolute duration of all GEPs, mean distance at onset of GEPs, as well as absolute duration of first GEP and distance at onset of first GEP. The model comprised of 2 within-subject factors including pedestrian location in the visual field (left, center or right) and direction of pedestrian approach (same or opposite). Significant main or interaction effects were further elaborated by post-hoc analyses using pairwise t-test comparisons with Bonferroni adjustments. All statistical analyses were performed using SPSS v.24 and the level of significance was set to $p < 0.05$.

RESULTS

Out of the total of 12 participants, none experienced collisions during the walking trials. No strollers, wheelchair users, carts, people walking with a walking aid or people running were present during the walking trials. In total, there were 373 pedestrians looked at by all participants combined across trials. There were only 14 non-obstructive static objects looked at across all trials, which included posters and signs. As those signs were not directly located on the walking path and did not impose a risk of collision for the participant, they were excluded from the analyses. Thus, all the comparisons between the outcomes were carried out while considering pedestrians only. At the beginning of all trials (first frame), the number of seen (marked and analyzed) and unseen pedestrians (not looked at throughout the trial) was examined and found to be similar between the left and the right visual field of participants, as illustrated in Figure 3. The average number of pedestrians present in each trial were 16.5 (range from 4-29).

Results for the first GEP

Despite this equal distribution of pedestrians in the environment, the distribution of first GEPs, that is the distribution of pedestrians' location when they were first gazed at by participants, was asymmetrical and skewed towards the right side (Figure 4). The analysis of group results revealed a significant main effect of pedestrian location for the distance at onset of the first GEP (X^2 (2, 373) = 6.06, p = 0.048), with larger distances being observed for pedestrians located centrally (mean difference = 1.77 m, p = 0.004) and on the right side (mean difference = 1.85 m, p = 0.00) compared to those located on the left (Figure 5A). There was no effect of pedestrians' direction of walking or interaction effect of pedestrian location X direction on distance at onset of first GEP. In addition, neither the pedestrian location nor the direction of walking of pedestrian approach was found to affect the absolute duration of first GEP (Figure 5B).

Results for total GEPs

The distributions of GEP-related outcomes while considering all GEPs, calculated for all 12 participants, are illustrated in Figure 6. It can be seen that the distributions roughly follow a gaussian pattern. For the number of GEPs (Figure 6A), pedestrians coming from the opposite direction were looked at less frequently compared to pedestrians walking in the same direction who were looked at more frequently. Participants also showed a wide range of distances at onset of GEPs that reached a maximal distance of ≈24m, while maintaining a minimum distance of 2m from the pedestrians (Figure 6B). Furthermore, while pedestrians walking in the opposite direction appeared to be looked at for a shorter time as compared to those walking in the same direction as participants (Figure 6C), the relative duration of all GEPs (in percentage) for the two directions of walking was roughly similar (Figure 6D).

Group results for the different GEP-related outcomes, while considering all GEPs in the walking trials, are illustrated for the different directions of walking and locations in the field of vision of participants in Figure 7, along with statistically significant comparisons. In terms of the number of GEPs, the GEE analysis revealed significant main effects of direction of pedestrian approach (X^2 (1, 373) = 9.86, p = 0.002), where significantly higher number of GEPs were observed on the pedestrians walking in the same direction as compared to those walking in the opposite direction. No main effect of pedestrian location or interaction effects were observed (Figure 7A).

For the mean distance at onset of GEPs, a significant main effect of pedestrian location (X^2 (2, 373) = 6.01, p = 0.005) was observed, with significantly larger distances being observed when looking at pedestrians located on the right as compared to the center (mean difference = 1.001 m, p = 0.01) and the left (mean difference = 2.24 m, p = 0.00). No effects in terms of direction of walking or interaction effects were observed (Figure 7B).

The total absolute duration of GEPs significantly varied as a function of pedestrian location (X^2 (2, 373) = 8.58, p = 0.014) and direction of walking (X^2 (1, 373) = 7.00, p = 0.008). It also displayed a significant interaction effect of pedestrian location X direction (X^2 (2, 373) = 10.57, p = 0.005). Post-hoc analyses revealed significantly longer total duration of all GEPs on the pedestrians walking in the same vs. opposite direction for the left (p = 0.033) and center (p = 0.00) pedestrian locations, but not for pedestrians located on the right (p = 0.093). In addition, the total duration of all GEPs was longer for pedestrians walking in the same direction when they were centrally located vs. those located on the left (p = 0.014) or right (p = 0.00) (Figure 7C). There were no significant effects of direction of walking, pedestrian location or interactions effects observed for total relative duration of GEPs (Figure 7D).

DISCUSSION

This study is the first, to our knowledge, that used an uncontrolled, real world perspective to characterize gaze behavior while ambulating in a shopping mall and performing complex locomotor tasks, such as avoiding collisions with multiple pedestrians walking in different directions and from different locations. While doing so, we also aimed to identify metrics of gaze behavior in a constantly changing environment, as experienced in a real-world setting as opposed to a laboratory setting where experimental conditions are controlled. Our results indicate that gaze behavior is modulated as a function of the location and direction of pedestrians in the environment, with some behavioral features that present with an asymmetrical spatial distribution. Potential mechanisms and implications are discussed below.

Modulation as a function of pedestrian location

A first interesting finding of this study is the observation of longer GEP durations for pedestrians located in the center, which was accompanied by a trend for more frequent GEPs for centrally located pedestrians vs. pedestrians located either on the left or right. Such finding is in agreement with earlier studies carried out in controlled laboratory environments or virtual reality environments, which reported a distribution of gaze centered around the midline (Kitazawa and Fujiyama 2010; Berton et al. 2020). In these studies, such a distribution was interpreted as an increase in visual attention devoted to riskier pedestrians, i.e., those located on a collision path. Similarly, avoidance strategies were shown to differ for head-on vs. diagonal/orthogonal approaches, as the former allow no alternatives other than a trajectory change to avoid a collision (as opposed to changing speed or stopping which can be used for diagonal/orthogonal approaches) (Basili et al. 2013; Huber et al. 2014; Souza Silva et al. 2018). In fact, the adoption of earlier onsets of avoidance strategy and larger clearances for obstacles approaching from head-on was proposed to be a direct consequence of the increased collision risk entailed by this condition (Buhler and Lamontagne 2018). It could also be argued that the centered gaze position observed in the present study is associated with a tendency to maintain the eyeballs centered within their orbit (Zambarbieri et al. 1995; Fuller 1996). It is important to note, however, that gaze and not eye-in-head data were used here to identify pedestrian location in relation to participants. Most importantly, a previous study on gaze behavior in natural indoor and outdoor environments reported a bias toward centered gaze, as observed here, but also off-centre peaks in eye-in-head fixation, which argues against a preference for centering the eyes in their orbit, as least when tested in unrestrained natural environments (Schumann et al. 2008), as done here.

While we agree that the perceived risk of collision is an important factor and have formulated our main hypothesis for this study accordingly, we also made additional observations which suggest that other factors are at play. First, longer GEPs were indeed observed for centrally located pedestrians but for pedestrians walking in the same direction and not for those walking in the opposite direction, even though the former should pose less risk of collision compared to the latter. Second, once the duration of GEPs was expressed in percentage, that is once we normalized for the time that pedestrians were present in the field of view of the observers, the relative duration of GEPs became similar between centrally located pedestrians and those located on the side. Previous research indicates that when two individuals walk together, locomotion is modulated as a result of a mutual interaction between the two walkers, for instance to regulate the distance between them as they walk (Ducourant et al. 2005). It was further observed that a follower unintentionally synchronizes its walking pattern to that of a leader (Zivotofsky and Hausdorff 2007; Zivotofsky et al. 2012), a phenomenon that is driven through different sensory modalities such vision, audition and touch (Zivotofsky et al. 2012). The latter studies have not examined gaze behavior and we have not examined the gait behavior of our participants in relation to that of other pedestrians present in the environment. Nevertheless, we suggest that a similar phenomenon of synchronization also applies, whereby the visual attention of followers is anchored to the leaders (here individuals located ahead and going in the same direction), allowing them to unintentionally mimic their trajectory and speed to maximize passability (i.e., obstacle free path) and maintain safe interpersonal distances, hence providing a simple solution to a complex problem (i.e., finding the ideal route amongst multiple options). In return, such visual anchoring towards centrally located pedestrians walking in the same direction and the possible adoption of similar navigation strategies contribute to maintaining the leaders in the central field of vision.

Other observations of this study which speak to a modulation of gaze behavior as a function of pedestrian location is the fact that not only centrally located pedestrians, but also pedestrians on the right, were looked at from further distances compared to those located on the left. In fact, when considering total GEPs, this distance at onset of fixation for right-sided pedestrians even exceeded that observed for centrally located pedestrians. Importantly, this was observed despite of an equal distribution of pedestrians present in the right vs. left visual field of participants. Reasons for this rightward bias are not entirely clear, but we suggest it could be explained, at least in part, by social convention. In North America, where this study was conducted, car circulation obeys a right-side traffic rule, which translates by individuals preferentially implementing a right-sided circumvention strategy when exposed to another pedestrian approaching from head-on (Lucas 2018; Souza Silva et al. 2018). Work from our laboratory carried out using virtual pedestrians has also shown that one’s gaze is rapidly and transiently reoriented in the direction of circumvention prior to initiating a trajectory change, suggesting that gaze reorientation assists with the feedforward control of the future walking trajectory (Boulanger and Lamontagne 2017; Lamontagne et al. 2019). In the present study, an earlier identification of pedestrians located on the right (i.e. at a further distance) may have served the purpose of planning for a future travel path that complies with the right-side traffic rule and which is also collision free.

Present findings also align with a recent meta-analysis on the allocation of spatial attention in healthy adults which shows that under situations of low to moderate alertness, a bias of attention towards stimuli located on the right hemispace is present (Chandrakumar et al. 2019). The authors also demonstrated, however, that handedness modifies the relationship between spatial attention and alertness. Gérin-Lajoie et. al (2008) further postulated that handedness possibly influences the distribution of one's personal space when circumventing an obstacle, due to faster processing speed of visuospatial information on the dominant side (Gérin-Lajoie et al. 2008). Thus, it cannot be excluded that the recruitment of exclusively right-handed participants in the present study may have further contributed to the earlier detection of pedestrians located on the right. Of note, however, this earlier detection of pedestrians on the right side was not accompanied by longer durations of GEP. We suggest that distances at the onset of GEPs reflect a process of orientation of attention that is subjected to this rightward bias, as opposed to the duration of GEPs which could rather reflect the visual monitoring of pedestrian displacement in space.

Gaze is modulated as a function of pedestrian direction

Based on the premise that risky pedestrians are looked at more frequently and for longer durations than non-risky pedestrians (Jovancevic-Misic and Hayhoe 2009; Meerhoff et al. 2018), we initially hypothesized that pedestrians coming from the opposite direction, as they potentially pose a greater risk of collision, would receive enhanced visual attention. While such hypothesis appears at first not supported by present findings, we suggest that the observed pattern of modulation according to pedestrian direction is a function of a combination of factors which goes beyond a binary classification of pedestrians according to their direction of walking in relation to that of the participant. First, and as mentioned earlier, pedestrians walking in the opposite direction were present for a shorter duration in the line of sight of individuals, explaining why overall they were looked at less frequently and for shorter absolute durations compared to those walking in the same direction as participants. However, when considering outcome variables that are less sensitive to the duration of exposure, such as the duration of the first GEP or the total relative duration of GEPs, consistent trends (yet not statistically significant) for longer durations of GEP on pedestrians walking in the opposite vs. same direction were observed. Second, collision avoidance during pedestrian interactions were shown to result from a mutual interaction between those involved (Huber et al. 2014). In such perspective, it might be easier to predict mutual intentions and trajectories when pedestrians are walking in the opposite direction and see each other, compared to when they are walking in the same direction where a sudden stop or change in the trajectory of the pedestrian located ahead could cause a collision. For that reason, and for the purpose of travel path planning, the attentional load devoted to pedestrians walking in the same direction, especially if they are in close vicinity, could be greater than we initially hypothesized. Third, Jovancevic et al. (2006) have shown that when participants are on a collision course with a virtual pedestrian, the enhanced visual attention allocated to that pedestrian completely vanishes when participants are instructed to follow a 'leader' (Jovancevic et al. 2006). Likewise, in the present study, pedestrians walking in the same direction as participants might have acted as leaders and may have reduced the visual attention devoted to pedestrians approaching from the opposite direction, although possibly to a lesser extent than in Jovancevic et al. (2006) as no specific instructions to follow a leader were given. Finally, upon further examination of the graphs related to the duration of first GEP and total relative duration of GEPs (Figure 5B and 7D), a large variability can be noticed, which suggests the concurrent presence of different behaviors.

A possible explanation for such variability is that the 'opposite walking direction', as analyzed here, did not imply that an approaching pedestrian necessarily lied on a collision course with the participant. Instead, it is its relative displacement in time and space with respect to the observer that better predicts a collision (Olivier et al. 2012; Meerhoff et al. 2018; Pfaff and Cinelli 2018). Similarly, the 'same walking direction' condition is not risk free of in terms of collision, as a speed differential between two pedestrians, due to the leader slowing down and/or the follower speeding up, would cause the distance between them to reduce and could eventually pose a risk of collision. Thus, classifying pedestrians as walking in the same vs. opposite direction does not capture the entirety of the collision risk. The present analyses represent a first step towards the understanding of factors modulating gaze behavior in the context of pedestrian interactions in a natural environment. In the future, the use indoor position systems (e.g., wi-fi beacons) and/or computer vision techniques that enable the measurement of relative positions of pedestrians (i.e., interpersonal distances) and their fluctuations in time will allow a deeper understanding of factors underpinning pedestrian interactions in complex community environments.

Pedestrians are looked at a minimum distance of 2 m

Results also revealed that pedestrians present in the field of view of participants were looked at minimum distances of about 2m and up to a distance of nearly 24m, with average distances at onset of GEP that ranged between 4m and 8m. The minimum distance of GEP of 2m observed here is close to the threshold of 1.5m previously identified in a laboratory environment (Kitazawa and Fujiyama 2010). In the latter study, closer proximity between pedestrians and thus slightly smaller distances of GEP may have been experienced due to environmental constraints (a 3.6m wide walking platform with rails on both sides) that provided limited space and enhanced the predictability of pedestrian movements (mainly approaching along a straight line from the front or behind). In a study on gaze behavior during obstacle crossing, Patla and Vickers (1997) also showed that the obstacle was looked at 1 to 2 steps prior to stepping over it, and not during the actual avoidance (Patla and Vickers 1997). Similarly, in the present study, this minimal distance of 2m might have been implemented to allow sufficient time and distance to control, in a feedforward manner, a successful circumvention strategy. As for the maximal distance of GEP in the present study which sometimes extended slightly beyond the 20m length of the shopping mall aisle leading to the subway station, it indicated that some participants were occasionally looking at pedestrians located beyond the end goal. It is reasonable to assume that such maximal distance can be influenced by the size of the environment, such that individuals ambulating in a large open space (for instance a park or football field) could be looking at people at even further distances.

Kitazawa and Fujiyama (2010) also reported that pedestrians approaching from the opposite direction were fixated on at a further distance (3.97m) compared to pedestrians walking in the same direction as participants (1.90m) (Kitazawa and Fujiyama 2010), but no such differences were observed in this present study. Again, while this apparent discrepancy could be attributed to differences in the configuration of the environments between the two studies, we also suggest that this result in particular from their study be interpreted with caution given the small number of observations (i.e., 3 for opposite vs. 24 for same direction).

Limitations

The main limitations of this study include the lack of quantification of gaze episodes on environmental features (e.g., the floor, ceiling, shops, etc.), the absence of measurement of avoidance strategy which could have provided further insight into the observed gaze behavior, and lack of continuous data on the position of participants in relation to surrounding pedestrians which would have allowed an analysis of instantaneous gaze behavior modulation as a function of variations in interpersonal distances. Also, we cannot exclude the possibility that pedestrians located in the periphery may have be monitored through peripheral vision (Jovancevic et al. 2006), which is a strategy that is not reflected in the actual GEP data. The authors further acknowledge the advantages and limitations inherent to the real-world testing. For instance, while this approach yields findings that are representative of what is observed when ambulating in the community, it also makes it more challenging from a measurement/technical perspective (e.g., to track people's position in space and in relation to one another). In addition, the richness of the environment (shops, noise, etc.) and diversity of the exposure of interest (pedestrians of different gender, size, race and age approaching at different speeds and from different directions) likely introduced greater variability in the results. While some have suggested that the impact of situational factors (relative position, speed and heading of the pedestrians) on pedestrian interactions prevails over that of personal factors such as gender and height (Knorr et al. 2016), others have reported that elements such as body size could influence the collision avoidance behavior (Bourgaize et al. 2020). Through the diversity it entails, the real-world approach employed in this study has enabled the identification of gaze behavior metrics which show a robust pattern of modulation as a function of situational factors such as the location and direction of approach of pedestrians. Such metrics can be used to quantify pedestrian interactions in a variety of settings, as well as to understand, from a visuomotor perspective, deficits in community ambulation presented by older adults and individuals with physical disability (e.g., stroke).

CONCLUSION

This study used a real-world perspective to characterize gaze behavior in a complex, community environment represented by the indoor environment of an urban shopping mall. Despite of the inherent diversity of individuals present in this environment and in spite their behaviors as pedestrians, robust patterns of modulation of gaze behavior as a function of pedestrian location and direction were identified. Some gaze outcomes further showed an asymmetrical distribution that suggests a prioritization of visual attention towards pedestrians located on the right and center as compared to the left. The observed modulation of gaze behavior is interpreted as being not only dictated by the actual risk of collision, but also by other factors such as pedestrian overall visibility, the presence of leaders in the environments, and social conventions. While adding to our understanding of gaze behavior during community ambulation, the present study also established a baseline measures for the quantification of defective visuomotor strategies in individuals with mobility disorders.

DECLARATIONS

Funding: This study was funded by the Fonds de la recherche en santé du Québec (FRQS) and The Natural Sciences and Engineering Research Council of Canada (NSERC) - RGPIN-2016-04471. HJ was the recipient of scholarship from the McGill Faculty of Medicine and CRIR.

Conflicts of interest/Competing interests: The authors have no conflict of interest/competing interests to declare.

Availability of data and material: Data presented in the context of this study cannot be made available, as this option was not included in the consent forms signed by participants. As per these consent forms, the data is to be destroyed by the research team 5 years after the end of the project.

Code availability: Non applicable.

Authors' contributions: HJ was responsible for data collection, analysis and generating the draft of the manuscript and figures. AL and WC also contributed to data collection and analysis. All authors contributed to the study design and edited the manuscript.

Figure captions

Figure 1. Bird's eye view of the evaluation setting in the mall.

Figure 2. (A) Representation of one of the video frames from a walking trial. Pedestrians present in the hallway were labeled offline for every video frame using boxes. A given box turns green when the point of gaze moves over the region defined by its contour, and otherwise remains red. The number next to the green box (5.15) represents the distance at onset of gaze episode on pedestrian (GEP). (B) Two-dimensional graph of the shifts in the point of gaze of a participant, for 2000 ms during a walking trial. Each point (grey and colored) represents a GEP, while the clusters are colored to illustrate all the GEPs for a given pedestrian. (C) Distance determination framework based on the viewer' eyes height and the angles his/her eyes form with the vanishing point (Alpha) and the object's ground position (Beta).

Figure 3. Number of pedestrians, seen and unseen, that were present in the visual field of all participants across all trials. Note the equal distribution of pedestrians present on the right and the left visual fields of the participants.

Figure 4. Distribution of pedestrians across the horizontal gaze angles at the onset of first GEPs, that is when they were first looked at. Note the normal distribution curve with a rightward skew for both the pedestrians walking in same and opposite directions, which indicates that a larger number of GEP were observed on the right vs. left visual field.

Figure 5. Group mean ± 1SD values for distance at onset of first GEP (A) and absolute duration of first GEP (B). Statistically significant effects are indicated, as applicable.

Likewise, post- hoc comparisons that were statistically significant are also illustrated. * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

Figure 6. Scatter plots where all 406 pedestrians are plotted across all 12 participants depicting the number of GEPs (A), mean distance at onset of GEPs (B), total absolute duration of GEPs (C) and total relative duration of GEPs (D) as a function of horizontal gaze angle. The two vertical lines represent the ±5° boundaries delimiting the central visual field.

Figure 7. Group mean ± 1SD values for the number of GEPs (A), mean distance at onset of GEPs (B), total relative duration of GEPs (C) and total absolute duration of GEPs (D). Values are represented separately for pedestrians walking in the opposite vs. same direction, as well as for the left, center and right visual fields. Statistically significant effects are indicated, as applicable. Likewise, post- hoc comparisons that were statistically significant are also illustrated. * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

References

Andersen K (2008) The geometry of an art: the history of the mathematical theory of perspective from Alberti to Monge. Springer Science & Business Media

APDM Wearable Sensors - APDM Wearable Technologies Manual. 2018

Aravind G, Lamontagne A (2017) Dual tasking negatively impacts obstacle avoidance abilities in post-stroke individuals with visuospatial neglect: Task complexity matters! Restor Neurol Neurosci 35:423-436 doi: 10.3233/RNN-160709

Basili P, Sağlam M, Kruse T, Huber M, Kirsch A, Glasauer S (2013) Strategies of locomotor collision avoidance. Gait Posture 37:385-390 doi: 10.1016/j.gaitpost.2012.08.003

Berton F, Hoyet L, Olivier A-H, Bruneau J, Le Meur O, Pettré J (2020) Eye-Gaze Activity in Crowds: Impact of Virtual Reality and Density. In: 2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR). IEEE, pp 322-331

Berton F, Olivier AH, Bruneau J, Hoyet L, Pettre J (2019) Studying Gaze Behaviour during Collision Avoidance with a Virtual Walker: Influence of the Virtual Reality Setup. In: 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR). IEEE, Osaka, Japan, pp 717-725

Bhushan B, Khan SM (2006) Laterality and accident proneness: a study of locomotive drivers. Laterality 11:395-404

Boulanger M, Lamontagne A (2017) Eye-head coordination during overground locomotion and avoidance of virtual pedestrians. In: 2017 International Conference on Virtual Rehabilitation (ICVR). IEEE, pp 1-2

Bourgaize SM, McFadyen BJ, Cinelli ME (2020) Collision avoidance behaviours when circumventing people of different sizes in various positions and locations. Journal of Motor Behavior:1-10

Buhler MA, Lamontagne A (2018) Circumvention of Pedestrians While Walking in Virtual and Physical Environments. IEEE Trans Neural Syst Rehabil Eng 26:1813-1822 doi: 10.1109/tnsre.2018.2865907

Chandrakumar D, Keage HA, Gutteridge D, Dorrian J, Banks S, Loetscher T (2019) Interactions between spatial attention and alertness in healthy adults: a meta-analysis. Cortex

Cinelli ME, Patla AE (2007) Travel path conditions dictate the manner in which individuals avoid collisions. Gait & posture 26:186-193

Cybis W (2019) Clair-mobility in the mall (v1.5). [Ocular movements analyser]. In, Longueuil, Centre de recherche CRIR – site INLB, CISSS de la Montérégie-Centre

Darekar A, Lamontagne A, Fung J (2015) Dynamic clearance measure to evaluate locomotor and perceptuo-motor strategies used for obstacle circumvention in a virtual environment. Hum Mov Sci 40:359-371 doi: 10.1016/j.humov.2015.01.010

Darekar A, Lamontagne A, Fung J (2017) Virtual environments to assess perceptuomotor factors that influence obstacle circumvention in the post-stroke population. In: 2017 International Conference on Virtual Rehabilitation (ICVR), pp 1-6

Dominguez-Zamora FJ, Lajoie K, Miller AB, Marigold DS (2020) Age-related changes in gaze sampling strategies during obstacle navigation. Gait Posture 76:252-258 doi: 10.1016/j.gaitpost.2019.11.015

Ducourant T, Vieilledent S, Kerlirzin Y, Berthoz A (2005) Timing and distance characteristics of interpersonal coordination during locomotion. Neurosci Lett 389:6-11 doi: 10.1016/j.neulet.2005.06.052

Fajen BR (2013) Guiding locomotion in complex, dynamic environments. Frontiers in behavioral neuroscience 7:85

Fuller JH (1996) Eye position and target amplitude effects on human visual saccadic latencies. Exp Brain Res 109:457-466 doi: 10.1007/BF00229630

Gérin-Lajoie M, Richards CL, Fung J, McFadyen BJ (2008) Characteristics of personal space during obstacle circumvention in physical and virtual environments. Gait & posture 27:239-247

Gerin-Lajoie M, Richards CL, McFadyen B (2005) The negotiation of stationary and moving obstructions during walking: anticipatory locomotor adaptations and preservation of personal space. Motor Control 9

Grasso R, Prévost P, Ivanenko YP, Berthoz A (1998) Eye-head coordination for the steering of locomotion in humans: an anticipatory synergy. Neuroscience Letters 253:115-118

Hessels RS, van Doorn AJ, Benjamins JS, Holleman GA, Hooge ITC (2020) Task-related gaze control in human crowd navigation. Atten Percept Psychophys 82:2482-2501 doi: 10.3758/s13414-019-01952-9

Hollands MA, Patla AE, Vickers JN (2002) "Look where you're going!": gaze behaviour associated with maintaining and changing the direction of locomotion. Exp Brain Res 143:221-230 doi: 10.1007/s00221-001-0983-7

Huber M, Su YH, Krüger M, Faschian K, Glasauer S, Hermsdörfer J (2014) Adjustments of speed and path when avoiding collisions with another pedestrian. PLoS One 9:e89589 doi: 10.1371/journal.pone.0089589

Imai T, Moore ST, Raphan T, Cohen B (2001) Interaction of the body, head, and eyes during walking and turning. Experimental Brain Research 136:1-18

Jovancevic J, Sullivan B, Hayhoe M (2006) Control of attention and gaze in complex environments. J Vis 6:1431-1450 doi: 10.1167/6.12.9

Jovancevic-Misic J, Hayhoe M (2009) Adaptive gaze control in natural environments. Journal of Neuroscience 29:6234-6238

Kaiser PK (2009) Prospective evaluation of visual acuity assessment: a comparison of snellen versus ETDRS charts in clinical practice (An AOS Thesis). Transactions of the American Ophthalmological Society 107:311

Kitazawa K, Fujiyama T (2010) Pedestrian Vision and Collision Avoidance Behavior: Investigation of the Information Process Space of Pedestrians Using an Eye Tracker. . In: Klingsch W, Rogsch C, Schadschneider A, Schreckenberg M (eds) Pedestrian and Evacuation Dynamics 2008. Springer, Heidelberg, pp 95-108

Knorr AG, Willacker L, Hermsdörfer J, Glasauer S, Krüger M (2016) Influence of person- and situation-specific characteristics on collision avoidance behavior in human locomotion. Journal of experimental psychology: human perception and performance 42:1332

Kolarik AJ, Cirstea S, Pardhan S, Moore BC (2014) A summary of research investigating echolocation abilities of blind and sighted humans. Hearing research 310:60-68

Lamontagne A, Bhojwani T, Joshi H, Lynch SD, Souza Silva W, Boulanger M, Archambault P (2019) Visuomotor control of complex locomotor tasks in physical and virtual environments. Neurophysiologie Clinique / Clinical Neurophysiology 49:434

Lucas B (2018) Which side of the road do they drive on? https://brianlucas.ca/roadside/ Access date: December 1, 2019.

Lynch SD, Kulpa R, Meerhoff LA, Sorel A, Pettré J, Olivier AH (2020) Influence of path curvature on collision avoidance behaviour between two walkers. Exp Brain Res doi: 10.1007/s00221-020-05980-y

Marigold DS, Patla AE (2007) Gaze fixation patterns for negotiating complex ground terrain. Neuroscience 144:302-313

Matthis JS, Yates JL, Hayhoe MM (2018) Gaze and the control of foot placement when walking in natural terrain. Current Biology 28:1224-1233. e1225

Meerhoff LA, Bruneau J, Vu A, Olivier AH, Pettre J (2018) Guided by gaze: Prioritization strategy when navigating through a virtual crowd can be assessed through gaze activity. Acta Psychol (Amst) 190:248-257 doi: 10.1016/j.actpsy.2018.07.009

Oldfield RC (1971) The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia 9:97-113

Olivier AH, Marin A, Crétual A, Pettré J (2012) Minimal predicted distance: a common metric for collision avoidance during pairwise interactions between walkers. Gait Posture 36:399-404 doi: 10.1016/j.gaitpost.2012.03.021

Patla AE (2001) Mobility in complex environments: implications for clinical assessment and rehabilitation. Journal of Neurologic Physical Therapy 25:82-90

Patla AE, Shumway-Cook A (1999) Dimensions of Mobility: Defining the Complexity and Difficulty Associated with Community Mobility. 7:7 doi: 10.1123/japa.7.1.7 10.1123/japa.7.1.7 10.1123/japa.7.1.7 10.1123/japa.7.1.7

Patla AE, Vickers JN (1997) Where and when do we look as we approach and step over an obstacle in the travel path? Neuroreport 8:3661-3665

Pfaff LM, Cinelli ME (2018) Avoidance behaviours of young adults during a head-on collision course with an approaching person. Exp Brain Res 236:3169-3179 doi: 10.1007/s00221-018-5371-7

Reio T, Czarnolewski M, Eliot J (2004) Handedness and spatial ability: Differential patterns of relationships. Laterality: Asymmetries of Body, Brain and Cognition 9:339-358

Rushton SK, Harris JM, Lloyd MR, Wann JP (1998) Guidance of locomotion on foot uses perceived target location rather than optic flow. Curr Biol 8:1191-1194 doi: 10.1016/s0960-9822(07)00492-7

Schumann F, Einhäuser W, Vockeroth J, Bartl K, Schneider E, König P (2008) Salient features in gaze-aligned recordings of human visual input during free exploration of natural environments. Journal of Vision 8:12-12 doi: 10.1167/8.14.12

Shumway-Cook A, Patla AE, Stewart A, Ferrucci L, Ciol MA, Guralnik JM (2002) Environmental demands associated with community mobility in older adults with and without mobility disabilities. Physical therapy 82:670-681

Souza Silva W, Aravind G, Sangani S, Lamontagne A (2018) Healthy young adults implement distinctive avoidance strategies while walking and circumventing virtual human vs. non-human obstacles in a virtual environment. Gait Posture 61:294-300 doi: 10.1016/j.gaitpost.2018.01.028

Stephenson JL, Lamontagne A, De Serres SJ (2009) The coordination of upper and lower limb movements during gait in healthy and stroke individuals. Gait & Posture 29:11-16 doi: 10.1016/j.gaitpost.2008.05.013

Strasburger H, Rentschler I, Jüttner M (2011) Peripheral vision and pattern recognition: A review. Journal of vision 11:13-13

Thomas JP, Shiffrar M (2010) I can see you better if I can hear you coming: Action-consistent sounds facilitate the visual detection of human gait. Journal of vision 10:14-14

Voyer SD, Voyer D (2015) Laterality, spatial abilities, and accident proneness. Journal of clinical and experimental neuropsychology 37:27-36

Wandell B (1995) Useful quantities in vision science. Inner cover pages in “Foundations of vision”. Sunderland, MA: Sinauer Associates

Warren WH, Jr., Kay BA, Zosh WD, Duchon AP, Sahuc S (2001) Optic flow is used to control human walking. Nat Neurosci 4:213-216 doi: 10.1038/84054

Washabaugh EP, Kalyanaraman T, Adamczyk PG, Claflin ES, Krishnan C (2017) Validity and repeatability of inertial measurement units for measuring gait parameters. Gait & posture 55:87-93

Zambarbieri D, Beltrami G, Versino M (1995) Saccade latency toward auditory targets depends on the relative position of the sound source with respect to the eyes. Vision Res 35:3305-3312 doi: 10.1016/0042-6989(95)00065-m

Zivotofsky AZ, Gruendlinger L, Hausdorff JM (2012) Modality-specific communication enabling gait synchronization during over-ground side-by-side walking. Hum Mov Sci 31:1268-1285 doi: 10.1016/j.humov.2012.01.003

Zivotofsky AZ, Hausdorff JM (2007) The sensory feedback mechanisms enabling couples to walk synchronously: an initial investigation. J Neuroeng Rehabil 4:28 doi: 10.1186/1743-0003-4-28

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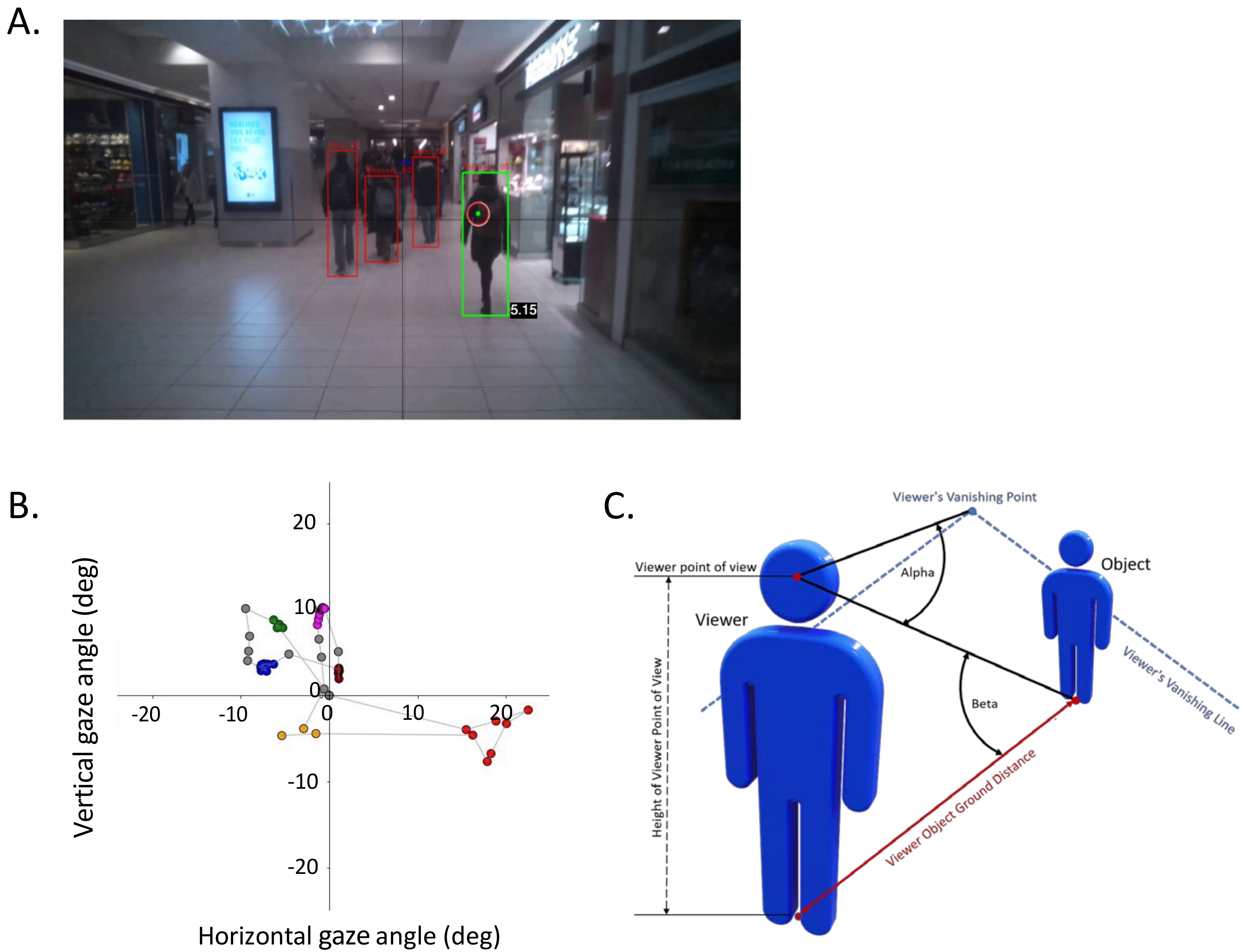
A.
5.15
B.
Vertical gaze angle (deg)
Horizontal gaze angle (deg)
20
10
0
-10
-20
-20
-10
0
10
20
C.
Viewer's Vanishing Point
Viewer point of view
Alpha
Object
Viewer
Beta
Height of Viewer Point of View
Viewer's Vanishing Line
Viewer Object Ground Distance

Figure 3

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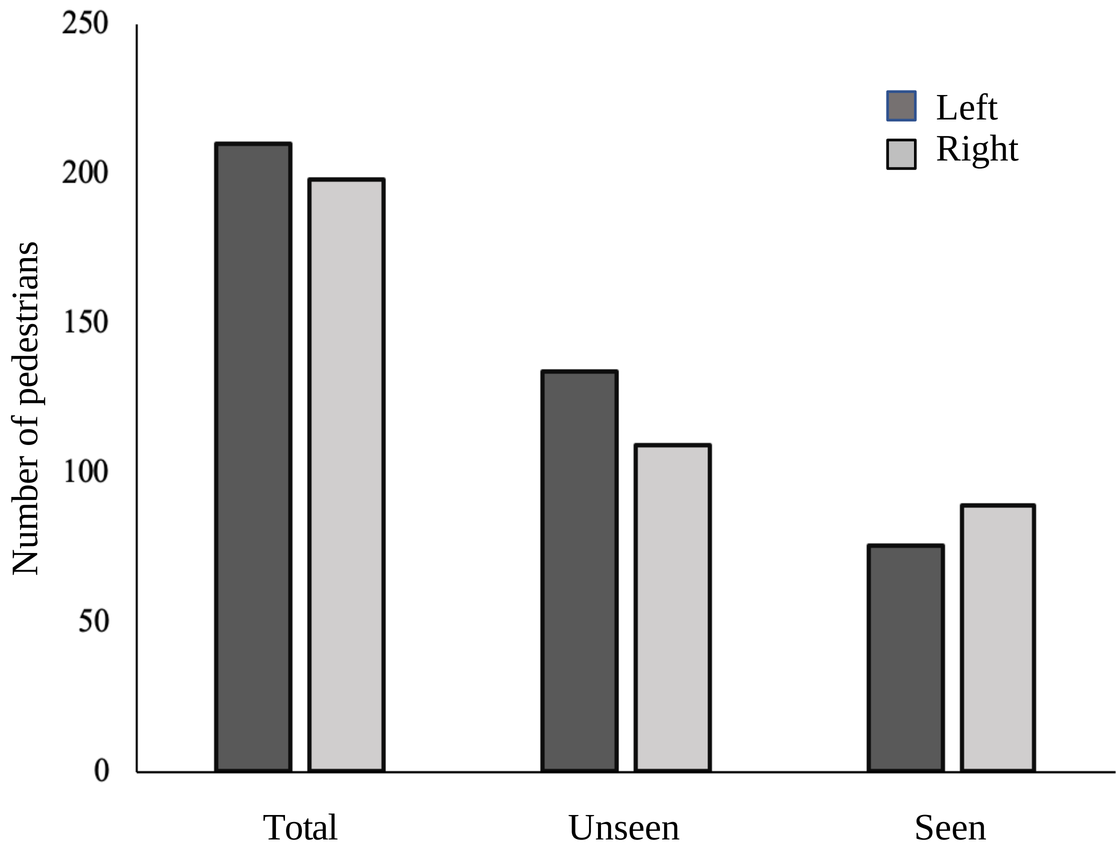
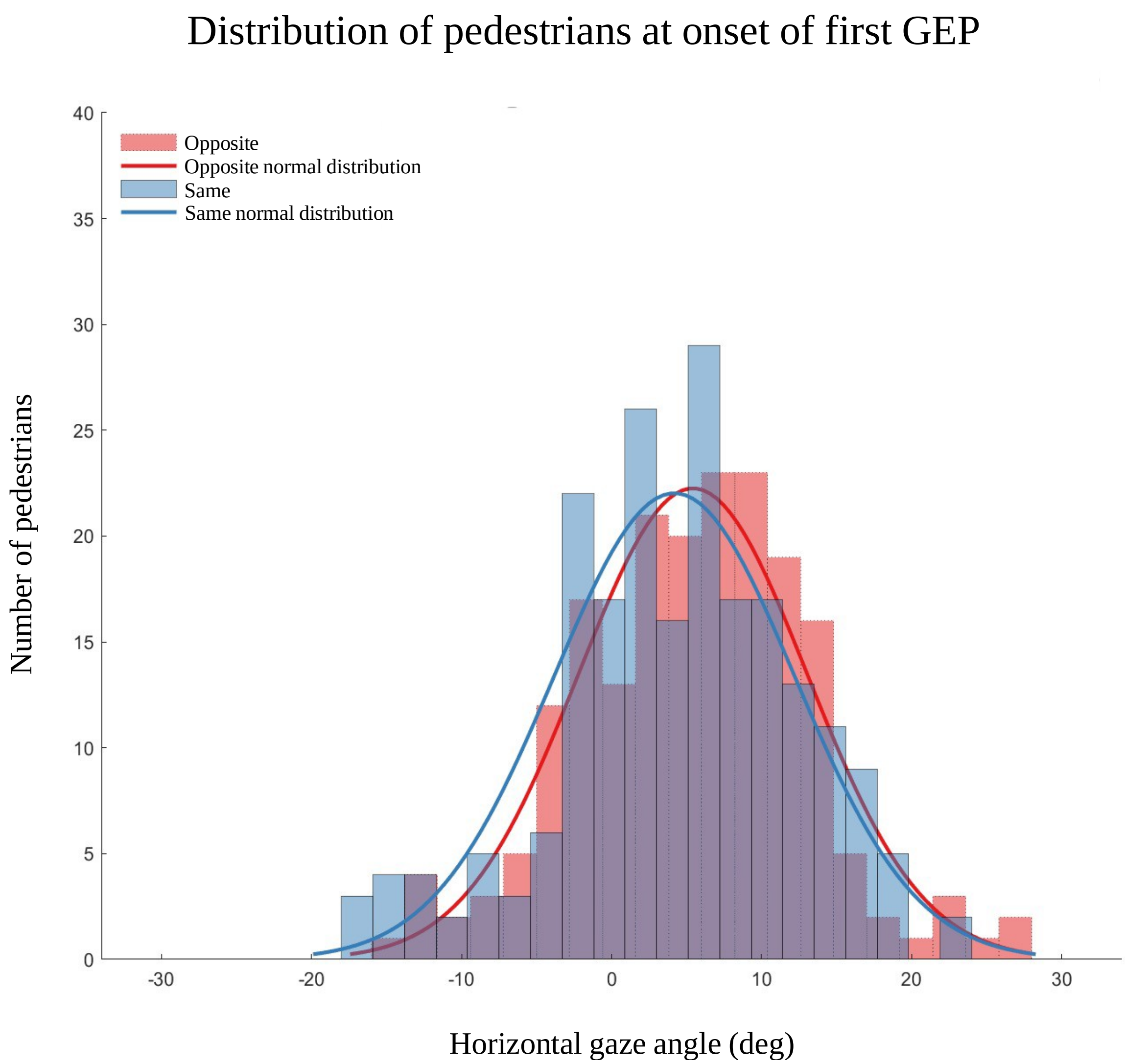



Distribution of pedestrians at onset of first GEP
Opposite
Opposite normal distribution
Same
Same normal distribution
Number of pedestrians
Horizontal gaze angle (deg)
0
5
10
15
20
25
30
35
40
-30
-20
-10
0
10
20
30

First Gaze Episode on Pedestrians

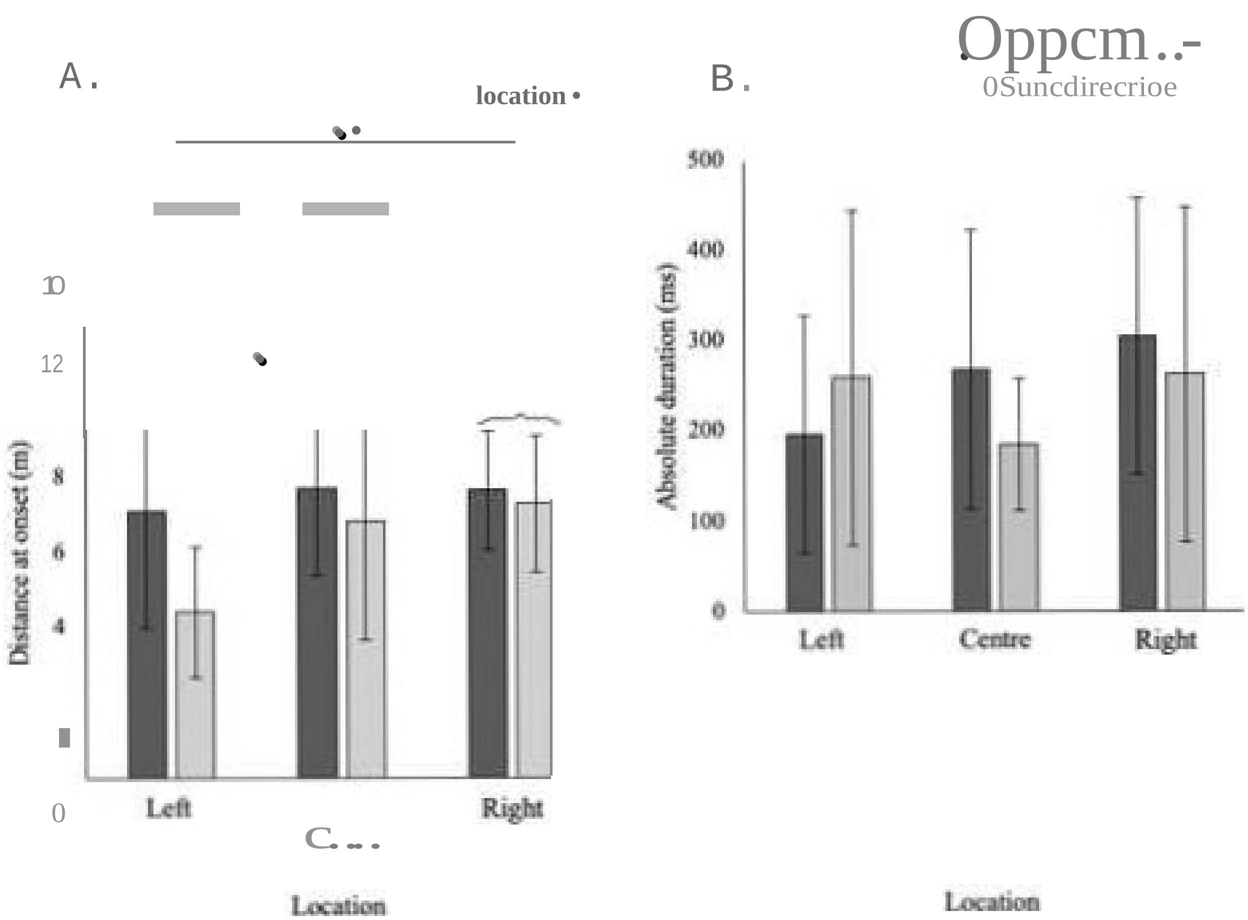
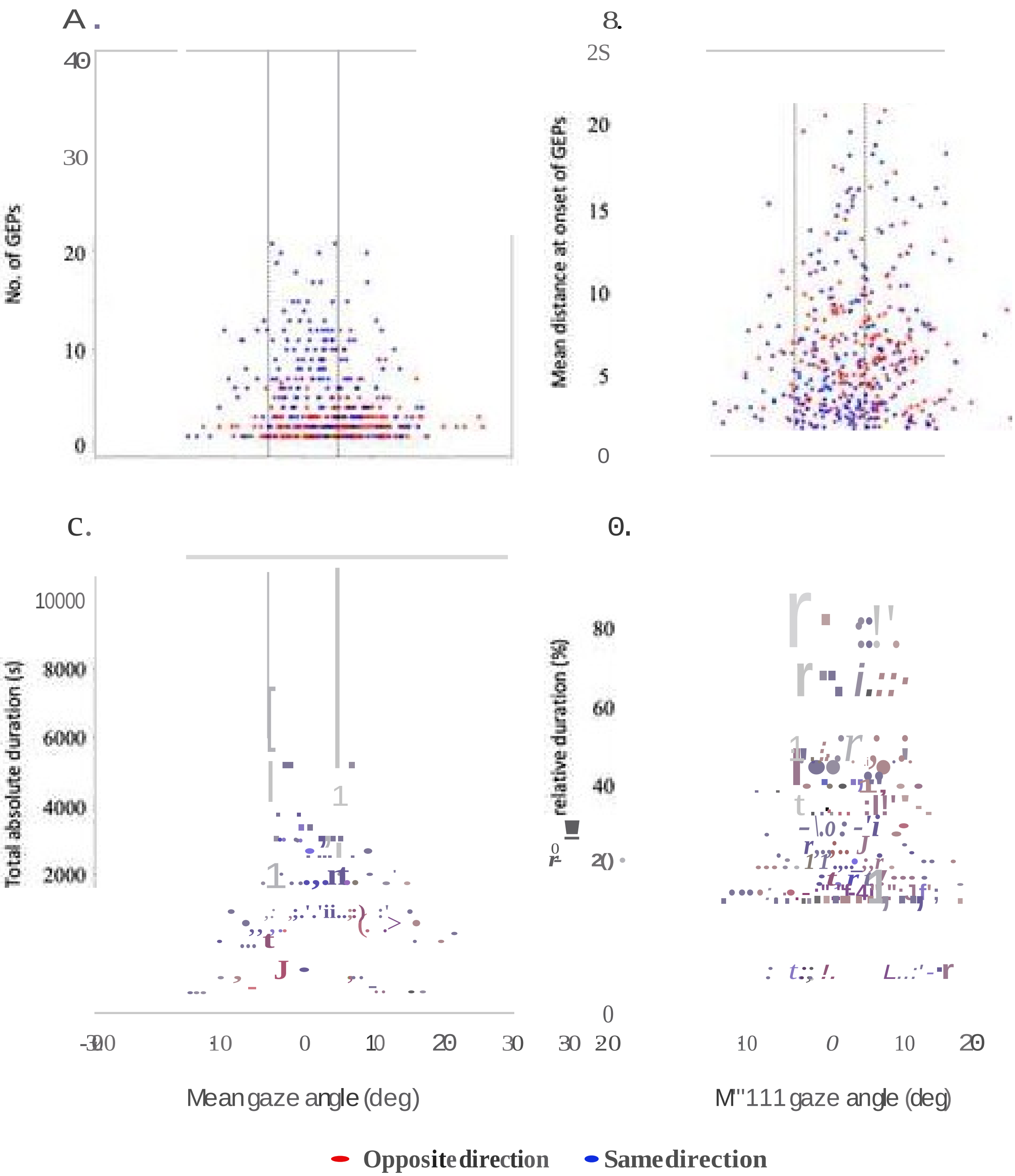


Figure 6


A.
8.
C.
0.
No. of GEPs
Mean distance at onset of GEPs
Total absolute duration (s)
relative duration (%)
10000
8000
6000
4000
2000
Mean gaze angle (deg)
Opposite direction
Same direction

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