Safety Science 89 (2016) 36–44

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Cell phone conversations and child pedestrian's crossing behavior; a simulator study

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ARTICLE INFO

Article history:
Received 28 October 2015
Received in revised form 1 April 2016
Accepted 26 May 2016

Keywords:
Pedestrian
Child
Road crossing
Cell phone
Distractions
Visual attention
Virtual environment
Eye tracking

ABSTRACT

Child pedestrians are highly represented in fatal and severe road crashes and differ in their crossing behavior from adults. Although many children carry cell phones, the effect that cell phone conversations have on children's crossing behavior has not been thoroughly examined. A comparison of children and adult pedestrians' crossing behavior while engaged in cell phone conversations was conducted. In a semi-immersive virtual environment simulating a typical city, 14 adults and 38 children (11 children aged 7–8; 18 aged 9–10 and 9 aged 11–13), experienced road crossing related traffic-scene scenarios. They were requested to press a response button whenever they felt it was safe to cross. Eye movements were tracked. Results have shown that all age groups' crossing behaviors were affected by cell phone conversations. When busy with more cognitively demanding conversation types, participants were slower to react to a crossing opportunity, chose smaller crossing gaps, and allocated less visual attention to the peripheral regions of the scene. The ability to make better crossing decisions improved with age, but no interaction with cell phone conversation type was found. The most prominent improvement was shown in 'safety gap'; each age group maintained a longer gap than its predecessor younger age group. In accordance to the current study, it is safe to say that cell phone conversations can hinder child and adult pedestrians' safety. Thereby, it is important to take those findings in account when aiming to train young pedestrians for road-safety and increase public awareness.

1. Introduction

Road accidents are known to be a major cause of deaths and injuries. Over a third of the road traffic deaths in low and middle income countries are among pedestrians (WHO, 2013). This high level of involvement is in particular meaningful for child pedestrians, as the proportion of child fatalities as pedestrians is significantly high relative to adults (Pace et al., 2012).

Crossing the road is not an easy task. It demands pedestrians to integrate cognitive, attentional and motor control abilities. In order to safely cross the road, pedestrians must look for approaching traffic, signs, signals, and listen to auditory cues indicating of approaching vehicles. Pedestrians are also required to complete several cognitive tasks, such as: estimate the speed and distance of traveling vehicles and assess their arrival time (Tabibi and Pfeffer, 2003). Thus, visual, auditory or cognitive based distractions, which may draw attention from the crossing task, can cause pedestrians to miss critical information from the environment, and as a consequence, make wrong assessments and be exposed to higher risk of collision (Bungum et al., 2005; Tabibi and Pfeffer, 2007).

People nowadays carry and use cell phones from very young age. A 2011 survey from the US reported that 20% of the third-graders (aged 8–9) owned cell phones, up to 40% of the fifth-graders (aged 10–11), and 83% of the middle school students (aged 11–14) (Englander, 2011). According to the Pew research center as of 2015 possession reaches 92% among all US adults (Anderson, 2015). The implications of cell phone use on driving have been extensively reviewed in several meta-analyses (Caird et al., 2014, 2008, 2004; Horrey and Wickens, 2006). The impact of cell phone conversations on drivers' behavior is not entirely coherent across all studies. Yet, impaired reaction times are unequivocal and consistent when combining phone conversation with driving. Overall, an increase in reaction time is expected when conversing using hand-held or hands-free phones, and regardless of the cognitive load imposed by the phone conversation (Caird et al., 2008, 2004; Horrey and Wickens, 2006). Other impairments were also found in drivers' speed control and response to hazards (Horberry et al., 2006), as well as in detecting road signals (Strayer and Johnston, 2001).

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http://dx.doi.org/10.1016/j.ssci.2016.05.013
0925-7535/

Observational studies frequently demonstrate that the negative impact that phone conversation have is not unique just for drivers. It has been estimated that nearly a third of the pedestrians are busy with distracting activities like eating, drinking, using cell phones, listening to music, smoking, and talking to a companion while crossing the road; which eventually leads them to adopt unsafe behaviors (Bungum et al., 2005; Hatfield and Murphy, 2007; Nasar et al., 2008; Thompson et al., 2012). For example, pedestrians that were observed talking on the phone while crossing had slower paces, tended to wait less for traffic to stop, and were less likely to look at the traffic before crossing (Hatfield and Murphy, 2007). Such observations suggest that talking on the cell phone can undermine the safety of the pedestrian. The consequences of these unsafe crossing behaviors are already apparent, as the number of reported cell phone related injuries among pedestrians increases every year and had already passed the number of cell phone related injuries among drivers (Nasar and Troyer, 2013).

A limited number of controlled studies have demonstrated the effect that cell phone conversations have on adult pedestrians (Nasar et al., 2008; Neider et al., 2011, 2010; Stavrinos et al., 2011). Overall, these studies confirm that pedestrians who converse on their cell phone while trying to complete a road crossing task display an increase in unsafe behaviors. They perform worse in crossing tasks, are less likely to cross the road safely, and more likely to get hit by a car in virtual testing environments (VE). Among others, distracted pedestrians suffered from deterioration of situation awareness (Nasar et al., 2008), it took them longer to initiate the crossing (Neider et al., 2010), and those that were engaged in a more complex cognitive conversation were less attentive to traffic than those involved in a naturalistic phone conversation (Stavrinos et al., 2011).

Studies have shown that children have different crossing behavior than adults and that their crossing ability is age and experience related (Barton and Schwebel, 2007; Congiu et al., 2008; Foot et al., 2006; Meir et al., 2015; Simpson et al., 2003; Tabibi and Pfeffer, 2007). Examined in various experimental methods, abilities such as identifying a safe place to cross the road (Tabibi and Pfeffer, 2007), choosing the appropriate safe crossing opportunity (Barton and Schwebel, 2007; Simpson et al., 2003), or predicting drivers intentions (Foot et al., 2006) are just some of the abilities that were found to be age related. A controlled study of hazard perception ability in a virtual environment with children aged 7–13 and adults, demonstrated that as pedestrians' age and experience-level increases, their ability to anticipate upcoming events while crossing is enhanced (Meir et al., 2013). When looking at specific age groups, the 9–13 year-olds were more hesitant to cross compared to experienced-adult pedestrians (Meir et al., 2013). With regard to child pedestrians' visual search strategy, it has been reported that major changes in looks frequency, pattern of scanning, and the exhaustiveness of the visual search occurs around the age of 7–8 (Whitebread and Neilson, 2000). It was also shown that children tended to spend more time looking at close range areas near the center of the crossing line, in comparison to adults who looked more toward the peripherals regions, and this effect was enhanced in younger children aged 7–8 (Tapiro et al., 2014).

The effect of cell phone conversation on child pedestrians was much less examined. Only a single study, that we are aware of, demonstrated the effect of cell phone conversations on child pedestrians (Stavrinos et al., 2009). The study examined the behavior of 10–11 year old children that were using a cell-phone while attempting to cross the road in a virtual environment. The results showed that participants acted in a riskier manner when distracted by phone conversations. It was portrayed by paying less attention to traffic, as measured by the number of looks per second to the left and right, slower response to the crossing opportunity, and having more close calls and hit events that indicate upon an experimental trial that could tentatively ended in a crash in the real world.

The current study was aimed to assess the impact that different types of distracting phone conversations may have on road crossing behavior of children aged 7–13 and in comparison to adults. Crossing behavior was assessed using objective measures based on crossing decisions as well as on the visual attention distribution derived from their eye-movements recording. It was hypothesized that phone conversations, and particularly the more demanding types of phone conversations, will have a larger impact on pedestrians' crossing behavior and their visual attention distribution. It was assumed that the influence will be intensified in younger children. Hence an interaction between the conversation type and the age group was anticipated.

2. Method

2.1. Participants

The human subject research committee at Ben-Gurion university approved the use of human subjects in this protocol (request number: 1198-1 http://web2.bgu.ac.il/ethics2/).

Fifty-two participants took part; 14 experienced-adults aged 22–29 (mean age = 25.4, SD = 1.8); 11 children aged 7–8 (mean age = 7.8, SD = 0.7); 18 children aged 9–10 (mean age = 9.7, SD = 0.7) and 9 children aged 11–13 (mean age = 12.0, SD = 1.0). Child participants were compensated with educational gifts equivalent to monetary value of $10. Adults were students given bonus credit in an introductory course. All participants had normal vision, with uncorrected Snellen static acuity of 6/12 or better. Participants were requested to sign an informed consent. Parental consent was given for participants under the age of 18. Child pedestrians were recruited via mass mail which was sent to the university employees, and from local elementary schools in the area.

2.2. Apparatus

2.2.1. Dome projection facility

The Dome simulator consists of 180° spherical screen (radius of 3.25 m) aligned with a very accurate projection system of three projectors. This setting allows measurement of the participants when watching pre-designed simulated scenarios of real-life situations from the roadside perspective, without the risk of harm (Fig. 1). The dome facility is equipped with an advanced 5.1 channels sound surround system that enables an immersive experience. Prior, validation of the dome simulator for pedestrians' perception of distance and speed was conducted. Young and adults participants were asked to estimate the distance and speed of vehicles in real life from the curb and inside the dome simulator. Findings showed a good fit in short range (up to 10 m), long ranges (over 50 m) and certain deviation in others. Speed perception matched the actual speed, but was somewhat estimated as higher than the estimated speed in real life. Hence, in real-life participants tended to underestimate the driving speed of the vehicle more than in the dome simulator. This trend in speed perception actually makes crossing decisions in the dome simulator more conservative (see Tapiro and Oron-Gilad, 2016 technical report for details on the validation).

2.2.2. Eye tracking system

The ASL HS-H6 eye tracker is utilizing an eye camera and infrared eye illuminator to produce a close image of the eye. Once identified, the computer calculates the pupil and cornea centers for use in determining eye line of gaze. When using a head tracker, a technique called Eye-Head integration can be performed, allowing for

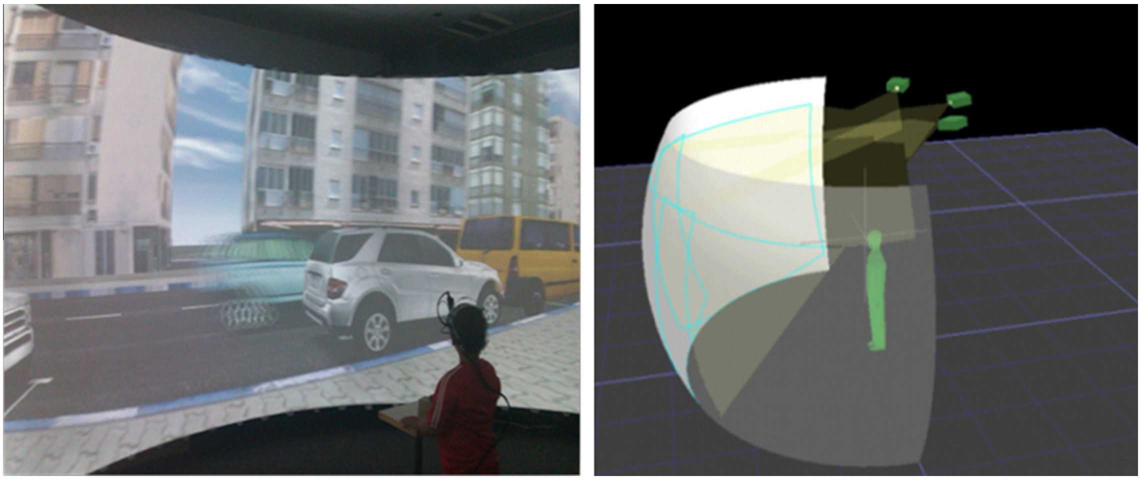

Fig. 1. Dome projection facility and pedestrian simulator at the BGU Ergonomics complex. Left: a child participant viewing the scenario on the Dome screen with the eye tracker strapped to his head. Right: a perspective of a participant facing the dome.

accurate mapping of line of gaze onto the pre-defined dome screen, which enables faster analysis of the data. The ASL Results software was used for the fixations analysis. Analysis was based on the 'dwell-time fixation detection' method (Duchowski, 2003), with minimum fixation time of 100 ms and a threshold of 1° of visual angle.

2.3. Scenarios and stimuli

Following practice, each participant observed a total of eight 90–110 s long typical urban road crossing scenarios in a VE, from a pedestrian's point of view, i.e., as if they were pedestrians standing on one side of the pavement intending to cross the road over to the other side of a two lane street with two-way traffic flow. Crossing scenarios were built using VT MAK simulation applications in a three dimensional generic model of a typical local city, ensuring that participants will be able to relate to environmental road and urban features and recognize them. The scene included typical urban environmental features, such as: street signs, bus stops, benches, garbage cans, and vegetation . Vehicles on the close lane traveled from left to right and the opposite on the far lane. All vehicles travelled at a constant speed of 60 km/h. Traffic flow was predefined by generating margins between adjacent travelling cars on the same lane, resulting in a 4.4 s mean gap (SD = 5.8) between adjacent travelling cars on the road. In each scenario at least one 'safe' crossing gap (minimum = 12 s, mean = 14.4 s, SD = 1.1 s) was available, which was more than sufficient time for any of the participants to cross the 10 m two-lane virtual road (Goh et al., 2012). Street surround-sounds were embedded in the scene and typical sounds were synced with the appearance of elements in the environment (e.g., passing vehicles).

2.4. Cell phone distraction

Four conditions were used: *Undistracted, Naturalistic, Visual search,* and *Arithmetic task.* The base condition was '*Undistracted*'-when participants completed the crossing task without conversing on the phone. In all phone conversation conditions participants were asked to handle a phone conversation with a research assistant whom they have been introduced to at the beginning of the training session. While performing the experiment participants could not see the assistant. In the '*Naturalistic*' phone conversation, participants were asked, over the phone, about casual things from their daily life (e.g., "How old are you?"/"How many siblings do you have?"). In the phone guided '*Visual search*' task, participants were asked, over the phone, to locate specific items in the scene (e.g. "How many people wearing red shorts do you see?", "What is written on the bill board sign to your right?"). To ensure that the participant was conducting the visual search task, the research assistant was instructed to encourage participants to answer the questions even when they were held up or have given the wrong answer (e.g., by asking them if they are sure that they can't see anyone wearing red shorts). In the '*Arithmetic task*' phone conversation participants were asked to answer simple arithmetic questions at a level suitable for their age (e.g. "How much is 6 multiplied by 11?", "How much is 6 plus 11?"). For each age group a pool of suitable arithmetic questions was assembled based on interviews with math teachers, from which the research assistant randomly chose the questions. In order to compensate for individual differences, when a participant was struggling with a question the research assistant was guided to skip it and choose an easier question from the pool of questions. When a wrong answer was given, the research assistant encouraged them to try again for a second time and if failed, a different question was given. Two fixed experimental scenarios (out of the eight) were assigned for each one of the four conversation types, so each time the scenario was played, the same phone conversation type was conducted. This ensured that all participants underwent the same scenarios-conditions but not necessarily in the same order.

2.5. Procedure

Participants were invited individually into the Dome facility for an hour long session. They were asked to sign the informed consent. Participants under the age of 18 were asked to arrive accompanied by an adult. Signed parental consent was mandatory for participation.

The laboratory was kept at constant temperature and illumination conditions. The facility and the staff were introduced to the participant, then, he or she went through Snellen static acuity test and contrast sensitivity test (Ginsburg, 1984; Snellen, 1862). Participants who had uncorrected static acuity of 6/12 or better and normal contrast sensitivity were able to participate in the experiment and were allowed to wear their corrective glasses during the experiment, if necessary. Participants' walking speed was then measured while they walked along a wide 10 m corridor back and forth for several times. They were instructed to walk at the same pace that they would have chosen if they were crossing a road, which is a practiced method to assess participants' walking speed (Schwebel et al., 2009). It was cleared to them that the speed they have walked would be considered as their crossing speed in the virtual reality road, were they to cross the road.

Next, participants returned to the Dome lab for the experimental trials. They received the instructions of the experiment and the experimental tasks. Then they wore the eye tracker and went through a stage of eye calibration while standing in the center of the dome screen. Following one practice scenario and ensuring that they understood the task instructions, the two experimental scenarios of crossing without phone conversing ('undistracted') were conducted. Then, the six phone conversation experimental scenarios were presented using a Latin Square matrix to vary the order of presentation among participants. For those, while observing the traffic scene and attempting to cross the road, participants conduct a phone conversation with the research assistant. Conversations started 15 s before the crossing scenario began.

Before each scenario has started a generic instructional message of the task was presented to them ("Press the response button whenever you feel it is safe to cross the road") on a grey background, for 8 s; just the time needed for the scenario to be loaded. Once loaded, the experimenter asked for the participant approval, only then he played the scenario for the participant to view. Participants were asked to determine when it was safe to cross the virtual road and immediately react by pressing a response button. They were told that pressing the button symbolizes the beginning of the crossing action that would have taken place. They were asked to base their crossing decision upon the walking speed they have demonstrated earlier in the corridor and not faster than that. If no response was obtained in the course of the scenario, the absence of a crossing response was registered. Immediately after a scenario has ended, due to a response or lack of one, the next scenario was loaded in the same manner, as described. Upon completion of all scenarios, participants were debriefed, compensated and the experiment ended.

2.6. Measures

Safety measures (a, b, c, and d) are based on participants' button press responses and walking speed.

a. 'Safety gap' (Seconds) - the shortest between two options: The elapsed time from the moment the participant safely crossed the first lane and before the next vehicle arrived to the crossing path on the first lane; or the elapsed time from the moment the participant safely crossed the first and second lanes and the next vehicle arrived to the crossing path on the second lane.
b. 'Crossing performance' (categorical variable of the 'safety gap', with four categories 1–4).
    1. 'Hit'- a 'safety gap' of less than 0 s, meaning that the participant might have been hit by a car in the real world.
    2. 'Close call'- a 'safety gap' of less than 1 s.
    3. 'Risky cross'- a 'safety gap' between 1 and 2 s.
    4. 'Safe cross'- a 'safety gap' larger than 2 s.
c. 'Initiate crossing' (Seconds) - the elapsed time from the beginning of the scenario and until the participant initiated the crossing, by pressing the button.
d. 'Response time' (Seconds) - the time elapsed since the crossing opportunity emerged, when the car passed the crossing path, and until the participant initiated the crossing, by pressing the crossing button.
e. 'Visual attention distribution' - the distribution of the total fixation time that was directed by each participant in each scenario, to each one of three predefined areas of interest (AOIs) superimposed on the 180° dome screen (Fig. 2): Left (0–10°), Center (10–170°, 80° to each side from the center of the field of vision), and Right (170–180°).

3. Results

For all safety measures (3.1–3.4), a general linear mixed model (GLMM) was applied with 'age group', 'cell phone distraction' and their interaction as the predicting effects in the model. 'Participant' was applied as a random effect to account for individual differences among participants. Applying a backward elimination procedure left both 'age group' and 'cell phone distraction' as main effects for all measures. The interaction was absent. This indicates that children and adults' crossing manner shifted in somewhat similar way when they talked on the phone.

3.1. Crossing performance

The GLMM analysis showed that both 'age group' and 'cell phone' distractions were significant factors in the model ($F(9,361) = 6.08$, $p < 0.001$; $F(9,361) = 2.04$, $p = 0.034$, respectively). Descriptive analysis of the results showed that adults performed the best (Fig. 3); more than 97% of the crossing attempts were successful, meaning they completed the crossing scenarios without a 'hit' event. Children aged 11–13 had the second best score without significant difference from the adults, with 88% successful crossings that ended safely. In accordance to this trend, the youngest group had more crosses ending with 'hit' events, with a vast gap from all other groups (proportion of 'hit' events from the youngest age group to oldest: 53.1%, 25.8%, 11.5%, and 2.8%). Both the first and second age groups (aged 7–8 and 9–10) were more likely than the adults to make crossing decisions that ended in a 'close call' or 'hit' ('close call': $\beta = 1.8$, $p = 0.017$; $\beta = 1.78$, $p = 0.005$, respectively; 'hit': $\beta = 4.3$, $p < 0.001$; $\beta = 2.8$, $p < 0.001$, respectively).

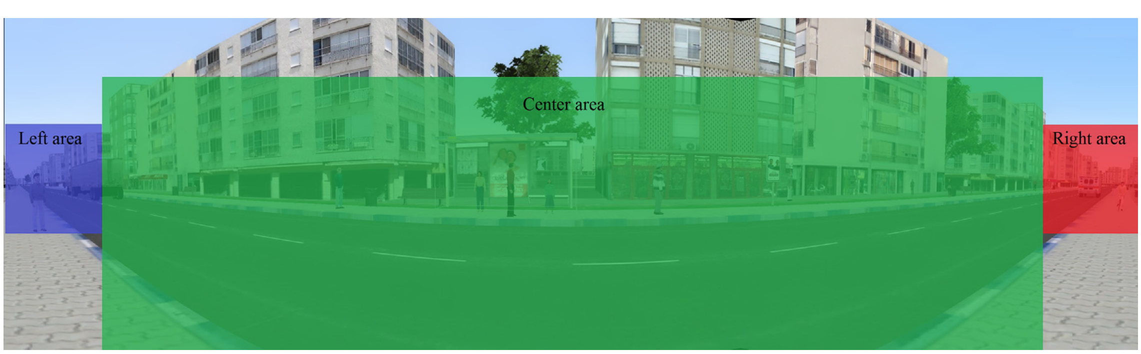

Fig. 2. An example of the virtual reality scene from the participant's point of view. The eye-tracking areas of interest (AOIs: Left, Center and Right) are superimposed on the image.

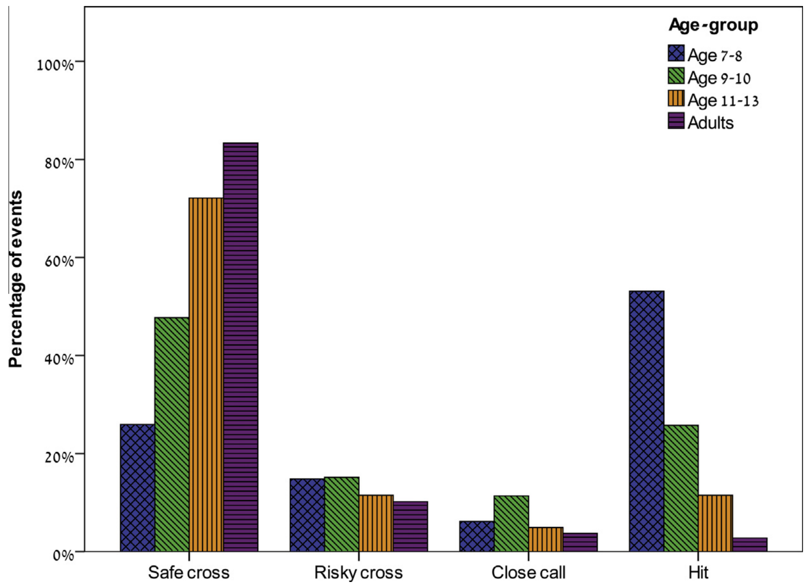

Fig. 3. Percentage of crossing performance events for each age group.

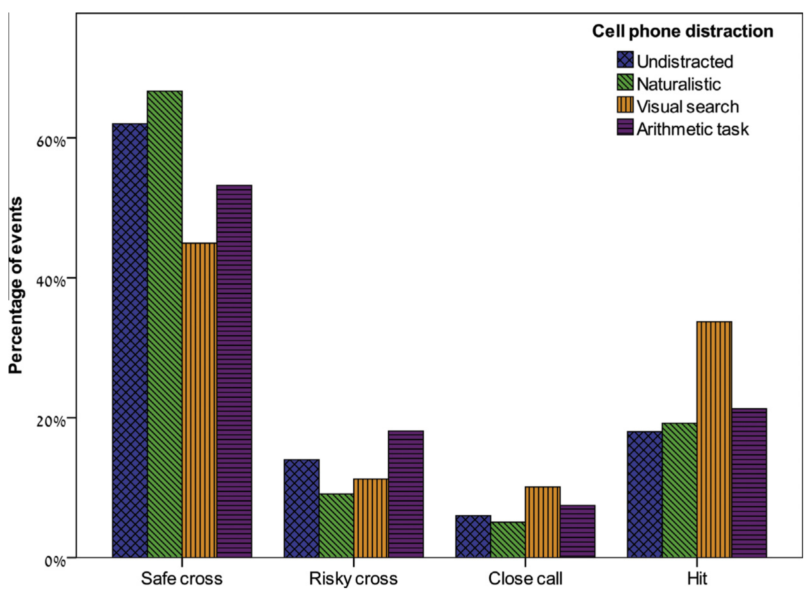

Fig. 4. Percentage of crossing performance events for each age group by conversation type.

Under the 'undistracted' as well as in the 'naturalistic' phone conversation conditions participants had crossed in a safer manner, with an average of 62 and 60% 'safe crosses', respectively (see Fig. 4). The 'visual search' phone conversation was more dangerous than any of the other phone conversation types. More than a third of all crossing attempts ended in a 'hit' or 'close call' when participants were busy with a 'visual search' phone conversation. The risk to end a crossing attempt in a 'hit' was the highest with this type of phone conversation ($\beta = 0.9$, $p = 0.036$).

3.2. Safety gap

The results showed in Table 1 indicate that age-group had a pronounced effect on the 'safety gap' measure. The safety gap increased from the youngest age group to the adults; but not always with a significant difference. Thus, adults had crossed the road in the safest manner, leaving the longest safety gap (Estimated mean = 6 s, Standard Error = 0.2), that was six and two times longer than the gap of the two youngest groups (aged 7–8: 1, 0.5, $p < 0.001$; aged 9–10: 3, 0.4, $p < 0.001$), but without a significant difference from the children aged 11–13. Children aged 7–8 showed the poorest performance, as their average safety gap was significantly shorter from all other age groups. As shown in Table 2, significant differences in safety gap were also apparent among conversation types. The safety gap mean time was the longest when participants were undistracted by a phone conversation (4.7, 0.4), which is longer then both the 'visual search' conversation that caused the participants to leave the shortest gap (2.5, 0.4, $p < 0.001$) and the 'arithmetic task' conversation (3.4, 0.4, $p = 0.009$).

3.3. Initiate crossing

In accordance to the results shown in Table 1 the oldest child group (age 11–13) has waited the longest time before crossing the road (Estimated mean = 36.5 s, Standard Error = 3.8), followed by the adults (26.4, 3). The two youngest groups (age 7–8 and 9–10) were significantly faster than the older children aged 11–13

Table 1
Mean scores (estimated by the GLMM) and statistically significant differences for the four age groups in 'safety gap', 'initiate crossing', and 'response time' measures.

Measure	7–8yrs (A1)		9–10yrs (A2)		11–13 yrs (A3)		Adults (A4)		F ratio df(3,375)	Sig. group differences
	Mean	SE	Mean	SE	Mean	SE	Mean	SE		
Safety gap	1	0.5	3	0.4	4.6	0.6	6	0.5	17.38***	A4 > A2 > A1 A3 > A1
Initiate crossing	15.2	3.4	20.4	2.7	36.5	3.8	26.4	3	6.58***	A3 > A1/A2
Response time	2.4	0.3	2.2	0.2	2.4	0.3	1.52	0.2	2.92*	A4<A3/A2/A1+

In this table, the F ratio is a measure of the overall significance of the differences between the four age groups.
The significance of differences between pairs of groups, reported in the last column, was tested with the sequential Bonferroni at level of 0.05. + tested out significance with the least significant difference at level of 0.05.
* $p < 0.05$.
*** $p < 0.001$.

Table 2
Mean scores (estimated by the GLMM) and statistically significant differences for the four conversation types in 'safety gap', 'initiate crossing', and 'response time' measures.

Measure	Undistracted (C0)		Naturalistic (C1)		Visual search (C2)		Arithmetic task (C3)		F ratio df(3,375)	Sig. group differences
	Mean	SE	Mean	SE	Mean	SE	Mean	SE		
Safety gap	4.7	0.4	3.9	0.4	2.5	0.4	3.4	0.4	8.88***	C0 > C2/C3 C1 > C2
Initiate crossing	21.5	2.1	24.4	2.1	27.7	2.1	25	2.1	2.73*	C2 > C0
Response time	1.6	0.2	1.9	0.2	2.2	0.2	2.7	0.2	7.09***	C3 > C0/C1

In this table, the F ratio is a measure of the overall significance of the differences between the conversation types.
The significance of differences between pairs of groups, reported in the last column, was tested with the sequential Bonferroni at level of 0.05.
* $p < 0.05$,
*** $p < 0.001$.

to make the crossing decision (aged 7–8: 15.2, 3.4, p = 0; aged 9–10: 20.4, 2.7, p = 0.003). According to Table 2 the crossing initiation was the longest when participants were busy with the 'visual search' conversation (27.7, 2.1) which significantly differ only from the crossing initiation under the 'undistracted' condition (21.5, 2.1, p = 0.028).

3.4. Response time

As shown in Table 1, the adults' 'response time' (Estimated mean = 1.52 s, Standard Error = 0.2) was significantly shorter than of all three child age groups (aged 7–8: 2.4, 0.3, p = 0.01; aged 9–10: 2.2, 0.2, p = 0.035; aged 11–13: 2.4, 0.3, p = 0.024), which mean they were the fastest to respond when a crossing opportunity had arrived. However, no significant differences in 'response time' were found among the child age groups. The two more demanding phone conversations had led to longer response times to the crossing opportunities (Table 2). However, the 'arithmetic task' phone conversation caused the longest response time (2.7, 0.2), which was significantly longer than under the 'undistracted' and the 'naturalistic' conversation conditions (1.6, 0.2, p < 0.001; 1.9, 0.2, p = 0.007, respectively).

3.5. Age group and cell phone distraction- trends of interaction

The interaction between 'age group' and 'cell phone distraction' did not come out statistically significant in any of the GLMM analyses (see Sections 3.1-3.4). However some trends can be seen when looking at the descriptive statistics shown in Fig. 5. To simplify the analysis, two alternate conditions were compared: crossing without talking (no conversation) and talking on the phone (all three types of phone conversations collapsed into one condition). Fig. 5

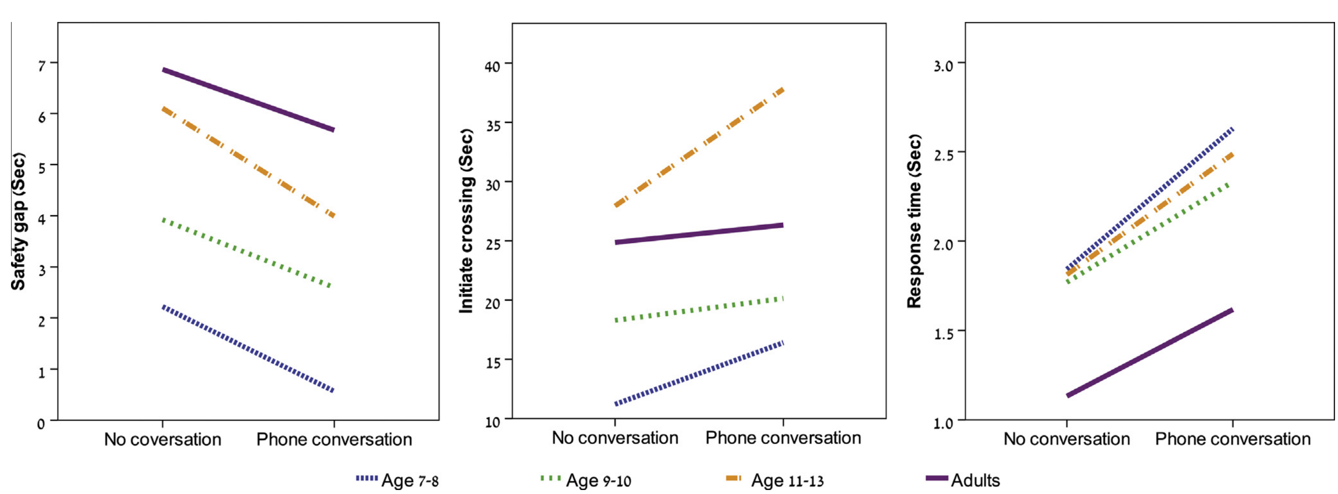

Fig. 5. The means for each of the age groups under an alternate binary phone conversation conditions: No conversation- when no phone conversation was conducted, and Phone conversation- all three types of phone conversations collapsed into one condition. From left to right, the graphs present means for 'safety gap', 'initiate crossing', and 'response time' measures.

illustrates that even under the two alternate conditions, differences were maintained (nearly parallel lines in the graphs, i.e., no interaction) for all age groups, and in all three measures. Nevertheless, a closer look at the graphs shown in Fig. 5 reveals some interaction trends. The most prominent trend is apparent in the 'initiate crossing' measure (Fig. 5-center). Children aged 11–13 showed a larger disparity in 'initiate crossing' values, between the two conditions (i.e., represent the largest incline in the graph). Hence, they were more affected by the phone conversation then the other age groups. Second to them were the children aged 7–8, while adults and children aged 9–10 had more moderate and similar inclines. Children aged 11–13 were also more affected then the other groups in the 'safety gap' measure (Fig. 5-left). That is, when conversing, their 'safety gap' value had the largest drop. In the 'response time' measure (Fig. 5-right), similar inclines are apparent for all age groups, thereby, it is hard to indicate on a certain interaction trend.

3.6. Visual attention distribution

In order to measure participants' visual attention-spread over the three AOIs in the scene (Fig. 2), a Dirichlet regression model was applied on the data set (Hijazi and Jernigan, 2009) with 'age group' and 'cell phone distraction' as the predicting effects in the model. Dirichlet regression is a regression model that was design to deal with compositional data and analyze the three AOIs simultaneously under the constrained that they sum-up to one. Results from the Dirichlet regression shown in Table 4 revealed differences among age groups and among the phone conversation conditions, yet, no interaction was found.

Table 3 shows the visual attention distribution among the three AOIs (see Fig. 2), for each category. Overall, for all age groups and in all conversation types, participants spent more time looking at the center area than they did to the left or right areas, yet with differences between the age groups. Adults spent relatively less time then all others looking at the center ($\beta = -1.86$, $p < 0.001$). They spent 53.3% of their time looking at the peripheral areas (left and right together), which is about 10–40% more than any of the other age groups. Children aged 7–8 are located at the other end; they spent 90% of their time looking at the center area, significantly longer than all other groups. If looking at the means (Table 3), adults spread their attention fairly equal between the left and right areas, unlike the children aged 9–10 and 11–13 that allocated more attention to one side than to the other.

All three conversation types had influenced participants' visual attention spread on the viewed scene; each type in a different manner. The most evident influence was that when speaking on the phone participants spent relatively more time looking at the center area and less to the periphery regions (Tables 3 and 4). This effect was strongest when participants were busy with 'visual search' and 'arithmetic task' phone conversation ($\beta = 0.88$, $p < 0.001$; $\beta = 0.63$, $p < 0.01$, respectively).

Table 3
The mean gaze distribution [%] for each of the age group and cell phone conversation categories over the three AOIs (Left, Centre, Right).

Variable	Category	Left	Centre	Right
Age group	Aged 7–8	3.3	90.9	5.8
	Aged 9–10	14.2	64.1	21.7
	Aged 11–13	24.8	57.6	17.6
	Adults	26.4	46.7	26.9
Cell phone distraction	Undistracted	18.2	51.7	30.1
	Naturalistic	17.0	62.7	20.3
	Visual search	19.1	66.7	14.2
	Arithmetic task	14.7	70.4	14.9

Table 4
The Dirichlet regression estimated coefficients for the set of AOIs.

Variable	Category	Left	Centre	Right
Intercept		-1.50^{***}	1.17^{***}	-1.14^{***}
Age group^{+}	Aged 9–10	0.51^{**}	-1.07^{***}	0.66^{***}
	Aged 11–13	1.14^{***}	-1.05^{***}	0.59^{**}
	Adults	0.60^{***}	-1.86^{***}	0.39^{*}
Cell phone distraction^{++}	Naturalistic	0.04	0.51^{**}	-0.20
	Visual search	0.46^{**}	0.88^{***}	0.09
	Arithmetic task	-0.18	0.63^{**}	-0.41^{*}

$^{+}$ Reference aged 7–8.
$^{++}$ Reference 'undistracted'.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

4. Discussion

The results of this study show a clear indication that cell phone conversations can hinder adult and child pedestrian's ability to safely cross the road. It was reflected in the 'safety gap' measure, which was shortened under all three conversation types. This corresponds to previously reported studies that included pedestrians, adults and children aged 10–11 (Stavrinos et al., 2011, 2009). This phenomenon was also evident in the 'initiate crossing' and 'response time' to a crossing opportunity. On average, across age groups, participants' response time to the crossing opportunity was slower when conversing on the phone, regardless of the conversation type. Consistent with many studies on drivers, which repeatedly demonstrated that an increase in reaction time is an expected behavior when drivers are engaged in a phone conversation (Caird et al., 2008, 2004; Horrey and Wickens, 2006). Adult and child participants exemplified an increase of 13–30% in the 'initiate crossing' time when conversing on the phone (depending on the conversation type), similar to Neider et al. (2010) that reported on 20% longer initiating times for adult pedestrians when conversing on the phone.

Participants' visual attention spread was altered in response to the phone conversations. When engaged in a phone conversation of any type, participants tended to focus more visual attention to the close range area (center) and less to the left and right peripheral areas in comparison to when not being distracted. This finding strengthens findings of previous lab and field studies that were conducted without utilizing an eye-tracker. For example, laboratory studies reported on lower attention to traffic, expressed by fewer looks to the left and right before beginning to cross, when adult and child pedestrian were busy with phone conversation (Stavrinos et al., 2011, 2009). Field studies revealed that pedestrians that were busy with phone conversations were less likely to look at upcoming traffic before crossing (e.g. Hatfield and Murphy, 2007). However, the utilization of eye-tracker gives better assessment of the severity of this phenomenon; demonstration of 10–20% reduction in attention allocation to the periphery of the scene, depending on conversation type.

It is safe to say, in accordance to the current results (Tables 1–4), that the two more cognitively demanding conversations had a stronger effect than the 'naturalistic' phone conversation and the 'undistracted' condition. This is partly contradicting previous findings with adult pedestrians (Stavrinos et al., 2011), that did not find broad evidence to larger effects of more cognitively demanding conversations. In the current study, calculation of arithmetic problems over the phone led to slower response times to the crossing opportunity. The 'visual search' conversation caused participants to perform even worse, they were slower to initiate the crossing and they made riskier crossing decisions. It should be remembered that the 'visual search' phone conversation required participants to listen to the instructions on the phone, search for objects in accordance to the instructions, and make the crossing decision, all at the same time. It seems that visual distraction combined with a phone conversation imposed more risk to pedestrians, than just conversing freely on the phone. However, our everyday phone conversations are not done in a controlled setting, and are not limited to one certain 'type' of conversation. Hence, it might be the distinction between talking and not talking that matters more (see Fig. 5).

Regarding age, it was seen that older children and adults perform crossing decisions better, thereby, crossing ability is age related. This result appears in the literature on non-distracted pedestrians (e.g., Meir et al., 2013). However, two notions are worth noticing. First, all children groups had very similar 'response times' to crossing opportunities, which was about a second longer than that of the adults. Response time is considered by some to be the best indication to development of pedestrian skills (Barton, 2006). Thus, it is important to remember that even 11–13 year-olds did not perform as well as adults. Second, unexpectedly, the oldest child group was also the slowest to make the crossing decision ('initiate crossing'). The children aged 11–13 year olds showed an overall safe behavior as it is was reflected in the 'crossing performance'; so, it is not completely clear what caused them to linger in making their decisions. It might be that their lack of confidence, knowing that they are being measured and monitored, nerviness, or their awareness of the danger involved in the crossing, led them to be "extra safe" and "over think" their actions. Something that they might not share with the younger age groups. The way participants spread their visual attention across the scene was also age dependent, this too was found in a previous study on non-distracted pedestrians (Tapiro et al., 2014). Older children and adults spent less time looking at the close proximity area than younger children that may indicate on superior visual-attention spread strategy of the firsts, which may be in part contributing for their effective crossing behavior.

In contrast to our hypotheses, no interaction between 'age group' and 'cell phone distraction' was found. This means that all age groups were affected in a similar magnitude when talking on the phone while crossing the road. Slight and statistically insignificant indication showed that 11–13 year olds tended to be more affected than others (see Fig. 5). As they probably were more sensitive to elements that may jeopardize their safety and to the fact they were monitored (see also Meir et al., 2013). However, it should be noted that the lack of interaction can also be a result of the sample size of the experiment, as larger sample size may reveal more significant effects. This is a limitation of the study that should be addressed in future studies. Note also that the adults' population were a sample of convenience, commonly used in such studies. Notably, even when using an up-to-date VR simulator, which is very common practice in road safety experiments, results might not be accurately fit to real-world behavior. Thus, use of numerical results per se should be handled with care (e.g. 'hit' rate). Still, the results are indicative for both child and adult pedestrians especially when examining groups' differences.

5. Conclusions

The study was aimed to explore the effect of cell phone conversation on child and adult pedestrians in controlled virtual environment settings and fixed conversation types. It is vital to keep investigating the effect of additional smartphone uses (e.g., texting, listening to music, or gaming) on children's crossing performance. It is also evident that the use of controlled simulation environments provides insights into pedestrians' behavior without the risk of harm. Finally, the use of eye tracking combined with performance and safety metrics enhances the knowledge gained from the experimental results.

For public safety, clear statements need to be made about the ability of adults and especially of children of various age groups to use a cell phone while crossing the road. This is key for creating regulation, parental awareness, and proper training programs for children. In general, we can conclude that crossing the road while speaking on the phone undermines children and adults' safety. Children might be more exposed to risk due to their already lower road-crossing abilities. More demanding phone conversations can pose higher risk. Finally, the ability to cross the road is age related, and even 13 year olds have different crossing behavior than adults. Pedestrians, regardless of their age, should limit the use of cell phones when attempting to cross the road.

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