Do Prohibitive Warnings Improve Road-Crossing Safety for Texting and Non-Texting Pedestrians?

SAFETY RESEARCH USING SIMULATION

UNIVERSITY TRANSPORTATION CENTER

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Abstract

Pedestrian injuries and deaths caused by collisions with motor vehicles are a major health problem in the U.S. [1]. In 2013 alone, 4,735 pedestrians were killed and 66,000 were injured in traffic crashes. Both field observations and controlled experiments indicate that distraction from mobile device use is a significant risk factor for pedestrian injuries. Despite the importance of the problem, relatively little is known about effective interventions to reduce the harmful effects of mobile device use on pedestrian road-crossing behavior. The goal of this project was to investigate how mobile devices can be used to assist pedestrians in making safe road crossings. We developed a cell phone app that warns pedestrians when they initiate unsafe crossings and tested the app in our state-of-the-art pedestrian simulator. The project expands on our first SAFER-SIM grant that investigated permissive alerts (ones that indicate when it is safe to cross). We found that texting pedestrians who were given permissive alerts took safer gaps than those without these alerts. However, they also paid much less attention to the traffic, relying on the alert system to identify when it was safe to cross. The current project investigated prohibitive alerts (ones that indicate when it is unsafe to cross). We hypothesized that prohibitive alerts will lead to safer gap choices for texting pedestrians without the decrease in visual attention to traffic that we found with permissive alerts. The results inform the design of Vehicle-to-Pedestrian (V2P) communication systems based on dedicated short-range communications (DSRC) technologies being incorporated into vehicles.

1 Introduction

Pedestrian injuries and deaths caused by motor vehicle collisions are a major public health concern worldwide. In the U.S., pedestrians were among the few categories of road users where deaths rose in the most recently released traffic safety data according to the National Highway Traffic Safety Administration [1]. Globally, the safety of vulnerable road users – pedestrians, cyclists, and motorcyclists – is a high priority [2].

The role of distraction as a contributing factor to vehicle crashes has gained heightened attention in recent years. Numerous studies have shown that driver attention is impaired by the use of mobile devices such as cell phones [3]. While the deleterious influence of texting and phone conversations on driving is well documented, there is relatively little research on the dangers of using a mobile device as a pedestrian. Recently, researchers have begun to address this question both through naturalistic observational studies and through controlled laboratory studies. This work has shown that pedestrians exhibit riskier road-crossing behavior when texting or talking on a cell phone [4-10]. The combination of drivers and pedestrians being distracted by mobile devices creates a particularly lethal mix.

Our research uses a large-screen, immersive virtual environment to study how the use of mobile technology influences pedestrian road crossing and how assistive information systems can help ameliorate the detrimental effects of texting while crossing roads (Figure 1). Participant motions are tracked in 3D to produce an accurate first-person perspective of the environment. Images are displayed in stereo to give a realistic sense of 3D location and vehicle motions. The simulator can send messages to the participant's cell phone to alert them to traffic conditions and potential hazards. This allows us to safely and systematically test the effectiveness of such information systems for texting pedestrians. The focus of this project was on investigating the influence of delivering warnings on a cell phone to texting and non-texting pedestrians to inform the design and development of Vehicle-to-Pedestrian (V2P) communication systems.

Figure 1.1 – Texting in the Hank Pedestrian Simulator

An important step in developing V2P technology is testing how pedestrians respond to alerts delivered via their smartphones. In particular, how can such information be most effectively presented to pedestrians, and will they trust and attend to the information delivered through a mobile device? In our first SAFER-SIM project, we conducted an experiment using a large-screen immersive virtual environment to evaluate how texting pedestrians respond to permissive traffic alerts delivered via their cell phone. We developed a cell phone app that signaled texting pedestrians when they could safely cross a stream of traffic. We call such alerts – ones that tell you when it is safe to cross – ***permissive alerts***. We compared gap selection and movement timing in three groups of pedestrians: texting, texting with permissive alerts, and no texting (control) [11].

The alerting system had a beneficial effect on road crossing – participants in the alert group chose larger gaps, were more discriminating in their gap choices, and had more time to spare when they exited the road than the texting group. However, the alert group also relied heavily on the alert system and paid much less attention to the roadway than the control or texting groups. The heavy reliance on the alert system for choosing gaps (and low attention to the traffic) may create serious problems, including reduced situational awareness and, as a result, a reduction in the ability to respond to unexpected events and technical failures.

This project extended our earlier work by developing and testing a prohibitive warning system that tells a pedestrian when it is NOT safe to cross a road. An alarm was set off on the pedestrian's cell phone whenever they began to cross a gap that was judged to be unsafe. An important question is whether such information can be sent in time for participants to react to alerts. Other critical questions include how pedestrians will respond to prohibitive warnings (e.g., by aborting a crossing or by crossing more quickly), how the alarms will influence attention and situational awareness, and how the alarms will influence gap selection.

2 Background Literature

The prevalence of mobile device usage while walking appears to be on the rise, particularly in teens and young adults. A study which observed more than 34,000 students crossing roads in front of schools found that one in five high school students and one in eight middle school students crossed the street while distracted by a mobile device (most often texting on a phone, 39%) [12]. Other observational work by Thompson et al. [9] showed that nearly one-third of the 1,102 pedestrians observed crossing a road were performing some kind of distracting activity (e.g., listening to music, sending text messages, talking on the phone). Similarly, Vilano et al. [13] report that nearly 19% of all pedestrians crossing two urban intersections were performing some type of distracting activity and, more specifically, 8% were using a digital device.

Distraction changes the way people interact with their environment. A recent study of gait patterns during walking and texting found that participants walked slower, took shorter step lengths, and had lower step frequencies and longer double support phases when texting as compared to walking while not texting [14]. Participants were also more cautious in navigating around obstacles, leaving greater clearances when texting. In a similar study, Lamberg and Muratori [15] found that pedestrians walked at a slower rate and had greater lateral deviations in their paths. These observations are further supported by observational studies of pedestrians crossing roads while using mobile phones. Hatfield and Murphy [4] reported that pedestrians using a mobile phone walked more slowly across the roadway, thereby increasing their exposure to traffic. In addition to walking more slowly, distracted pedestrians are more likely to engage in unsafe crossing behaviors such as walking unsafely into oncoming traffic or violating traffic lights and failing to look both ways before crossing [16, 17]. Using a semi-immersive virtual environment, Schwebel and colleagues examined how mobile device use impairs pedestrian road-crossing performance and found that young adults who were distracted by using a mobile device were more likely to be hit or have close calls in a road-crossing task in the virtual environment [7, 8, 18, 19]). They also looked left and right less often and looked away from the roadway more often. Taken together, these studies provide convincing evidence that cell phone use causes distraction that increases the likelihood of harmful outcomes, including roadway injuries and deaths.

The source of the distraction (mobile technology) also offers a potential means of remediation to improve safety and reduce the dangerous consequences of pedestrians crossing roads while texting through integrating pedestrians into the roadway communication loop. Recent advances in connected vehicles technology allow cars to “communicate” with each other through dedicated short-range communication (DSRC) [20]. Vehicle-to-vehicle (V2V) communications technology holds great promise for improving traffic safety by alerting drivers to road hazards and potential collisions with other vehicles, so much so that the National Highway Transportation Safety Administration (NHTSA) announced plans to mandate DSRC for all new light vehicles in the near future [21]. A number of recent efforts have been directed at bringing pedestrians and bicyclists into the roadway communication network by incorporating DSRC into smartphones [22-24]. This would allow phones and vehicles to exchange information about their locations and movements – called vehicle-to-pedestrian (V2P) communication. For example, pedestrians would be “visible” to drivers even when they were out of sight behind an obstacle or in the dark. Qualcomm and Honda researchers collaborated on the development of a mobile phone app that exchanges information with surrounding vehicles and sends warnings to both the driver and the pedestrian/cyclist when a collision is imminent [25].

While progress is being made on the development of the technology to support V2P communications, little is known about how such information can be most effectively presented to pedestrians and whether pedestrians will trust and attend to the information delivered through a mobile device. Most of the research on V2P communications has focused on technology for detecting imminent collisions between vehicles and pedestrians [26]. Studies of collision warnings from the perspective of a driver show that the context of the warning has an important influence on the driver’s response to the warning [27]. In particular, warnings that are judged to be false alarms decrease drivers’ trust and compliance. Research on how warnings influence pedestrian behavior are needed to inform the design and development of P2V technology. For example, the thresholds for detecting a pedestrian movement to cross a road requires a balance between early detection (to give the pedestrian time to take evasive action) and confidence that a crossing has been initiated (to avoid large numbers of false alarms).

3 Objectives

While progress is being made on the development of the technology to support V2P communications, little is known about how such information can be most effectively presented to pedestrians and whether pedestrians will trust and attend to the information delivered through a mobile device. The primary goal of this study was to examine how such information systems influence pedestrian road crossing. We studied this question using our large-screen, immersive virtual environment, Hank, in which participants physically walk across a lane of simulated traffic while texting on a cell phone (Figure 3.1). Most of the research on V2P communications has focused on generating collision warnings—alerting both the driver and the pedestrian to imminent collisions [26]. However, prediction of likely collisions between vehicles and pedestrians is a challenging problem. Pedestrians frequently stand at the edge of a road waiting for a safe gap to cross. Cars driving by, even at high speeds, do not present a threat as long as pedestrians remain off the road. However, a single step can put the pedestrian in harm's way. Predicting such conflicts in time for the driver, pedestrian, or both to react and avoid a collision is an enormously challenging problem. If warnings are sent whenever a pedestrian is near the road, there is a danger that the frequency of such alerts will be so high that they will be ignored. If warnings are sent only when the pedestrian steps into traffic, there is the risk that it will come too late for evasive action.

Figure 3.1 – Photograph of person texting while crossing a street in the Hank pedestrian simulator (the visual angles are correct from the viewpoint of the pedestrian)

In this project, we examined how warnings delivered to texting pedestrians when they initiate unsafe crossings influence gap choices and crossing behavior. We developed a method to detect pedestrian crossing movements based on real-time motion tracking, designed an interface to signal the pedestrian that a collision is imminent, and conducted an experiment in our pedestrian simulator to see how people respond to such warnings.

4 Methods

4.1 Task

We used a pedestrian road-crossing task to examine the effects of texting with and without warnings sent when they begin to cross a gap that is too small to be safely crossed. Participants stood at the edge of a one-lane road and watched a continuous stream of traffic coming from the left. Their goal was to safely cross the road. Once they had selected a gap to cross, participants physically walked to the other side of the virtual road. The traffic ceased to be generated after participants reached the other side of the road. Participants then walked back to the starting place, and a new trial commenced.

4.2 Experiment Design

The experiment used a between-subjects design with three conditions: texting, warning, and control. In the texting condition, participants continually received and responded to automated text messages throughout the road-crossing session. The warning condition was identical to the texting condition except that participants also received an auditory alarm on their cell phone when they began to cross a gap that was judged to be unsafe. In the control condition, participants held a cell phone throughout the road-crossing session but did not text with Hank or receive alerts.

4.3 Apparatus

The study was conducted using our large-screen virtual environment, Hank, which consists of three screens placed at right angles relative to one another, forming a three-walled room (Figure 4.1). Three DPI MVision 400 Cine 3D projectors rear-project high-resolution, textured graphics in stereo onto the screens. An identical projector front-projects high-resolution stereo images onto the floor. Participants wore Volfoni ActiveEyes stereo shutter glasses that were synchronized with the displays so that images were alternately visible in the left and right eyes. This permitted us to show stereo images with the correct perspective for each participant. The side screens are 14.2 feet long, which allowed participants to physically walk across a one-lane virtual road. Reflective markers were mounted on the cell phone and on a helmet worn by the participant. An OptiTrack motion capture system was used to determine the position and orientation of the cell phone and the participant’s head based on the marker locations viewed from 17 Flex 13 cameras surrounding the volume. The participant’s eye point was estimated from the head data and used to render the scene for the participant’s viewpoint. The virtual environment software is based on the Unity3D gaming platform. In-house code generated traffic and recorded the positions and orientations of vehicles, the pedestrian, and the cell phone during the experiment for later analysis.

Figure 4.1 – The Hank Virtual Environments Laboratory Pedestrian Simulator

4.4 Traffic Generation

A top-down view of the roadway environment is shown in Figure 4.2. A stream of traffic traveled from left to right on a one-lane road. Vehicles were generated from behind a building on the left-hand side of the road, passed through the screen volume, and then disappeared behind a building to the right. The road initially curved and then approached the participant along a straight section of roadway that was perpendicular to the left screen. The length of the visible portion of the road was selected so that the tail vehicle in the next gap always appeared before the lead vehicle passed the participant. Thus, participants could always see the entire gap before they began to cross the road. Vehicles drove at a constant speed of either 25 or 35 mph.

Figure 4.2 – Perspective view of the roadway environment.

Vehicles were timed so that the temporal gap at the point of crossing (i.e., the time between the moment the tail of the lead vehicle crossed the path of the participant and the moment the front of the tail vehicle crossed the path of the participant) was one of five pre-selected gap sizes (2.5 s, 3.0 s, 3.5 s, 4.0 s, or 4.5 s). Note that the temporal and spatial gap between two vehicles with different speeds changed continuously as the vehicles approached the intersection. To create moderately dense traffic, small gaps occurred more frequently than large gaps according to the distribution shown in Figure 4.3.

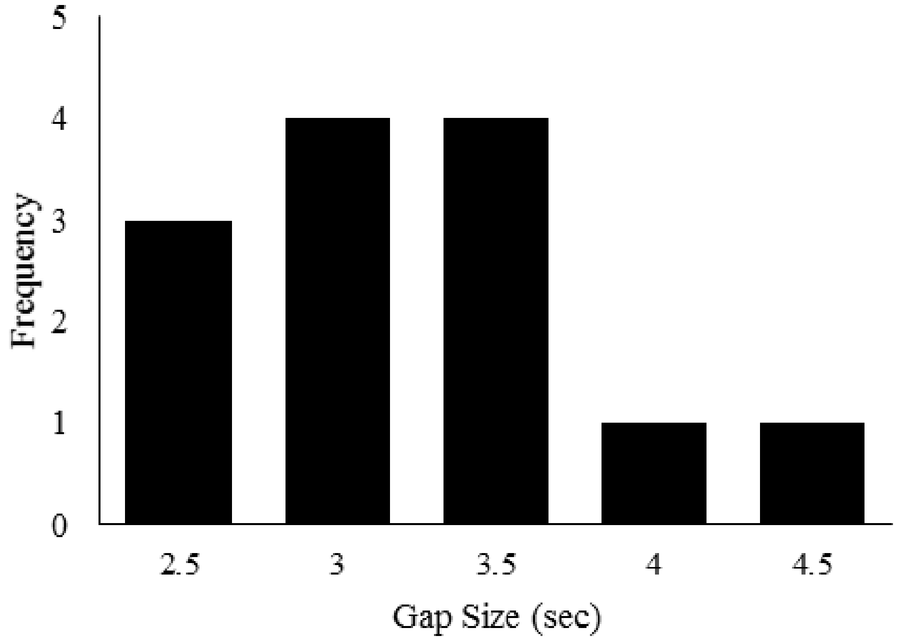

Figure 4.3 – Distribution of gap sizes.

4.5 Texting

An Android messenger application was developed in-house and installed on a cell phone. To minimize the message exchange latency, the cell phone communicated with the master computer through a wireless network using TCP/IP. To give the appearance of a natural conversation, messages sent to the participant's cell phone were shown as coming from our virtual environment, Hank. The conversation began with a message from Hank introducing himself. Hank then asked a sequence of pre-recorded questions, one at a time, waiting for the response to one question before sending the next message. Participants were asked to respond to each question with a single reply. Participants were free to use the swipe and auto-correction features. Participants were notified of the arrival of a new message by a half-second vibration of the cell phone. Questions were grouped by topic and could be answered by a short message. The following is an excerpt from a conversation between Hank and a participant:

…

Hank: What classes are you taking this semester?

Pedestrian: chemistry

Hank: What do you want to do when you get out of school?

Pedestrian: physical therapy

Hank: What is your least favorite class?

Pedestrian: history

Hank: Why is that?

Pedestrian: its difficult for me to learn

Hank: What are some of your hobbies?

Pedestrian: i like to run and workout at the gym

Hank: What do you do in your free time?

Pedestrian: watch netflix

4.6 Cell Phone Warning

A warning system was developed to (1) detect when a participant was initiating a crossing motion, (2) determine if there was sufficient time to safely cross through the current gap, and (3) send an alarm to the participant's cell phone if the gap to be crossed was judged to be unsafe. A method to detect the initiation of a crossing motion was developed based on an analysis of crossing trajectories from previous experiments encompassing 875 road-crossing trials. The method used position data from the real-time tracking of the helmet worn by participants to estimate when participants initiated a crossing motion. The raw position data was first smoothed by normalizing the 7 most recent positions. A trigger fired when the change in average position was greater than a threshold value. The method was tested on trials from previous experiments. It correctly detected crossing motion before road entry in 77.37% of the trials.

When the initiation of a crossing motion was detected, the warning system calculated the time to arrival of the approaching tail vehicle in the gap to be crossed. Based on previous experiments, the average time to cross the single lane of roadway was about 2.0 s. A .5 s margin of error was added to average crossing time to get a threshold value for safe crossing of 2.5 s. An auditory alarm was sent to the participant's phone whenever they initiated a crossing motion and the time to arrival of the tail vehicle in the gap to be crossed was less than 2.5 s.

4.7 Data Recording and Performance Variables

The master computer recorded the position and orientation of all movable entities in the virtual environment, including the pedestrian's head, the cell phone, and all vehicles on every time step. In addition, it recorded the text messages sent to and received from the participant along with the time step that the message was sent or received. This method of data recording allowed us to reconstruct key aspects of the experiment off-line. A 3D visualizer was developed in-house in Unity 3D to graphically replay trials. This application enabled researchers to visualize the pedestrian motion and traffic from different viewpoints (e.g., top-down, first-person, or third-person views) and navigate through the entire recorded experiment using the play, pause, stop, fast-forward, and rewind buttons. In addition, the visualizer automatically produced a record of the following performance variables:

Waiting time: summation of all gaps seen except the taken gap.

Gap taken: the size (in seconds) of the gap crossed.

Timing of entry: the time between the moment the rear of the lead vehicle in the gap passed the participant and the moment the participant entered the path of the vehicles.

Road-crossing time: the time it took the participant to cross the road (from the moment they entered to road to the moment they exited the road).

Time to spare: the time between the moment the participant cleared the path of the vehicles and the moment the front of the tail vehicle in the gap passed the participant.

Close call: a road crossing was classified as a close call if the time to spare was less than or equal to 0.5 s.

Collisions: a road crossing was classified as a collision if time to spare was ≤ 0.

Attention to traffic: percentage of time the participant was looking at the traffic over a trial.

All measures were averaged across the 20 road-crossing trials to arrive at aggregate scores. We also computed a variability of timing of entry score by calculating the standard deviation of each participant's timing of entry across all 20 test trials.

4.8 Gaze Direction Estimation

A learning algorithm was used to develop a method to estimate participant gaze from head position and orientation, in order to determine participants' attention to the traffic, the cell phone, and elsewhere. Gaze classification is based on the position and orientation of the participant's head. Training and test data sets were collected in which the viewer's gaze was known. The training data set served as the input to a support vector machine (SVM), which computed parameters for classification of gaze direction from data recorded during the experiment trials. At each moment of the simulation, the participant's gaze is classified as either Looking at Traffic, Looking at the Cell Phone, or Looking Elsewhere. The classification is based on a spherical coordinate system centered on the participant's eyepoint. Bounding boxes that surround the vehicles currently approaching the participant and the cell phone are projected onto a sphere centered on the participant's head along with the participant's facing direction.

4.9 Participants

A total of 47 undergraduate students participated in this study. Participants were recruited through the Elementary Psychology course at the University of Iowa and earned course credit for their participation. There were 16 participants (8 females and 8 males) in each of the control and texting groups, and 15 participants (7 females and 8 males) in the warning group.

4.10 Procedure

Participants were first fitted with a tracking helmet, shutter glasses, and a harness that was connected to a post at the back of the VE to prevent them from walking into the front screen. Participants were then given a brief introduction to the virtual neighborhood and instructed to cross the roadway as they would in the real world. Each trial began with the road clear of traffic. A continuous stream of vehicles approached from the left-hand side. The first vehicle in the stream was always purple. Participants were asked to wait until the purple car passed in order to prevent them from crossing the empty space in front of the stream of traffic. They were told that they could wait as long as they wished before attempting to cross the road. Once participants reached the sidewalk on the other side of the road, traffic generation ceased, allowing the participant to return to the starting position. Once the participant had returned to the starting position, traffic was again generated in the same fashion as described above. Each participant performed three practice crossings followed by 20 test trials. After finishing the test trials, participants filled out a demographics questionnaire and were debriefed about road-crossing safety. The study took approximately 30 minutes to complete.

Participants in the control group were asked to hold the cell phone in their hand. However, the cell phone was turned off throughout the experiment. Participants in the texting group were asked to respond to the texts they received as quickly as they could. On the first practice trial, they crossed without texting; on the remaining two practice trials they received texts and responded to them. Participants in the warning group performed one practice trial without texts or warnings. On the second practice trial, they received texts and responded to them without warnings. Prior to the third practice trial, they were given a brief description of how the warning system worked. They were instructed to hold the cellphone and lean toward but not cross the roadway when a vehicle was very close to the intersection. The cellphone detected a forward motion and alerted the participant with an auditory alarm. Participants were given no explicit instructions about whether or not to cross the road based on the warnings. All participants performed 20 test crossings.

5 Results

5.1 Data Analysis Strategy and Performance Means

Examination of gap selection used mixed-effects logistic regression to model the likelihood of accepting (or rejecting) a gap based on condition and gap size. Log likelihood ratio tests for the logistic regression model revealed that the best model fit supported by the data included a random intercept for participant, a random slope for gap size, and fixed effects of gap size and condition.

All dependent measures were analyzed in one-way analyses of variance (ANOVAs) with condition (control, texting, alert) as the between-subjects factor. Post-hoc tests were conducted using Fischer’s Least Square Difference test with alpha = .05. Table 5.1 shows a summary of means (and standard deviations) for all performance variables for the control, texting, and warning groups.

Preliminary analyses yielded no significant main effects or interactions involving gender. Therefore, the analyses reported below were collapsed over gender.

Table 5.1 – A summary of means and standard deviations for all performance variables for the control, texting, and warning groups.

	Control (n = 16) M (SD)	Texting (n = 16) M (SD)	Warning (n= 15) M (SD)
Waiting Time	5.20 (3.63)	5.17 (3.64)	8.42 (3.64)
Mean Gap Taken (s)	3.56 (0.14)	3.50 (0.22)	3.68 (0.17)
Timing of Entry (s)	0.65 (0.12)	0.67 (0.10)	0.70 (0.15)
Variability of Timing of Entry (s)	0.13 (0.05)	0.33 (0.24)	0.21 (0.09)
Road-Crossing Time (s)	2.08 (.23)	2.04 (0.21)	2.11 (0.22)
Time to Spare (s)	0.86 (0.26)	0.76 (0.36)	0.88 (0.33)
Collisions (%)	0.03 (.07)	0.11 (0.17)	0.07 (0.10)
Attention to Traffic (%)	96.14 (3.56)	59.50 (27.76)	41.91 (34.14)

5.2 Gap Selection

Gaps seen: Analysis of the average waiting time revealed a main effect of condition, $F(2,44) = 3.51$, $p = .04$. Those in the alert condition waited longer than those in the control and texting conditions, but did not differ from each other.

Mean gap size taken: Analysis of the average gap size taken revealed a significant effect of condition, $F(2,44) = 3.82$, $p = .03$. Compared to those in the warning condition, participants in the texting condition took significantly smaller gaps for crossing, while those in the control condition were only marginally more likely to take smaller gaps. However, participants in the texting and control conditions did not differ from one another in this regard.

Likelihood of taking a gap: Mixed-effects regression analyses were used to determine whether the likelihood of choosing a given gap differed significantly between the control, texting, and warning conditions. Participants in all conditions were more likely to choose larger rather than smaller gaps, $z = 10.28$, $p < .001$, with the average odds of accepting a gap increasing by 10.28 with each .5 s increase in gap size. Participants' gap acceptance thresholds in the texting group were significantly less conservative than those in the alert group, $z = 2.70$, $p = .01$, with 2.36 increased odds of accepting a given gap in the texting condition compared to those in the alert condition. Additionally, participants' gap acceptance thresholds in the control group were significantly less conservative than those in the alert group, $z = 2.24$, $p = .03$, with 2.05 increased odds of accepting a given gap compared to those in the alert condition (Figure 5.1).

5.3 Movement Timing

Crossing time: There were no differences among the three groups for road-crossing time, $F(2, 44) = .45$, ns.

Timing of entry: There were no differences among the three groups for timing of entry, $F(2, 44) = .70$, ns.

Variability of timing of entry: Analysis of variability in timing of entry revealed a significant effect of condition, $F(2, 44) = 6.79$, $p = .003$. Participants in the texting condition were significantly more variable in their timing of entry compared to the control and warning conditions. Participants in the control and alert conditions were not different from one another on this measure.

Time to spare: There were no differences among the three groups for time to spare, $F(2, 44) = .67$, ns.

Collisions: No differences were found among the three groups for collisions, $F(2, 44) = 1.67$, ns.

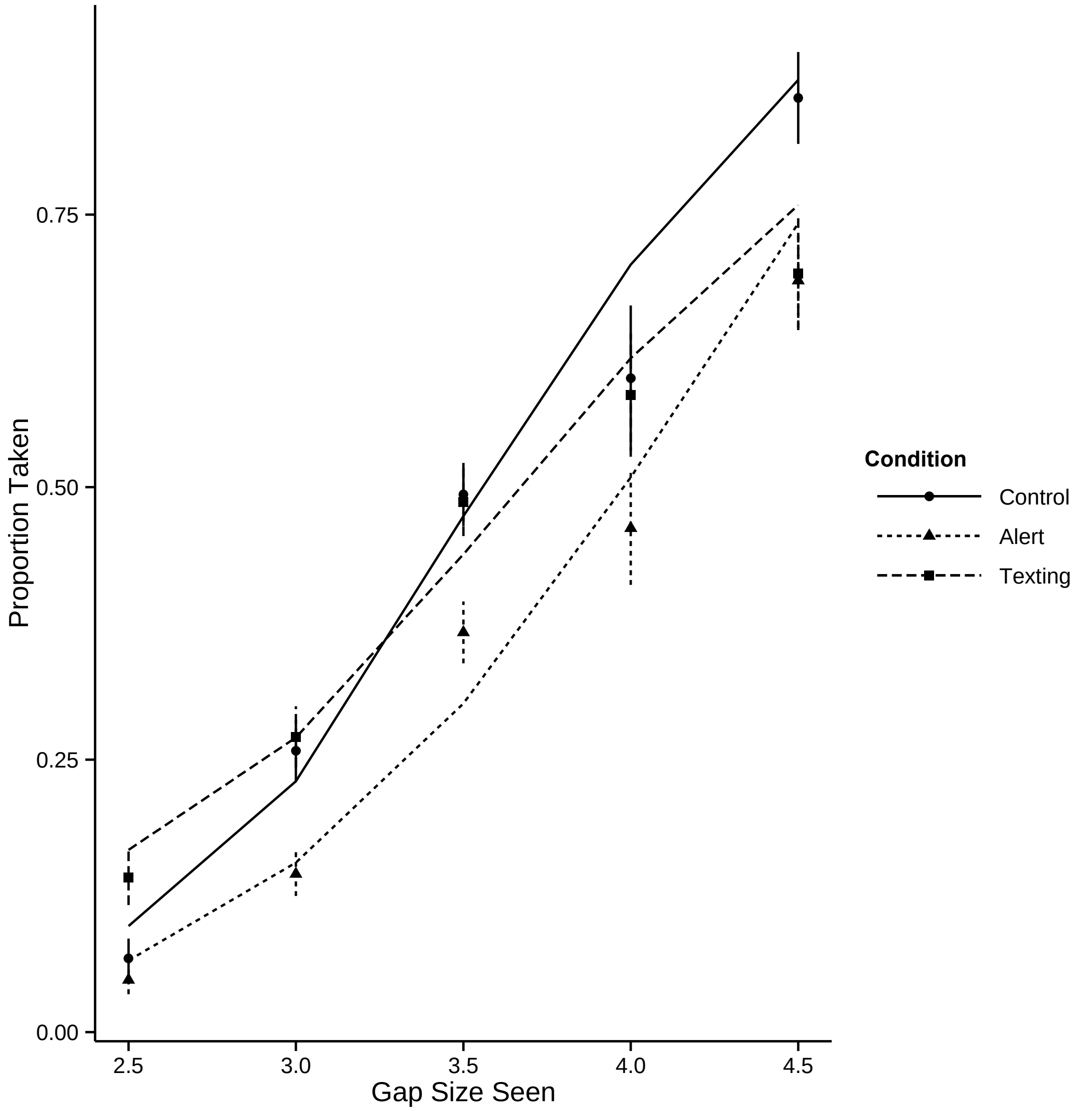

Figure 5.1 – Logistic regression curves showing the likelihood of selecting a given gap in the control, warning, and texting conditions.

5.4 <u>Gaze Direction</u>

Analysis of overall attention to traffic revealed a main effect of condition, $F(2, 44) = 18.74$, $p < .001$. Post hoc comparisons showed that each group varied significantly from the others, with those in the control condition spending the most time attending to traffic and those in the warning condition spending the least amount of time attending to traffic.

6 Discussion and Conclusions

The goal of this study was to evaluate how texting pedestrians responded to a warning delivered via their cell phone that indicated when they were crossing an unsafe gap. To safely and systematically study this problem, we examined gap selection, movement timing, and gaze direction in an immersive pedestrian simulator. We found that participants in the warning group chose larger gaps than participants in both the control and texting groups. This was true even though the warnings were relatively infrequent – there were only 22 warnings issued on 300 trials, and four of the participants received no warnings. Participants in the warning group also waited significantly longer to choose a gap than participants in the control and texting groups. Similar to the alert group in our previous project, participants in the warning group spent less time looking at the road than those in the control or texting groups, although the differences between groups were not as large as in the alert experiment. Because the warning provides no assistance in picking a gap, it is not surprising that participants spent more time looking at traffic in the warning condition as compared to the alert condition. In fact, it is not clear why participants in the warning group spent less time looking at the road relative to the texting group.

The most surprising aspect of the results was that those in the warning group almost never responded to the warning by aborting the crossing even though the warning was highly predictive of risk (participants had collisions on 62% of the trials on which they received a warning and continued to cross the road). We had predicted that participants would either abort their crossing action (i.e., return to the edge of the road) or increase their walking speed to cross more quickly when they received a warning that they had initiated an unsafe crossing. On the large majority of trials, when they received a warning they did neither.

Why would participants have ignored the warning? It may be that the perceived risk was not sufficient to cause them to adjust their behavior. Another possibility is that once they started to move, they judged that it was quicker and safer to finish crossing than it would be to reverse direction and return to the curb. Participants stand close to the edge of the road, and since the road is a single lane wide, they cross it relatively quickly. By the time they received and processed a warning, they may have been well into their crossing. For warnings to be effective, it may be necessary to detect movement into the roadway sooner, thereby generating the warnings more quickly. However, this may, in turn, increase the false alarm rate, which may cause additional problems with compliance and use.

This study, in combination with our previous study on permissive alerts, highlights the adverse effects pedestrian texting can have on safe road crossing and both the potential and challenges of using cell phone alerts and warnings to reduce the risk of being hit by a vehicle when walking across roads while texting. The most striking difference between texting and non-texting participants in our experiment was in where they directed their gaze. Participants who texted without alerts or warnings looked at traffic for only half as much time as non-texting participants. The reduction in attention to traffic had serious consequences – texting pedestrians crossed more small gaps, had less time to spare, and were hit more often than the non-texting group. Participants who texted with alerts or warnings spent even less time looking at traffic (they looked at traffic about ¼ as much time as non-texting participants). However, their crossing behavior was less risky than those who texted without alerts. On average, participants who texted with alerts or warnings chose larger gaps, had more time to spare, and had fewer collisions than those who texted without alerts (although not all of these differences were statistically significant).

While these results offer promise for the use of assistive communication technology in promoting safe road crossing, the degree to which participants focused on their cell phones raises concerns about overreliance on technology for making crossing decisions. The reduced attention to traffic could leave them vulnerable to unexpected changes in traffic or technological failures in predicting gap affordances, resulting in unsafe entry into traffic-filled roadways. Extensive testing of such assistive technologies is critical before taking steps to deploy them on real roads.

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