Determining the Effect of Smartphone Alerts and Warnings on Older-Adult Street-Crossing Behavior

SAFETY RESEARCH USING SIMULATION

UNIVERSITY TRANSPORTATION CENTER

Kyle Rector, PhD
Assistant Professor
Computer Science
The University of Iowa

Joseph Kearney, PhD
Professor
Computer Science
The University of Iowa

Jodie Plumert, PhD
Professor
Psychol. and Brain Sciences
The University of Iowa

Determining the Effect of Smartphone Alerts and Warnings on Older-Adult Street-Crossing Behavior

Kyle Rector, BS, MS, PhD
Assistant Professor
Computer Science
The University of Iowa
https://orcid.org/0000-0003-4607-0920

Joseph Kearney, BA, MA, MS, PhD
Professor
Computer Science
The University of Iowa
https://orcid.org/0000-0002-0443-8152

Jodie Plumert, BA, PhD
Professor
Psychological and Brain Sciences
The University of Iowa
https://orcid.org/0000-0002-2150-7922

Jeehan Malik, BS
PhD Student
Computer Science
The University of Iowa
https://orcid.org/0000-0002-0462-991X

Morgan Di Napoli Parr, BS
PhD Student
Psychological and Brain Sciences
The University of Iowa
https://orcid.org/0000-0003-3248-9640

Jessica Flathau, BS
Lab Manager
Psychological and Brain Sciences
The University of Iowa
https://orcid.org/0000-0001-7807-303X

A Report on Research Sponsored by

SAFER-SIM University Transportation Center

Federal Grant No: 69A3551747131

March 2020

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated in the interest of information exchange. The report is funded, partially or entirely, by a grant from the U.S. Department of Transportation's University Transportation Centers Program. However, the U.S. Government assumes no liability for the contents or use thereof.

Table of Contents

List of Figures

List of Tables

Abstract

Research has shown that older pedestrians have more difficulty making road-crossing decisions than younger adults. This presents an opportunity for vehicle-to-pedestrian (V2P) communication to assist older adults' street-crossing decisions. We developed ability-based permissive alerts (safe to cross) and prohibitive warnings (not safe to cross) for a smartphone in a virtual street-crossing environment. We conducted a between-subjects study with 66 participants ages 65-84 to understand the effects of these alerts and warnings. We found differences between the permissive alerts and prohibitive warnings: (1) permissive participants were more likely to take smaller gaps than control participants (prohibitive had no effect); (2) permissive participants were more compliant with alerts (Cohen's Kappa: .80) than prohibitive participants (Kappa: .50); and (3) 10/22 prohibitive participants reported the warnings as annoying (none for permissive). These findings give insights into V2P design and raise questions about how V2P alerts affect older-adult street-crossing behavior.

1 Introduction

Pedestrian injuries and deaths caused by motor vehicles are a major concern worldwide. Globally, the number of annual road traffic deaths has reached 1.35 million, with the highest rates in developing countries [1]. In the U.S., the number of pedestrians killed along roadways in 2018 was the highest since 1990 [2]. Older pedestrians represent a particularly vulnerable population, as 20 percent of all pedestrian fatalities in 2017 were people 65 years and older [3].

Research studies investigating road-crossing behavior have shown that older adults have more difficulty than younger adults in making road-crossing decisions. For example, Dommes and Cavallo investigated how age-related decline affects the ability of older adults to choose safe temporal gaps (i.e., the time between two vehicles) when physically crossing a virtual road [4]. They found that older pedestrians were more likely than younger pedestrians to make road-crossing decisions that would lead to collisions when car speeds were higher (50 km/h and above) and to miss opportunities to cross when car speeds were lower (30 km/h). Research suggests that the factors influencing older pedestrians' road-crossing decisions include perceptual, cognitive, and physical performance decline due to aging [4–6].

In a virtual environment setting, research has shown that providing smartphone alerts that inform younger texting pedestrians whether it is safe or unsafe to cross can improve road-crossing behavior [7,8]. Smartphone alerts have the potential to inform older adults as well given that smartphone usage increased by 24 percent between 2013 and 2017 among older adults (ages 65+) [9]. To the best of our knowledge, however, there is no research on how to use mobile devices to help older pedestrians make safe road-crossing decisions.

To address this problem, we conducted a between-subjects user study with 66 participants ages 65-84 to study the effect of smartphone alerts and warnings on their road-crossing decisions. We developed two types of systems that provided visual, haptic, and auditory alerts or warnings to older pedestrians as they decided when to cross a road in a virtual environment. Our systems were ability-based; we used each user's brisk walking speed to determine whether it was safe to cross the street in a stream of traffic.

We determined that participants in the control condition (who received no alerts or warnings) were conservative in their gap choices and missed many opportunities to cross. Participants who received permissive alerts were more compliant with the alerts (Cohen's Kappa: .80) than participants who received prohibitive warnings (Kappa: .50). Consequently, participants who received permissive alerts were more likely to take smaller gaps than participants who received prohibitive warnings or control participants. Participants described the prohibitive warnings as "annoying," while this was not the case for permissive alerts. Our findings have design implications for vehicle-to-pedestrian (V2P) systems that provide information about street crossing for older adults.

2 Background and Related Work

2.1 Road-Crossing Characteristics for Older Adults

Given the concerns about pedestrian injuries and fatalities in older populations, researchers have studied road-crossing behavior in older adults. Zito et al. conducted a head- and eye-tracking study to compare road-crossing behavior in younger and older pedestrians [10]. Participants indicated their crossing decision by taking a step forward in a virtual environment with cars approaching at two different speeds on a one-lane road. They found a significant effect of age on the number of potential crashes and the number of missed opportunities to cross at both slower and faster speeds. They also found that the number of gaze fixations towards the ground was higher in the older group. Naveteur et al. [11] showed that older adults take longer when stepping from a curb to cross the street, and that this delay increases with age and fear of falling. Together, this suggests that negotiating the demands of planning movements while making crossing decisions places a heavier burden on older pedestrians.

Another study, by Dommes and Cavallo [4], used a virtual environment to examine differences between three groups: young adults (20-35 years), younger-old adults (60-67 years) and older-old adults (70-84 years). The study aimed to investigate how age-related decline affected the ability of older adults to choose safe temporal gaps when physically crossing a virtual road. Both the younger-old and older-old adults made a greater number of unsafe decisions than the young adults when car speeds were high (50 km/h and above), but there was no difference between the two old adult groups. They also found that the younger-old participants missed significantly more opportunities to cross when cars were traveling at 30 km/h (25 mph), suggesting that they underestimated their road-crossing ability when traffic was moving slower. Other work in which older and younger participants viewed videos of simulated traffic and made key presses to indicate their willingness to cross has also shown that, while older participants sometimes choose unsafe gaps to cross, they also miss opportunities to cross [12].

Together, the research on road-crossing skills in older pedestrians indicate that they have more difficulty than younger pedestrians in making road-crossing decisions. This difficulty manifests itself in choosing gaps that are unsafe when traffic speeds are high, and in missing opportunities to cross when traffic speeds are low.

2.2 Vehicle-to-Pedestrian Communication

Smartphone apps have the potential to inform older adults about when it is safe or risky to cross a roadway. Smartphone usage among older people has increased from 18 percent to 42 percent between 2013 and 2017 [9]. Further, over three quarters of smartphone owners above 50 years of age say that they use smartphones to get directions or traffic information [13].

There is increasing research on how to use V2P communication to improve pedestrian safety by incorporating connected-vehicles technology into smartphones [14–16]. The goal is for vehicles and phones to exchange information about their positions and movements. V2P communication could make pedestrians "visible" to drivers even when occluded by an object or in the dark (and vice versa). Researchers have developed phone apps that exchange information with nearby vehicles and send collision warnings to both the driver and pedestrian [17,18]. Despite this, there is little research on how smartphone alerts can help older pedestrians.

Recently, Rahimian et al. examined whether V2P communication delivered via a cell phone app could mitigate the harmful effects of texting on pedestrian road-crossing safety. They conducted two experiments with college-age participants in a virtual environment to investigate the impact of sending "permissive alerts" or "prohibitive warnings" to texting pedestrians [7,8]. The first study informed the texting participant when a safe gap was approaching by using a countdown clock and an auditory alert on the phone ("permissive alerts"). They found that participants who received alerts were highly likely to cross the first alerted gap. On average, they selected larger gaps and had more time to spare when they crossed the road than texting participants who did not receive alerts. However, texting participants who received alerts spent much less time looking at oncoming traffic, indicating an overreliance on technology.

The second study used a complementary approach—an auditory alarm went off when texting pedestrians began to cross a dangerously small gap ("prohibitive warnings"). Participants in the warning group exhibited more cautious road-crossing behavior overall than the no-texting and texting-without-warnings groups, waiting significantly longer and choosing larger gaps for crossing. However, participants who received a warning after they entered the road never reversed their motion and returned to the side of the road. This highlights the importance of the timing of alerts relative to when people make decisions and actions—once people start an action, it is difficult for them to stop.

These two studies provide insight on how smartphone warning systems can positively affect road-crossing behavior. However, these studies were based on a younger population (college-age students). Because these participants were young, healthy adults with no mobility issues, the cell phone alerts and warnings used a one-size-fits-all approach in terms of the size of gaps alerted or warned. With older adults, however, this approach is unlikely to work because older adults may walk at different speeds [19]. As a result, a given temporal gap that is crossable for one older person may not be crossable for another older person. To address this problem, we need to tailor alerts and warnings to the ability of the user. In this project, we aimed to examine how alerts and warnings based on individual walking speeds influence older pedestrians' road-crossing performance.

2.3 Designing Outdoor Mobile Interactions for Older Adults

Researchers have explored how older adults respond to visual, auditory, and haptic information in navigation settings. Arab et al. examined haptic patterns to help older pedestrians while they navigate. Haptic patterns on a vibrotactile wrist band indicated which direction participants should move while they navigated outdoors (e.g., back, right, left) [20]. They found that repeating a pattern of sequential vibrations was not crucial for their discrimination and in fact can cause confusion. As a design recommendation for haptic aids, they suggested making the design of important messages as simple as possible, with strong continuous signals and minimum repetitions.

Montuwy et al. compared auditory, visual, and haptic feedback in navigational aids for older pedestrians [21]. Each participant individually went through four types of navigation: paper maps, auditory feedback provided through bone-conduction headphones, visual guidance embedded in the virtual environment, and haptic feedback transmitted through a wristband. They found that all participants easily perceived and understood the visual and auditory feedback. The study supported the claim that visual and auditory modalities displaying adequate types of feedback could help in compensating for age-related declines in functioning. They also found that using haptic patterns alone caused difficulties in navigation for older pedestrians.

In order to aid physical activities among older adults, Qian et al. used a mobile phone with a built-in accelerometer and haptic feedback [22]. The phone monitored and maintained walking speeds of 15 participants. They chose two distinguishable haptic patterns to tell the participant to walk faster or slower. They found that on average participants took more steps when presented with haptic cues. Thirteen participants agreed that haptic cues would be helpful.

To understand the mobility challenges of older adults, Felberbaum et al. [23] conducted 17 semi-structured interviews and focus group sessions with adults aged 73-90. They used the International Classification of Functioning, Disability and Health to analyze mobility challenges by considering health conditions and contextual factors. They uncovered design requirements to support the mobility of older adults, including that the technology should run automatically without having to learn it and should not disconnect users from the environment, and that users should be able to walk and use the technology simultaneously.

Based on this research, we designed our alerts to provide three modes of feedback: visual, haptic, and auditory. Our haptic feedback was simple and non-repetitive, our auditory feedback repeated after a short pause, and our visual feedback was visible for the duration of the alert or warning.

3 Alert and Warning Design and Implementation

3.1 Smartphone Alerts and Warnings

We developed an Android application in C# (installed on a Huawei smartphone running on the EMUI 4.0 operating system). The phone communicated with the main computer through a wireless network using TCP/IP. When the phone did not display an alert, the screen was black.

3.1.1. *Permissive Alerts*

When the phone received a message to display a permissive alert, the phone displayed a black screen with green text on it saying, “SAFE TO CROSS!” The phone played an audio message saying, “Safe to cross.” We played the auditory message once shortly before a safe gap opened; the video display remained on until the gap was determined to no longer afford safe crossing. Alongside the display and audio, the phone vibrated three times for 0.5 seconds each time (Figure 3.1).

Figure 3.1 - Photo of the permissive alert (left) and prohibitive warning (right)

3.1.2. *Prohibitive Warnings*

When the phone received a message to display a prohibitive warning, the phone displayed a red screen with white text on it saying, “DO NOT CROSS!” At the same time, the phone played an audio message saying, “Do not cross,” which repeated every 2.0 seconds until the phone received a message to clear the alert. Alongside the display and audio, the phone vibrated three times for 0.5 seconds each time. The visual display remained on the screen, and only the audio kept repeating until the phone received a message to clear the alerts (Figure 3.1).

3.2 Smartphone Alerts and Warnings

We generated alerts based on each participant's individual walking pace, measured before participants performed the road-crossing task. Our main computer used the participant walking times and the length of our virtual road (3.048 m excluding sidewalks) to calculate the time it would take them to cross. Previous research showed that the timing of entry relative to the lead car in the gap for college-aged adults was 0.65 seconds and for children was 0.9 seconds [24]. Based on the notion that older adults' movement initiation would be more similar to that of children than that of young adults, we created a time buffer of 1.0 second for older adults to account for their timing of entry relative to the lead car in the gap. We also added a 1-second buffer as a safe time to spare relative to the tail car in the gap when exiting the roadway. Thus, in total, we added a 2-second buffer to the individualized estimate of crossing time to determine whether gaps were safe to cross.

To generate permissive alerts, the main computer kept track of the positions of the lead and tail car of each gap. We designed the alerts so the audio would finish as the safe gap was in front of the user. Therefore, the main computer sent a signal to turn on the permissive alert 0.8 seconds before the lead car drove through the center of the simulator (Figure 3.2). The computer sent a signal to turn off the alert if the tail car was too close to the user (therefore no longer safe to cross).

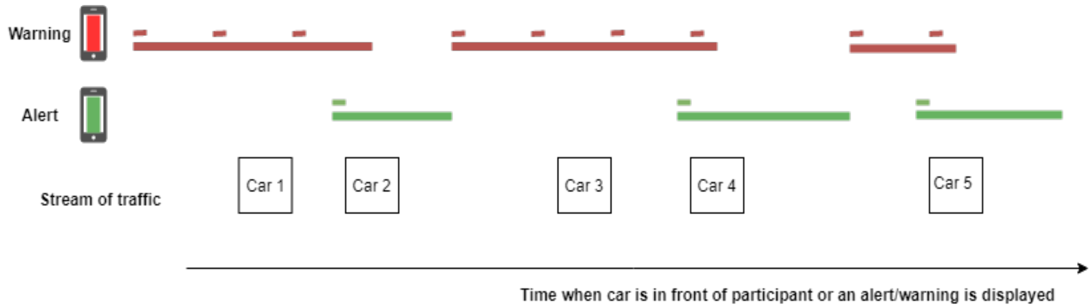

Figure 3.2 - Diagram showing when the warnings or alerts turned on and off based on the gap between the lead and tail car; the phone displayed visuals (long solid lines), played audio (dashes), and vibrated once at the beginning of the solid line

To generate prohibitive warnings, the main computer kept track of the lead car position approaching the pedestrian. If the time for the car to reach the center of the simulator was less than the individualized safe crossing time, the main computer sent a signal to turn on the prohibitive warning (Figure 3.2). Like the permissive alerts, the computer sent the signal 0.8 seconds before the unsafe gap opened. Then, when no car was too close to the pedestrian, the computer sent a signal to turn off the phone warning. The warning duration could include more than one gap when there were consecutive cars with uncrossable gaps between them. In these cases, the visual warning remained on and the audio repeated every 2 seconds.

4 Participant Crossing Task with Mobile Alerts

To examine how ability-based mobile alerts and warnings influence older pedestrians' road-crossing performance, we conducted an experiment in an immersive virtual environment. The scenario was a one-lane road in a residential neighborhood. Participants stood at the edge of the roadway and viewed continuous 25 mph traffic traveling from left to right with varying size gaps between cars (Figure 4.1). We chose this car speed based on previous work indicating that older pedestrians underestimate their ability to cross at speeds lower than 25 mph and overestimate their ability to cross at speeds higher than 25 mph [4]. Their task was to physically cross the virtual roadway without colliding with a vehicle. They carried a cellphone in their hand that would alert them when it was safe to cross in our permissive condition and when it was not safe to cross in our prohibitive condition. There was also a control condition in which participants held a cell phone, but it did not deliver alerts or warnings. While they stood at the edge of the roadway and decided when to cross, they kept receiving alerts giving them visual, auditory, and haptic feedback on whether it was or was not safe to cross.

Figure 4.1 - A person using the smartphone alert system in our street-crossing scenario; note that the visual angles are correct from the viewpoint of the user

4.1 Experimental Design

We conducted a between-subjects experiment where the independent variable was the mobile alert type with 3 levels:

Permissive: Participants held a cellphone and received alerts telling them when it was safe to cross.

Prohibitive: Participants held a cellphone and received warnings telling them that it was not safe to cross.

Control: Participants held a cellphone throughout the road-crossing session but did not receive any alerts.

4.2 Participants

Our inclusion criteria for participants were that they were adults ages 65-85, fluent in written and spoken English, had normal or corrected-to-normal vision and hearing, and could walk unassisted. We screened all participants over the phone using a brief version of the Mini Mental State Exam (MMSE) [25]. We included only participants who scored at least 14 out of 16 correct (seven people did not qualify). The final sample included 66 older adults ages 65-84. Table 4.1 shows demographic information for each condition.

Table 4.1 - Participant age and gender in each condition

Condition	Mean Age	Age Range	M/F
Control	71.32	65-83	11/11
Prohibitive	69.67	65-84	10/12
Permissive	71.39	65-79	10/12

We randomly assigned each participant to a condition (i.e., control, prohibitive, or permissive). After data collection, we assessed randomization by examining the correlation between age and condition ($r = .009$, $p = .95$). Therefore, we successfully randomized participants. We present the means and range of ages between groups in Table 4.1.

4.2.1. *Participant Smartphone Experience*

We asked participants questions about their smartphone usage, including whether they owned a smartphone, and if so, their level of comfort using a smartphone (from 1 = not at all comfortable to 5 = very comfortable) and level of skill using a smartphone (from 1 = not at all skillful to 5 = very skillful). If participants did not own a smartphone, we asked if they had experience with a smartphone or had used a smart mobile phone. The experience data did not have normal distributions, so we compared the three groups using a Kruskal-Wallis test. We found no statistically significant differences between the participants in each condition.

The majority of participants owned a smartphone, reported being comfortable with a smartphone, and reported neutral to comfortable responses with regard to skill (Table 4.2). Out of the seven participants who did not own a smartphone, one had experience using a smartphone. Five participants out of those who did not own a smartphone reported that they had used a smart mobile phone, one reported they did not have a phone, and the final person did not answer this question.

Table 4.2 - Participant smartphone usage: # who own a smartphone and means and standard deviations (in parentheses) for comfort and skill using a smartphone

Smartphone Qs	Permissive	Prohibitive	Control
Own	21	20	18
Comfort	4.14 (0.78)	4.18 (0.85)	4.00 (1.04)
Skill	3.65 (1.17)	3.58 (0.82)	3.72 (1.00)

4.2.2. *Participant Walking/Street Crossing Experience*

We also asked participants questions about their experience walking and crossing the street. We asked questions about walking with the clause “weather permitting,” including:

- #Times/week they walk in the morning and afternoon (e.g., to work, to a bus stop, for exercise, social activity)
- How far they walk each way: (1) < 4 city blocks, (2) 4 city blocks or quarter mile, (3) 8 city blocks or half a mile, (4) >= 16 city blocks or >= a mile, (5) N/A

Our street-crossing questions included:

- Crossing streets where the cross traffic does not stop (e.g., no stop signs or traffic lights for the cross traffic): (1) Never, (2) Sometimes, (3) Often, (4) Almost Always
- Comfortable crossing streets on own: (1) Very Comfortable, (2) Somewhat Comfortable, (3) Somewhat Uncomfortable, (4) Very Uncomfortable
- Pedestrian skill from 1: Not Skillful to 5: Very Skillful
- Pedestrian Caution from 1: Not Cautious to 5: Very Cautious

Four response groups were normally distributed[1], but all questions had at least one set of responses that were not normally distributed. Therefore, we compared the three groups using a Kruskal-Wallis test. We found no statistically significant differences in walking or street crossing experience between the three conditions.

Of the participants, 61/66 reported walking regularly. On average, participants walked at least half the week in both the morning and afternoon for half a mile each way. Of the 61 participants who walked regularly, 28 participants walked ≥ 1 mile, 13

---

[1] #times/week walk in morning: prohibitive; #times/week walk in the afternoon: control & permissive; how far they walk each way: control

participants walked 0.5 miles, 9 participants walked 0.25 miles, and 11 walked < 4 blocks each way. On average, participants crossed at intersections where traffic does not stop between "sometimes" and "often." They reported themselves as very comfortable crossing streets on their own, and as both skillful and cautious street crossers (Table 4.3).

Table 4.3 - Means and standard deviations (in parentheses) of participant walking and street-crossing experience

Walking/Street-Crossing Qs	Permissive	Prohibitive	Control
# Times/week Walk in Morning	3.76 (2.30)	4.82 (1.97)	3.75 (2.62)
# Times/week Walk in Afternoon	3.95 (2.77)	4.27 (2.00)	3.05 (1.98)
Cross Streets where Traffic Does not Stop	2.41 (0.67)	2.64 (0.73)	2.50 (0.94)
Comfort Crossing Streets on Own	1.27 (0.77)	1.09 (0.29)	1.68 (1.29)
Skill as a Pedestrian	4.55 (0.91)	4.55 (0.60)	4.59 (0.65)
Caution as a Pedestrian	4.14 (1.04)	4.00 (0.76)	4.18 (0.83)

4.3 Apparatus

We conducted the experiment in a large-screen virtual environment with three screens placed at right angles to each other, forming a three-walled room (4.33 m long x 3.06 m wide x 2.44 m high, Figure 4.1). The length of the side screens allowed participants to physically walk across a 3.06 m wide virtual road. Three DPI MVision 400 Cine 3D projectors back-projected high-resolution (1920x1080) graphics in stereo onto the screens. An identical projector front-projected high-resolution (1920x1080) stereo images onto the floor (4.33 x 3.06m).

Participants wore Volfoni ActiveEyes stereo shutter glasses, synchronized with the displays. We used an OptiTrack motion capture system to determine the position and orientation of the participant's head based on reflective markers mounted on a helmet (Figure 4.1). This system allowed us to render the images with the correct perspective for each participant as they moved. Participants also wore a harness connected to a post at the back of the simulator to ensure that they would not run into the front screen.

To play car sounds, we used Logitech THX certified speakers as a surround sound system. We placed the larger speaker on the right side of the virtual environment and the four small speakers on each corner of the environment; two speakers were on the floor to the left and right of the participant, and two were on the opposite corners midway up the wall. The speakers generated spatialized traffic sounds.

We built the traffic scenario using the Unity3D gaming platform. In-house code generated traffic and recorded the positions and orientations of vehicles and the participants.

4.4 Traffic Generation

A stream of continuous traffic traveled from left to right on a straight, one-lane road at the local residential speed of 25 mph (11.176 m/s). Randomly ordered temporal gaps between cars ranged in size from 2 to 7 seconds (similar to that used by Dommes et al. [5]). The cars were all small sedans of approximately the same size but varied in color.

4.5 Procedure

After providing informed consent, participants performed a baseline walking task to measure their walking speed. The experimenter asked participants to walk briskly down a hallway between two marked lines while timing with a stopwatch.[2] Participants started

---

[2] Pilot testing showed that participants tended to cross roads in the virtual environment more quickly than their comfortable walking speed. Therefore, we measured their brisk walking speed so that we could more accurately tailor the app to their crossing ability.

when the experimenter said “go” and stopped at a marked line. Participants performed the baseline walking task twice to ensure a stable estimate of brisk walking speed. We entered the two walking times into the Unity3D application to individualize the alerts. We calculated the average baseline walking speed from the two walking times. We compared the average baseline speed to their walking speed within the virtual environment during the experiment. These two speeds correlated reliably with one another ($r = .42$, $p < .001$). See Table 4.4 for means and variability of baseline walking speeds across conditions.

Table 4.4 - Means and variability of baseline walking speeds

Condition	Mean	Range
Control	2.13 m/s	1.53-2.66 m/s
Prohibitive	1.96 m/s	1.63-2.38 m/s
Permissive	1.96 m/s	1.65-2.42 m/s

After the baseline walking task, participants performed the road-crossing task in the room with our simulator. We fitted them with the tracking helmet, shutter glasses, and harness.

Each trial began without any traffic on the road. Participants stood on the edge of the roadway and viewed a continuous stream of vehicles approaching from the left. Participants were told that they should wait for the first car to pass (to prevent them from crossing in front of the stream of traffic) but that they then could wait as long as they wanted before attempting to cross the road without being “hit” by a vehicle. Once they selected a gap to cross, participants physically walked to the other side of the road. Traffic generation ceased once they reached the sidewalk on the other side of the road, allowing them to return to the starting position.

The road-crossing session took place in two phases. The first phase consisted of three practice trials in which the experimenter walked with participants. On the first practice trial, participants crossed without traffic or a cellphone to become familiar with the virtual environment. On the second trial, participants crossed with traffic but without a cellphone. On the third trial, we asked participants to hold a cellphone in their hand. The cellphone was inactive for the Control group. For the Permissive and Prohibitive groups, we turned on the cellphone and gave a demo of the alert to familiarize participants with the sight, sound, and feel of the alert or warning. We gave the following instructions to participants in the alert and warning conditions:

Permissive alert condition: *"The cellphone will give you a signal to help you cross safely. When it is safe to cross, you will hear, see, and feel a signal. So, when it is safe to cross, you will hear the cell phone say, "Safe to Cross." At the same time, you will see the message "Safe to Cross" on the cell phone display and you will feel the phone vibrate. The "Safe to Cross" message will stay on the cell phone display during the time it is safe to cross. In essence, the cell phone is like a crosswalk signal in your hand."*

Prohibitive warning condition: *"The cellphone will give you a warning to help you avoid a collision. When it is not safe to cross, you will hear, see, and feel a warning. So, when it is not safe to cross, you will hear the cell phone say, "Do Not Cross." At the same time, you will see the message "Do Not Cross" on the cell phone display and you will feel the phone vibrate. You will continue to hear and see the "Do Not Cross" message during the time it is not safe to cross. The message will be cut off if a gap becomes safe to cross while the message is being said. In essence, the cell phone is like a crosswalk signal in your hand."*

The second phase included 20 test trials in which participants crossed on their own. The road-crossing task took about 20 minutes to complete. After finishing the road-crossing task, we conducted a 10-minute interview about the participants' experience with the alerts/warnings:

What did you notice first about the phone alerts: the display, the sound, or the vibration?

Overall, what was most prominent about the phone alerts: the display, the sound, or the vibration?

What did you like about the alerts?

What did you dislike about the alerts?

What improvements would you suggest?

Lastly, participants filled out a Qualtrics survey that asked them about their pedestrian habits and experience. After completing the survey, we debriefed them about the study.

4.6 Data Recording and Performance Variables

Every ~0.02 seconds, we recorded the x- and y-position and orientation of the participant's head, the smartphone, and all vehicles. We recorded the times at which the main computer sent messages to the phone and the message round-trip time between the main computer and the phone. We also measured performance variables including gap selection, movement timing, and alert compliance.

4.6.1. *Gap selection*

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

4.6.2. *Movement timing*

Timing of entry: The time (in seconds) between the participant and the rear of the lead car in the gap when the participant entered the path of the cars. This measure provides information about how tightly participants timed their entry into the gap relative to the lead car.

Road crossing time: The time (in seconds) between when the participant entered and exited the path of cars.

Time to spare: The time (in seconds) between the participant and the front of the tail car in the gap when the participant cleared the path of cars. This measure provides information about the margin of safety when exiting the roadway.

Collisions: We recorded a collision when time to spare was ≤ 0 seconds. We did not analyze collisions because they were rare, occurring in only one permissive trial (0.032 percent of all trials). A participant took 1.8 seconds to enter the roadway, making the gap no longer safe.

4.6.3. *Alert compliance*

We recorded whether a participant complied with the permissive alerts and prohibitive warnings. We had four cases for permissive alerts:

Alert Heeded: participant crossed after a permissive alert was on

Alert Ignored: participant did not cross after a permissive alert was on

Lack of Alert Heeded: participant did not cross when the permissive alert was off

Lack of Alert Ignored: participant crossed when the permissive alert was off

Our four cases for prohibitive warnings were:

Warning Heeded: participant did not cross after the prohibitive alert was on

Warning Ignored: participant crossed after the prohibitive alert was on

Lack of Warning Heeded: participant crossed after the prohibitive alert was off

Lack of Warning Ignored: participant did not cross after the prohibitive alert was off

4.7 <u>Data Analysis</u>

4.7.1. *Quantitative analysis*

Our primary goals were to determine whether there was a significant difference in performance across permissive and prohibitive conditions as compared to the control condition (no alert) and whether overall performance was related to age. We examined the bivariate measure of gap selection using mixed-effects logistic regression analyses to model the likelihood of accepting (or rejecting) each gap that was seen on all 20 trials as a function of condition, age, and gap size. The final model included fixed-effects predictors of condition (as a categorical variable), age (as a continuous variable), and gap size (as a continuous variable), as well as a random intercept for participant and a random slope for gap size, as log-likelihood ratio testing determined that this was the maximal random-effects structure justified by the data. We examined the continuous measures of movement timing using separate mixed-effects linear regression analyses to model the effects of condition and age on timing of entry, crossing time, and time to spare (across the 20 trials). The model included fixed-effects predictors of condition (as a categorical variable) and age (as a continuous variable), as well as a random intercept for participant. Each model (e.g., gap selection, movement timing) included the maximal mixed-effects structure justified by the data using procedures outlined by Baayen et al. [26].

Our second goal was to explore whether participants' self-reported real-world pedestrian experience related to their performance in the virtual road-crossing task. We analyzed the data using a correlational approach assessing relationships between key self-report questions (e.g., cautiousness when crossing roads, average distance walked in a day, comfort when crossing roads, and experience crossing continuous traffic).

4.7.2. *Qualitative analysis*

We audio-recorded and transcribed the interviews with categorical responses and open-ended responses. Because all categorical responses were non-normally distributed, we conducted Mann-Whitney U-tests between the two alert groups.

For the non-numeric responses, we conducted open coding [27] of the transcripts. Two researchers independently read the transcripts and identified themes. The researchers then synthesized a set of codes including aspects liked and disliked and suggestions for improvement. The researchers re-coded all the interviews by coding each interview response individually. The researchers met regularly to discuss each other's codes until they agreed on all code assignments and revised the codes as necessary.

5 Results

5.1 Quantitative Results

5.1.1. *Gap selection*

Figure 5.1 shows the results of mixed-effects logistic regression analyses modeling the likelihood of taking a gap as a function of condition and gap size. We found an effect of gap size. All groups preferred larger over smaller gaps, $z = 12.64$, $p < .001$, with 16.11 increased odds of accepting a gap with each 1-second increase in gap size. Our logistic regression model also revealed that participants in the permissive condition ($b = 2.16$, $z = 4.67$, $p < .001$) selected reliably smaller gaps overall than participants in the control condition. Participants in the prohibitive condition ($b = -.47$, $z = -.83$, ns) did not differ reliably from participants in the control condition. There was no effect of age on gap selection ($b = .03$, $z = .59$, ns).

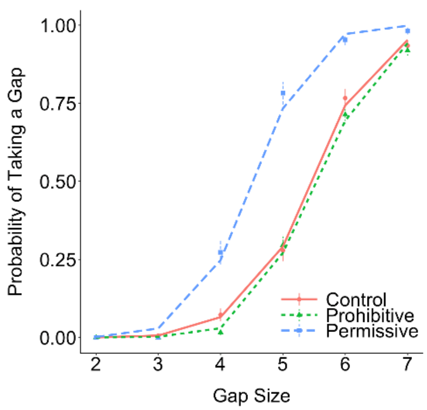

Figure 5.1 - Logistic regression curves modeling probability of taking a gap as a function of condition and gap size

5.1.2. *Movement timing*

Table 5.1 provides means and standard deviations for our movement timing measures for each condition.

Table 5.1 - Means and standard deviations (in parentheses) of movement timing measures (seconds) for each condition

Condition	Timing of Entry	Crossing Time	Time to Spare
Control	0.79 (0.18)	2.17 (0.26)	3.37 (0.42)
Prohibitive	0.87 (0.22)	2.12 (0.22)	3.38 (0.53)
Permissive	0.72 (0.16)	2.16 (0.28)	3.09 (0.45)

Timing of entry. There was no significant difference between the control condition and the permissive and prohibitive conditions in timing of entry (prohibitive condition: *t (*62.06) =1.74 *p* = .09; permissive condition: *t (*62.01) = -1.33 *p* = .19). However, age was a significant predictor of timing of entry such that older participants took longer to initiate movement relative to the lead car in the gap, *t* (62.01) = 2.45 *p*=.02. With each 5-year increase in age, timing of entry increased by .05 seconds.

Crossing time. There was no significant difference between the control condition and the permissive and prohibitive conditions in road crossing time (prohibitive condition: *t* (62.01) = -.16 *p* = .88; permissive condition: *t* (60.00) = -.22 *p* = .83). However, there was a significant effect of age such that older participants took longer to cross the road (*t* (61.99) = 2.85 *p* = .006). With each 5-year increase in age, crossing time increased by .1 seconds.

Time to spare. As might be expected given the gap selection results, participants in the permissive condition had marginally less time to spare than those in the control condition (*t (*61.87) =-2.04 *p*=.05), and the permissive condition did not significantly differ from the control condition (*t (*62.00) =.15, ns). Again, age was significantly associated with time to spare, such that older participants had less time to spare than younger participants (*t* (61.87) = -2.39 *p* = .05); with each 5-year increase in age, time to spare decreased by 0.1 seconds.

5.1.3. *Alert compliance*

We determined whether participants were complying with the alerts and warnings (or lack thereof). For permissive alerts, we found a 90 percent agreement between participants and full compliance—in other words, we compared the actions of all participants to a “fully compliant” set of participants. Out of the 801 total gaps that participants experienced, participants had 437 total *Alerts Heeded* and 287 *Lack of Alerts Heeded.* There were 77 gaps where a participant chose not to cross even though the permissive alert said it was safe to so do (*Alert Ignored)*. However, there were no instances when the permissive alert was off and the participant chose to cross anyway (*Lack of Alert Ignored).* Table 5.2 shows the counts for each classification of compliance. To account for participants “agreeing” with the app, but actually making their own judgment, we calculated a Cohen’s Kappa between the participants and a “fully compliant” set of participants (514 *Alerts Heeded,* 287 *Lack of Alerts Heeded*). The Cohen’s Kappa agreement is 0.80 (or strong agreement [28]).

Table 5.2 - Table displaying how often participants complied or did not comply with the permissive alerts.

	Crossed	Did not cross
Alert on	*Alert Heeded* = 437	*Alert Ignored* = 77
Alert off	*Lack of Alert Ignored = 0*	*Lack of Alert Heeded* = 287

Participants in the prohibitive warning condition were less compliant with the alerts, with a 73 percent agreement, and only 0.50 Cohen’s Kappa (or weak agreement [28]). In general, participants agreed when the smartphone turned on a warning. Out of the 408 gaps when the smartphone displayed a prohibitive warning, participants chose not to cross 407 times (*Warning Heeded).* Only one participant chose to cross one gap when the smartphone said it was not safe to cross (*Warning Ignored).* Most noncompliance was when the prohibitive warnings were off. Ideally, when the prohibitive warning turns off, the participant can cross the street. However, this happened at only 430 out of 732 gaps (*Lack of Warning Heeded)*. Participants chose not to cross, despite the prohibitive warning turning off, 302 times (*Lack of Warning Ignored)*. The *Lack of Warning Ignored* occurred 102 times for 4-second gaps, 129 times for 5-second gaps, 129 times for 6-second gaps, and 19 times for 7-second gaps. Table 5.3 shows the counts for compliance with prohibitive warnings. The considerable number of *Lack of Warning Ignored* suggests that participants made their own decisions about whether to cross during the prohibitive warning condition.

Table 5.3 - Table displaying how often participants complied or did not comply with the prohibitive warnings.

	Did not cross	Crossed
Warning on	*Warning Heeded* = 407	*Warning Ignored* = 1
Warning off	*Lack of Warning Ignored* = 302	*Lack of Warning Heeded* = 430

5.1.4. *Pedestrian experience*

We did not find any significant relationships between movement timing and participant-reported real-world pedestrian and street-crossing experience.

5.2 Qualitative Results

5.2.1. *Categorical responses*

Participants reported whether they noticed the visual, auditory, or vibratory elements of the alerts or warnings first, and which of those three elements was the most prominent. In both conditions, 73 percent of participants noticed the auditory cue first and 77 percent of participants felt that the auditory cue was most prominent. Few participants reported that the vibratory and visual cues were noticed first or were most prominent (Figure 5.2). There were no statistically significant differences between the conditions.

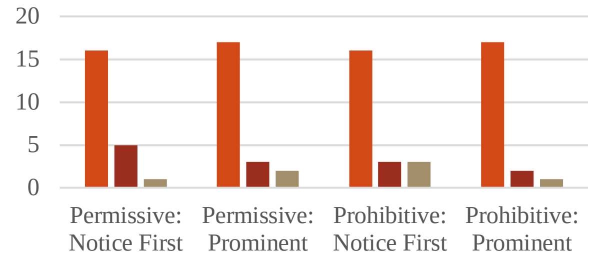

Figure 5.2 - Number of participants who reported whether they noticed audio (left), vibration (middle), or visual (right) first or thought they were most prominent

5.2.2. *Open-Ended Responses*

We determined that permissive (Pe1-Pe22) and prohibitive participants (Pr1-Pr22) had reasons to view the alerts/warnings as positive and reasons to not need them.

Sixty-eight percent of participants in the permissive alert condition and 50 percent of participants in the prohibitive warning condition mentioned that the alerts/warnings helped them make decisions and made the task easier: *"it was easy... it was like you just didn't have to think about it"* [Pe1]. They also had the potential to help when the participant was less attentive: *"It was accurate enough that it was going to help me if I wasn't paying good attention"* [Pr11]. Conversely, Pe10 reported they *"would be hesitant without [the alerts]."* Participant statements triangulated with our findings that they were more likely to take smaller gaps: *"[The alert] was helpful cause some of the times I wouldn't have crossed because there was that other car coming"* [Pe6]. Participants reported the alerts were useful as a prompt, as opposed to being a decision maker: *"I felt comfortable using [the alerts] as a prompt"* [Pe9].

Fifty percent of permissive participants and 55 percent of prohibitive participants mentioned that they did not need the alerts/warnings, ignored the alerts/warnings, or preferred using their own judgement. However, people expressed the utility of the alerts or warnings in the future: *"I would use them especially as I get older"* [Pe4]. Participants also mentioned the potential of use in other contexts: *"If it gave directions and I was in an unknown city I would use it."* [Pe6]. Two participants in the permissive condition and seven in the prohibitive condition mentioned that they would be helpful in riskier contexts. However, most participants spoke to relying on their own judgement solely or more than the alerts: "*If it feels to me like oh there's time to cross the street, I'm probably going to ignore my alert and go"* [Pr21].

We also uncovered a notable difference between the permissive alerts and prohibitive warnings; 45 percent of prohibitive participants mentioned that the warnings were annoying in general or with the voice, likely due to repetition: *"Well like anything if you hear it over and over. After a while you're just like, ok, I'm tired of hearing that"* [Pr11]. No permissive participants expressed annoyance.

6 Discussion

This study examined how older pedestrians respond to smartphone alerts and warnings that inform them when it is safe or unsafe to cross a stream of traffic. We looked at two complementary ways to assist pedestrians: (1) permissive alerts that tell the pedestrian when there are safe times to cross, and (2) prohibitive warnings that tell pedestrians when it is unsafe to cross. Both methods were based on the ability of the individual to safely cross a road. We included a control condition in which we gave participants no assistance with making road-crossing decisions.

6.1 Lessons Learned

We found that the participants who received permissive alerts took smaller gaps than participants who received prohibitive warnings or those in the control condition. Participants in the prohibitive condition did not differ from those in the control condition. Importantly, even though participants in the permissive condition took smaller gaps, they still had substantial time to spare when they exited the roadway (3.09 s on average). This indicates that the app provided accurate information to participants about the crossability of gaps.

Participants in the control condition were conservative overall, letting gaps go that were crossable given their walking speed. The finding that older adults miss opportunities to cross with 25 mph traffic is consistent with previous work showing that older adults frequently miss opportunities to cross when traffic is slower [4,12]. Our results show that the permissive alerts can help older adults avoid missed opportunities for crossing because they instilled trust in the alerts. The lack of difference in gap selection between the prohibitive and control conditions, however, suggests that participants in the prohibitive condition largely ignored the warnings and relied on their own judgment to make road-crossing decisions.

The interview responses of participants aligned with these quantitative results—nearly half of participants who received the prohibitive warnings stated that the app was annoying, whereas none of the participants who received permissive alerts mentioned them being annoying. Consistent with this, people complied with the permissive alerts but often did not comply with the prohibitive warnings. Participants found utility in the alerts, including making road crossing easier, but realized that they may not need them immediately in real life. However, participants saw the potential of the alert to help in riskier settings, including when they get older or are in riskier contexts (e.g., high traffic, reduced vision).

The movement timing analyses largely showed no differences in performance across the three conditions. The only exception was a marginal difference between the permissive condition and the control condition in time to spare, which we expected given that participants in the permissive condition took smaller gaps. As noted earlier, however, the margin of safety was quite large for all three groups. Interestingly, we found that age (in years) was a significant predictor of all our movement timing measures. As age increased, participants initiated their movement less quickly and crossed the road more slowly. Therefore, there were age-related declines in time to spare when exiting the roadway. This provides further support for the need to design apps for older pedestrians that are ability-based.

6.2 Limitations and Future Work

While we were careful in the design of the app and task, there are limitations to this study. First, our study population came from an active and highly educated community, so our findings may not generalize to all older adults. Second, the cars all drove at the same speed, which made the virtual road-crossing task simpler than real-world road crossing. Finally, in the real world, V2P technology will not uniformly deploy to all cars at once; there will exist times in which some cars have this capability and others do not. However, as a starting point, we designed our study to evaluate safely and systematically how older adults respond to alerts and warnings delivered via a smartphone under ideal conditions.

There are opportunities for future work that could build upon our results. First, researchers should conduct research with older adults in different settings (e.g., urban, rural). Researchers could pursue these efforts in more realistic (controlled) street-crossing settings, including the roads with higher and varied car speeds. For comparison purposes, it would also be interesting to look at the effects of the ability-based alerts and warnings on young adults who tend not to miss opportunities for crossing and tend to take risky gaps.

6.3 Design Considerations – Timings of Alerts and Warnings

Our results underscore the difficulty of providing useful prohibitive warnings to pedestrians. Prior research demonstrated that warnings were ineffective when sent very close in time to when participants had initiated a crossing movement [8]. Participants continued their crossing after receiving a warning even though the warnings were highly predictive of risk.

In this experiment, we attempted to warn participants that crossing opportunities were risky before they began to cross. We timed the verbal warnings so that the spoken warning ended just before the dangerous gap opened and the verbal warning repeated every two seconds until it was safe to cross (e.g., just after a safe gap opened). Participants seemed to have difficulty linking the repeated warnings to the approaching gaps. At times, a warning came close to the time a safe gap reached the intersection. The warning was based on the preceding unsafe gap. However, the participants were likely focusing their attention on the approaching safe gap. In such situations, it may be difficult to cognitively link the auditory warning to the visually perceived gap.

We also timed the permissive alerts such that the verbal indication of “Safe to Cross” was complete before the gap appeared. This decision is in line with the fact that participants were paying attention to the audio. We wanted the participant to be able to hear the message in its entirety and be able to cross the opportune gap. However, when the alert appears, there is still a car in front of the person, which can cause confusion. One alternative to improve both alerts and warnings would be to use augmented reality (AR) to visually highlight the risky gaps (e.g., by highlighting the approaching gap in an AR display).

7 Conclusion

Older pedestrians experience more difficulty in crossing the street than younger pedestrians. In response, we designed two smartphone systems—permissive alerts and prohibitive warnings—to help older pedestrians make safer street-crossing decisions. We conducted a between-subjects study to compare permissive alerts, prohibitive warnings, and a control group and found that participants were more compliant with the permissive alerts than the prohibitive warnings. As a result, participants with permissive alerts crossed the street with smaller (yet safe) gaps than participants in the control or prohibitive warning conditions. Our findings can inform V2P communications technology when communicating with older pedestrians and give us insights about how older pedestrians use (or do not use) smartphone alerts. We also hope the findings will inform research working with older adults in outdoor settings.

References

1. World Health Organization. WHO | Global status report on road safety 2018 [Internet]. WHO. [cited 2019 Aug 15]. Available from: http://www.who.int/violence_injury_prevention/road_safety_status/2018/en/

2. LeBeau P. Pedestrian deaths hit 28-year high, and big vehicles and smartphones are to blame [Internet]. CNBC. 2019 [cited 2019 Aug 15]. Available from: https://www.cnbc.com/2019/02/28/pedestrian-deaths-hit-a-28-year-high-and-big-vehicles-and-smartphones-are-to-blame.html

3. Pedestrians: 2017 data. [Internet]. Washington, DC: National Highway Traffic Safety Administration; 2019 Mar p. 11. (National Center for Statistics and Analysis). Report No.: DOT HS 812 681. Available from: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812681

4. Dommes A, Cavallo V. The role of perceptual, cognitive, and motor abilities in street-crossing decisions of young and older pedestrians. Ophthalmic and Physiological Optics. 2011;31(3):292–301.

5. Dommes A, Cavallo V, Oxley J. Functional declines as predictors of risky street-crossing decisions in older pedestrians. Accident Analysis & Prevention. 2013 Oct 1;59:135–43.

6. Oxley J, Charlton JL, Fildes B. The effect of cognitive impairment on older pedestrian behaviour and crash risk. Melbourne, Australia: Monash University Accident Research Centre; 2005. Report No.: 244.

7. Rahimian P, O’Neal E, Paul Yon J, Franzen L, Jiang Y, Plumert J, et al. Using a virtual environment to study the impact of sending traffic alerts to texting pedestrians. In: IEEE Virtual Reality (VR). 2016. p. 141–9.

8. Rahimian P, O’Neal E, Zhou S, Plumert J, K. Kearney J. Harnessing Vehicle-to-Pedestrian (V2P) Communication Technology: Sending Traffic Warnings to Texting Pedestrians. Human Factors: The Journal of the Human Factors and Ergonomics Society. 2018 Jun 19;60:001872081878136.

9. Anderson M, Perrin A. Technology use among seniors [Internet]. Pew Research Center: Internet, Science & Tech. 2017 [cited 2019 Aug 15]. Available from: https://www.pewinternet.org/2017/05/17/technology-use-among-seniors/

10. Zito GA, Cazzoli D, Scheffler L, Jäger M, Müri RM, Mosimann UP, et al. Street crossing behavior in younger and older pedestrians: an eye- and head-tracking study. BMC Geriatrics. 2015 Dec 29;15(1):176.

11. Naveteur J, Delzenne J, Sockeel P, Watelain É, Dupuy MA. Crosswalk time estimation and time perception: An experimental study among older female pedestrians. Accident Analysis & Prevention. 2013 Nov 1;60:42–9.

12. Oxley JA, Ihsen E, Fildes BN, Charlton JL, Day RH. Crossing roads safely: An experimental study of age differences in gap selection by pedestrians. Accident Analysis & Prevention. 2005 Sep 1;37(5):962–71.

13. Anderson GO. Getting Connected: Older Americans Embrace Technology to Enhance Their Lives [Internet]. AARP. 2018 [cited 2019 Aug 19]. Available from: http://www.aarp.org/research/topics/technology/info-2018/technology-use-attitudes.html

14. Anaya JJ, Merdrignac P, Shagdar O, Nashashibi F, Naranjo JE. Vehicle to Pedestrian Communications for Protection of Vulnerable road Users. In: 2014 IEEE Intelligent Vehicles Symposium. Dearborn, Michigan, United States; 2014. p. 1–6.

15. Hussein A, García F, Armingol JM, Olaverri-Monreal C. P2V and V2P communication for Pedestrian warning on the basis of Autonomous Vehicles. 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC). 2016;2034–9.

16. Laberge J, Creaser J, Rakauskas M, Ward N. Design of an Intersection Decision Support (IDS) interface to reduce crashes at rural stop-controlled intersections. Transportation Research Part C: Emerging Technologies. 2006 Feb 1;14:39–56.

17. Wang T, Cardone G, Corradi A, Torresani L, Campbell AT. WalkSafe: a pedestrian safety app for mobile phone users who walk and talk while crossing roads. In: Proceedings of the Twelfth Workshop on Mobile Computing Systems & Applications - HotMobile ’12 [Internet]. San Diego, California: ACM Press; 2012 [cited 2019 Aug 15]. p. 1. Available from: http://dl.acm.org/citation.cfm?doid=2162081.2162089

18. Wu X, Miucic R, Yang S, Al-Stouhi S, Misener J, Bai S, et al. Cars Talk to Phones: A DSRC Based Vehicle-Pedestrian Safety System. In: 2014 IEEE 80th Vehicular Technology Conference (VTC2014-Fall) [Internet]. Vancouver, BC, Canada: IEEE; 2014 [cited 2019 Aug 15]. p. 1–7. Available from: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6965898

19. Shumway-Cook A, Patla A, Stewart A, Ferrucci L, Ciol MA, Guralnik JM. Environmental Components of Mobility Disability in Community-Living Older Persons. Journal of the American Geriatrics Society. 2003;51(3):393–8.

20. Arab F, Panëels S, Anastassova M, Coeugnet S, Morellec FL, Dommes A, et al. Haptic patterns and older adults: To repeat or not to repeat? In: 2015 IEEE World Haptics Conference (WHC). 2015. p. 248–53.

21. Montuwy A, Dommes A, Cahour B. Helping older pedestrians navigate in the city: comparisons of visual, auditory and haptic guidance instructions in a virtual environment. Behaviour & Information Technology. 2019 Feb 1;38(2):150–71.

22. Qian H, Kuber R, Sears A. Maintaining levels of activity using a haptic personal training application. In: CHI ’10 Extended Abstracts on Human Factors in Computing Systems. 2010. p. 3217–22.

23. Felberbaum Y, Lanir J, Weiss PL (Tamar). Challenges and Requirements for Technology to Support Mobility of Older Adults. In: Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems [Internet]. New York, NY, USA: ACM; 2018 [cited 2019 Sep 8]. p. LBW545:1–LBW545:6. (CHI EA ’18). Available from: http://doi.acm.org/10.1145/3170427.3188637

24. O’Neal EE, Jiang Y, Franzen LJ, Rahimian P, Yon JP, Kearney JK, et al. Changes in perception–action tuning over long time scales: How children and adults perceive and act on dynamic affordances when crossing roads. Journal of Experimental Psychology: Human Perception and Performance. 2018;44(1):18–26.

25. PAR, Inc. Mini-Mental State Examination Second Edition | MMSE-2 [Internet]. [cited 2019 Sep 10]. Available from: https://www.parinc.com/Products/Pkey/238

26. Baayen RH, Davidson DJ, Bates DM. Mixed-effects modeling with crossed random effects for subjects and items. Journal of Memory and Language. 2008 Nov 1;59(4):390–412.

27. Burnard P. A method of analysing interview transcripts in qualitative research. Nurse Education Today. 1991 Dec 1;11(6):461–6.

28. McHugh ML. Interrater reliability: the kappa statistic. Biochemia Medica. 2012;276–82.