Ben-Gurion University of the Negev

Towards understanding child-pedestrian's deficits in perceiving hazards when crossing the road

Final Report

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תקציר בעברית

תאונות דרכים הינן אחד הגורמים העיקריים לתמותה, פציעה ופגיעה בקרב ילדים במדינות מפותחות. ילדים מעורבים בתאונות דרכים באופן שאינו פרופורציונאלי למספרם באוכלוסיה, במקרים רבים בשל הקושי שחווים בביצוע מטלת חציית כביש. מחקרים מצביעים על מגוון קשיים וליקויים במיומנויות וביכולות הקוגניטיביות של ילדים בהקשר של חציית כביש (למשל ,קשיים באומדן זמנים ובמיקוד קשב). המחקר הנוכחי מהווה מחקר חלוץ המתעתד לבחון מיומנות ספציפית- מיומנות תפיסת הסכנות (hazard perception)- בקרב ילדים כהולכי-רגל , תוך שימוש בעקרונות המתודולוגיים ובכלי המחקר הייחודיים שמצאנו במחקרי עבר כיעילים עבור נהיגת צעירים (Meir et al., 2010). ארבעים ושישה נבדקים, 21 הולכי רגל מבוגרים ומנוסים ו- 25 הולכי רגל צעירים וחסרי נסיון (שמונה ילדים בגילאי 7-9, חמישה ילדים בגילאי 9-10 ושניים עשר ילדים בגילאי 10-13) הגיעו לסביבת מציאות וירטואלית המדמה עיר טיפוסית בישראל, נחשפו למגוון תסריטים הכוללים מצבי סכנה והתבקשו לבצע החלטת חצייה. נבחנו ההבדלים בין יכולות האיתור וחיזוי הסכנות של הנבדקים באמצעות בחינת רגישות תגובותיהם (החליטו לחצות או לא), זמני תגובותיהם והתיאורים המילוליים שסיפקו במהלך המטלה. נעשה שימוש בסביבה וירטואלית המאפשרת עריכת מחקר מבוקר תוך הימנעות מסיכון חיי אדם. בהתאם למשוער, נמצא כי עם העלייה בגיל וברמת הניסיון של הנבדקים חלה עלייה ביכולתם לאתר ולהתייחס לסכנות פוטנציאליות (למשל, קיומו של שדה ראייה החסום על ידי מכוניות חונות) ולהשתמש ביכולת זיהוי זו בעת ביצוע מטלת חצייה. תוצאות המחקר צפויות לתרום רבות להבנתנו את יכולות ומגבלות תפיסת הסכנות בקרב ילדים לעומת הולכי-רגל בוגרים ואת יכולתם לחצות את הכביש בביטחה. תוצר חשוב של המחקר יהיה הקמת תשתית תיאורטית לבניית תוכנית אימון בתפיסת סכנות עבור ילדים כהולכי-רגל. מימוש יעדים אלו יכול לתרום רבות להפחתת מעורבות ילדים כהולכי-רגל בתאונות דרכים.

דו״ח זה מחולק למספר פרקים. בפרק הראשון מובאת סקירה ספרותית מורחבת של נושאים הקשורים להולכי רגל והולכי רגל ילדים בפרט. בפרק השני מוצג הניסוי הראשון שבוצע בבתי ספר יסודיים בבאר-שבע עם ילדים בגילאים 6- 12 ומבוגרים ושימש כשלב ביניים לקראת הניסוי העיקרי ולימוד התחום בקרב ילדים בישראל. בפרק השלישי מוצג הניסוי העיקרי של המחקר, שיטת המחקר,השערות הצגת תוצאות נרחבת ודיון בממצאים. הפרק האחרון מוקדש למסקנות ולהמלצות למחקרי המשך.

מילות מפתח: הולכי רגל; ילדים; תפיסת סכנות; אימון; ניסיון.

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1. SCIENTIFIC BACKGROUND

1.1. INTRODUCTION

Pedestrian road crashes pose one of the most serious threats to contemporary life. Research has indicated that they are amongst the most substantial causes of death, injury and long-term disability among children, particularly among those in the age range of 5-to 9-years (e.g., Whitebread & Neilson, 2000; Tabibi & Pfeffer, 2003), who endure four times the injury rate of adults, in spite of their lower levels of exposure to traffic (Thomson et al., 2005).

Statistical data regarding pedestrian-involved accidents in urban areas in Israel suggest that on average, over the past 5 years there were more than 3000 accidents involving pedestrians every year in urban areas (Central Bureau of Statistics, 2011). Specifically, examining the most recent data available from the Israeli Bureau of Statistics for the past 18 months (2010 and Q1-Q2 of 2011) in urban areas, there were 3838 accidents. Of those, about 20% (786) were considered severe or fatal. Children pedestrians aged 5-9 were involved in 9% of the accidents and in 13% of the severe accidents. Children pedestrians aged 10-14 were involved in 8% of the accidents and in 7% of the severe accidents.

Negotiating traffic requires a variety of cognitive and perceptual skills (e.g., Tabibi & Pfeffer, 2003; Thomson, Tolmie, Foot, & McLaren, 1996). When a pedestrian's skills are not properly developed, his or her road-related decisions will probably be inadequate (Thomson, Tolmie, Foot, & McLaren, 1996). Indeed, past research has indicated that young children are less competent in traffic than adults (e.g., Tabibi & Pfeffer, 2003; Hill, Lewis & Dunbar, 2000).

Israeli pedestrian crash data suggest that the majority of children's crashes take place at the end of school hours (Shinar, 2008). Central Bureau of Statistics' (2011) data suggest, that when examining the location of the accident (i.e., whether it occurred in a road-junction or not in a junction) about two thirds from the rate of the total accidents that occur in urban areas and about 75% of the severe and fatal accidents, occur in non-junction areas of the road. Children pedestrians aged 5-9 were involved in 17% of the severe and fatal accident in non-junction areas. The rate of involvement of children pedestrians aged 10-14 in severe and fatal accidents does not change between junction and non-junction areas (i.e., remains 7%). Thus, non-junction areas in general pose a larger threat to the pedestrian population and specifically to the population aged 5-9.

One might have thought that prohibiting children's crossing the road alone until the age of 9 would be enough to reduce their over-involvement in pedestrian crashes. Much research, however, has shown that elementary-school children do tend to cross the road without adults' accompaniment, especially when coming back from school (e.g., Van der Molen, 1981; Macpherson et al., 1998). For example, Richard (1974) in Van der Molen (1981) found in his interviews that 50% of the 5-year-olds and 90% of the 7-year-olds were allowed to cross the street independently. A similar trend was found in an observational study showing an increase of independent road crossing with age up to 9 years in the 20-minute range after school hours period (Routlege et al., 1974 in Van der Molen, 1981). Moreover, some research has shown that parents consider children as young as 7.6 years as old enough to cross a road (MacGregor, Smiley & Dunk, 1999).

Clearly, in order to reduce road crashes amongst child-pedestrians it is insufficient to assume that young children will avoid crossing roads by themselves. Rather, there is a need to examine and assess the skills and knowledge necessary for children in order to behave safely when coping with the traffic environment, so as to provide them with means for increasing those abilities (Hill, Lewis & Dunbar, 2000).

1.2. PEDESTRIAN-RELATED ABILITIES

Thomson, Tolmie, Foot, & McLaren (1996) have suggested that pedestrians require several underlying abilities in order to interact safely with traffic: (1) Making judgments about whether crossing places are 'safe' or 'dangerous'. This process involves the co-ordination of past experience, current information and prediction about future possibilities (Whitebread & Neilson, 2000); (2) Detecting the presence of traffic that could be a source of danger. This process involves the interplay of selective attention, systematic visual search and judgments about speed and time (Whitebread & Neilson, 2000) and (3) Integrating information from different parts of the relevant traffic environment including different directions. This process involves the ability to hold and process multiple components of information simultaneously in one's working memory (Whitebread & Neilson, 2000).

1.3. CHILD-PEDESTRIANS ABILITIES

Previous studies have shown that rather than attitudinal shortcomings, young children suffer from poor pedestrian skills and visual search strategies (Whitebread & Neilson, 2000; Tolmie, Thomson, Foot, McLaren, & Whelan, 1998) as well as other limitations in identifying the factors which compose of dangerous road-crossing sites (Ampofo-Boateng & Thomson, 1991).

As noted above, the ability of making judgments about whether crossing places are ‘safe’ or ‘dangerous’ is required for pedestrians in order to interact safely with traffic (Thomson, Tolmie, Foot, & McLaren, 1996). This process requires the capacity to detect potential hazards that are not physically and momentarily present in the environment. Recent studies have indicated that the ability to identify safe and dangerous road-crossing sites increases with age (e.g., Tabibi & Pfeffer, 2003). Similarly, Ampofo-Boateng & Thomson (1991) have clearly shown, using both on-road and off-road experiments (traffic scenes photographs, table-top board), that 5-7 year-olds exhibit very poor skill in identifying dangerous road-crossing sites. These young participants' judgments relied exclusively on the visible presence of cars in the vicinity. The researchers also found that other situations such as blind summits, obscuring obstacles or complex junctions were never recognized as threatening situations. In contrast, 9-year-olds showed a higher level of ability and 11-year-olds demonstrated quite good skills in these judgments (Ampofo-Boateng & Thomson, 1991). Further findings showed that at the most quiet locations (low traffic intensity) the percentage of children making no head movements before or during crossing decreases with age between 6-8 and 9-11 (Ocio, 1973 in Van der Molen, 1981), where the opposite phenomenon occurs at high traffic intensity locations (Grayson, 1975 in Van der Molen, 1981). On the other hand, adults were shown to keep smaller safety margins, and perform indirect crossing (crossing the road zigzagging among cars) much more than child-pedestrians (Van der Molen, 1981). Their behavior may imply that when identifying the hazard instigator, adults feel less threatened by it.

The second ability which was declared as critical for safe road behavior by Thomson, Tolmie, Foot, & McLaren (1996), is the ability to detect the presence of traffic that could be a source of danger. This ability is mainly based on the link between traffic features and the specific environment in which they are most likely to appear. Research has shown that the ability to resist interference from irrelevant stimuli increases with age (e.g., Tabibi & Pfeffer, 2003).

For example, it was shown that 4- to 9-year-old children have difficulty paying attention to the features that made a road-crossing situation dangerous; that is, they had difficulty paying attention to relevant information while ignoring irrelevant information (Hill et al., 2000). Similarly, Tolmie et al. (1998) have used three contexts (computer simulation, video, and road side) for presenting 24 traffic scenarios to children aged 5, 7, 9, 11 years and adults. The scenarios varied along several dimensions: length, informational complexity, and presence/absence of distracters. Findings showed that in all three contexts, older children were much more attuned to traffic-relevant features than younger children. Based on their results, the authors concluded that "young children had no special problem in coping with information: their problem is that they have difficulty telling which features are relevant to road crossing and which are not and are therefore unable to give the former priority when this is what the task requires" (Tolmie et al, 1998, page 1).

Lastly, the ability of integrating information from different parts of the relevant traffic environment, including different directions, was examined (Whitebread & Neilson, 2000). Underwood, Dillon, Farnsworth & Twiner (2007) asked children of three age groups (7–8 years; 9–10 years and 11–12 years) to complete two sorting tasks: (1) a free sort- where they were requested to classify 20 photographs of road scenes on self-selected criteria and (2) a cued sort- where they were requested to reclassify the scenes on the basis of the safety of each scene. When participants operated a free sort, age differences were apparent in both the number and type of categories produced. However, these age differences were not evident in the cued sort. Findings have shown that the younger children were strongly influenced by cueing. The researchers concluded that younger children exhibit an idiosyncratic perspective of the road, as compared to the older children, who are able to observe the road from a global perspective (Underwood, Dillon, Farnsworth & Twiner, 2007). Similarly, Whitebread & Neilson (2000) investigated the nature of visual search strategies adopted by children faced with the pedestrian task, while recoding their head and eye movements (only duration and location of the eye without an accurate measure of fixations and saccades). Using intersection movie presentations (either on one or three screens simultaneously) and photographs, the researchers found a strong relationship between a quick checking strategy in the 4-seconds before the children decided to cross the road (participants were instructed to declare 'cross' each time they thought it was safe to cross according to the movie) and their scores in the pedestrian skills examination taken earlier. The researchers also showed that the number of looks to the three screens (left, right and center) was highly correlated with pedestrian skills of 7-8 year-olds children. They concluded that a major change in the strategic approach to visual information-sampling occurred around this age. Another major difference at the strategic level of information processing was found for 10-11-year-olds and for adults, where the mean duration of each ‘look’ was much shorter than that of the other groups. Specifically, 10-11-year-old pedestrians and adults pedestrians looked at the center screen (where a side road was coming onto the main road and it was not possible to see very far down along it) much more often than the other younger groups and for shorter mean durations, suggesting that the adults recognized that traffic could emerge from this side road rather promptly (Whitebread & Neilson, 2000).

1.4. HAZARD PERCEPTION AMONG CHILD-PEDESTRIANS

When inspecting the abilities suggested by Thomson, Tolmie, Foot & McLaren (1996) as vital for inducing safe road behavior, the common denominator between them is revealed. All of these abilities are hazard-perception-related. Hazard perception can be defined as the process of evaluating the hazardousness of a traffic situation (Benda & Hoyos, 1983). It can also be described as the ability to 'read the road' and anticipate forthcoming events; a situation awareness for hazardous situations in the traffic environment (Horswill & McKenna, 2004). Situation awareness (SA) was described by Endsley (1995) as a state of knowledge which enables a holistic perception of the environment. Achieving this state involves a three-level process which includes perception of elements in the environment, comprehension of their integrated meaning in order to create a holistic appreciation of the current situation and projection of their status in order to predict near future events (Endsley, 1995). Early research has indicated that part of the reason for the higher accident rate with young children may be their relative inability to perceive hazards correctly (Martin & Heimstra, 1973). More recent studies have also indicated that an important ability for child-pedestrians is the ability to ‘read the road’ (e.g., Foot et al., 2006). According to Hill, Lewis & Dunbar (2000) there is evidence that young children are poor at identifying unsafe situations. These researchers argue that the high accident rate for child-pedestrians is a result of the failure to recognize a potential danger when unprompted, thus, they suggested that young children's understanding of danger is not robust (Hill, Lewis & Dunbar, 2000). For this reason, it seems logical for a road safety study to concentrate on developing specific training programs which will suit the needs of child-pedestrians in order to enhance their ability to detect hazards.

1.5. TRAINING YOUNG CHILDREN

A common view in the road-safety field is that children are inherently incapable of dealing with the traffic environment until they have reached a certain level of cognitive development. However, according to Thomson, Tolmie, Foot & Mclaren (1996), developmental theories (e.g., Piaget, 1969; Vygotsky, 1978) have long argued for the natural progression of understanding from action to concept. These theories place an emphasis on learning as a bottom-up process constructed from specific actions in specific contexts. In the context of pedestrian training methods, it was suggested that practical training programs can lead to significant improvements in developing children's skills. In fact, there is a substantial literature within the field of road safety, demonstrating the success of training a variety of road crossing skills (Thomson, Tolmie, Foot & Mclaren, 1996), such as children's ability to make roadside timing judgments (Demetre et al., 1992), plan safe routes (Thomson et al., 1992) and cross safely at junctions (Rothengatter, 1981). For example, Ampofo-Boateng et al. (1993) found that 5- and 7-year-olds were largely unaware of the dangers posed by parked cars and other visual restrictions. However, when individually trained in finding safe places to cross, 5-year-olds showed a substantial improvement in performance. Accordingly, researchers suggested that road crossing skills are not utterly dependent upon maturational factors (Ampofo-Boateng et al., 1993). It seems that when being used, practical training techniques may well result in improvements in the road-safety-related skills of child-pedestrians.

1.6. SIMILARITIES BETWEEN CHILD-PEDESTRIANS AND YOUNG-NOVICE DRIVERS

The literature on young-inexperienced drivers shows that some of the major causes for their over involvement in traffic crashes can be attributed to their lack of driving experience. Interestingly, these impediments entail high resemblance to those reported previously with regard to child pedestrians. For example, Armsby et al. (1989), asked novice and experienced drivers to rate traffic scene photographs in terms of level of hazardousness (i.e. more or less hazardous). Novice drivers rated a photograph of a pedestrian crossing the road as more hazardous than experienced drivers, but rated a photograph of fog as less hazardous than the experienced drivers. Hence, as in the case of child-pedestrians (e.g., Ampofo-Boateng & Thomson, 1991), the lack of experience prevented novice drivers from considering potential hazards unless they are salient and physically present in the environment.

The resemblance between child-pedestrians and novice drivers with respect to their ability to pay attention to relevant information while ignoring irrelevant information should also be acknowledged. Benda and Hoyos (1983) found that inexperienced drivers pay attention to unimportant details and therefore were unable to extract important road-related information. This finding resembles Hill et al.'s (2000), which have showed that 4- to 9-year-old children have difficulty focusing on the features which are creating a dangerous road-crossing situation.

Lastly, Benda & Hoyos (1983) found that novices assess traffic hazards on the basis of a single characteristic, so that all situations which share a certain characteristic (e.g., slippery road) are perceived by them as equally dangerous. In contrast, experienced drivers perceive situations more holistically, on the basis of multiple characteristics (Benda & Hoyos, 1983). Similarly, Borowsky et al., (in press) have shown that novices, as opposed to experienced drivers, rarely fixate at merging roads when driving a car. As in the case of child-pedestrians, these young-novice drivers' ability of integrating information from different parts of the relevant traffic environment, is poor (Whitebread & Neilson, 2000). Instead, they tend to concentrate on the most salient factor (Ampofo-Boateng & Thomson, 1991; Demetre & Gaffin, 1994; Foot et al., 1999).

1.7. IMPLICATIONS FOR THE CURRENT STUDY

Considering the evidence shown earlier it is believed that there is yet no comprehensive research that links a well-established theory regarding skill acquisition with pedestrian skills. As shown earlier, there is a tight link between the behavior of young-novice drivers in their ability to detect hazards and the task requirements of pedestrians crossing a road. In addition, the methods and sophistication which have been developed for assessing hazard perception among drivers, such as using eye-tracking systems, might be helpful in providing in-depth understanding of prominent road crossing deficits among child pedestrians that will create a platform for developing a training program for young pedestrians. A first step in developing such a program requires a more established understanding of children traffic behavior patterns (e.g., when and where do children cross the road?). Comparing adults and children in their eye-movements will also provide a better picture of what elements in the traffic environment are crucial for the road crossing task. Some of the research on hazard perception (e.g., Borowsky et al., in press) shows that – as in all learning - feedback is necessary for later prediction of potential hazards. Similarly, once crucial environmental elements and strategies of information processing are identified, children should experience traffic scenes in which actual hazards are present so that they can later anticipate potential hazards. Since similar patterns of results were shown in both on and off road experiments (e.g., Tolmie et al., 1998) video technique should be a useful tool to train children in pedestrian skills (e.g., Pitcarin & Edlmann , 2000). Real life, outdoor traffic environments are unpredictable, making it difficult to control all relevant variables and to design a training program which will comprise a variety of traffic situations (e.g., Novak, 2009). It is possible that other techniques of exposing pedestrians to a range of hazardous situations may improve child-pedestrians skills. One such promising technique in reducing child pedestrian injury risk can be achieved by the utilization of a virtual environment (e.g., Schwebel, Gainesa & Seversonb, 2008; Novak, 2009). Virtual reality (VR) may be described as a computer or video generated environment, designed to mimic real world situations by providing a user with a sense of being immersed in a displayed virtual world through realistic graphics, high-quality sound and the ability to interact with the virtual world (e.g., Reid, 2002; Schwebel, Gaines & Severson, 2008; Novak, 2009). VR offers an alluring alternative which enables participants to be repeatedly exposed to a variety of realistic hazardous situations without the threat of enduring injury- a critical advantage when dealing with child-pedestrians in the hazardous traffic environment (e.g., Schwebel, Gainesa & Seversonb, 2008). Moreover, the utilization of virtual environment for training can aid in reproducing identical situations for each of the participants and controlling confounding variables (e.g., Schwebel, Gaines & Severson, 2008; Novak, 2009). Evidence indicates that VR is a valid strategy for training in other domains, such as educating operative skills in surgical trainees (e.g., Seymour, 2002). Research on a VR as a methodological tool for training child-pedestrians in road safety behavior is in its preliminary stages; yet, evidence suggests that VR environment might be utilized as an appropriate methodology, both for etiological research on the sources for child-pedestrians' injuries and for intervention research (e.g., Schwebel, Gaines & Severson, 2008). Indeed, several studies have successfully utilized a virtual environment for training children various pedestrian skills (e.g., McComas et al., 2002; Thomson et al., 2005).

Mixed Reality (MR) is a particular subset of VR-related technologies which involves the merging of real and virtual worlds along a "virtuality continuum", which connects completely real environments to completely virtual ones (Milgram, 1994). According to Hughes, (2005), an MR experience takes place when a user is positioned in an interactive setting which is either real, containing virtual asset augmentation (augmented reality), or virtual, containing real-world augmentation (augmented virtuality). Novak (2009) suggests that training programs, attempting to enhance child-pedestrians skills, need to enable the generalization of knowledge and the transformation of behaviors learned in the training into real-life situations. Indeed, it was suggested that the blurring of the boundary between real and unreal, made possible with VR and MR, may help to transfer the material learnt into the real world (Carlin, 1997). On the basis of these arguments, it seems that using a Dome projection environment technique, which enables accurate, controllable and immersive simulation of diverse crossing environments, will be particularly beneficial in enhancing child-pedestrians' HP skills. Accordingly, HP-based scenario-array was tailored on the basis of the experience gained from training young-novice drivers in hazard perception, and its effectiveness tested.

1.7.1 DEFINITION OF HAZARDOUS SITUATIONS

The scenario database was created according to several parameters and consideration:

1. Findings derived from the exhaustive literature review regarding factors found to differentiate between pedestrians with varying levels of road-crossing experience or factors which were found to correlate with traffic crashes.
2. Equivalent factors to the one found to create differentiation between drivers with varying levels of experience (i.e., novice versus experienced drivers).
3. The experimental Dome- settings limitations and strengths.

1.7.1.1 Findings derived from the literature

The first parameter taken into account was factors differentiating between experienced and novice pedestrians and factors found to correlate with child-pedestrians' poor HP ability.

Previous research had shown that the majority of children are injured on non-arterial roads, particularly in residential areas (e.g., Lawson, 1990; Roberts et al., 1994). Moreover, pedestrians' traffic crashes which occur in inhabited areas tend to take place in locations presenting complex configurations- i.e., junctions, crossroads and other intersections where traffic might arrive from several different directions (thus challenging the child-pedestrian's search and information-processing capacities) (Ampofo-Boateng & Thomson, 1990).

Past research had also suggested that pedestrians' traffic crashes which occur in inhabited areas tend to take place in locations where visibility is restricted, e.g., at curves, near parked cars (Ampofo-Boateng & Thomson, 1990). Thus, on-street vehicle parking presents a particular risk for child-pedestrians (Petch & Henson, 2000). Parked cars interfere with their ability to detect oncoming vehicles, while also obstructing the motor vehicle drivers' vision, preventing them from noticing child-pedestrian who may be masked by stationary vehicles along the road (e.g., Aoki and Moore, 1996; Petch & Henson, 2000).

Studies from USA and Canada have suggested that there are lower pedestrians road crashes rates on one-way streets as compared with two-way streets (Zegeer, 1991). However, Summersgill & Layfield (1998) have indicated that there is no difference in the level of pedestrians' crash risk between one-way and two-way roads with the same cross-section.

Ekman (1996) have argued that marked crossing with no other facilities (e.g., Zebra crossing) possess a high risk for road crashes. These researchers suggested that marked crossing with no other facilities provide pedestrians with a false sense of security as they are not visible to vehicles and likewise vehicles are not visible to pedestrians. Additionally, misinterpretation of zebra crossing's purpose has been observed to result in traffic crashes (Van der Molen, 1981; Vinje, 1981).

According to Ampofo-Boateng & Thomson (1991), the younger child-pedestrians are, the more they are likely to base their evaluation of a crossing site as safe or dangerous on a single factor- the presence or absence of cars on the road. Children aged 5 and 7 were found to determine the safety of a site purely on whether they can see cars on the road, where the presence of a vehicle anywhere (even remotely in the vicinity of the location) was correlated with these younger children judgment of the situation as dangerous.

Another critical factor is familiarity. Using a virtual road crossing environment, Johnston & Peace (2007) investigated the road crossing behavior of pedestrians in familiar and unfamiliar environments. Environment familiarity was manipulated using traffic direction. Approximately half of the participants were from a country where traffic flows from right to left, while the others came from countries were traffic flows from left to right. Each participant was requested to cross the road when traffic was coming from both the familiar and the unfamiliar direction for them. Results have indicated that pedestrians had a lower safety ratio in crossing when presented with an unfamiliar direction, indicating of an unsafe crossing behavior and a higher risk for traffic crashes in such traffic environments compared to familiar environments.

1.7.1.2 Findings derived from analogous conditions to novice versus experienced drivers

The second parameter taken into account consisted of factors differentiate between drivers with varying levels of experience. As aforesaid, the literature suggests that there are many similarities between young-novice drivers' hazard perception ability for driving a motor vehicle and child-pedestrians hazard perception ability while road-crossing. Thus, it was logical to use our previous research regarding young-novice drivers' hazard perception ability (summarized in the RN report "Towards developing a hazard perception training program for young inexperienced drivers"- Meir, Borowsky, Oron-Gilad, Parmet & Shinar, 2010) as a starting point for the process of defining hazardous situations in the context of road crossing. This research yielded a matrix of factors regarding hazardous situations which are able to differentiate between hazard perceptions abilities of drivers with varying levels of driving experience (see Table 1).

In our previous Ran Naor research summary "Towards developing a hazard perception training program for young inexperienced drivers"- by Meir, Borowsky, Oron-Gilad, Parmet & Shinar, 2010, three of the categories which distinguished the most between experienced and novices' responses were: presence of pedestrians, intersections and field of view. Indeed, these results bear some resemblance to the literature regarding child-pedestrians, as the factors of limited field of view and intersections plays an important role in these road users' decision whether it is safe to cross the road.

Table 1. Unified Factor/sub factor classification for drivers (novice and experienced drivers) derived from our previous research "Towards developing a hazard perception training program for young inexperienced drivers"- Meir, Borowsky, Oron-Gilad, Parmet & Shinar, 2010

A Pedestrians	B Intersections	C Field of View (FOV)	D Roadway Hazard	E Vehicle Behavior	F Road signs and traffic lights
Pedestrian on sidewalk	Intersection	Dazzle	Defective road	Vehicle stopping	Traffic lights
Bus stopping to load/unload passengers	Circle	No FOV	Obstacle on road	Bus Stopping	Road signs
Pedestrians on road	Entrance to a residential/commercial parking	Parked vehicles	Narrow road	Vehicle ahead	Billboards
A driver as a pedestrian (i.e., stepping out of a car)		Curvature in road	Merging of lanes	Lead vehicle braking	Street crossing
Residential area - potential presence of pedestrians		Driving uphill	Curvature in road	*Overtaking	Missing road markings
			Parked vehicle is sticking out on road	*Lane changing	
			Bumpers	Rear Mirror (vehicle in rear)	
			Construction work	*Inappropriate vehicle speed	
			Steep downhill drive	Vehicle too close	
				Vehicle in junction	
				Vehicle not maintaining lane	
				Heavy vehicles ahead	

1.7.1.3 Limitations and strengths of the experimental Dome settings

The third parameter taken into account regarded the Dome- settings limitations and strengths. With regard to strength: (1) The use of a virtual urban environment simulation enables us to create crossing situations at any location within the virtual city. Thus, different levels of complexity derived from the geometry of the road or from proximity to intersections can be easily generated. (2) Furthermore, the experimental scenario generation mechanism allows replications of similar situations with obscured FOV and without it (e.g., parked vehicles present or not), in addition the use of different types of vehicles can be implemented for the same situation (e.g., a truck, a bus, a private vehicle, a motorcycle can be used to obscure FOV as parked vehicles or as the moving vehicles on the road). (3) Lastly, the density of traffic can be controlled (e.g., a single vehicle versus multiple vehicles tailgating one another).

The last two parameters have not been thoroughly examined in the literature and can be rather easily implemented with the VR/MR experimental setup. One of the factors found to affect pedestrians road crossing behavior was familiarity with the crossing environment. As aforesaid, Johnston & Peace (2007) used a virtual road crossing environment to investigate the road crossing behavior of pedestrians in familiar and unfamiliar environments, by manipulating traffic direction, thus, making use of participants from different nationalities. However, the current study takes place in Israel and with Israeli child-pedestrians. Moreover, even though the VR/MR environment created by the Dome settings has many apparent advantages (e.g., enabling a safe environment for examining and training child-pedestrians ability where mistakes can be made without physical danger), it is hard to create a sense of familiarity in the broad sense of the word, in the participants. Thus, this factor would not, as we see it now, be a part of the experimental factors' array. Nevertheless, this factor was examined in the first pilot study described in Chapter 2 of this document.

1.7.1.4 Summary of factors

To conclude, several different factors were found to influence pedestrians and child-pedestrians' road crossing behavior. Seven prominent (yet not orthogonal) factors can be manipulated within our experimental setup:

(1) Complexity of road configurations, i.e. the presence of intersections (yes/no),
(2) Presence of vehicles in the lane closest to the pedestrian (yes/no),
(3) Field of view (limited (by road geometry/stationary objects) vs. unrestricted),
(4) Presence of zebra crossing (Zebra crossing vs. no Zebra crossing),
(5) Type of road (one vs. two-way streets),
(6) Type of moving vehicle (e.g., approaching vehicle vs. approaching truck).
(7) Traffic density (no traffic, low/single vehicle, multiple vehicles).

All of our scenarios display urban areas. However, taking into account the all possible combinations of the 7 factors described above leads to a very large number of scenarios.

Due to the fact that taking into account all possible combinations of the factors described above will lead to a very large number of scenarios, the present study concentrated on a sub-set of factors while taking into account the research setting's constrains and limitations as well as the experimental participants' limited span of attention. In order to explore the HP abilities and deficiencies of child-pedestrians in the context of road-crossing, and in order to try and gain a clearer understanding regarding the implications of their lack of experience as pedestrians for their road safety behavior, we created a taxonomy of factors which will be able to differentiate among pedestrians at different age and experience levels. It was hoped that the creation of this taxonomy will lay the ground towards a better understanding of child-pedestrians' HP ability and would provide an initial step towards the process of producing proper guidelines for future HP training program regarding this population. Consequently, an attempt was made to account for a variety of factors. Factors were first divided into two main groups: static and dynamic (see Table 2). Static factors were characterized as stationary, still, motionless factors, and were utilized for defining the scenario's environmental setting. Conversely, dynamic factors were utilized for defining the scenario's behavioral setting.

Table 2. The categorization of the factors into static and dynamic.

Static factors	Dynamic factors
Field of view	Presence of vehicles in the lane closest to the pedestrian
Type of road	Traffic speed
Presence of zebra crossing	Moving vehicle's type
Complexity of road configurations	Traffic density

Taking into account the all possible combinations of the factors described above would have again led to a very large number of scenarios, thus a sub-set of the most essential, applicable factors was used for the scenarios tailoring process (see Table 3 in the Method section).

As the majority of children are injured on non-arterial roads, particularly in residential areas (e.g., Lawson, 1990; Roberts et al., 1994), scenarios were all placed in a generic residential simulated environment. Each scenario displayed a specific road-crossing environment and was presented from a pedestrian's point of view (i.e., as if they were pedestrians standing on one side of the pavement intending to cross over to the other side).

1.7.2 TARGET PARTICIPANTS

There is general agreement among traffic safety professionals in Israel that children under the age of 9 should not cross roads alone. In other countries it was even suggested to prohibit children from crossing roads alone until the age of ten (e.g., Percer, 2009).

According to Piaget's (1969) influential theory of development, cognitive development is composed of four main stages: the sensori-motor stage (0-2 years of age), the pre-operational stage (2-7 years), the concrete operational stage (7-11 years) and the formal operational stage (11 years upwards). During each stage, critical cognitive abilities are achieved. Pre-operational children are characterized by the lack of ability to focus on two dimension of a task at the same time. Furthermore, they often encounter difficulties in assuming the perspective of another person (i.e., an egocentricity effect). Around the age of 7, children progress from the pre-operational stage to the concrete operational stage, and begin to think logically about concrete events. Accordingly, their abilities of differentiating time and space and of understanding drivers' intentions, also tend to progress. Indeed, evidence from the road safety domain demonstrated the success of training a variety of road crossing skills to young children (e.g., Thomson, Tolmie, Foot & Mclaren, 1996; Demetre et al., 1992; Thomson et al., 1992; Rothengatter, 1981). It was concluded that 7-to-11 years of age are the most formative for the development of road crossing skills among children (e.g., Thomson et al., 1996; Foot et al., 2006). Taken together with the findings indicating that child-pedestrians' crashes are a significant cause of injury mainly in the age range of 5-to 9-years (e.g., Whitebread & Neilson, 2000; Tabibi & Pfeffer, 2003), the current research will concentrate on primary-school children at the age range of 7-to-13. The age-group allocation would refer to young children, under the age of 9 (which has been suggested should not engage in road-crossing alone), children in the age-range of 9-10 and older children (over the age of 10).

To summarize, in the present study, 6-13-year-olds children and adults observed road crossing scenarios displaying a variety of traffic situations from the point of view of pedestrians and were asked to perform a road-crossing task, i.e., to press a button each time they thought it is safe to cross the road. Throughout the experiment participants' eye movements were recorded for later analysis.

2. STUDY 1 – CLASSIFIACTION OF CROSSING SCENES

Presented below is a summary review of Study 1. For complete review see Meir, Oron-Gilad, Borowsky & Parmet, (2011).

2.1 METHOD

2.1.1 PARTICIPANTS

Sixty participants, Twenty 6-8-year-olds, twenty two 9-12-year-olds, twenty one 24-28-year-olds experienced pedestrians completed this experiment as volunteers. All participants had normal vision, with uncorrected Snellen static acuity of 6/12 or better and normal contrast sensitivity. Participants were all requested to sign an informed consent form, approving their participation in the experiment. In addition, parental consent was required for participants under the age of 18.

2.1.2 APPARATUS

As aforesaid, several different factors were found to influence pedestrians and child-pedestrians' road crossing behavior. Each of the 12 still pictures (see Figure 1) depicting traffic-scenes taken from a pedestrian's perspective was portrayed as a different combination of values given to each of the factors: (1) Traffic density (high density / low density), (2) Field of view (limited Field of view / open field of view), and (3) Familiarity (familiar scenery / unfamiliar scenery).

2.1.3 PROCEDURE

Each of the participants observed 12 still pictures depicting traffic-scenes taken from a pedestrian's perspective as hard copies. Participants were asked to categorize these hard-copy pictures by dividing them into an arbitrary number of non-overlapping groups according to similarities in their level of hazardousness. After the classification procedure had ended, participants were asked to suggest an appropriate title for each of the groups.

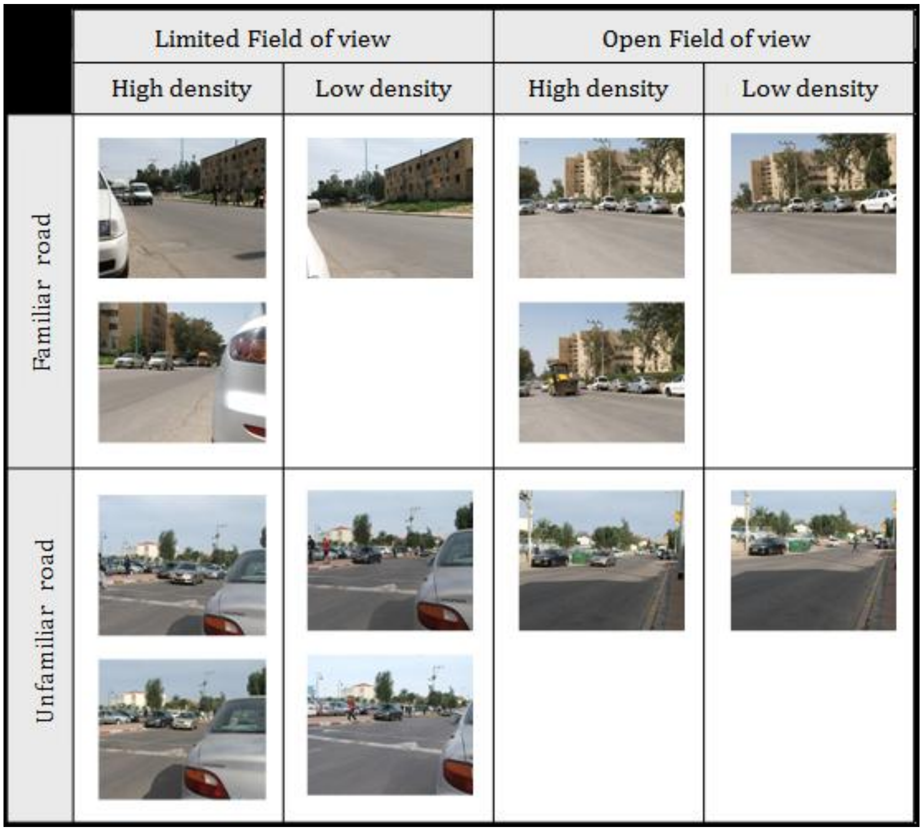


Figure 1. Traffic-scenes database in pilot study 1. Each traffic-scene was portrayed as a different combination of values given to the factors: (1) Traffic density (high density or low density), (2) Field of view (limited Field of view or open field of view), and (3) Familiarity (familiar scenery or unfamiliar scenery). Familiarity was gained by presenting school children with scenery from the proximity of their school which was while non-familiarity was gained by presenting them with scenery from the area near the university and vice versa for BGU students.

2.2 RESULTS

Overall, the results showed (see Figure 2) that experienced-adult pedestrians tended to be more aware of potential hazards (Mean number of verbal references=2.43, SD=1.21, e.g., obscured field of view from where a hazard instigator might appear) than both younger (0.05, 0.22) and older child-pedestrians (0.64, 1.05). No group referred to the familiarity factor.

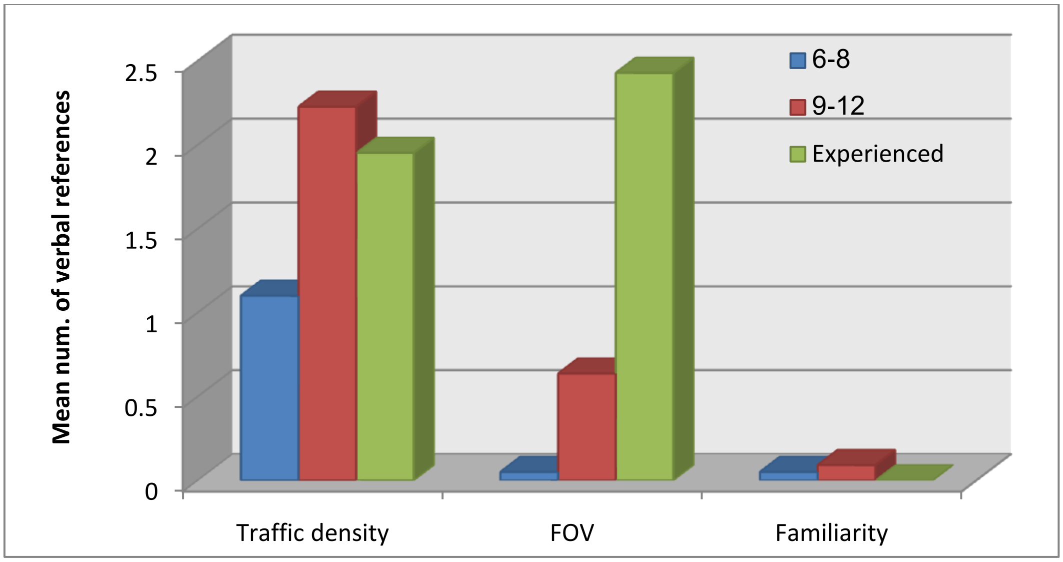


Figure 2. Distribution of pedestrians' verbal references to each traffic-related factor, according to age-group.

Classification analysis with the Clementine- Decision tree model revealed that experienced adult pedestrians referred more to the element of FOV than both child groups. 6-8-year-olds- classified according to a single criterion (primarily traffic density), while experienced pedestrians tended to classify according to combination of several criteria (e.g., traffic density and field of view). No specific classification patterns characterized the 9-12-year-olds group.

2.3 DISCUSSION

The study used an innovative paradigm to investigate child pedestrians' conceptions regarding road crossing situations. This paradigm has been used by us previously for analysis of comparing HP performance of drivers varying in age and experience-level (see Borowsky et al. 2009) and for the analysis of young novice drivers' HP training program (see Meir et al., 2010).

Understanding child-pedestrians shortcomings in accurately assessing the traffic situation may help in creating intervention techniques which may increase child-pedestrians' awareness to potential and hidden hazards and help in reducing their over-involvement in traffic crashes. It was important to note that the familiarity element, mentioned previously in the literature as a contributor to pedestrians' behavior was not perceived as a critical element in hazard classification and had much lower importance than the FOV and the presence of vehicles on the road. As such, it was decided that familiarity is not an essential factors in examining pedestrians' behavior in favor of the use of a typical Israeli urban MR environment for the major experiment. Nevertheless, this study had its limitations. The utilization of still traffic-scenes did not account for dynamics factors (e.g., moving vehicles, time and distance), did not examine the differences between pedestrians' performance in crossing decision tasks and did not examine participants' eye-movements' patterns. Those were therefore further examined in study 2.

3. STUDY 2 – CROSSING DECISION IN A MIXED REALITY DYNAMIC ENVIROMNENT

Study 2 which was the main experiment in this research program aimed to examine pedestrian crossing decisions in a dynamic environment. Structures and more complex scenarios were designed based on the factors specified in Chapter 1 of this report. Research hypotheses stated that (1) Experienced-adult pedestrians would be more sensitive to potential hazards compared to child-pedestrians; (2) The older a child-pedestrian, the more he or she would pay attention to potential hazards.

3.1 METHOD

3.1.1 PARTICIPANTS

Forty six participants, 21 experienced-adult participants (20-27-year-olds; mean age=25.11, SD=1.88) and 25 child-pedestrians (eight 7-to-9-year-olds with mean age=7.89, SD=0.70; five 9-to-10-year-olds with mean age=9.72, SD=0.33; and twelve 10-to-13year-olds with mean age=11.49, SD=0.98) completed this experiment in exchange for an educational compensation equivalent of 30 NIS (approx. $10) or bonus credit in an introductory to ergonomics course. All participants had normal vision, with uncorrected Snellen static acuity of 6/12 or better and normal contrast sensitivity. Participants were all requested to sign an informed consent form, approving their participation in the experiment. In addition, parental consent was required for participants under the age of 18.

3.1.2 APPARATUS

3.1.2.1 Dome projection facility

The research was conducted in the Virtual Environment Simulation Laboratory (Dome Projection Facility) at the Ergonomics complex in Ben-Gurion University. The 3D Perception™ "CompactClick" Dome screen system consists of a 180 degrees spherical screen 3.25 meters in radius aligned with a very accurate projection system consisting of three projectors ideal for simulation. This array allows a simultaneous projection from three different sources to be tailored into a single wide angle 3 dimensional view (see Figure 3). The screen is supported by a steal frame which combines the screen parts and is adaptable to changes in the screen size. The screen comprises a number of elements; each consists of 15 sensors which enable the precise calibration of the screen parts. The system is equipped with operational software, essential for calibrating and managing the projectors and the screen.

The facility is both temperature- and noise-controlled. The dome projection system integrates the natural visual and motor skills of an operator into the system he or she is controlling. The dome is large enough to have participants and their workstation immersed within its circumference. In addition, physical movement can be added to enhance strain and to improve simulation fidelity. The dome can be used as a simulation of reality, as an extension of human senses through tele-presence, and as an information enhancer through augmented reality.

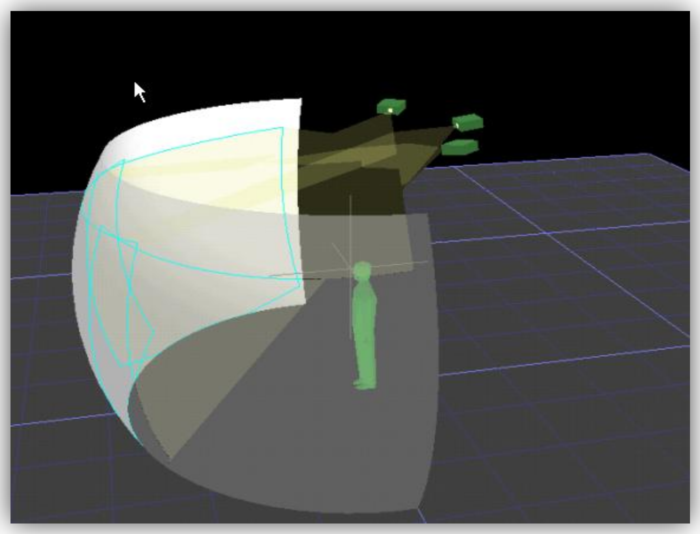


Figure 3. Dome projection facility at BGU Ergonomics complex.

3.1.2.2 Designated software

A Visual Basic designated program was developed, validated and installed in the Dome laboratory. The program allowed the synchronization between the main five control-units applied in the study: (1) the main management unit- placed on the main computer, utilized to serve the experimenter and to run the Data Logger. The main management unit control the other 4 computers through TCP/IP communication based on LAN; (2) VR-Vantage main display computer; (3-4) 2 computers running VR-Vantage Display Engines; and (5) a computer utilized for running the Eye Tracking System (ETS). Overall, this designated program allowed presenting the scenarios, recording the participants' responses (utilizing designated means of response) and analyzing the responses on a single frame basis.

3.1.2.3 Eye tracker

Participants' eye-movements were recorded throughout the experiment utilizing an ASL High-Speed Head Mounted Eye Tracker (Model H6-HS, Eyetrack 6000) Head-Mounted Eye Tracking System (ETS), thus allowing an investigation of the attended features which might have assisted the participants in reaching their decision.

This system (see Figure 4) is used to perform correct measurement of pupil diameter and gaze direction. It utilizes a technique of filming infrared light reflected from the cornea and pupil. When the light meets the eye its travels through the cornea and the pupil until its reach the back of the eye, the eye returns part of the light. The system measures the relationship between the relative position of the pupil and a reflection from the cornea's surface. The relationship between the center of this cornea reflection and the center of the pupil are used as the raw measured data of the eye tracker. Combining these measurements with a calibration procedure allows the system to measure an individual's point of gaze with respect to the field of view of the head mounted scene camera. The HS-H6 head mounted Eye Tracker is designed to track gaze direction over approximately a 30-35 degree vertical visual angle and a 40-45 degree horizontal visual angle. The system precision in measuring the gaze- direction is better than 0.5 degrees and the resolution is 0.1 degrees. The high speed models of the H6 contain a camera with multiple selectable update rates that reaches up to 360Hz. Embedding the ASL head mounted high speed eye tracking system in the virtual reality lab made it possible to follow an individual point of gaze on the 180 degrees dome screen. By analyzing the participant's eye movements it was possible to identify areas or objects of interest and individual or groups' unique behaviors.

Figure 4. ASL Eye Head-Mounted Eye Tracking System. ASL (Model H6-HS, Eyetrack 6000) Head-Mounted Eye Tracking System used for measuring eye-movements' data.

3.1.2.4 Stimuli

During the experiment each participant was instructed to observe an array of 21 typical urban scenarios from a pedestrian's point of view, i.e., as if they were pedestrians standing on one side of the pavement intending to cross over to the other side.

This crossing-scenario database utilized a custom built three dimensional generic model (e.g., Vega prime model) of a typical Israeli city and a scenario generator (i.e., DI-Guy). To achieve a three dimensional database of scenarios, a prototypical Israeli city was built in cooperation with b.design (http://www.b-d.co.il/), a leading provider of 3-D content (see Figure 5). Cars, trees, billboards and various other urban elements were also designed uniquely for this environment. Using the VT-Mak applications (http://www.mak.com/) VR-Vantage and VR-Forces different scenarios were developed to examine crossing behavior at various conditions.

As aforesaid, several different factors were found to influence pedestrians' and child-pedestrians' road crossing behavior. The scenario-database included (1) an array of 18 scenarios consisting of a structured combination of elements (i.e., presence of a Zebra crossing or not, when FOV is obscured or not, and when vehicles are present or not) and (2) and an array of three scenarios depicting several more complex road configurations (T-intersection, roundabout and vehicles stopping in front of a crosswalk, respectively), aiming to decipher participants' responses in those situations.

Each of the first 18 scenarios was portrayed as a different combination of values given to each of the dynamic and static factors. As aforementioned, taking into account all of the possible combinations of the factors described above would have led to a very large number of scenarios, thus a sub-set of the most essential, applicable factors was used for the scenarios tailoring process. We used one dynamic factor - presence of vehicles (no moving vehicles, one-way street where moving vehicles are traveling in one direction, two-way street where moving vehicles are traveling in two directions) – and two static factors: (1) Presence of a zebra crossing (with zebra-crossing, without zebra-crossing), and (2) Field of view (unrestricted, partially obscured by the road's curvature or partially obscured by parked vehicles- see Figure 6). Overall, 21 different scenarios, each 10-45 seconds long and each presenting a specific road-crossing environment were portrayed (see Table 3). Two additional scenarios were used as practice scenarios for accommodation to the task and to the system.

Notably, the distinction between a one-way street and a two-way street was conveyed to the participant in a form of motion, i.e., a two-way street presented vehicles arriving from both sides of the road, heading in opposite directions, whilst a one-way street presented vehicles arriving only from one direction to the other. Thus, when presented with no vehicles on the road, participants had neither knowledge nor a requirement to differentiate between road types.

Figure 5. The generic city simulated environment presented in the Dome setting. A side view (above) and a bird's-eye view (below).

Figure 6. The Field of View factor as displayed in the Dome scenarios: (1) Unrestricted (above); (2) Partially obscured by the road's curvature (middle); (3) Partially obscured by parked vehicles (below).

Table 3. Scenarios database. Each scenario was portrayed as a different combination of values given to the dynamic factor: (1) Presence of vehicles; and to the static factors: (1) Presence of zebra crossing, and (2) Field of view.

Scenario #	Presence of zebra crossing	Presence of vehicles	Field of view
S1	No Zebra crossing	No moving vehicles	Unrestricted
S2	Zebra crossing	No moving vehicles	Unrestricted
S3	No Zebra crossing	No moving vehicles	Restricted by parked vehicles
S4	Zebra crossing	No moving vehicles	Restricted by parked vehicles
S5	No Zebra crossing	Vehicles traveling in one direction	Unrestricted
S6	Zebra crossing	Vehicles traveling in one direction	Unrestricted
S7	No Zebra crossing	Vehicles traveling in one direction	Restricted by parked vehicles
S8	Zebra crossing	Vehicles traveling in one direction	Restricted by parked vehicles
S9	No Zebra crossing	Vehicles traveling in two directions	Unrestricted
S10	Zebra crossing	Vehicles traveling in two directions	Unrestricted
S11	No Zebra crossing	Vehicles traveling in two directions	Restricted by parked vehicles
S12	Zebra crossing	Vehicles traveling in two directions	Restricted by parked vehicles
S13	No Zebra crossing	No moving vehicles	Restricted by the road's curvature
S14	Zebra crossing	No moving vehicles	Restricted by the road's curvature
S15	No Zebra crossing	Vehicles traveling in one direction	Restricted by the road's curvature
S16	Zebra crossing	Vehicles traveling in one direction	Restricted by the road's curvature
S17	No Zebra crossing	vehicles traveling in two directions	Restricted by the road's curvature
S18	Zebra crossing	Vehicles traveling in two directions	Restricted by the road's curvature

3.1.3 MEAN OF RESPONSE

Research suggests that child-pedestrians training programs be designed so that the knowledge gained in training would be intuitively generalized and transferred to behaviors in real-life situations (Novak, 2009). Indeed, one may argue that pressing a response button is not as intuitive as crossing a road (as is, for example, stepping on a simulated zebra crossing) though it may be faster and more accurate. Comparing these two alternatives via a preliminary, pilot experiment suggested that pressing a response button was more easily understood by participants and enabled participants to become more engaged in the task, and created a higher variance of responses. Thus, it was determined as the appropriate mean of response to be used.

3.1.4 PROCEDURE

Participants were invited individually into the Virtual Environment Simulation Laboratory (Dome Projection Facility) at the Ergonomics complex at Ben Gurion University of the Negev (see Figure 7) for an hour and a half session. They were each asked to provide the experimenter with a signed informed consent form approving his or her participation in the experiment. As required, parental consent was also given for participants under the age of 18.

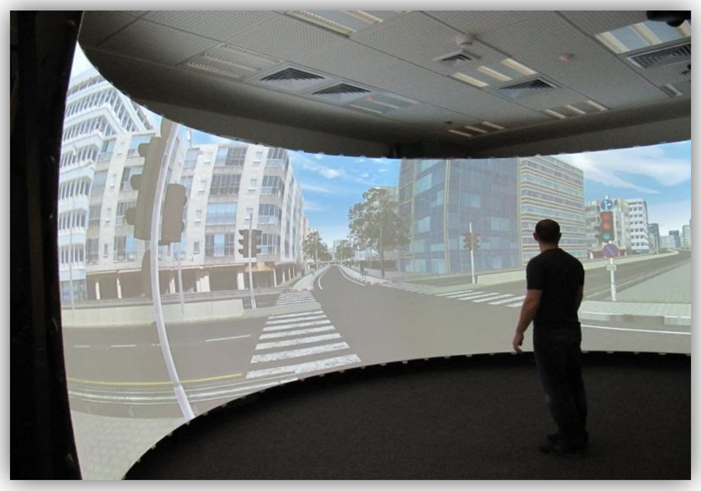


Figure 7. Ben-Gurion University of the Negev's Dome projection facility

The laboratory was kept at the same temperature and illumination conditions throughout the entire experiment, in order to maintain the experimental setting standardized throughout the entire study. Each participant was introduced to the laboratory, then, he or she went through Snellen static acuity test and contrast sensitivity test. Participants who had uncorrected static acuity of 6/12 or better and normal contrast sensitivity were able to participate in the experiment.

Subsequently, participants went through a stage of eye calibration, after which their eye-movements were recorded via the ETS. The experimenter then uploaded the experiment's designated software. Participants were then requested to settle in front of the laboratory's computer monitor at an approximate distance of 2.5 meters. Participants either read or were read (if needed) the instructions which included a comprehensive explanation of the experiment and the experimental task.

Each participant was instructed to observe several typical urban scenarios from a pedestrian’s point of view (i.e., as if they were pedestrians standing on the pavement facing the road and intending to cross over to the other side, see Figure 8) and to engage in a crossing decision - i.e., to determine whether it is safe or unsafe to cross by pressing a response button each time he or she believed it was safe to cross the road. Participants were asked to respond as quickly as possible once decided to cross, and further instructed to press only once for each crossing decision. The participants were also told that pressing the button would symbolize the crossing action that would have taken place.

Figure 8. Simulated environment from a child-pedestrian’s point of view

Two practice movies were used in order to get participants familiarized with the experimental task; participants were to observe them and respond accordingly. After making sure that the participants understood the task and were ready to continue, the experiment begun.

Participants were instructed to observe the 21 scenarios in a random order without knowing the exact number of movies they were about to see. Prior to each HP training movie, participants were to observe a fixation screen. Once the experimenter saw (via the ETS) that the participant's eye fixated on the fixation mark situated in the middle of the fixation screen, he or she activated the movie by pushing the "start" button. If the participant pressed the response button (i.e., indicating of his or her decision to cross the road), a pop-up window would reveal containing the phrase: "You have decided to cross the road. Why have you decided to cross?” However, if the participant did not press the response button until the end of the scenario (i.e., indicative of his or her decision that it was not possible to cross the road safely) a pop-up window would reveal the phrase: "You have decided not to cross the road. Why have you decided not to cross?” Either way, participants were then instructed to fill in (either by themselves or with the experimenter’s assistance) the blank field with their reason of why they had decided whether or not to cross (see Figure 9).At the end of the session, participants were asked to fill in a computerized demographic questionnaire.

Figure 9. Pop-up windows appearing after a button press was made (right) and after no button press was made throughout the scenario (left).Text boxes appear in Hebrew.

3.2 RESULTS

The present study aimed to examine experienced-based hazard perception differences in road-crossing performance among pedestrians with varied levels of road-crossing experience, in the hope of demonstrating how better awareness to hazardous factors becomes established along the continuum of road crossing experience.

Towards achieving the goal, three types of analyses were applied on participants' responses: (1) Response sensitivity- examining whether a specific group of pedestrians tend to cross more often than other groups and which types of hazardous factors are identified as relevant to the crossing decision by pedestrians with varied levels of road-crossing experience. (2) Response time analysis- examining whether a specific group of pedestrians tend to decide to cross faster than other groups. Notably, only pedestrians who responded by crossing were considered in this analysis. (3) Verbal description analysis was applied to the pedestrians' descriptions of the reasons why they had decided whether or not to cross, in order to decipher which dimensions of the traffic environment were identified by each of the pedestrian groups as hazardous.

Descriptive results derived from the eye scanning measurement are provided separately in section 3.2.4.

Analyses were applied together to results from scenarios 1-18, each consisting of a structured combination of three elements (i.e., presence of a Zebra crossing or not, when FOV is obscured or not, and when vehicles are present or not) and separately for each one of the more complex scenarios 19-21, each referring to a different complex settings- i.e., T-section, Roundabout and Vehicles stopping in front of a crosswalk (which are not necessarily defined within the three factor categories).

3.2.1 SCENARIOS 1-18 (STRUCTURED ELEMENTS SCENARIOS)

3.2.1.1 Response Sensitivity analysis

A logistic regression with a logit link function within the framework of Generalized Estimating Equations (GEE) model was applied. The dependent variable was binary distributed (a decision to cross=1, a decision not to cross =0). The between group fixed effect was Pedestrians' age-group (7-9-year-olds, 9-10-year-olds, 10-13-year-olds and experienced-adult pedestrians), and the within-group fixed effects were (1) Presence of Zebra-crossing (with zebra-crossing, without zebra-crossing), (2) Presence of vehicles (no moving vehicles, one-way street where moving vehicles are traveling in one direction, two-way street where moving vehicles are traveling in two directions), (3) Field of view (unrestricted, partially obscured by the road's curvature, or partially obscured by parked vehicles). Participants were included as a random effect to account for individual differences among participants.

Using a backward elimination procedure, the final model yielded three main effects: Presence of Zebra-crossing, Field of view, and Pedestrians' age-group, were statistically significant (Wald χ_1^2 =12.15, p=0; Wald χ_2^2 =28.50, p=0; Wald χ_2^2 =11.68, p=0.01, respectively). In addition, several interactions were statistically significant: Presence of Zebra-crossing and Presence of vehicles (Wald χ_2^2=10.40, p=0.01), Presence of Zebra-crossing and Field of view (Wald χ_2^2= 18.76, p=0), Presence of vehicles and Pedestrians' age-group (Wald χ_2^2= 16.56, p= 0.01), and Field of view and Pedestrians' age-group (Wald χ_2^2= 19.00, p=0). Overall, the results suggested that given time, pedestrians prefer crossing to not crossing (estimated average likelihood=0.74, Standard Error = 0.04).

Post hoc analysis for the Presence of Zebra-crossing main effect using Sequential Bonferroni correction revealed that in situations depicting zebra-crossing pedestrians' likelihood to cross (estimated average likelihood = 0.81, Standard Error = 0.04) was significantly higher (p=0.001) than in situations depicting no zebra-crossing (0.66, 0.05).

Post hoc analysis for the Field of view main effect using Sequential Bonferroni correction revealed that when the field of view was unrestricted, pedestrians' likelihood to cross (estimated average likelihood = 0.86, Standard Error = 0.03) was significantly higher (p=0.02, p<0.001, respectively) than when it was partially obscured by the road's curvature (0.74, 0.06) or when it was partially obscured by parked vehicles (0.57, 0.07). Moreover, pedestrians' likelihood to cross was significantly higher (p=0.01) when the field of view was partially obscured by the road's curvature than when it was partially obscured by parked vehicles.

Post hoc analysis for the Pedestrians' age-group main effect using Sequential Bonferroni correction revealed that experienced-adult pedestrians' likelihood to cross (estimated average likelihood=0.87, Standard Error = 0.04) was significantly higher (p=0.04, p=0.03, respectively) than that of 9-10-year-olds' (0.50, 0.13) and that of 10-13-year-olds' (0.70, 0.05). No other significant difference was found in the tendency to cross between the various Pedestrians' age-groups.

Results of the post hoc analysis of the interaction between the Presence of Zebra-crossing and the Presence of vehicles, using Sequential Bonferroni correction (see Table 4), suggest that in situations depicting zebra-crossing pedestrians' likelihood to cross was significantly higher when presented with moving vehicles, either vehicles traveling in one direction (0.85, 0.05) or vehicles traveling in two directions (0.80, 0.05) compared to situations involving no vehicles (0.76, 0.05). However, in situations depicting no zebra-crossing, pedestrians' likelihood to cross was significantly lower when presented with moving vehicles, either vehicles traveling in one direction (0.60, 0.06) or vehicles traveling in two directions (0.62, 0.08) compared to situations involving no vehicles (0.76, 0.05).

Table 4. The interaction between the Presence of Zebra-crossing and the Presence of vehicles

Presence of vehicles / Presence of zebra-crossing	No moving vehicles	One-way street- Vehicles traveling in one direction	Two-way street- Vehicles in two directions
Zebra-crossing	0.76, 0.05	0.85, 0.05	0.80, 0.05
No zebra-crossing	0.76, 0.05	0.60, 0.06	0.62, 0.08

Values stand for the estimated average likelihood of button presses and the standard errors, respectively

Results of the post hoc analysis of the interaction between the Presence of Zebra-crossing and Field of view, using Sequential Bonferroni correction (see Table 5), suggest that while pedestrians' likelihood to cross in situations depicting unrestricted field of view and zebra-crossing (0.91, 0.03) did not differ from situations depicting unrestricted field of view with no zebra-crossing (0.76, 0.05), and while pedestrians' likelihood to cross in situations depicting field of view partially obscured by parked vehicles and zebra-crossing (0.54, 0.06) was not found to differ from situations depicting field of view partially obscured by parked vehicles with no zebra-crossing (0.60, 0.08), pedestrians' likelihood to cross in situations depicting field of view partially being obscured by the road's curvature was significantly higher when these situations included zebra-crossing (0.85, 0.05) than when these situations included no zebra-crossing (0.58, 0.08).

Table 5. The interaction between the Presence of Zebra-crossing and Field of view

Presence of Zebra-crossing \ Field of view	Unrestricted	Restricted by parked vehicles	Restricted by the road's curvature
Zebra-crossing	0.91, 0.03	0.54, 0.06	0.85, 0.05
No zebra-crossing	0.79, 0.05	0.60, 0.08	0.58, 0.08

Values stand for the estimated average likelihood of button presses and the standard errors, respectively

Results of the post-hoc analysis of the interaction between the Presence of vehicles and Pedestrians' age-group, using Sequential Bonferroni correction (see Table 6), suggest that child-pedestrians in the age range of 9-to-10-years' likelihood to cross was significantly higher ($p=0.04$) in situations presenting no moving vehicles (0.68, 0.10) than in those presenting vehicles traveling in one direction (0.35, 0.14).

Table 6. The interaction between the Presence of vehicles and Pedestrians' age-group

Presence of vehicles \ Age-group	7-9	9-10	10-13	Adults
No moving vehicles	0.76, 0.09	0.68, 0.10	0.66, 0.08	0.88, 0.04
One-way street- Vehicles traveling in one direction	0.85, 0.09	0.35, 0.14	0.74, 0.05	0.89, 0.04
Two-way street- Vehicles traveling in two directions	0.84, 0.09	0.47, 0.17	0.69, 0.07	0.81, 0.05

Values stand for the estimated average likelihood of button presses and the standard errors, respectively

Results of the post-hoc analysis of the interaction between Field of view and Pedestrians' age-group, using Sequential Bonferroni correction (see Table 7), suggest that in situations depicting unrestricted field of view, experienced-adult pedestrians tended to cross (0.97, 0.02) significantly ($p=0.04$) more often than child-pedestrians in the age range of 9-to-10-years (0.61,0.11). Furthermore, experienced-adult pedestrians decided to cross significantly ($p<0.001$) more often in situations either depicting unrestricted field of view (0.97,0.02) or depicting field of view partially being obscured by the road's curvature (0.89,0.04) than in situations depicting field of view partially obscured by parked vehicles (0.49,0.06); and child-pedestrians in the age range of 9-to-10-years tend to cross significantly ($p<0.001$) more often in situations depicting unrestricted field of view (0.61,0.11) than in situations depicting field of view partially obscured by parked vehicles (0.36,0.15).

Table 7. The interaction between Field of view and Pedestrians' age-group

Field of view \ Age-group	7-9	9-10	10-13	Adults
Unrestricted	0.86, 0.06	0.61, 0.11	0.83, 0.04	0.97, 0.02
Restricted by parked vehicles	0.81, 0.12	0.36, 0.15	0.57, 0.10	0.49, 0.06
Restricted by the road's curvature	0.79, 0.11	0.53, 0.20	0.64, 0.10	0.89, 0.04

Values stand for the estimated average likelihood of button presses and the standard errors, respectively

3.2.1.2 Response Time analysis

Next, response times for those who responded were examined. Since response times are not normally distributed they were log-transformed. Then, a Linear Mixed Model (LMM) including a backward elimination procedure was utilized. The between-group fixed effect included in the model was Pedestrians' age-group (7-9-year-olds, 9-10-year-olds, 10-13-year-olds and experienced-adult pedestrians), and the within-group fixed effects included (1) Presence of Zebra-crossing (with zebra-crossing, without zebra-crossing), (2) Presence of vehicles (no moving vehicles, one-way street where moving vehicles are traveling in one direction, two-way street where moving vehicles are traveling in two directions), (3) Field of view (unrestricted, partially obscured by the road's curvature or partially obscured by parked vehicles). The dependent variable was the participants' log transformed response time: the time that elapsed from the beginning of the event up until the pressing took place. Participants were included as a random effect to account for individual differences among participants.

Applying a Linear Mixed Model (LMM) revealed a significant main effect of Presence of vehicles ($F_{2, 534.1}= 95.23$, $p<0.001$). LSD pair-wise comparisons analysis suggested that pedestrians tended to cross significantly ($p<0.001$) faster (Mean crossing time=6.23 sec, Mean log transformed crossing time=1.83 sec, Mean log transformed standard error=0.06) when encountering situations involving no vehicles than when presented with moving vehicles, either vehicles traveling in one direction (11.94, 2.48, 0.06) or vehicles traveling in two directions (13.33, 2.59, 0.06). However, no significant difference was found between participants' responses to the latter two.

There was also a significant main effect of Field of view ($F_{2, 543.6}= 33.06$, $p<0.001$). Conducting LSD post hoc pair-wise comparisons analysis revealed that pedestrians tended to cross significantly ($p<0.001$) faster (Mean crossing time=7.77 sec, Mean log transformed crossing time=2.05, Mean log transformed standard error=0.06) when encountering limited field of view caused by a curve than when encountering limited field of view caused by parked vehicles (10.18, 2.32, 0.06) or an unrestricted field of view (12.43, 2.52, 0.06). Moreover, pedestrians tended to cross significantly ($p=0.001$) faster when encountering limited field of view caused by parked vehicles than when encountering unrestricted field of view.

Applying a Linear Mixed Model (LMM) revealed a significant main effect of Pedestrians' age-group ($F_{3, 46.2}= 4.82$, $p<0.01$). LSD pair-wise comparisons analysis revealed that the youngest child-pedestrians (7-9-year-olds) tended to cross (Mean crossing time=7.77 sec, Mean log transformed crossing time=2.05, Mean log transformed standard error=0.09) significantly faster ($p<0.001$, $p=0.03$; respectively) than the oldest child-pedestrians (i.e., 10-13-year-olds; 12.30, 2.51, 0.08) and the experienced-adult pedestrians (9.97, 2.30, 0.06). Moreover, experienced-adult pedestrians tended to cross significantly ($p=0.04$) faster than the oldest child-pedestrians.

The LMM also revealed a significant interaction between Presence of Zebra-crossing and Field of view ($F_{2, 530.6}= 4.92$, $p<0.01$). As can be seen in figure 10, while the difference between pedestrians' crossing times when presented with unrestricted field of view in situations depicting no zebra-crossing (Mean crossing time=11.02 sec, Mean log transformed crossing time=2.40, Mean log transformed standard error=0.07) and in those depicting zebra-crossing (14.15, 2.65, 0.06) was large, the difference between pedestrians' crossing times when presented with field of view partially being obscured by the road's curvature in situations depicting no zebra-crossing (7.85, 2.06, 0.08) and in those depicting zebra-crossing (7.77, 2.05, 0.06) was much smaller.

Moreover, a significant interaction between Presence of Zebra-crossing and Pedestrians' age-group ($F_{3, 534.3}= 2.73$, $p=0.04$). Notably, as can be seen in figure 11, while the youngest child-pedestrians (7-9-year-olds) tended to cross faster (Mean crossing time= 8.33 sec, Mean log transformed crossing time=2.12, Mean log transformed standard error=0.10) in situations depicting zebra-crossing than in situations depicting no zebra-crossing (7.24, 1.98, 0.10), pedestrians in all other age-groups tended to linger more in situations depicting zebra-crossing (11.59, 2.45, 0.14; 13.20, 2.58, 0.09; 10.59, 2.36, 0.06) than in situations depicting no zebra-crossing (9.39, 2.24, 0.16; 11.36, 2.43, 0.09; 9.39, 2.24, 0.07).

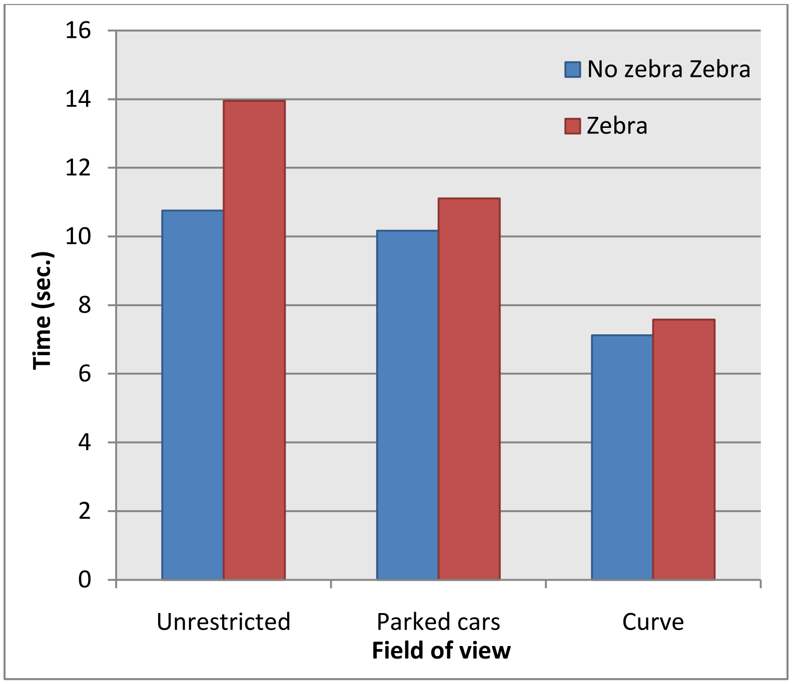


Figure 10. The interaction between Presence of Zebra-crossing and Field of view on reaction time to cross.

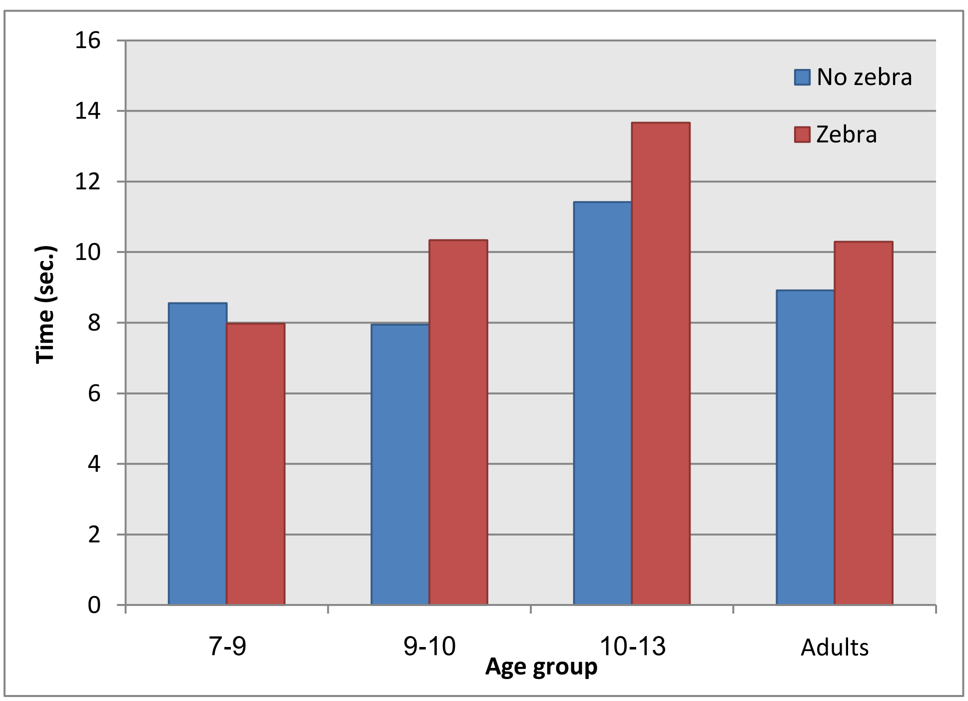


Figure 11. The interaction between Presence of Zebra-crossing and Pedestrians' age-group.

Lastly, a significant interaction between Field of view and Pedestrians' age-group ($F_{6, 540.4}$= 5.35, p<0.001) was found. As can be seen in figure 12, experienced-adult pedestrians tended to linger more in situations depicting field of view partially obscured by parked vehicles (Mean crossing time=12.55 sec, Mean log transformed crossing time=2.53, Mean log transformed standard error=0.08) than in situations depicting unrestricted field of view (11.47, 2.44, 0.07), while pedestrians in all other age-groups tended to cross faster in situations depicting field of view partially obscured by parked vehicles (6.62, 1.89, 0.11; 11.13, 2.41, 0.19; 11.59, 2.45, 0.10) than in situations depicting unrestricted field of view (11.13, 2.41, 0.11; 12.06, 2.49, 0.16; 15.80, 2.76, 0.09).

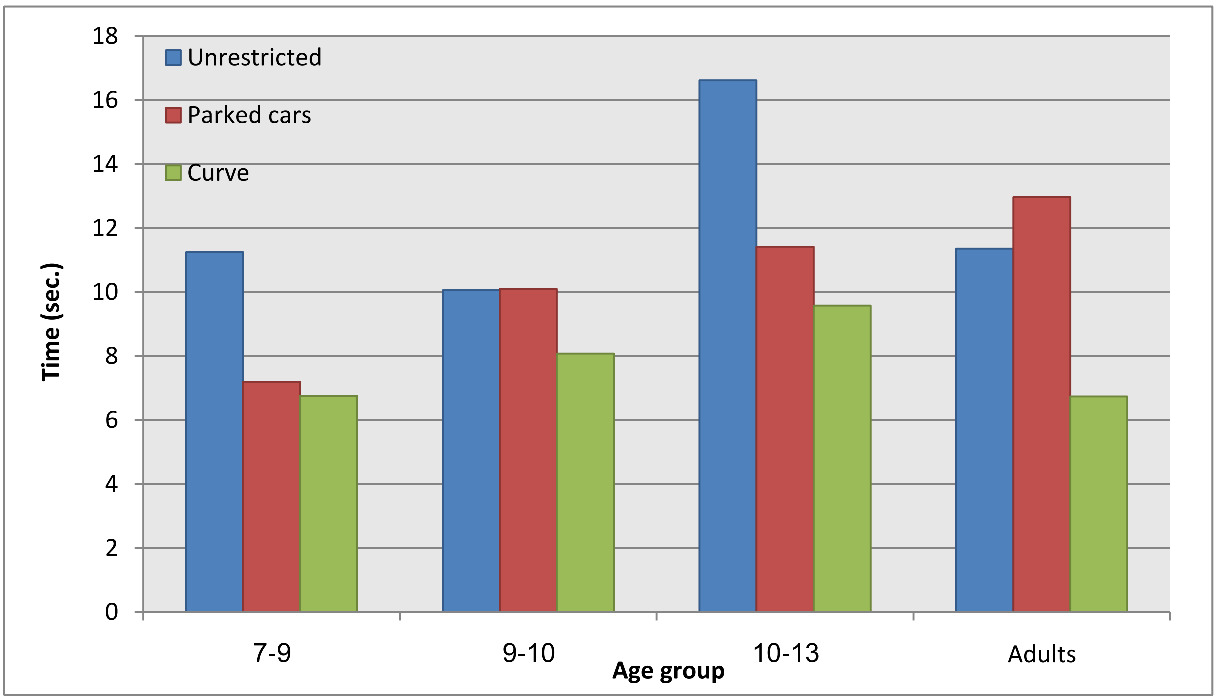


Figure 12. The interaction between Field of view and Pedestrians' age-group.

3.2.2 SEPARATE ANALYSES FOR SCENARIOS 19-21 (COMPLEX SCENARIOS)

3.2.2.1 Response Sensitivity analysis

A logistic regression with a logit link function within the framework of Generalized Estimating Equations (GEE) model was applied. The dependent variable was binary distributed (a decision to cross=1, a decision not to cross =0). The between group fixed effect was Pedestrians' age-group (7-9-year-olds, 9-10-year-olds, 10-13-year-olds and experienced-adult pedestrians). Analyses were utilizing the backward elimination procedure.

3.2.2.1.1 T-intersections

The final model yielded a significant main effect of Pedestrians' age-group (Wald χ_1^2 =613.059, p=0). Pair-wise comparisons analysis using Sequential Bonferroni correction revealed that experienced-adult pedestrians' likelihood to cross in complex situations depicting T-intersections (estimated average likelihood=1, Standard Error=0) was significantly higher (p=0.04) than that of 9-10-year-olds' (0.40, 0.22). No other significant difference was found between the various Pedestrians' age-group tendencies to cross.

3.2.2.1.2 Roundabouts

The final model yielded no significant main effect of Pedestrians' age-group regarding complex situations depicting roundabouts (Wald χ_1^2 =3.79, p=N.S.).

3.2.2.1.3 Vehicles stop in front of a crosswalk

The final model yielded a significant main effect of Pedestrians' age-group (Wald χ_1^2 =12.15, p=0). Pair-wise comparisons analysis using Sequential Bonferroni correction revealed that experienced-adult pedestrians' likelihood to cross in complex situations depicting Vehicles stop in front of a crosswalk (estimated average likelihood=1, Standard Error=0) was significantly higher (p=0.04) than that of 9-10-year-olds' (0.40, 0.22). No other significant difference was found between the various Pedestrians' age-group tendencies to cross.

3.2.2.2 Response time analysis

Response times for those who responded were examined. Since response times are not normally distributed they were log transformed. Then, a Linear Mixed Model (LMM) including a backward elimination procedure was utilized. The between-group fixed effect included in the model was Pedestrians' age-group (7-9-year-olds, 9-10-year-olds, 10-13-year-olds and experienced-adult pedestrians).

3.2.2.2.1 T-intersections

Applying a Linear Mixed Model (LMM) revealed no significant main effect of Pedestrians' age-group regarding complex situations depicting T-intersections ($F_{3, 37}$= 0.86, N.S.).

3.2.2.2.2 Roundabouts

Applying a Linear Mixed Model (LMM) revealed a significant main effect of Pedestrians' age-group regarding complex situations depicting roundabouts ($F_{3, 36}$= 3.79, p<0.05). LSD pair-wise comparisons analysis revealed that the experienced-adult pedestrians' tended to cross (Mean crossing time=7.32 sec, Mean log transformed crossing time= 1.99, Mean log transformed standard error=0 .20) significantly faster ($p<0.01$) than the oldest child-pedestrians (i.e., 10-13-year-olds; 23.57, 3.16, 0.30).

3.2.2.2.3 Vehicles stop in front of a crosswalk

Applying a Linear Mixed Model (LMM) revealed a marginally significant main effect of Pedestrians' age-group regarding complex situations depicting vehicles stop in front of crosswalks ($F_{3,\ 41}$= 2.66, $p=0.06$). LSD pair-wise comparisons analysis revealed that the older child-pedestrians- i.e., 10-13-year-olds, tended to cross (Mean crossing time=23.81 sec, Mean log transformed crossing time=3.17, Mean log transformed standard error=0.26) significantly slower ($p<0.05$, $p=0.01$; respectively) than the youngest child-pedestrians (i.e., 7-9-year-olds; 9.78, 2.28, 0.32) and the experienced-adult pedestrians (10.18, 2.32, 0.20).

3.2.3 VERBAL DESCRIPTION ANALYSIS

Next, participants' verbal descriptions of the reasons why they had decided whether or not to cross were examined in order to decipher which dimensions of the traffic environment were identified by each of the pedestrian groups as hazardous (see Table 8). Notably, some descriptions related to more than one dimension (e.g., limited field of view and presence of vehicles - "it is not safe to cross since a curve obstructs the view from the left and a vehicle approaches from the right"), and were counted several times.

Examining participants' verbal descriptions regarding the Presence of Zebra-crossing (e.g., "It is safe to cross at a zebra-crossing"), a significant difference was found between the pedestrians' age-groups ($\chi2$= 35.04, $p<0.001$). Pair-wise comparisons analysis indicated that the 10-13-year-olds mentioned the Presence of zebra-crossing significantly (χ^2= 20.69, $p<0.001$; χ^2= 36.58, $p<0.001$; χ^2= 12.28, $p<0.001$, respectively) less (average number of descriptions=(0.58) than the 7-9-year-olds (average number of descriptions=3.25), 9-10-year-olds (5) and the experienced-adult pedestrians (2.19). Moreover, experienced-adult pedestrians suggested significantly (χ^2= 11.67, $p<0.01$) less verbal descriptions regarding the Presence of Zebra-crossing in comparison to the 9-10-year-olds.

Table 8. Distribution of the dimensions of the traffic environment identified by each of the pedestrians' age-groups as hazardous across their verbal descriptions to the road-crossing scenarios.

Verbal description	7-9	9-10	10-13	Adults	Total
Presence of Zebra-crossing	26 (3.3)	25 (5.0)	7 (0.6)	46 (2.2)	104 (2.3)
Presence of vehicles	140 (17.5)	76 (15.2)	200 (16.7)	294 (14.0)	710 (15.4)
Field of view	8 (1.0)	17 (3.4)	41 (3.4)	94 (4.5)	160 (3.5)
Time factor	4 (0.5)	3 (0.6)	4 (0.3)	19 (0.9)	30 (0.7)
Distance factor	27 (3.4)	5 (1.0)	18 (1.5)	86 (4.1)	136 (3.0)
Speed factor	5 (0.6)	2 (0.4)	6 (0.5)	42 (2.0)	55 (1.2)
Late response	8 (1.0)	4 (0.8)	21 (1.8)	6 (0.3)	39 (0.9)

The numbers represent the total number of trials from each age-group who responded to a crossing scenario, the numbers in the parenthesis represent the average number of responses in each age-group (i.e., relative to the number of participants in each group).

Examining participants' verbal descriptions regarding the Presence of vehicles (e.g., "there are no vehicles coming towards me- the road is clear", "a car approaches from the left"), no significant difference was found between the pedestrians' age-groups (χ^2= 6.21, N.S.).

Examining participants' verbal descriptions regarding Field of view (e.g., "it is not safe to cross since parked cars obstruct the view"), a significant difference was found between the pedestrians' age-groups (χ^2= 20.16, $p<0.001$). Pair-wise comparisons analysis indicated that the 7-9-year-olds suggested significantly (χ^2= 9.22, $p<0.01$; χ^2= 11.44, $p<0.001$; χ^2= 19.90, $p<0.001$, respectively) less (average number of descriptions=1.00) verbal descriptions regarding Field of view in comparison to the 9-10-year-olds (average number of descriptions=3.40), to the 10-13-year-olds (3.42) and to the experienced-adult pedestrians (4.48).

Examining participants' verbal descriptions regarding the Time factor (e.g., "I have sufficient time to cross"), no significant difference was found between the pedestrians' age-groups (χ^2= 4.23, N.S.). However, note that relatively few statements were made altogether regarding the Time factor.

Examining participants' verbal descriptions regarding the Distance factor (e.g., "vehicles are far away- it is safe to cross"), a significant difference was found between the pedestrians' age-groups (χ^2= 24.77, p<0.001). Pair-wise comparisons analysis indicated that the 9-10-year-olds suggested significantly (χ^2= 7.05, p<0.01; χ^2= 11.05, p<0.01, respectively) less (average number of descriptions=1.00) verbal descriptions regarding the Distance factor in comparison to the 7-9-year-olds (average number of descriptions=3.38) and to the experienced-adult pedestrians (4.10). Moreover, the 10-13-year-olds suggested significantly (χ^2= 7.50, p<0.01; χ^2= 16.32, p<0.001, respectively) less (1.50) verbal descriptions regarding the Distance factor in comparison to the 7-9-year-olds and to the experienced-adult pedestrians.

Examining participants' verbal descriptions regarding the Speed factor (e.g., "vehicles are approaching slowly"), a significant difference was found between the pedestrians' age-groups (χ^2= 21.05, p<0.001). Pair-wise comparisons analysis indicated that the experienced-adult pedestrians suggested significantly (χ^2= 6.76, p<0.01; χ^2= 6.11, p<0.05; χ^2= 11.81, p<0.001, respectively) more (average number of descriptions=2.00) verbal descriptions regarding the Speed factor in comparison to the 7-9-year-olds (0.63), to the 9-10-year-olds (0.40) and to the 10-13-year-olds (0.50).

Since time, distance and speed are different indicators aiming to measure the same underlying concept, participants' verbal descriptions combining all three categories were examined, and , a significant difference was found between the pedestrians' age-groups (χ^2= 44.66, p<0.001). Pair-wise comparisons analysis indicated that the experienced-adult pedestrians suggested significantly (χ^2= 5.74, p<0.05; χ^2= 16.72, p<0.001; χ^2= 31.36, p<0.001, respectively) more (average number of descriptions=7.00) verbal descriptions regarding the Time, Distance and Speed factors in comparison to the 7-9-year-olds (average number of descriptions=4.50), to the 9-10-year-olds (2.00) and to the 10-13-year-olds (2.33). Moreover, the 7-9-year-olds suggested significantly (χ^2= 5.43, p<0.05; χ^2= 7.04, p<0.01, respectively) more verbal descriptions regarding the Time, Distance and Speed factors in comparison to the 9-10-year-olds and to the 10-13-year-olds.

Lastly, examining participants' verbal descriptions regarding their late response (e.g., "I meant to cross just as the scenario ended"), a significant difference was found between the pedestrians' age-groups (χ^2= 19.58, p<0.001). Pair-wise comparisons analysis indicated that the experienced-adult pedestrians suggested significantly (χ^2= 6.12, $p<0.05$; χ^2= 20.01, $p<0.001$, respectively) less (average number of descriptions=0.29) verbal descriptions regarding their late response in comparison to the 7-9-year-olds (1.0) and to the 10-13-year-olds (1.75).

3.2.4. EYE SCANNING PATTERNS

To examine eye scanning patterns, three Areas of Interest (AOIs) were defined: Far left, Close range center and Far right. Eye scanning patterns of 9 participants were analyzed for scenarios 1-10. The mean dwell duration (MDD), i.e., the average duration of dwells falling inside an AOI (a dwell is the summation of the duration of a sequence of consecutive fixations falling inside an AOI) and the total dwell duration (TDD) on each one of the AOIs were examined. Descriptive analysis of the findings is provided. It is provided in frames (frame rate was 25 frames per second) for MDD and in percentage of time relative to the time spent in all three AOIs for TDD. Eye scanning patterns can be used to support the objective findings and the verbal description given by the participants.

3.2.4.1 Summary of fixation patterns by age group

Brought here are results concerning analysis of participants' eye-movements according to the age-group factor. **Notably, however, due to the limited sample-size, results should be reviewed with caution.**

Mean dwell durations for each participant in each age-group are shown in Figure 13. MDDs for each age-group are shown in Figure 14. It can be seen that the youngest participant (#29) was the only one whose MDD was higher on the peripheral left and right areas.

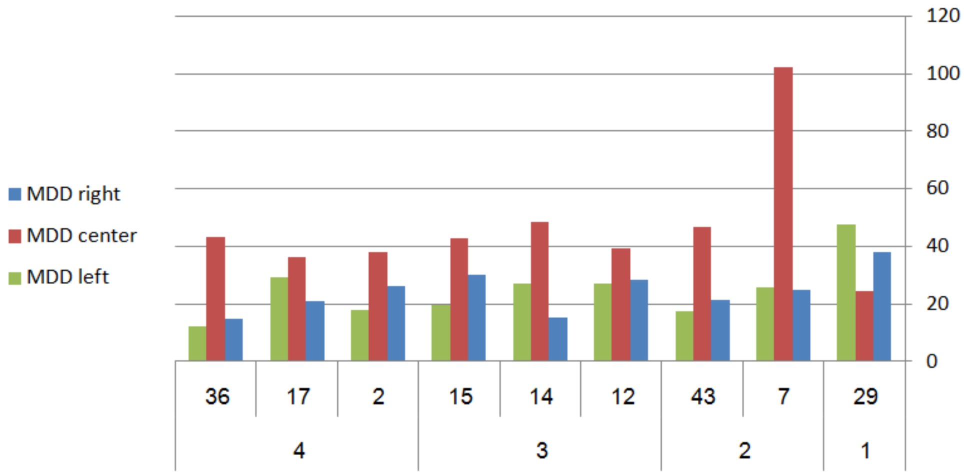


Figure 13. The mean dwell duration (frames) on each one of the AOIs, as a function of age-group and participant. Upper numbers on the horizontal axis refer to participants numbers (e.g., 36, 14, 29), lower numbers on the horizontal axis indicate age-group number (1=7-9-year-olds, 2=9-10-year-olds, 3-10-13-year-olds and 4=experienced-adult pedestrians).

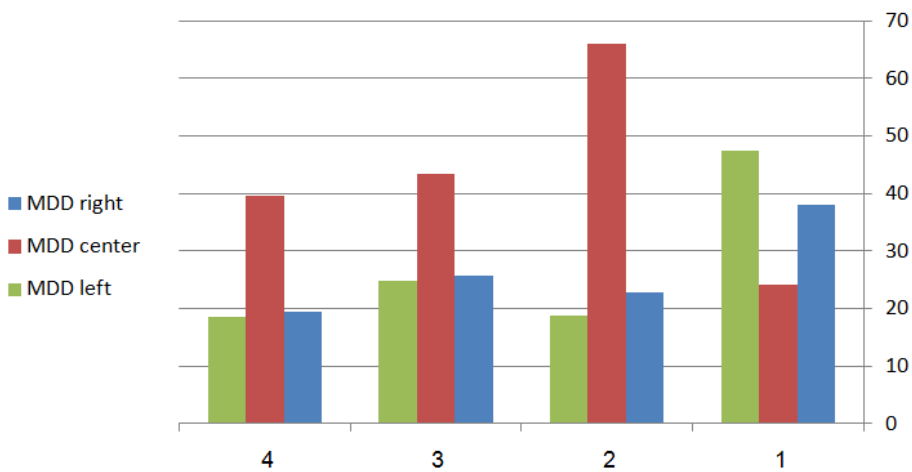


Figure 14. The mean dwell duration (frames) on each one of the AOIs, as a function of age group. Horizontal axis indicates age-group number (1=7-9-year-olds, 2=9-10-year-olds, 3-10-13-year-olds and 4=experienced-adult pedestrians).

Total dwell durations for each participant in each age-group are shown in Figure 15. TDDs for each age-group are shown in Figure 16. It can be seen that in general, participants focus mostly on the center area close to the crossing area (on average, ~ 60% of the time spent on AOI). The youngest participant (#29) was the only one whose TDD pattern does not follow this pattern, hence reflecting perhaps the immediacy of response time in this age-group.

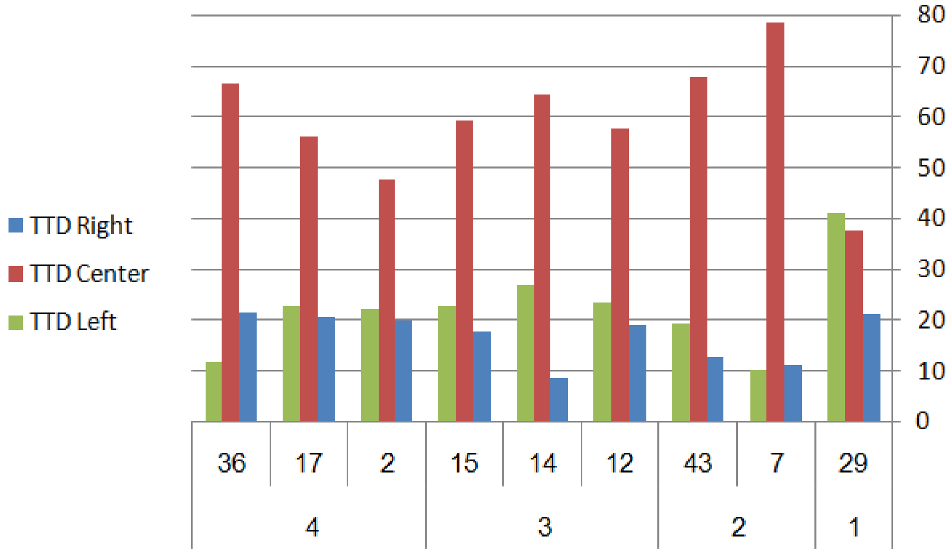


Figure 15. The total dwell duration (in % of total time spent on all three AOIs) on each one of the AOIs, as a function of age group and participant. Upper numbers on the horizontal axis refer to participants numbers (e.g., 36, 14, 29), lower numbers on the horizontal axis indicate age-group number (1=7-9-year-olds, 2=9-10-year-olds, 3-10-13-year-olds and 4=experienced-adult pedestrians).

It can also be seen in Figure 16 that pedestrians from age groups 2 tended to spend more time observing the road, mainly in the close range AOI, than all three other groups (38, 73, 60 and 57 percent respectively for the 1-4 age groups). This longer duration on center may stem in part from their hesitation in making a decision to cross.

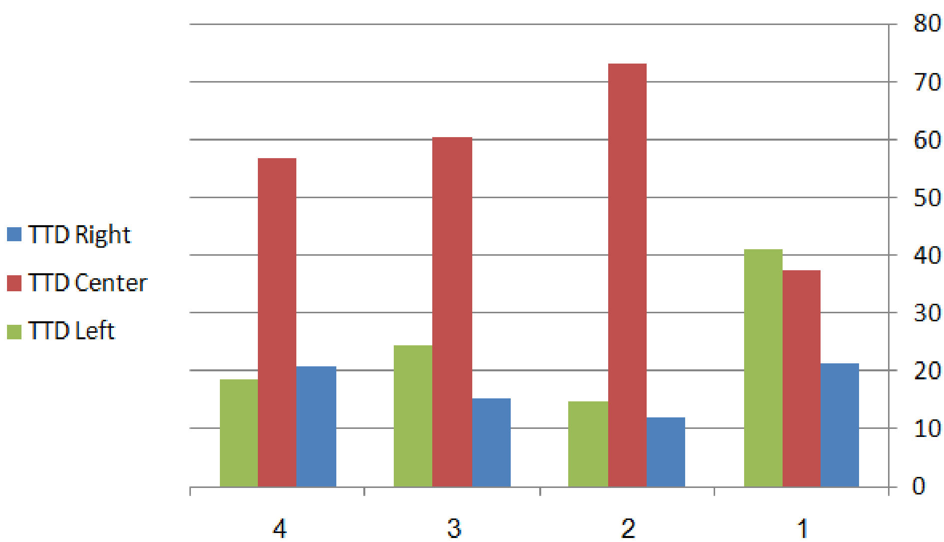


Figure 16. The total dwell duration (in % of total time spent on all three AOIs) on each one of the AOIs, as a function of age group.

3.2.4.2 Analysis by scenario type

3.2.4.2.1 General

Scenarios were categorized by three factors, presence of zebra crossing (0-not, 1-present), presence of vehicles (0-no vehicles, 1-vehicles in one direction,2- in both directions) and FOV (0-unrestricted FOV, 1- FOV obscured in part by parked vehicles). MDD and TDD across scenarios 1-10 is given hereby. As can be seen in figure 17, when vehicles arrived from only one direction, the mean dwell duration in general was longer on the side from which the vehicles came (i.e., left). When vehicles approached from both directions, the MDD on each one of them was almost the same. In both conditions the MDD on all AOI's was longer when there were approaching vehicles than when no vehicles were present in the scenario.

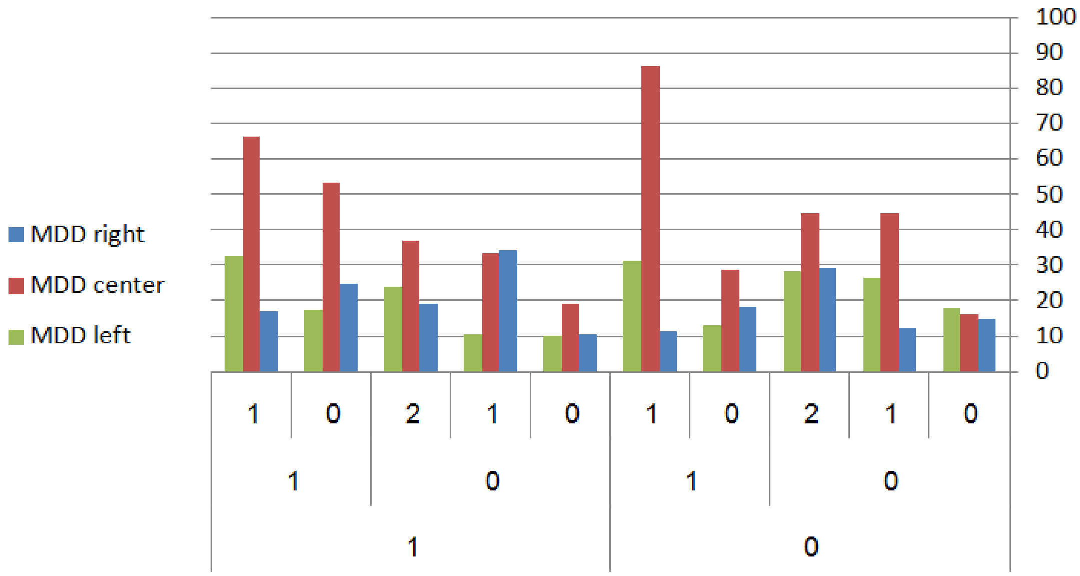


Figure 17. The mean dwell duration (frames) on each one of the AOIs, as a function of presence of zebra crossing (lowest breakdown), FOV, and presence of vehicles.

Figure 18 presents the total dwell durations. Overall, participants spent most the time focusing on the center AOI.. We now turn into the examination of each factor separately.

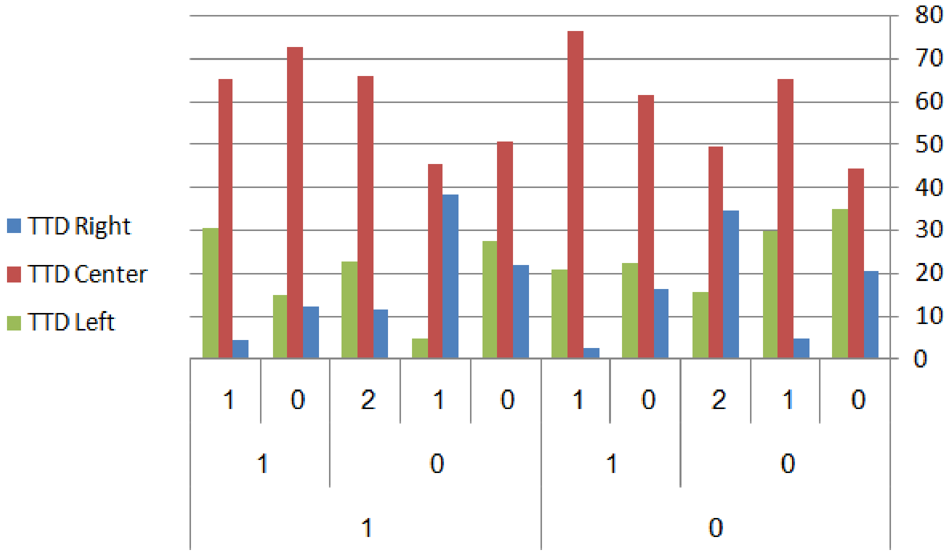
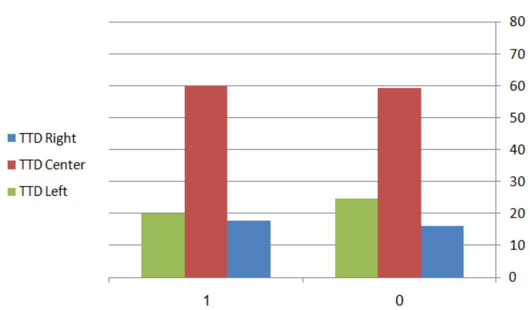


Figure 18. The total dwell duration (in % of total time spent on all three AOIs) on each one of the AOIs, as a function of presence of zebra crossing (lowest breakdown),, FOV, and presence of vehicles.

3.2.4.2.2 Scenario characteristics

3.2.4.2.2.1 Presence of Zebra crossing

As can be seen from Figure 19, the pattern of scanning with/without the presence of zebra crossing is quite similar. The presence of zebra crossing facilitated less total time spent on the far left (25% versus 20% respectively) and for shorter dwelling durations. As can be seen in Figure 20, the presence of a zebra crossing primarily affects age-group 1 (i.e., 7-9-years-old participant #29) scanning patterns.



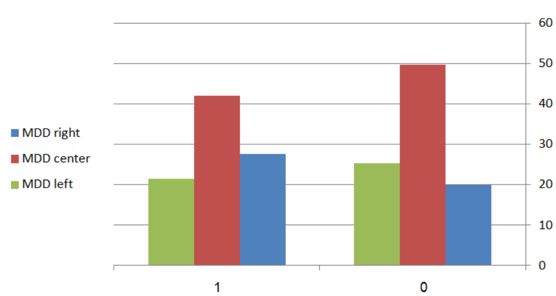


Figure 19. Right: The mean dwell duration (frames) on each one of the AOIs, as a function of presence of zebra crossing (0-no crossing, 1-crossing present). Left: The total dwell duration (in % of total time spent on all three AOIs) as a function of presence of zebra crossing.

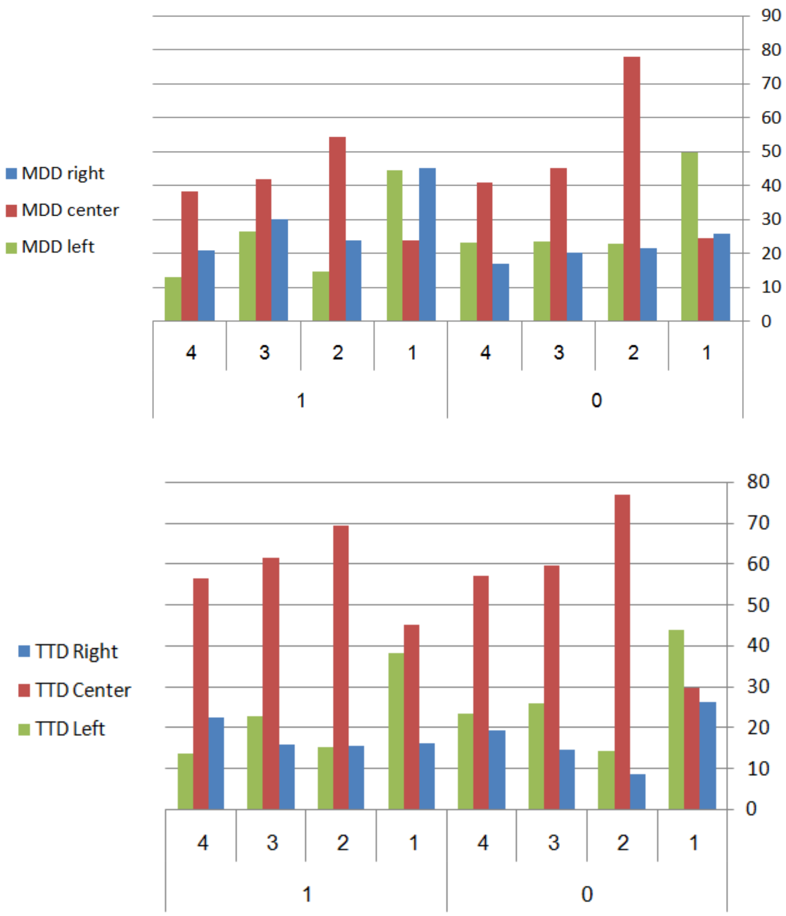


Figure 20. Figure D. Top: The mean dwell duration (frames) on each one of the AOIs, as a function of presence of zebra crossing and age group. Bottom: The total dwell duration (in % of total time spent on all three AOIs) as a function of presence of zebra crossing and age group.

3.2.4.2.2.2 Presence of vehicles

As shown in Figure 23, the presence of vehicles generated longer dwell times than the absence of vehicles. Since the results here are a summation of all scenarios, they combine two types of one-way streets, i.e., vehicles arriving from the left and vehicles arriving from the right, were analyzed together, counterweighing the additive results. Therefore, it may seem that participants allocate rather equal MDDs to both sides.

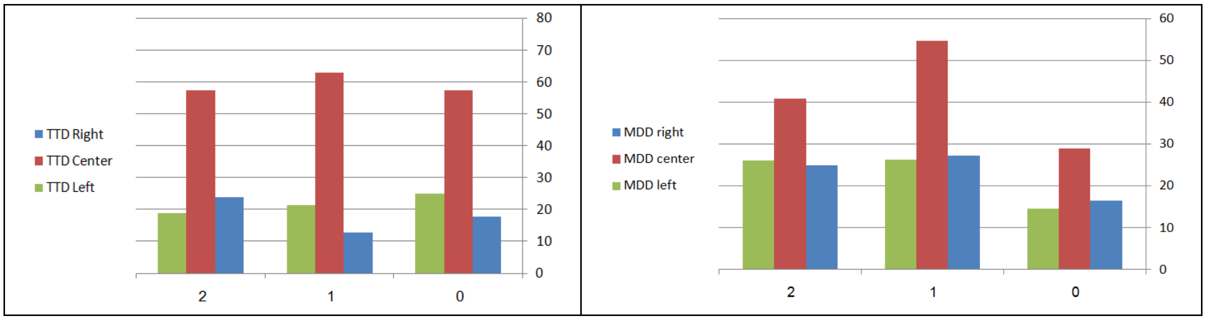


Figure 23. Right: The mean dwell duration (frames) on each one of the AOIs, as a function of presence of vehicles (0-no vehicles, 1-one way, 2-two-way). Left: The total dwell duration (in % of total time spent on all three AOIs) as a function of vehicles.

3.2.4.2.2.3 Field of view

As can be seen from Figure 21, FOV affects the scanning patterns. The partially obscured FOV causes participants to focus for longer durations on the center (MDD) at the expense of allocating time to viewing the far right area (TDD).

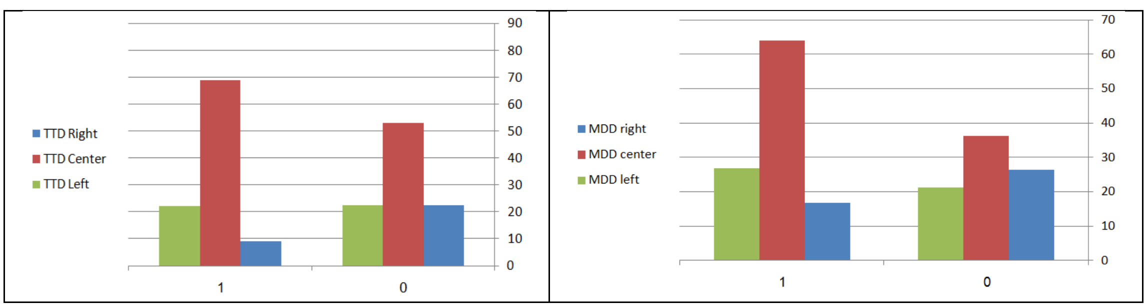


Figure 21. Right: The mean dwell duration (frames) on each one of the AOIs, as a function of FOV (0-open, 1-partially obscured by parked vehicles). Left: The total dwell duration (in % of total time spent on all three AOIs) as a function of FOV.

To conclude, although based upon a limited, non-representative sample, the eye movements' patterns exemplified here are consistent with the results described in previous sections and may be used to strengthen current research findings. Two main issues should be noted: (1) the eye-movements patterns exemplified here suggest of the underling difference between the youngest children age-group and the experienced-adult pedestrians' performance, thus emphasizing once more the ETS potential as a supporting tool in analyzing participants' performance; and (2) running the experiment it was revealed that young children, as young as 7 years of age, are capable of undergoing a long session connected to the ETS, and that the data emerging is valid and usable for analysis.

3.2.5 SUMMARY

When examining the results, several issues should be noted:

1. The results demonstrate that, over time, and given the need, participants eventually preferred crossing to not crossing within the time limit allowed in this study. Traffic density was such that it allowed participants to cross, i.e., if traffic density was higher they would most likely never have an opportunity to cross.
2. The presence of a zebra crossing facilitated crossing. Examining response times, it can be seen that when presented with unrestricted field of view, pedestrians tended to cross faster in the absence of zebra-crossing than in its presence. This may be due to the sense of security its presence tends to provide to pedestrians (Ekman, 1996) in contrast to a sense of urgency which may be generated in its absence. It may also be that zebra-crossing was utilized by participants as a decision support tool. Hence, while not affected by the Presence of Zebra-crossing when they needn't seek help in deciding when to cross (i.e., regarding unambiguous situations, e.g., when encountered by unrestricted field of view or when encountered by field of view partially obscured by parked vehicles), participants tended to rely on and be affected by the Presence of Zebra-crossing in their decision to cross regarding limited field of view partially being obscured by road's curvature (i.e., more ambiguous situation).
3. Experienced-adult pedestrians were more inclined to cross than either the 9-10-year-olds or the 10-13-year-olds, however, did not differ from the 7-9-year-olds in their readiness to cross. These youngest child-pedestrians (7-9-year-olds) also tended to cross faster than the experienced-adult pedestrians and the 10-13-year-olds. Indeed, 7-9-year-olds tended to cross more often, as well as faster, compared to the other child-pedestrians' groups, thus it can be said that their performance bore some resemblance to that of experienced-adult pedestrians. However, it should be noted that, in contrast to the 7-9-year-olds, the experienced-adult pedestrians have demonstrated higher level of awareness to potential hazards (e.g., presented lower likelihood towards crossing in situations depicting limited

field of view by parked vehicles) which may indicate of the underlying difference between their calculated, informed decision to cross considering potential hazards to the 7-9-year-olds spontaneous responses of fast crossing, regarding not much but approaching vehicles as a criterion for crossing decision. This pattern also emerges from examining participants' verbal descriptions- indeed, 7-9-year-olds referred much less to the potential hazardousness of the field of view factor in comparison to all other age-groups. This pattern is additionally exemplified in the eye scanning patterns of participant #29 who differed from the patterns of all other participants.

3.3 DISCUSSION

Pedestrian road crashes are amongst the most substantial causes of death, injury and long-term disability among children, particularly among those in the age range of 5-to 9-years (e.g., Whitebread & Neilson, 2000; Tabibi & Pfeffer, 2003), who endure four times the injury rate of adults, in spite of their lower levels of exposure to traffic (Thomson et al., 2005). Early research had indicated that young children's higher accident rate may be correlated with their relative inability to perceive hazards correctly (Martin & Heimstra, 1973). More recent studies have also indicated that the ability to 'read the road' in anticipation for forthcoming events- i.e., hazard perception (HP), is one of the most important skills for child-pedestrians (e.g., Foot et al., 2006). According to Hill, Lewis & Dunbar (2000) there is evidence that young children are poor at identifying unsafe situations. These researchers argue that the high accident rate for child-pedestrians is a result of the failure to recognize a potential danger when unprompted, thus, they suggested that young children's understanding of danger is not robust (Hill et al. 2000). The objective of the proposed research was to lay the foundations for examining whether training child-pedestrians' HP skills while crossing a road may improve their ability to perceive potentially hazardous situations and to predict hazards prior to their materialization.

The present study aimed to examine experienced-based hazard perception differences in road-crossing performance among pedestrians with varied levels of road-crossing experience, in the hope of explaining how better awareness to hazardous factors becomes established along the continuum of road crossing experience. Research hypotheses stated that (1) Experienced-adult pedestrians would be more sensitive to potential hazardousness compared to child-pedestrians.

(2) The older a child-pedestrian, the more he or she would pay attention to potential hazardousness.

The research had met its aims and supported both of its hypotheses. The results presented in previous chapters demonstrated the different responses viewed between the four experimental groups to each of the factors examined by measurement of response sensitivity, response time and verbal description. The following will discuss the main results of the study with reference to the literature reviewed. The chapter will end with a discussion about optional direction for future research and some of the current research limitations.

3.3.1 PERFORMANCE ON THE SPECIFIC DEPENDENT MEASURES

Forty six participants were allocated into four experimental groups: three young-novice pedestrian-groups and one experienced pedestrians' group. Participants were all requested to observe 21 typical urban scenarios, filmed from a pedestrian's perspective, and to engage in a crossing decision- i.e., to determine whether it is safe or unsafe to cross by pressing a response button each time he or she believed it was safe to cross the road.

It was decided to explore road factors which may contribute to pedestrians' crossing performance, and specifically, to child-pedestrians' performance. Three main factors were chosen: Presence of Zebra-crossing, Presence of vehicles and Field of view. As past research had shown, the majority of children are injured on non-arterial roads, particularly in residential areas (e.g., Lawson, 1990; Roberts et al., 1994). Thus, the Dome-scenarios were all located in residential areas.

3.3.1.1 Zebra-crossing factor

Overall, it can be said that the presence of a zebra crossing facilitated crossing. Indeed, it was revealed that in situations depicting zebra-crossing pedestrians' likelihood to cross was higher than in situations depicting no zebra-crossing. It can also be suggested that, as was viewed in past research, the presence of zebra-crossing provided participants with a sense of security (Ekman, 1996), helping them to feel they can cross the road safely. Indeed, in situations depicting zebra-crossing pedestrians' likelihood to cross was higher when presented with moving vehicles compared to situations involving no vehicles. However, in situations depicting no zebra-crossing, pedestrians' likelihood to cross was lower when presented with moving vehicles compared to situations involving no vehicles.

Zebra-crossing was also applied as a decision support tool for ambiguous situations. Indeed, it was evident that while pedestrians' likelihood to cross in situations depicting unrestricted field of view and zebra-crossing was not found to differ from situations depicting unrestricted field of view with no zebra-crossing , and while pedestrians' likelihood to cross in situations depicting field of view partially obscured by parked vehicles and zebra-crossing was not found to differ from situations depicting field of view partially obscured by parked vehicles with no zebra-crossing, pedestrians' likelihood to cross in situations depicting field of view partially being obscured by the road's curvature was higher when these situations included zebra-crossing than when these situations included no zebra-crossing.

It should also be noted that the younger children, namely the 7-9-year-olds and the 9-10-year-olds tended to refer to the Presence of zebra-crossing in their verbal descriptions compared to the older participants. A plausible explanation may suggest that for the youngest children the zebra-crossing provided with a salient cue, helping them in their decision whether to cross. Children in the age range of 9-10 still in the initial stage of road-crossing skill acquisition, namely, are just being taught of the rules of the road, thus their knowledge is still only in the declarative level and was not practiced enough to solidify and transform into a procedural level (Anderson, 1995).

3.3.1.2 Moving vehicles factor

Overall, the presence of vehicles was taken into account as a main factor in the participants' road-crossing decision. Indeed, most (42%) of the 1,694 factors referred to in the participants' verbal descriptions regarded the Presence of vehicles (i.e., 710 descriptions). However, being a salient factor, addressed broadly by most of the participants, not many differences were found between the pedestrians age-groups' performance to this dimension. The main finding suggested that pedestrians tended to cross faster when encountering situations involving no vehicles than when presented with moving vehicles, either vehicles traveling in one direction or vehicles traveling in two directions, reminiscing of Summersgill & Layfield's (1998) research which have indicated that there is no difference in the level of pedestrians' crash risk between one-way and two-way roads with the same cross-section.

3.3.1.3 Field of view factor

Past research had also suggested that pedestrians' traffic crashes which occur in inhabited areas tend to take place in locations where visibility is restricted (e.g., at curves, near parked cars) (Ampofo-Boateng & Thomson, 1990). Indeed, it was revealed that when the field of view was unrestricted pedestrians' likelihood to cross was higher than when it was partially obscured by the road's curvature or than when it was partially obscured by parked vehicles. Moreover, pedestrians' likelihood to cross was higher when the field of view was partially obscured by the road's curvature than when it was partially obscured by parked vehicles. Thus, on-street vehicle parking presents a particular risk for child-pedestrians (Petch & Henson, 2000). Parked cars interfere with their ability to detect oncoming vehicles, while also obstructing the motor vehicle drivers' vision, preventing them from noticing child-pedestrian who may be masked by stationary vehicles along the road (e.g., Aoki and Moore, 1996; Petch & Henson, 2000). In consistence with the literature, it was revealed that experienced-adult pedestrians tended to linger more in situations depicting field of view partially obscured by parked vehicles than in situations depicting unrestricted field of view, while pedestrians in all other age-groups tended to cross faster in situations depicting field of view partially obscured by parked vehicles than in situations depicting unrestricted field of view. It can also be suggested that the 7-9-year-olds were the least aware of the field of view aspect, suggesting less verbal descriptions regarding Field of view in comparison to the 9-10-year-olds to the 10-13-year-olds and to the experienced-adult pedestrians.

3.3.1.4 Age-group factor

Examining age-group differences may reveal two main modes of responses: (1) the older child-pedestrians responses (i.e., children in the age range of 9-13), and (2) the younger children and the experienced-adult pedestrians. Both the 9-10-year-olds and the 10-13-year-olds tended to present a less decisive performance compared to both the experienced-adult pedestrians and the 7-9-year-olds. Overall, they tended to be less likely to cross and less likely to cross fast when decided to do so. Comparing between these two age-groups, both were more inclined to take the time to decide what to do and when to do it, however, while 9-10-year-olds tended to wait and not engage in action, 10-13-year-olds were more incline to wait but to cross afterwards. Since reaction times were calculated according to those crossing, this pattern of responses sometimes led to higher likelihood of crossing with longer response time in 10-13-year-olds compared to the 9-10-year-olds. This pattern is also exemplified in the eye scanning patterns where both of these groups tend to focus more on the center area, and in general dwell for longer durations on it as well.

Examining age-group patterns it can be seen that experienced-adult pedestrians were more inclined to cross than either the 9-10-year-olds or the 10-13-year-olds, however, did not differ from the 7-9-year-olds in their readiness to cross. These youngest child-pedestrians (7-9-year-olds) also tended to cross faster than the experienced-adult pedestrians and the 10-13-year-olds. Indeed, 7-9-year-olds tended to cross more often, as well as faster, compared to the other child-pedestrians' groups, thus it can be said that while their performance bore some resemblance to that of experienced-adult pedestrians (which have shown a marked resemblance to experienced **drivers**' characteristics in previous studies- see Borowsky et al., 2010 for details), the 7-9-year-olds have demonstrated a lower level of awareness to potential hazards (e.g., presented higher likelihood towards crossing in situations depicting limited field of view by parked vehicles) which may indicate of the underlying difference between the experienced-adult pedestrians' calculated, informed decision to cross considering potential hazards to the 7-9-year-olds' spontaneous responses of fast crossing. This pattern also emerges from examining participants' verbal descriptions- indeed, 7-9-year-olds referred much less to the potential hazardousness of the field of view factor (e.g., only 8 times compared to the 140 it referred to the presence of vehicles- i.e., 17.5 times more) in comparison to all other age-groups (e.g., the experienced-adult pedestrians referred to the field of view factor 94 times compared to the 294 it referred to the presence of vehicles- i.e., only 3.13 times more). Furthermore, the 7-9-year-olds tended to rely more heavily on the zebra-crossing cue, crossing faster in situations depicting zebra-crossing than in situations depicting no zebra-crossing, compared to pedestrians in all other age-groups.

Past research had suggested that pedestrians' traffic crashes which occur in inhabited areas tend to take place in locations presenting complex configurations- i.e., junctions, crossroads and other intersections where traffic might arrive from several different directions, thus challenging the child-pedestrian's search and information-processing capacities (Ampofo-Boateng & Thomson, 1990). The current research referred to this type of situations in the complex scenarios (19-21). As before, both the 9-10-year-olds and the 10-13-year-olds tended to present a less decisive performance compared to the experienced-adult pedestrians, causing the same pattern of result where experienced-adult pedestrians' likelihood to cross in complex situations depicting T-intersections or Vehicles stop in front of a crosswalk was higher than that of 9-10-year-olds', while being more inclined to cross faster than the 10-13-year-olds when encountered by situations presenting Roundabouts or Vehicles stop in front of a crosswalk.

3.3.1.5 Conclusions

To summarize, the current research had suggested that engaging in a road-crossing decision task, of observing HP scenarios and pressing a response button each it is safe to engage in crossing, can differentiate between child-pedestrians and experienced-adult pedestrians- i.e., this methodology may be utilized as a validated tool for differentiating between diverse levels of road-crossing experience. Examining the differences between the various age-groups' responses by a variety of performance measurements (response sensitivity, response time, verbal descriptions) it was evident that experienced-adult pedestrians are be more sensitive to potential hazardousness compared to child-pedestrians, and that the older a child-pedestrian, the more he or she pays attention to potential hazardousness. Overall, finding indicated that the older children, both the 9-10-year-olds and the 10-13-year-olds, tended to present a less decisive performance compared to both the experienced-adult pedestrians and the 7-9-year-olds. The 9-10-year-olds tended to wait and not engage in action, while the 10-13-year-olds tended to linger, but cross nonetheless, leading to higher likelihood of crossing with longer response for the later. Experienced-adult pedestrians were more inclined to cross than either the 9-10-year-olds or the 10-13-year-olds but did not differ from the 7-9-year-olds in their readiness to cross. Indeed, 7-9-year-olds tended to cross more often, as well as faster, compared to the other child-pedestrians' groups; however, they have demonstrated a lower level of awareness to potential hazards (e.g., referred much less to field of view limited by parked vehicles) indicative of the underlying difference between their rushed response and the experienced-adult pedestrians'.

Results serve applicable meaning- the differences emerged between the various children age groups reinforce that child pedestrians cannot be trained as a group but rather that training needs to be adjusted to the level of experience the child has gained. To conclude, the current research had met its aims and supported the hypotheses which suggested that the utilization of the Dome-projection settings may be effective as a tool for differentiating between pedestrians varying in their experience level of road-crossing's ability to detect hazards prior to their materialization.

4. CONCLUSIONS AND SUMMARY

4.1 RESEARCH LIMITATIONS

The current study involved several limitations, each of which will be addressed in the present section.

Sample size- the relatively small number of participants in each of the experimental groups might have created a bias in the results, as the random sample might have not been a representative one. Replication of the results utilizing a larger sample size would provide further support for the findings.

Another limitation regards the confounding variables of age and experience, which are common confounding variables in the road safety domain (e.g., Mcknight & Mcknight, 2003; Horswill & McKenna, 2004). Due to the coincidental timing of the two, it is difficult to assess whether participants' behavior stems from their age or level of experience. Although age is an important factor to consider, research has shown that road crossing skills are not utterly dependent upon maturational factors (Ampofo-Boateng et al., 1993) and that the experience factor plays an important role as well.

Furthermore, the current study faced the limitation of external validity. As in all experimental studies, the generalization of the current study's results to the external environment is limited. Real-life road-crossing is a complex task which involves, besides the necessity to identify potential and actual hazards, various other components. These components, such as making roadside timing judgments, and the necessity to deal with various external components (e.g., familiarity with certain crossing areas, crossing-vehicles' drivers-attentions) as well as internal factors (e.g., distraction, fatigue and stress levels), create unique conditions which are very hard to replicate in a laboratory settings. Nevertheless, literature suggested that the blurring of the boundary between real and unreal, made possible with VR and MR, may help in bridging the gaps between the laboratory-setting to the real world (Carlin, 1997).

Lastly, the study has also shown that children, as of the age of 7 are capable of undergoing a long session in the MR environment. However, preliminary testing with younger children around 6 years old showed that those had difficulties in maintaining focused in this MR environment. Future research aiming for this age-range should take this limitation into account.

4.2 DIRECTIONS FOR FUTURE RESEARCH

Taken together, results may suggest an initial evident to the notion stating that the more a pedestrian responds to events and experience road-crossing, the more he or she learn how to estimate properly the probabilities that hazards might appear in specific environments and how to assess the possible outcomes that such hazard may produce based on past experience. It seems that in this case experience indeed enables pedestrians, as it was found to do in the case of drivers (e.g., Borowsky et al., 2010), to integrate elements in the environment and predict future events (Endsley, 1995).

The experimental environment that has been developed allows for generating a plethora of simple and complex scenarios in a typical Israeli urban environment. Enabling the development of very structured situations on one hand and of unstructured scenarios with multiple elements on the other hand may be valuable for training, as it has been suggested that exposure to a variety of actual hazards may increase young-novice road-users' awareness to potential hazardousness in the road-safety realm (Meir et al., 2010).

The current research is an important first step in the process of building an intervention technique which may reduce child-pedestrians' over-involvement in traffic crashes. Its significance stems from the opportunity it offers to engage in a novel training methodology concerning child-pedestrians' road safety behavior in an off-road settings, without exposing them to the risks of being injured and without jeopardizing their lives. Moreover, the current research provided an evident suggesting that children young as the age of 7 are capable of undergoing a long session in the MR environment, thus helped promoting the idea of utilizing HP scenarios as a tool to train child-pedestrians to detect hazards and to predict hazardous situations prior to their materialization. Indeed, if developed into a comprehensive, coherent intervention, this type of intervention may become a beneficial component in the Israeli road safety system, as part of the effort of reducing child-pedestrians' involvement in traffic crashes.

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