Using a Virtual Environment to Study the Impact of Sending Traffic Alerts to Texting Pedestrians

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ABSTRACT

This paper presents an experiment conducted in 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 delivered information to texting pedestrians about when traffic conditions permit safe crossing. We compared gap selection and movement timing in three groups of pedestrians: texting, texting with alerts, and no texting (control). Participants in the control and alert groups chose larger gaps and were more discriminating in their gap choices than participants in the texting group. Both the control and alert groups had more time to spare than the texting group when they exited the roadway even though the alert group timed their entry relative to the lead car less tightly than the control and texting groups. By choosing larger gaps, participants in the alert group were able to compensate for their poorer timing of entry, resulting in a margin of safety that did not differ from those who were not texting. However, they also relied heavily on the alert system and paid less attention to the roadway. The discussion focuses on the potential of assistive technologies based on Vehicle-to-Pedestrian (V2P) communications technology for mitigating pedestrian-motor vehicle crashes.

Keywords: Pedestrian simulation; Texting; Mobile device use; Pedestrian safety; Connected vehicles technology; Vehicle-to-pedestrian (V2P) communication.

Index Terms: Human-centered computing--Empirical studies in HCI • Human-centered computing--Mobile phones • Computing methodologies--Virtual reality • Applied computing--Psychology.

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]. In 2011, 4,432 pedestrians were killed and an estimated 69,000 were injured in traffic crashes. Globally, an estimated 400,000 pedestrians die in traffic crashes each year with the highest rates occurring in developing countries [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 [4-9]. 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

Figure 1: Photograph of person crossing a street in the pedestrian virtual environment. The visual angles are correct from the viewpoint of the pedestrian.
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. This paper presents the results of a study comparing the road-crossing behavior of texting pedestrians with and without an alerting system that informed them about when it was safe to cross the road.

2 RELATED WORK

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%) [10]. Other observational work by Thompson, Rivara, Ayyagari and Ebel [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, Roney, and Bechtel [11] 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, had lower step frequencies and longer double support phases when texting as compared to walking while not texting [12]. Participants were also more cautious in navigating around obstacles, leaving greater clearances when texting. In a similar study, Lamberg and Muratori found that pedestrians walked at a slower rate had greater lateral deviations in their paths [13]. 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 [14, 15]. Using a semi-immersive virtual environment, Schwebel and colleagues examined how mobile device use impairs pedestrian road-crossing performance [7, 8, 16, 17] 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. 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) [18]. This 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 [19]. A number of recent efforts directed at bringing pedestrians and bicyclists into the roadway communication network by incorporating DSRC into smartphones [20-22] allows phones and vehicles to exchange information about their locations and movements – so-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 [23].

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. Most of the research on V2P communications has focused on generating collision warnings – alerting both the driver and the pedestrian to imminent collisions [24]. However, prediction of likely collisions between vehicles and pedestrians is a challenging problem [23]. Pedestrians frequently arrive 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 of 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.

An alternative to collision warning is to provide information to pedestrians about traffic conditions to guide their decisions. Such systems have been examined to assist drivers on minor roads in choosing gaps to cross major roads [22]. Using a driving simulator, Creaser and colleagues compared four different Intersection Decision Support (IDS) systems that informed drivers when oncoming traffic made it unsafe to enter the major road, including dynamic warnings and count down clocks that showed the time to arrival of the next vehicle. Results showed that all forms of the prohibitive information led to improved gap acceptance by drivers as compared to a baseline condition in which there was simply a stop sign.

In this paper, we examine how permissive information influences pedestrian gap choice and crossing behavior. A permissive information system provides information about when it is safe to cross as opposed to information about when it is unsafe to cross. We present this information in two forms: a countdown clock that indicates when the next opportunity to safely cross the road will occur and an audible alert indicating that a safe gap is about to arrive at the intersection.

3 THE ROAD-CROSSING EXPERIMENT

Texting while crossing roads can be dangerous, particularly in situations where traffic is dense. A texting pedestrian may misjudge the size of a gap or not notice changes in traffic such as a vehicle lane changes and vehicle accelerations. To examine the influence of texting with and without permissive alerts, we conducted an experiment in our large-screen, immersive pedestrian VE in which participants physically walked across a single lane of simulated traffic. The road-crossing scenario was designed to place high attentional load on the participants, thereby mimicking the dangerous combination of texting while crossing roads with high-density traffic. Participants stood at the edge of a (virtual) curved, one-lane road facing a steady stream of dense traffic. The gaps
between vehicles varied dynamically as the vehicles approached the participant. The combination of a short range view, high density traffic, and dynamically variable gap sizes made this a highly challenging task. The simulator automatically generated and sent text messages to participants and recorded the messages sent by participants. In the alert condition, the simulator sent alerting messages to the cell phone to inform the participants about when it was safe to cross the road. The text exchanges and alerts were stored in the stream of simulation data for analysis of performance. We present the differences between how texting (with and without alerts) and non-texting pedestrians attend to traffic, select gaps for crossing, and time their movements through gaps when crossing busy roads.

4 Method

4.1 Task

We used a pedestrian road-crossing task to examine the effects of texting with and without alerts to inform pedestrians about when it was safe to cross the road. 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, alert, and control. In the texting condition, participants continually received and responded to automated text messages throughout the road-crossing session. The alert condition was identical to the texting condition except that participants also received alerts on their cell phone informing them that a safe gap was approaching. 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 (4.33×3.06×2.44 m). Three DPI MVisio 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 (4.33×3.06 m). 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 4.33 m long, which allowed participants to physically walk across a one-lane (roughly 3.6m wide) virtual road. Stereo surround sound was used to generate spatialized traffic sounds. Reflective markers were mounted on the cell phone and on a helmet worn by the participants. 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.

4.4 Traffic Generation

A top-down view of the roadway environment is shown in Figure 2. A stream of traffic travelled from left to right on a one-lane road. Vehicles were generated from behind a building on the left-hand

Figure 2: Perspective view of the roadway environment.
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 40.23 or 56.33 km/h.

Vehicles were timed so that the temporal gap between vehicles at the point of crossing (i.e., the time between the moment the tail of the lead vehicle crossed the center of the CAVE and the moment the front of the tail vehicle crossed center of the CAVE) was one of five pre-selected gap sizes (2.5s, 3.0s, 3.5s, 4.0s, or 4.5s). 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 3 which simulator randomly drew a gap from given 13 gaps and vehicle speed (either 40.23 or 56.33 km/h).

Participants were free to use the swype 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 Alerts

In the alerting condition, participants were informed when a crossable gap (a gap of size 4.0s or 4.5s) was approaching the crosswalk. There is an extensive literature on aviation, ground vehicle, and pedestrian warning systems. Research has examined the effectiveness of presenting warnings through different modalities (visual, auditory, and tactile) and with different stimulus properties [25]. A number of studies have shown the benefit of having combined visual and auditory signals as opposed to having either visual or auditory signals alone [26-28]. In an attempt to achieve a maximal effect, we designed an interface that presented both visual and auditory information about when the next crossable gap was to arrive at the crosswalk area. The visual information was in the form of a countdown clock that showed the time to the arrival of the next gap in half-second intervals. The clock appeared whenever a crossable gap was 10 seconds from the crosswalk (Figure 4). Once the gap reached the crosswalk, the red box turned green and the counter disappeared. The countdown clock appeared inside the cursor to keep the timer in the pedestrian’s field of view. The auditory signal was a “ding” sound on the cellphone that notified the pedestrian one second before the arrival of the gap.

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 cellphone, and all vehicles on every time step. In addition, it recorded the text messages sent to and received from 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 play, pause, stop, fast-forward, and rewind buttons. In addition, the visualizer automatically produced a record of the following performance variables:

1. Number of gaps seen: the number of gaps seen before crossing the roadway; including the gap crossed (a measure of waiting).
2. Gap taken: the size (in seconds) of the gap crossed.

4.5 Texting

An Android messenger application was developed in-house and installed on a cellphone. To minimize the message exchange latency, the cellphone 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 cellphone 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 the 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.

![Screenshot](A) ![Screenshot](B)

Figure 4. Screenshot of a texting conversation with alert. Panel A shows a countdown clock inside the cursor. Panel B shows that it is safe to cross when the countdown box changes from red to green upon the arrival of a safe gap.
3. **Timing of entry**: the time between the moment the rear end of the lead vehicle in the gap passed the participant and the moment the participant entered the roadway.

4. **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).

5. **Time to spare**: the time between the moment the participant exited the road and the moment the front of the tail car in the gap passed the participant.

6. **Close call**: a road crossing was classified as a close call if the time to spare was ≤ 0.5 s.

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

8. **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 relative to the cell phone and the vehicles on the road. 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 was 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. The model returned by the SVM achieved 93% correct classification with the test data set.

### 4.9 Participants

A total of 48 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 three groups: control, texting, and alert.

### 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 min. to complete.

Participants in the control group were asked to hold the cellphone 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 fast 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 alert group performed one practice trial without texts or alerts. On the second practice trial, they received texts and responded to them without alerts. Prior to the third practice trial, they were given a brief description of how the alert system worked. They were instructed to wait for three safe gaps (4.0s and 4.5s) to pass by to give them experience with the alerting system. They then performed a single practice trial with the alert system activated. They were given no explicit instructions about how to use the alerts and whether or not to cross the road based on the alerts. All participants performed 20 test crossings.

### 4.11 Data Analytic Strategy

Mixed effects logistic regression analyses were conducted to determine if condition (control, texting, alert) was predictive of the likelihood of taking a gap. The model fit best supported by the data included a random intercept for subject, a random slope for gap size, and fixed effects of gap size and condition.

For all other measures, we conducted one-way Analyses of Variance (ANOVA) with condition (control, texting, alert) as the 

<table>
<thead>
<tr>
<th>Measure</th>
<th>Control (n = 16)</th>
<th>Texting (n = 16)</th>
<th>Alert (n = 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Gaps Seen</td>
<td>3.45 (.35)</td>
<td>3.55 (3.37)</td>
<td>3.01 (1.00)</td>
</tr>
<tr>
<td>Mean Gap Taken (s)</td>
<td>3.72 (.18)</td>
<td>3.50 (.21)</td>
<td>3.71 (.27)</td>
</tr>
<tr>
<td>Timing of Entry (s)</td>
<td>.7 (.13)</td>
<td>.74 (.11)</td>
<td>.86 (.18)</td>
</tr>
<tr>
<td>Variability of Timing of Entry (s)</td>
<td>.13 (.03)</td>
<td>.21 (.07)</td>
<td>.33 (.13)</td>
</tr>
<tr>
<td>Road Crossing Time (s)</td>
<td>2.11 (.18)</td>
<td>2.11 (.29)</td>
<td>2.03 (.17)</td>
</tr>
<tr>
<td>Time to Spare (s)</td>
<td>.88 (.28)</td>
<td>.66 (.32)</td>
<td>.84 (.26)</td>
</tr>
<tr>
<td>Collisions (%)</td>
<td>5 (9)</td>
<td>14 (18)</td>
<td>6 (7)</td>
</tr>
<tr>
<td>Close Calls (%)</td>
<td>18 (15)</td>
<td>25 (12)</td>
<td>19 (13)</td>
</tr>
<tr>
<td>Time gaze is directed at traffic (%)</td>
<td>96.7 (1.12)</td>
<td>45.5 (25.47)</td>
<td>23.5 (15.42)</td>
</tr>
</tbody>
</table>
5.2 Movement Timing

Crossing time: There were no differences between the three groups in road crossing time, $F(2, 45) = .78, ns$.

Timing of entry: There was a main effect of condition, $F(2, 45) = 3.77, p = .03$, indicating that participants in the alert condition timed their entry relative to the lead vehicle less precisely than did those in the control and texting conditions. There were no differences between the texting and control conditions.

Variability of timing of entry: Analysis of variability in timing of entry also revealed a significant effect of condition, $F(2, 45) = 19.54, p < .001$. Participants in the alert condition were more variable in timing their entry relative to the lead vehicle than were...
participants in both the texting and control conditions. In addition, participants in the texting condition were more variable in their timing of entry than participants in the control condition.

**Time to spare:** There was a marginal overall effect of condition in time to spare, \( F(2,45) = 2.62, p = .08 \). As seen in Table 1, the general pattern indicated that participants in the control and alert conditions had similar amounts of time to spare when they cleared the path of the cars, whereas participants in the texting condition had less time to spare. To further examine pairwise differences between the three groups, we conducted post-hoc tests. These comparisons revealed that participants in the control condition had significantly more time to spare than those in the texting condition, and that participants in the alert condition had marginally more time to spare than those in the texting condition (\( p = .08 \)).

**Collisions:** There was also a marginal overall effect of condition in the percentage of trials resulting in a collision, \( F(2,45) = 2.50, p = .09 \). Again, the general pattern indicated that participants in the control and alert conditions had a similar rate of collisions and participants in the texting condition had more collisions. Further post-hoc testing showed that participants in the texting condition experienced significantly more collisions with traffic than did participants in the control condition.

**Close Calls:** Analysis of close calls did not reveal an effect of condition, \( F(2,45) = 1.13, ns \).

### 5.3 Gaze Direction

Analysis of overall attention to traffic revealed a main effect of condition, \( F(2,45) = 75.48, p < .001 \). Each group differed significantly from the others, with those in the control condition spending the most time attending to traffic (96.7\%, \( SD = 3.12 \)) and those in the alerting condition spending the least amount of time attending to traffic (23.5\%, \( SD = 15.42 \)).

To provide a more fine-grained look at gaze direction, the gaze direction was estimated at 0.1 sec intervals for the 2-sec window before and after entry into the road. Figure 6 shows the percentage of gaze in each of the three directions (phone, traffic, other) for each time interval. The zero point on the horizontal axis represents the time of entry into the road, negative and positive values account for waiting before entry into the roadway and crossing time respectively. Additionally, the time of the audio notification of the alert system is illustrated by a green bar on the corresponding traffic time for the alert condition (bottom panel). For both groups, the highest proportion of attention to the oncoming traffic was about a half second before crossing. The “other” category was highest as they crossed the road (predominantly looking forward). Notably, participants in the alert condition paid less attention to the traffic than those in either the control group or the texting group.

### 6 Discussion

The goal of this study was to evaluate how texting pedestrians responded to permissive traffic alerts delivered via their cell phone. To safely and systematically study this problem, we examined gap selection, movement timing, and gaze direction in an immersive virtual environment. We found that participants in the control and alert groups chose larger gaps and were more discriminating in their gap choices than participants in the texting group. Both the control and alert groups had more time to spare than the texting group when they exited the roadway even though the alert group timed their entry relative to the lead car less tightly than the control and texting groups. By choosing larger gaps, participants in the alert group were able to compensate for their poorer timing of entry, resulting in a margin of safety that did not differ from those who were not texting.

In many ways, our results are consistent with observational studies of real pedestrian behavior. The most notable difference between our results and the reports of observational studies is that texting participants in our study did not walk more slowly than non-texting participants [4, 12, 13]. This difference may be due to the relatively short distance of our crossing (roughly 3.6 m) and the repeated practice from making many crossings.

We were struck by the ease with which participants adapted to the alert system, the speed with which they came to trust it, and the effectiveness with which they used it. The primary positive impact was on the decisions they made – participants in the alert condition selected larger gaps and as a consequence, had more time to spare when they exited the roadway. However, those using the alerts also had deficits in their road crossing performance – notably, they timed their entry into the road less tightly and were more variable in timing their road entry. What stands out in the results is the impact that texting and alerts had on where participants looked. Texting participants spent much less time looking at traffic than did non-texting participants, and those with alerts looked the least at traffic. The alert group most often looked at traffic during a period of about one-second before they crossed the road. Thus, it appears that the alert group relied on their phone to select the gap and then glanced at traffic to time their crossing. This outsourcing of cognitive processing may create serious problems including reduced situational awareness and as a result, a reduction the ability to respond to unexpected events and technical failures.

As awareness of the dangers of distracted walking grows, communities are examining ways to reduce risky pedestrian behaviors including public information campaigns and fines for distracted walking on sidewalks. Several cities have experimented with street markings aimed at encouraging pedestrians to be pay attention as they cross intersections. New York City launched the “Look” campaign in 2012 that involved both safety ads and road markings [29]. The City of New Haven, Connecticut stenciled, “DON’T READ THIS. LOOK UP!” on sidewalks at intersections. An observational study of pedestrian behaviors at two interactions in New Haven (one with warnings stenciled on the sidewalk and one without such warnings) showed no differences in the proportion of pedestrians who were distracted at the two intersections [11]. Others are exploring creative approaches to bring attention to distracted walking including express lanes marked with “No Cellphones” painted on sidewalks in Washington D.C. by workers at National Geographic and a prank done by the New York City performance art collective Improve Everywhere that involved a team posing as “Seeing Eye People” who wore orange vests and guided texting pedestrians with a leash along public sidewalks [30]. Likely all of these measures are needed to increase awareness of the risks of distracted walking.

### 7 Summary and Conclusions

This study highlights the adverse effects pedestrian texting can have on safe road crossing and the potential of cell phone alerts to reduce the risk of being hit by a vehicle while 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 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 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 chose larger gaps, had more time to spare, and 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 permissive alerts in promoting safe road crossing, the degree to which participants focused on their cell phone 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.

One concern that arises with simulation-based experiments is the degree to which the behaviors of participants in virtual environments correspond with how people behave in similar situations in the real world. In particular, the high rate of (virtual) collisions in this experiment (especially in the texting condition) suggests that participants may have taken risks they would not take in crossing real traffic. One reason the collision rate was high was that traffic was intentionally designed to present challenging conditions for crossing in order to investigate differences between groups. Small gaps occurred more frequently than large gaps; vehicles traveled at different speeds causing gaps to vary in size as they approached the intersection; and gaps were visible for a relatively short period of time. Differences in performance are most detectable in ambiguous conditions (i.e. gaps that are either uncrossable or easily crossable). The high collision rate was likely due in part to the difficulty of task.

A large number of studies have examined the validity of behavioral studies done with driving simulators (see [31, 32] for a review of the findings). The general finding is that there is a medium to strong correlation between behaviors in the real and simulated worlds. Less work has examined the validity of pedestrian simulators, but this work also indicates that there is significant correspondence between behavior in simulated and real environments. Schwebel et al. compared the behaviors of children and adults in a pedestrian virtual environment to behaviors in real-world analog tasks (for children and adults) and actual road crossing for adults. Participants stood on a simulated curb from which they viewed a virtual roadway displayed on three large monitors. The task was to step off the curb when they judged it was safe to cross. The step triggered a person avatar that walked across the virtual roadway at the participant’s normal walking speed. Key performance variables, including gap size, hits, close calls, wait time, and start delay, were compared with two commonly used real-world road crossing analog tasks: The “shout” technique, in which participants stand at the edge of road and call out when they think it is safe to cross, and the “two step” technique in which participants stood sufficiently far back from the road such that they could take two steps to initiate a crossing motion when they judged it was safe to cross. In addition, adult participants actually crossed a road.

They found highly significant correlations between performance in a pedestrian virtual environment and in the analog tasks and actual road crossing. In addition, they found that parent-reported measures of child temperament that are correlated with injury risk, including impulsivity and inhibitory control, predicted the riskiness of the behavior in the simulator. These results provide support for the validity of the results reported in this paper. In particular, we believe the relative levels of performance across the conditions are indicative of how texting and non-texting pedestrians behave in the real world, and the performance in the alert condition provides important evidence of how pedestrians would likely behave with such alerts in crossing real roads.

Our research underscores the utility of virtual environments for studying the impact of mobile technology on distracted walking, particularly in high-risk situations like road crossing. Our pedestrian virtual environment provides a safe platform for conducting controlled experiments on cell phone use that would be too dangerous to do on a real roadway. Importantly, the extended length of our side screens allows us to study how pedestrians physically walk across traffic-filled roads. Much of the previous work on pedestrian road crossing has involved analog tasks in the real world (e.g. the “shout” and “two-step” techniques), virtual environments with treadmill or virtual environments in which participants take a single step which initiates the motion of an avatar. Having participants physically walk across a road engages a wide range of mechanisms underlying perception/action and establishes an important feedback loop that supports calibration of perception/action. In addition, participants can naturally adapt the timing and rate of their movements to the continuous movements of vehicles (e.g. quickening their pace to respond to close calls). Previous studies that compared gap decisions in tasks that involved physically walking through a gap vs. gap decisions made at the roadside found that those who actually crossed the road more finely tuned their actions and made more safe crossings [33, 34].

Because of the flexibility of the VE, we can rapidly develop scenarios and try out variations in traffic patterns, road layout, and user interface design. During the early stages of this work, we implemented several prototypes of the interface for our alert system. We were able to test variations of the interface in pilot studies and quickly refine the design. Most importantly, the VE allows us to do fine-grained analysis of participant behavior that would be difficult or impossible to do in observational studies. We record the locations of all vehicles, the position and orientation of the participant’s head, and the position and orientation of the cell phone on each time step of the experiment. This allows us to replay individual road-crossing trials, to estimate gaze behavior, and to analyze decisions and actions with high fidelity.

In our future studies, we plan to explore how the timing of the permissive information system influences crossing behavior. For example, will participants continue to rely so heavily on the permissive system if the selected gaps are smaller than those used in this experiment? Likewise, how will participants respond if the permissive system only selects very large (and possibly infrequent) gaps?

In addition, we plan to investigate prohibitive information systems that tell pedestrians when it is NOT safe to cross a road. This includes “don’t walk” icons on the phone to indicate when it is unsafe to enter the road and warning signals that alert a pedestrian when they begin to cross a dangerous gap. An important question is whether information can be sent in time for participants to react to alerts. Another critical question is how pedestrians will respond to prohibitive alerts (e.g., by aborting a crossing or by crossing more quickly). Mobile devices and short range communication technologies offer enormous potential to assist road users in and outside of vehicles. Further study is needed to better understand how to provide useful information in a timely manner.

Acknowledgments
This research was supported by National Science Foundation awards BCS-1251694 and CNS-1305131, and by the US Department of Transportation, Research and Innovative Technology Administration, Prime DFDA No. 20.701, Award No. DTRT13-G-UTC53 through the SafeSim University Transportation Center.

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