Visual search strategies of child-pedestrians in road crossing tasks

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Abstract

Children are overrepresented in road accidents, often due to their limited ability to perform well in road crossing tasks. The present study examined children's visual search strategies in hazardous road-crossing situations. A sample of 33 young participants (ages 7-13) and 21 adults observed 18 different road-crossing scenarios in a 180° dome shaped mixed reality simulator. Gaze data was collected while participants made the crossing decisions. That was used to characterize their visual scanning strategies. Results showed that age group, limited field of view, and the presence of moving vehicles affect the way pedestrians allocate their attention in the scene. Therefore, we can deduce that adults tend to spend relatively more time in further peripheral areas of interest than younger pedestrians do. It was also found that the oldest child age group (11-13) demonstrated more resemblance to the adults in their visual scanning strategy, which can indicate a learning process that originates from gaining experience and maturation. Characterization of child pedestrian eye movements can be used to determine readiness for independence as pedestrians. The results of this study emphasize the differences among age groups in terms of visual scanning. This information can contribute to promote awareness and training programs.

Introduction

Over a third of road traffic deaths in low and middle-income countries are among pedestrians. Even in more developed countries the rates of pedestrian deaths do not fall much behind; in Europe and in the Americas, the pedestrian death rate is 27% and 23%, respectively (WHO, 2013). Accident statistics consistently show that children are overrepresented as a group in pedestrian accidents. Children aged 15 and younger are accounted for 7% of the pedestrian fatalities in 2009 and 25% of all pedestrians injures in traffic crashes (NHTSA, 2009). The NHTSA report revealed that pedestrians are fully or partially accounted for most of the accidents, and that children are more likely than adults to be the cause of the accident. In an earlier study, pedestrians under the age of 10 were found to be responsible for 77% of the motor-pedestrian accidents, children aged 10 to 14 were the guilty party in 60% of the accidents, and those aged 15 or older were to blame in 33% of the accidents (Hunter et al., 1996). Thus, children more than adults, are at risk as pedestrians, often due to their own actions.

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Much of the success in making the crossing decision relies on the pedestrian's ability to focus attention on relevant elements in the traffic environment and to ignore irrelevant stimuli. It has been recognized in several studies that pedestrians' selective attention abilities are linked to their performance in road crossing tasks (Dunbar et al., 2001; Foot et al., 1999; Tabibi & Pfeffer, 2007). It was also demonstrated that children have limited attention abilities compared to adults, and that those improve with age developing during middle childhood (Akhtar & Enns, 1989; Lin, et al., 1999). Overall, the literature suggests that due to their inferior attention abilities, young children are less competent to act in traffic than older children and adults (Dunbar et al., 2001; Tabibi & Pfeffer, 2007; Whitebread & Neilson, 2000).

Children suffer from inadequate visual searching behaviour that exemplifies the importance of efficient visual search strategy for safe road-crossing. Early literature review revealed that while the proportion of children that failed to look before stepping down to the road was significant but inconsistent, age was always an effecting factor (van der Molen, 1981). More recent studies estimate that over 50% of the children are not looking at the traffic before stepping into the road and the younger they are, the less likely they do so. When looking does occur it is often restricted to a single observation, often in the wrong direction (Zeedyk et al., 2002). Analysis of accident data demonstrates the consequences of this behaviour, and thus it is estimated that 39% of child-pedestrian victims do not look for approaching vehicles at all before crossing (Grayson, 1975). Nevertheless, it is not just that children do not 'look'. Studies have shown cases where children that have looked in the right direction still failed to detect the approaching vehicle. For example, Grayson (1975) estimated that in 31% of the cases, children had 'looked but failed to see' the hitting vehicle. This kind of failure might be difficult to explain, as it is reasonable to assume that when looking at an object directly one will 'see' it and respond accordingly. However, this phenomenon is not so surprising. For example, one can stare at the right direction but attend to something else like sounds or thoughts, a phenomenon known as the "inattentional blindness" (Mack, 2003). It is also possible that one is not interpreting the scene correctly or quickly enough. Just like in the case of inexperienced drivers, that delayed in processing the representation of a still-image traffic scene when a potentially hazardous object is present in it, but able to fixate upon the object just as fast as an experienced driver (Huestegge et al., 2010). In either way, no matter what cause children to fail spotting the approaching vehicle the results of the above studies strongly suggest that gaze-related behaviour is part of the reason for child-motor accidents.

Children's search process is affected by conspicuous parts in the visual field, and with age, this process becomes more systematic, exhaustive, focused and rapid (Day, 1975). Other studies exemplify additional aspects of failures in children's visual search; children before age 9 have limited ability to adapt their visual search strategy to fit different tasks (Hall, 1985), and young children's visual attention is more adversely affected by the presence of distractors than older children and adults (Pastò & Burack, 1997). Age-related differences also exist in a more simple aspects of eye-movements; six-year-old children make shorter fixations, and shorter and more rapid eye movements in comparison to adults (Mackworth & Bruner, 1970).

Whitebread and Neilson (2000) examined the relationships between pedestrian skills and visual search strategies. According to their findings, major changes in strategy occurred around the age of 7-8 years; this change expressed in the frequency and pattern of looking at different directions, having a sophisticated ‘last-minute’ checking approach, exhaustive visual search strategy, and the speed of making the crossing decision.

The work of Whitebread and Neilson (2000) justifies the need to further examine child pedestrian visual search behaviour among age groups. Meir et al. (2013) contrasted the crossing behaviour of three different child pedestrian age groups and an adults group. The current work adds the layer of visual search behaviour to their results. The aim of the current study is to get better understanding of the pedestrian visual behaviour and visual attention distribution in the environment in various roadside situations, with regard to the age of the pedestrian. The research hypothesis was that age has a direct link to visual behaviour and attention distribution; meaning that the older the children are they will show more resemblance to the experienced-adults group.

Method

Participants

Fifty-four participants were recruited, 21 experienced-adult participants aged 20-27 (mean age=25.3, SD=1.8), fourteen 7-to-8 year-olds (mean age=7.8, SD=0.7) eighteen 9-to-10-year-olds (mean age=9.6, SD=0.3) and nine 11-to-13 year-olds (mean age=11.5, SD=0.9). Children completed the experiment in exchange for an educational compensation equivalent of 30 NIS (approx. $10). Adults received the monetary compensation or bonus credit in an introductory course. Participants signed an informed consent form. Parental consent was given for participants under the age of 18.

Eye tracker and Dome facility

The head mounted ASL eye tracking system HS-H6 was used to perform correct measurement of pupil diameter and gaze direction (see Figure 1). After a short 9-points calibration process, the eye tracker accurately tracks the subject’s eye movements and gaze direction by sampling the eye at 60Hz. The HS-H6 head mounted eye tracker was designed to track gaze direction over approximately a 30-35 degree vertical visual angle and a 40-45 degree horizontal visual angle, with 0.5 degrees precision and a 0.1 degrees resolution. The head mounted helmet is equipped with a front camera recording the same scene viewed by the participant. The video from the scene camera was recorded with an overlay of the participant’s gaze location (Figure 2).

The 3D Perception™ Dome consists of a 180 degrees cylindrical screen (radius of 3.5 meters) aligned with a very accurate projection system of three projectors. This setting allows measurement of the participants when watching pre-designed simulated scenarios of real life situation from the roadside environment without the risk of harm (Figure 3).

Figure 1. The ASL Head-Mounted HS-H6 Eye Tracking System.

Figure 2. Capture from the scene video with the gaze location layer marked by a black cross.

Procedure

Participants arrived at the Dome facility for an hour-long session. Participants went through a stage of eye calibration, after which their eye-movements were recorded via the eye tracker. Each participant observed the 18 scenarios in a random order and engaged in a crossing decision by pressing a response button each time quickly when it was safe to cross the road. Two practice scenarios were used to familiarize with the experimental task. For each scenario and for each participant a video with the superimposed eye gaze data was saved on file using the scenario and the participant number as identifier. At the end of the session, participants were asked to fill a computerized demographic questionnaire, then received the compensation and left.

Stimuli

Eighteen typical urban simulated scenarios, each one lasting 10-45 seconds, shown from a pedestrian’s point of view, as seen in Figure 4. The scenarios consisted of a structured combination of elements: (1) Traffic Movement (no moving vehicles, one-way street where moving vehicles are traveling in one direction, two-way street where moving vehicles are traveling in two direction), (2) obscured Field of View (unrestricted, partially obscured by the road’s curvature on the left, or partially obscured by parked vehicles, see Fig. 4), and (3) Presence of Zebra-crossing (with zebra-crossing, without zebra-crossing), aiming to decipher participants’ responses to those situations.

Eye-data collection

A fixation happens when the eye focuses on a specific detail, and during this time, the eye collects information. Fixation duration varies and is estimated to be between 150-to-600ms, as 100ms is the minimum time required for the eye to receive information. In order to collect the fixation data from the videos, a manual coding method was applied. A trained research assistant did the manual process of fixation-identification.

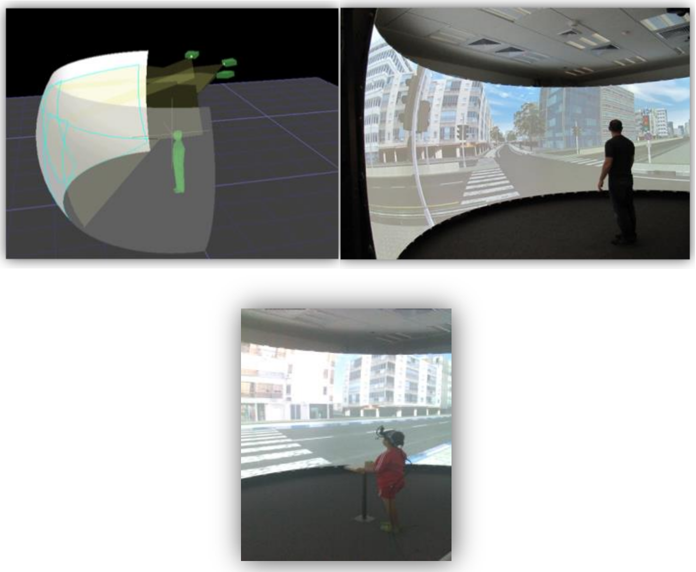

Figure 3. Dome projection facility at BGU Ergonomics complex.

In each frame in the video, a dynamic black cross was observed symbolising the participant gaze location in the scene at that time. The pinnacle digital video capture card recording at 25 FPS. Fixation was defined as a sequence of at least three consecutive video frames (120ms) during which the participant gaze's illustrated by the black cross remained focused on a specific detail in the scene. The manual coder watched each video frame-by-frame and manually documented each fixation (only those that fell in one of the areas of interest) in an Excel table, registering fixation duration and location.

Areas of Interest (AOIs)

For each scenario, five areas of interest (AOIs) were defined (Figure 5). The close range central area was defined as the 10 meters of road in each side from the pedestrian's point of view (AOI 3). Then symmetrically areas to the right of the centre and to the left were defined. The middle right/left range (AOIs 2/4) was the part of the road distant at least 10 meter to the right/left of the point of view but less than 100 meters away. The far right/left range (AOIs 1/5) was the part of the road at least 100 meter or more to the right/left of the pedestrian point of view.

Measures of visual search behaviour

Gaze distribution [%]: This is the distribution of fixation-time, that was directed by each participant in each scenario, between the defined AOIs.

Fixation duration [milliseconds]: The mean duration of fixations made by each participant in each scenario.

Dwells [seconds]: The mean duration of dwells made by each participant in each scenario. A single dwell is defined as the time during which a contiguous series of one or more fixations remains within an AOI.

Frequency of fixations [fixations/min]: This is a calculation of the mean number of fixations, made by each participant in each scenario, per minute.

Figure 4. The Field of View factor as displayed in the virtual scenarios: (1) Unrestricted (above); (2) Partially obscured by the road's curvature (middle); (3) Partially obscured by parked vehicles (below).

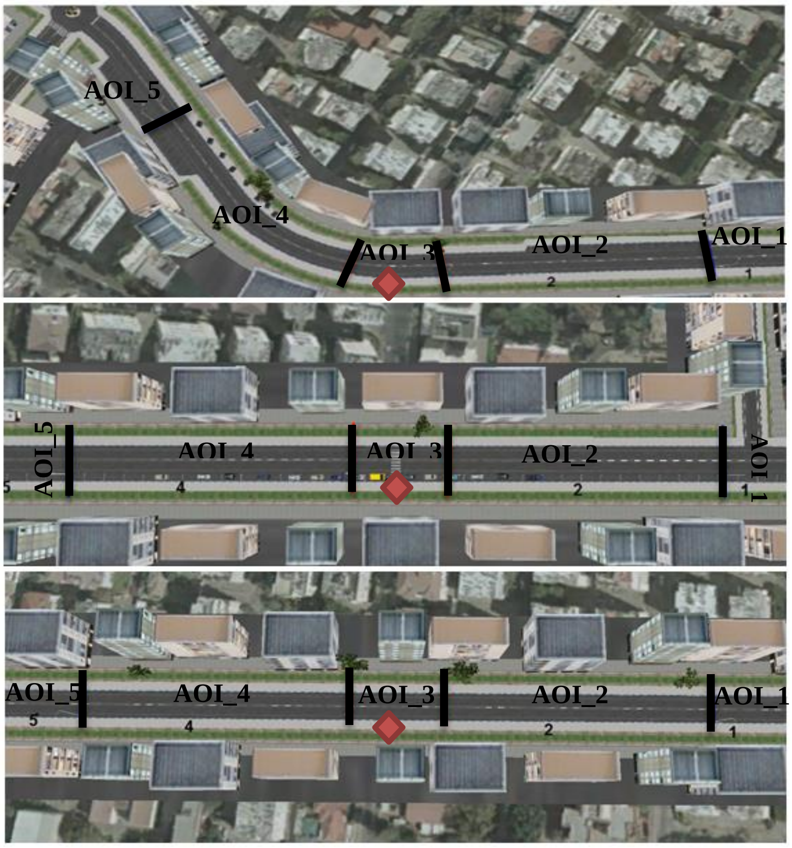

Figure 5. The Field of View factor as displayed in the virtual city terrain from a 2D perspective: (1) Unrestricted (below); (2) Partially obscured by the road's curvature (middle); (3) Partially obscured by parked vehicles (above). The division into areas of interest (AOIs) marked 1-5 is shown in each scene. The diamond shape icon represents the pedestrian point of view.

Results

Gaze distribution

For each participant and scenario, the Gaze distribution over the five AOI's sums up to one and therefore Gaze distribution is compositional data i.e., non-negative proportions with unit-sum. These types of data arise whenever we classify objects into disjoint categories and record their resulting relative frequencies, or partition a whole measurement into percentage contributions from its various parts. Therefore, attempts to apply statistical methods for unconstrained data often lead to inappropriate inference. Dirichlet regression suggested by Hijazi and Jernigan (2009) is more suitable. Dirichlet regression is a regression model that was design to deal with compositional data and analyse the five AOIs simultaneously under the constrained that they sum-up to one. The Dirichlet regression model was fitted using

DirichletReg package, in R Language. Applying a backward elimination procedure found the best fitting model has three significant main effects. The dependent variable was the vector of AOIs and the independent variables were Age-group, Traffic-Movement (TM) and Field of View (FOV); all of them to be statistically significant (p<0.05). Results from the Dirichlet regression shown in Table 2 revealed differences among age groups and among the crossing conditions. Table 3 shows the Gaze distribution for each category.

Table 2. The Dirichlet regression estimated coefficients for the set of five AOIs.

Variable	*Category*	*Far-left*	*Mid-left*	*Centre*	*Mid-right*	*Far-right*
Intercept		-1.90***	-1.76***	-1.63***	-1.72***	-1.76***
Age-group+	Aged 9-10	0.03	0.17	0.4***	0.26*	-0.06
	Aged 11-13	0.06	0.13	0.02	0.03	-0.02
	Adults	0.19*	0.01	-0.23*	0.02	-0.02
Traffic Movement++	One-way traffic movement	0.14	0.32***	0.47***	0.23**	0.16*
	Two-way traffic movement	0.11	0.17*	0.57***	0.63***	0.29***
Field of View+++	Restricted by parked vehicles	0.07	0.25**	0.54***	-0.22**	-0.15
	Restricted by road curvature	-0.31***	0.42***	-0.21**	-0.41***	-0.23**

+*Reference aged 7-8.* ++*Reference "no-traffic".* +++*Reference unrestricted field of view.*
$* p < 0.05$, $** p < 0.01$, $*** p < 0.001$.

Table 3. The mean Gaze distribution [%] for each of the Age-group, Traffic-movement, and Field of view categories.

Variable	*Category*	*Far-left*	*Mid-left*	*Centre*	*Mid-right*	*Far-right*
Age-group	Aged 7-8	9.3	29.9	32.9	15.0	12.9
	Aged 9-10	7.3	29.8	37.2	16.9	8.8
	Aged 11-13	9.5	34.7	27.8	15.8	12.2
	Adults	17.0	31.5	21.9	15.5	14.1
Traffic Movement	No-traffic	13.5	34.3	30.0	12.1	10.1
	One-way traffic movement	13.1	37.7	26.2	11.5	11.5
	Two-way traffic movement	9.7	23.2	27.7	23.4	16
Field of View	Unrestricted field of view	15.2	21.7	21.7	22.7	18.7
	Restricted by parked vehicles	16.7	25.0	38.8	11.9	7.6
	Restricted by road curvature	4.4	48.4	22.8	12.7	11.7

Children aged 9-10 spent relatively more time than all other age groups looking at the close range (AOI_3), while the adults showed a significant opposite, by spending relatively less time in the close area than all other groups. Adults spend relatively more time looking to the far left range (AOI_5) than all child-groups, thus they allocate more attention to the cars travelling on the close lane (i.e., in their perspective from left to right).

Traffic movement also had an effect on the participants' visual search distribution. The most evident phenomenon was that traffic movement, either one-way or two-way caused participants to spend relatively more time looking at the close proximity area than in scenarios where no travelling vehicles were present. With regard to FOV, it led to statistically significant distribution differences evident in both restricting conditions. When restricted on both sides by parked vehicles, participants spent more time looking at the close proximity area than in the unrestricted condition. It seems that when encountered with blocked field of view on both sides, participants tend to spend more time on the part of the scene that is not restricted, hence the immediate close area; and attempt to allocate more visual attention to the left. When restricted by a road curve on the left, statistically significant effects were shown in all AOI's. The curve, that limited participants from seeing the oncoming vehicles, was to the left of the participant point-of-view; once the vehicle coming from the curve became visible, it was less than 6 seconds until the vehicle arrived into the participant path of crossing. As a result participants spent more time looking at the mid-range left side (AOI_4) and less time at all the other AOIs than they did in the unrestricted scenarios.

Fixation duration

The mean fixation duration for each age group reveals a constant incline of average fixation duration with age (Table 4). While the youngest group had the shortest fixations in all AOIs, the adults had the longest average fixation in all AOIs but AOI_5 (Far-left). Fixation duration increases as are farther from the centre, almost twice as long in some cases. Although in far peripherals AOIs the difference between groups was larger, it was not statistically significant; which means that as fixations got longer, variance increased as well. Although not statistically significant, the longer average fixations for all groups were at the far-left area, about 500ms for the 3 oldest groups and 378ms for the youngest group.

Dwells duration

The results show that all groups had longer dwells in peripheral areas than in the centre (Table 4). Age differences were again very clear; adults' dwellings in peripheral areas were much longer than the two youngest age groups, especially on the left where the adults' average dwell was 1.54 s. in comparison to 1.03 s. for the children aged 7-8 and 1.1 s. for the children aged 9-10. The oldest group of children were again the most resembling to the adults.

Frequency of looks

The number of fixations each participant made in each scenario inside any of the AOIs was divided by length of the scenario, which gave the frequency of looks. The highest frequency was viewed in the youngest age group (Mean=52.2), and this score was significantly different than of the oldest child group aged 11-13 and the adults that scored 41.9 and 45.4 fixations/minute, respectively. Age group 9-10 was similar (2 fixation/minutes less) than that of the youngest group. Overall, two clusters of groups were visible, that of the two youngest age groups and that of the oldest child and adults.

Table 4. Mean scores and one-way ANOVA for visual search strategy variables

	AG1 (Aged 7-8)	*AG2 (Aged 9-10)*	*AG3 (Aged 11-13)*	*AG4 (Adults)*	*F ratio*	*Sig. group differences*
Fixation duration (ms)						
Far-left	378	515	493	499	0.59	
Mid-left	290	333	356	374	7.12***	AG1< AG3/AG4
Centre	236	260	254	271	4.47***	AG1 < AG4
Mid-right	266	325	303	340	3.99***	AG1 < AG4
Far-right	369	408	413	451	1.11	
Dwells (Seconds)						
Far-left	1.03	1.10	1.23	1.54	2.94*	
Mid-left	1.06	1.35	1.48	1.49	2.84*	AG1< AG4
Centre	0.76	1.04	0.92	0.76	2.89*	
Mid-right	0.75	1.08	1.21	0.99	2.76*	AG1<AG3
Far-right	1.13	0.98	1.50	1.43	1.75	
Frequency of fixations (fixations/min)	52.2	50.3	41.9	45.4	6.34***	AG1> AG3/AG4 AG2>AG3

*In this table, the F ratio is a measure of the overall significance of the differences between the four age groups. *p < .05, ***p<.001. The significance of differences between pairs of groups, reported in the last column, was tested with the Tukey HSD at level of 0.05.*

Discussion

The present experiment studied children's visual search strategies in hazardous road crossing situation by examining their gaze data while they were engaged in crossing decision tasks. The hypothesis stated that age has a direct link to visual behaviour and attention distribution, that is, that the older the child, the more his or her performance will resemble that of an experienced-adult.

Results indicated that age, limited field of view and the presence of moving vehicles affect the way pedestrians allocate their visual attention in the scene; and that age is associated with several measures of visual search. Indeed, adults were found to spend relatively less time in the centre area than children, shifting more visual attention to the far left area. It was also shown that the oldest child group (aged 11-13) showed partial resemblance to the adults, by spending relatively less time viewing the centre area than the younger children and relatively more time in the mid-left area. The measure of visual attentiveness, outside the scope of age reveals that pedestrian's visual search strategy is flexible and versatile giving the environment. Thus, pedestrians were more attentive to the road when driving vehicles were present than in scenarios with no traffic, and more importantly they accommodated their visual attention to restrictions such as parked vehicles and curvatures in the roadway.

This trend was apparent in all other gaze related measures. Fixation duration extends with age and as they moved from the centre to the peripheral areas, especially to the left, which coincides with the way they allocate their attention. The reoccurring diverse results the left side is not random, it may reflect a calculated manner of estimating the source of risk. Vehicles coming from the left are traveling in the close lane to the pedestrians and therefore constitute the immediate threat when stepping into the road. The dwells, much like the fixation, extends with age and adults seem to dwell longer in comparison to children, especially than the two youngest groups. It was also visible in all groups that peripheral dwells were longer than those in the centre. The frequency of fixations measure demonstrates again the age related differences; adults and the oldest group of children have a lower frequency of fixations than the younger children aged 7-10. It seems from the results that younger children tend to do more and shorter fixations; possibly, reflecting that younger children scan the environment in a more hectic manner.

Meir et al., (2013) showed that both 9–10-year-olds and 11–13-year-olds presented a less decisive performance reflecting upon higher attentiveness towards potential hazards along with better prediction of the upcoming events of adults. Taken together with previous behavioural findings (Meir et al., 2013) that crossing behaviour is age related. The pattern of the results presented here, serves as an additional indication for distinguishing between the middle age groups, a learning process that originates from gaining experience. The present research showed that gaze data might serve as a tool for differentiating between pedestrians with varied age and experience levels in a dynamic simulated environment. Findings serve applicable meaning, that is, further development of the characterization of children and adults' eye-movements patterns may be used as a methodology to determine potential pedestrians' readiness for crossing independence.

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