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The impact of leaving a voicemail, environment familiarity, and pedestrian predictability on driving behavior

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ABSTRACT

Talking on a cell phone can impair driving performance, but the dynamics of this effect are not fully understood. We examined the effects of leaving a voicemail message on driving when there are critical driving targets to attend to (crosswalks and pedestrians). Participants engaged in an ecologically-valid "voicemail" task while navigating a virtual environment using a driving simulator. We also examined the potential weakening or strengthening of effects of leaving a voicemail message on driving as the familiarity and predictability of critical targets changed. Participants completed four experimental runs through the same driving environment in a driving simulator. There were two crosswalks, one with a pedestrian entering the roadway and one without a pedestrian and the location of the pedestrian was predictable (the same pedestrian consistently used the same crosswalk) for the first three runs and then unpredictable for the fourth. Half of the participants left voicemail messages using a hands-free headset, while the other half drove in silence. Leaving a voicemail message increased steering deviation and velocity. Drivers who were leaving a voicemail message decelerated for pedestrians in the roadway to a similar speed as drivers who were not leaving a voicemail message, but they were delayed in braking. Drivers who were leaving a voicemail message also had worse memory for roadway landmarks. These effects were relatively stable across runs through the same driving environment, suggesting that familiarity and predictability did not impact the effects of leaving a voicemail message while driving. Therefore, leaving a voicemail message leads to poorer driving behavior; faster speed, variable steering, and worse memory for roadway landmarks. Interestingly, although drivers who were leaving a voicemail message were slower to react to local targets, they slowed as much as drivers who were not leaving a voicemail message and familiarity with the driving environment did not impact the effects of leaving a voicemail message on driving.

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1. Introduction

1.1. Background

Driving is a critical task that requires the strategic allocation of a driver's finite cognitive resources (see Wolfe, Dobres, Rosenholtz, & Reimer, 2017 for a review). For example, while driving, it is important to monitor the location of other vehicles on the roadway, detect pedestrians, and scan the environment for traffic signs and other forms of traffic control. In addition, other tasks that require cognitive resources are often completed while driving (listening to the radio, talking to passengers or on a cell phone, etc.). Although information from the whole visible driving environment has the potential to impact driving performance (e.g., peripheral vision is used for lane keeping; Summala, Nieminen, & Punto, 1996), there is a limit to the amount of information that can be processed and responded to at any given moment (Cowan, 2001; Olsson & Poom, 2005; Öztekin, Davachi, & McElree, 2010). Consequently, not all information can be processed effectively, leading to a lack of awareness for non-attended, and possibly critical, information (Simons & Chabris, 1999). For example, while attending to a crash on the side of the road or while talking on a cell phone, a driver may be delayed in noticing and responding to an approaching crosswalk or may fail to notice if they are maintaining their lane position and traveling at an appropriate speed. A critical question to answer is: How and when is driving behavior most affected by a distracting non-driving task (i.e., leaving a voicemail)?

Distraction from cell phones while driving is a critical, preventable cause of traffic crashes. Every year, thousands of people are killed in traffic crashes attributable to distracted driving (e.g., 3166 deaths in 2017). In 2017, 14 percent of the distracted related fatalities were due to cell phone use (National Center for Statistics and Analysis, 2019). According to a report written by the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA), one of the main causes of distracted driving is cell phone use while driving (Pickrell, Li, & KC, 2016). It is estimated that, every day, over 600,000 drivers use cell phones while driving. Over four percent of all drivers are either holding cell phones to their ears or wearing visible headsets while driving (Pickrell et al., 2016). Even more drivers are likely using a hands-free method to talk on a cell phone while driving (e.g., blue tooth enabled car). Given that talking on a cell phone while driving is a common form of distracted driving, what effects does talking on a cell phone while driving have on driving performance?

1.2. Limits of attention while driving

Driving sub-tasks or non-driving tasks that require visual attentional resources can interfere with driving performance (Ericson, Parr, Beck, & Wolshon, 2017; Mackenzie & Harris, 2017; Marciano & Yeshurun, 2015; Murphy & Greene, 2015). In one study, drivers counted the number of times specific vehicles in front of them changed lanes (Ericson et al., 2017). This high visual attention load task impaired driving performance. When participants were tracking two vehicles instead of only one, they braked slower and swerved more when a pedestrian entered the roadway (Ericson et al., 2017). Murphy and Greene (2015) found that drivers were less likely to notice pedestrians when under a high visual load. Participants had to determine if their vehicle could fit through a gap that was either obviously large enough or too small (low load) or very near the size of their vehicle (high load). Under a high load, drivers were more likely to collide with other vehicles and drive more erratically and were less likely to notice pedestrians (Murphy & Greene, 2015). These studies demonstrate that completing other visual tasks while driving can impair driving performance, although some of these tasks (counting lane changes and deciding if a vehicle can fit in a gap) may lack strong ecological validity.

Visual processing resources are often heavily taxed while driving because there are many visual components to the driving task, and complex and/or multiple visual tasks restrict the processing of visual information needed for the driving task. Driving can cause the attentional window to narrow, which can lead to a failure to detect critical information in peripheral vision (Park & Reed, 2014). Park and Reed (2014) asked participants to detect a peripheral target at varying eccentricities. The functional field of view for target detection (i.e., the eccentricity at which targets could be accurately detected) was smaller when completed with a driving background that required steering than when steering was not required (Park & Reed, 2014). Given that driving can lead to a failure to detect targets in peripheral vision, it is possible that adding a secondary task (e.g., leaving a voicemail) could further impair responses to critical targets (e.g., pedestrians and crosswalks) while driving.

In addition to perceptual demands of driving, there are demands that require responding to stimuli in the driving environment, forming memories for the driving event, etc., and these demands likely add to the overall cognitive load of the driving task. Tasks that add a non-visual/cognitive load can impair memory for elements in the driving environment (Atchley et al., 2014, Blalock et al., 2014; Ferlazzo, Fagioli, Noceraa, & Sdoia, 2008; Shomstein & Yantis, 2004; Treffner & Barrett, 2004). For example, when drivers were asked to count backwards, their memory for moving elements of the driving environment was impaired (Blalock et al., 2014). In addition, remembering instructions for a complex driving route lead to an increase in driving speed (Murphy & Greene, 2017b).

Furthermore, tasks that require attending in one modality can decrease processing and awareness of stimuli in another modality. For example, shifting attention from visual stimuli to auditory stimuli can result in a decrease in activation in the visual cortex and an increase in the auditory cortex (Shomstein & Yantis, 2004). Consistent with this, talking on a hands-free device while driving leads to decreased braking time, slower response time to road hazards, and faster cornering (Treffner & Barrett, 2004). Additionally, participants are less likely to notice unexpected visual information while talking on a cellphone with or without a hands-free device (Ferlazzo et al., 2008). The current study aimed to expand on this literature by looking at the effects of producing speech (i.e., leaving a voicemail) on overall driving performance (e.g., speed and steering) and on the ability to respond to expected and unexpected targets (e.g., crosswalks and pedestrians).

Consistent with the idea that talking while driving requires resources critical for driving, research has shown that generating speech can tax central attention resources (Kunar, Cartern, Cohen, & Horowitz, 2008; Spence, Jia, Feng, Elserafi, & Zhao, 2013). Therefore, talking or producing speech can impair driving performance, because of a decline in attentional resources allocated to the roadway (Atchley & Dressel, 2004; Drews, Pasupathi, & Strayer, 2008; Kubose, Bock, Dell, Garnsey, Kramer, & Mayhugh, 2006; Strayer & Drews, 2001). If processing the roadway and talking both rely on common attentional resources, then talking while driving can decrease available attentional resources and affect processing and memory for visual information while driving. Consistent with this prediction, research has shown that drivers engaged in a verbal task showed lower memory for billboards along the roadway (Atchley et al., 2014).

Generally, research supports that talking on a cellphone while driving can impair driving performance (see Caird, Simmons, Wiley, & Johnston, 2018 for a meta-analysis). However, in some cases, verbal tasks can lead to an improvement in driving behavior (Atchley & Chan, 2011; Atchley et al., 2014). Atchley et al. (2014) had participants free associate a word in response to a presented word. When the verbal task was only completed at the end of a monotonous drive, it led to less steering deviation (i.e., better lane keeping). Therefore, when attention is waning leading to fewer attentional resources being devoted to the driving task (Young & Stanton, 2002), a verbal task can increase alertness (as measured by a decrease in steering deviation and EEG signatures of alertness) or attention to the driving task (Atchley et al., 2014).

Studies examining the effects of talking while driving can vary widely in type of talking task. Studies have included tasks such as generating single words to a letter prompt (Gugerty, Rakauskas, & Brooks, 2004), solving math problems (Ma & Kaber, 2005), and playing a game of 20-questions with the experimenter (Heenan, Herdman, Brown, & Robert, 2014). In some cases, cognitive tasks (e.g., adding numbers, generating words) can have a smaller effect than conversation tasks on reaction times during driving, but both cognitive tasks and conversation tasks similarly affect speed while driving (see Caird, Simmons, Wiley, & Johnston, 2018 for a meta-analysis). Therefore, driving impairments can be found across a wide variety of "talking" tasks.

In the current study we examined the effect of an ecologically valid verbal task (i.e., leaving a voicemail) on driving performance. Participants in the current study were not engaged in a full conversation as would occur when talking to a person on a cell phone, but participants were asked to talk about common everyday events (e.g., classes, recent movie watched) while leaving a voicemail. Talking about everyday events is something that would commonly be part of a having a conversation. Furthermore, talking while driving occurs not only during conversations but also when using voice-to-text features and voice activated functions on in-vehicle information systems. Importantly, using voice-activated functions can also lead to an increase in cognitive load (Strayer, Cooper, Turrill, Coleman, & Hopman, 2016). Therefore, talking while driving, even if the talking is not part of a conversation, can decrease attentional resources available for the driving task.

1.3. Environment familiarity

If talking reduces attentional resources, then the effects of talking on driving behavior should be greatest when there is higher demand for attentional resources to the roadway. Research has shown that when a specific driving route is driven repeatedly, the driving task becomes more automatized and requires (or uses) fewer attentional resources (Charlton & Starkey, 2011, 2013). Furthermore, repeatedly driving in the same environment can lead to passive fatigue (Matthews, Naubauer, Saxby, Wohleber, & Lin, 2019), and passive fatigue can lead to a decrease in attention to the driving task (see Malleable attention theory, Young & Stanton, 2002).

Charlton and Starkey (2011) found that as drivers drove the same route repeatedly, their speed and lane position became less variable, and they reported that the driving task was easier. The decrease in speed variability was evident in the second drive in the environment and lane variability declined in the third drive and reached its lowest level on the fourth drive in the environment. This suggests that familiarity effects can appear by the fourth drive in an environment. Furthermore, Martens and Fox (2007a) found that with five trips within the same environment on a single day, the number of fixations to roadside signs decreased and driving speed increased. This suggests that less attention is being allocated to elements of the driving environment as familiarity within the driving environment increases, and that these effects develop within approximately four trips through the same environment (Charlton & Starkey, 2011; Martens & Fox, 2007a; Yanko & Spalek, 2013).

If the driving task requires less attention in familiar driving environments, then the effect of talking on driving may decrease as familiarity with the driving environment increases. Cooper and Stryer (2008) had participants drive in the same simulated driving environment repeated over several days. Driving while participating in a conversation was compared to driving in silence. Repeated driving in the same environment lead to a decrease in collisions. Importantly, the number of collisions in the conversation condition decreased with increased familiarity with the environment. However, other driving variables (forward following distance and brake reaction time) did not show a similar effect (Cooper & Stryer, 2008). In contrast, Shinar, Tractinsky, and Compton (2005) reported improved driving behavior after five runs through the same driving environment. They also reported a decrease in the effect of talking while driving with repetition in the driving environment. In the current study we further investigated the effects of familiarity with the driving environment and the degree to which familiarity may reduce the effects of talking while driving. For example, familiarity with the driving environment could lead to better awareness of where the driver is in the environment allowing for better predictions and reaction to critical driving targets (i.e. pedestrians), which could counter the negative effects of talking while driving.

1.4. Responding to critical targets while driving

An important task while driving is detecting and responding to critical targets on or near the roadway. For example, pedestrians near the roadway need to be detected, and if they enter the roadway, a response is required (slowing the vehicle). Detecting and responding to targets in the environment requires attentional and executive working memory resources (Peterson, Beck, & Wong, 2008). If leaving a voicemail taps into some of the same resources needed for detecting and responding to visual targets while driving, then leaving a voicemail may impair the ability to respond effectively.

Previous research has examined the effects of cognitive load on the ability to detect a pedestrian entering the roadway (Ericson et al., 2017; Yoshizawa & Iwasaki, 2015). When participants completed a high cognitive load task (i.e., tracking the lane changes of two vehicles on the roadway) while driving, they responded more slowly to the pedestrian entering the roadway. Slowed detection of pedestrians may also occur when doing other tasks that increase cognitive load (e.g., talking on a cell phone). For example, both novice and experienced drivers are more likely to hit pedestrians when engaging in a cell phone conversation (Kass, Cole, & Stanny, 2007), and even answering simple questions can delay initial eye movements towards pedestrians and slow braking time (Yoshizawa & Iwasaki, 2015). Therefore, in the current study, we predict that leaving a voicemail will be detrimental to driving performance when attention needs to be allocated to pedestrians at crosswalks. To look at this question, we examined the effects of leaving a voicemail while driving as drivers approached crosswalks with pedestrians that either entered the roadway or did not enter the roadway.

Being able to predict the location of critical driving targets may reduce the amount of resources needed to successfully detect the target. Research has shown that responses to pedestrians are improved when the pedestrians are in predictable locations (e.g., residential areas versus urban areas) and when salient cues (e.g., crosswalk signs) are present (Borowsky, Oron-Gilad, Meir, & Parmet, 2012; Obeid, Abkarian, Abou-Zeid, & Kaysi, 2017). This suggests that expectations for pedestrians to be present directs attention to the crosswalks where pedestrians are expected. Detection of highly task relevant targets that appear consistently in a given location of a driving environment (i.e., probable) can improve over repeated drives in the environment (Charlton & Starkey, 2013). However, detection of targets that are in unexpected (i.e., improbable) locations (Borowsky, Shinar, & Parmet, 2008) or were not previously present in a familiar driving environment (Martens & Fox, 2007b) is impaired. Response time to a target is quicker when observers know when and where the target will appear (Posner, 1980; Beck, Hong, van Lamsweerde, & Ericson, 2014). In addition, observers' expectations about the stability of visual information over time influence their ability to detect a change in the visual world from one glance to the next (Beck, Angelone, & Levin, 2004). Therefore, driving performance while leaving a voicemail may vary depending on expectations, based on prior experiences in the driving environment, that a critical target (e.g., a pedestrian in the roadway) will be present. In the current study, we manipulated the predictability of pedestrians entering the roadway at different crosswalks to examine if predictability or a violation in the predictability of a pedestrian impacts the effect of leaving a voicemail on responses to pedestrians and crosswalks.

1.5. The current study

In the current experiment, we examine how leaving a voicemail message impacts driving performance as familiarity with the driving environment increases. Therefore, we examined driving performance (e.g., velocity and steering) when drivers were leaving a voicemail message versus when drivers were not leaving a voicemail message on a hands-free cell phone across runs of driving in the same environment. Participants completed multiple short runs (approximately 1.5 min each) to increase familiarity with the environment quickly and to keep the voicemail task short enough to reduce fatigue and difficulty in thinking of things to talk about when leaving the voicemail. The 1.5-minute drives were long enough for the driver to encounter sections of roadway without critical targets (i.e., crosswalks or pedestrians) and to encounter two separate crosswalks within different blocks of the roadway, one with a pedestrian in the roadway and one without a pedestrian in the roadway.

As the driving task becomes more familiar (more runs in the same driving environment), the effect of the attentional load caused by talking on the phone may decline. We examined if leaving a voicemail leads to more erratic driving (increased velocity and increase deviation in steering), and if the effect of leaving a voicemail message while driving will persist when there are critical targets in the roadway (crosswalks). Finally, we examined the degree to which these effects change as the driving environment becomes more familiar and the location of critical targets is more or less predictable. Specifically, during the first three runs in the environment, a pedestrian always entered the roadway, making this crosswalk a location where pedestrians in the roadway can be expected. While at another crosswalk, pedestrians did not enter the roadway, making pedestrians in the roadway at this location unexpected. On the fourth run, these expectations were violated by moving the pedestrian that entered the roadway to the other crosswalk. By examining driving behavior at the crosswalks across these four runs, we can examine the effects of this predictability on driving performance when leaving a voicemail message versus when not leaving a voicemail message and how predictability and leaving a voicemail message may interact with each other.

2. Method

2.1. Participants

Ninety Louisiana State University (LSU) undergraduate students were recruited to participate. Fifteen participants did not complete the experiment resulting in 75 participants total for the experiment. Fourteen participants were unable to complete the experiment due to motion sickness, and one participant's data were lost due to experimenter error. Thirty-eight participants were randomly assigned to the voicemail condition and 37 were randomly assigned to the no voicemail condition. The average age of the participants was 20 years (SD = 2.5), and 52 of the 75 participants (69 percent) were female. All participants also had normal or corrected-to-normal vision and normal color vision. All participants were able to present a valid driver's license.

2.2. Design

The study had a 2 $\times$ 4 $\times$ 2 mixed factorial design. The variables were voicemail (voicemail, no voicemail), run (1, 2, 3, 4), and pedestrian probable crosswalk (Crosswalk 1 probable, Crosswalk 2 probable). The "voicemail" independent variable was manipulated between subjects. Participants were randomly assigned to either the voicemail or no voicemail condition. Run was manipulated within subjects. Each participant completed four experimental runs through the driving environment. The "pedestrian probable crosswalk" variable was manipulated between subjects. All participants drove in a driving environment with two crosswalks, one in which a pedestrian entered the roadway and one in which a pedestrian did not enter the roadway. Which of the two crosswalks had the pedestrian was counterbalanced across participants. Therefore, the crosswalk (1 or 2) in which the pedestrian entered the roadway was a between subjects variable.

2.3. Apparatus and stimuli

2.3.1. Driving simulator

The study was conducted using a driving simulator manufactured by Realtime Technology, Inc (see Fig. 1). The simulator is a full-size Ford Focus that is mounted without wheels surrounded by three projection screens in the front and one screen in the back. The virtual environment is also projected on the side mirrors to produce a high-fidelity virtual environment. The virtual environments were created using the Internet Scene Assembler and SimVista control interface was used to run the environments and collect the data.

2.3.2. Audio recording

An Olympus digital voice recorder collected voice data while the participants left their voice messages. A headset was worn by the participants that had a microphone that was attached to the right headphone. To evaluate vocal output during the speaking conditions, computerized acoustic analysis was conducted on all recordings using a standardized protocol (Cohen, Renshaw, Mitchell, & Kim, 2016). We were primarily interested in ensuring that vocal characteristics were similar across conditions, notably in terms of vocal production and vocal variability. Vocal production was defined in terms of the percentage of time talking and the number of vocal utterances produces (i.e., speech bounded by silence 300 ms or longer). Vocal variability was defined in terms of mean and standard deviation of fundamental frequency (i.e., "pitch", the lowest perceptible frequency) and intensity (i.e., vocal volume). These vocal characteristics have changed in response to increased cognitive load using experimentally manipulated dual speaking-visual memory tasks in several studies (Cohen, et al., 2015; Cohen, McGovern, Dinzeo & Covington, 2014; Cohen, Morrison, Brown, & Minor, 2012). Due to the nonlinear nature of the hertz frequency scale, F0 values were converted to semi-tones– a linear scale employed for parametric statistics of hertz-scale data.

2.3.3. Virtual environment

All participants completed two practice runs and four experimental runs through the same driving course. The driving course contained a four-lane road (two opposing lanes on each side of the road centerline) lined with buildings and trees (see Fig. 2). The driving environment appeared to be a sunny day at noon, with the sun high in the sky, some dark clouds off in the distance and no shadows visible. There were no other vehicles on the roadway. The driving course started with a straight away leading into an S-curve. Coming out of the S-curve, the course entered another straight away that contained two four-way intersections. The intersections did not contain cross traffic, stop signs, or signals to allow a constant driving speed. The first crosswalk was 15 m before the first four-way intersection. The second crosswalk appeared 15 m after the second four-way intersection. There were several salient landmarks along the drive. For example, near the beginning of the drive just after the s-curve there was a Blockbuster video store. Later in the drive after the first intersection there was a gas station on the right-hand corner, and later between the two crosswalks, there was a KFC restaurant on the right. After the second intersection, the second crosswalk ends at a grocery store on the left side of the road. At the end of the run, there was a flagpole in front of a post office on the right that indicated that the driving course was coming to an end. Par-

Fig. 1. View of Realtime Technologies Inc. Driving simulator from outside of the car (top). View of Realtime Technologies Inc. Driving simulator from inside of the car (bottom). Note that there were no other cars on the roadway in the current experiment. These images are meant to show the layout of the simulator. For examples of the simulated driving in the current study, see Fig. 2.

ticipants stopped at a stop sign at a T-intersection that triggered the end of the run. Directly in front of the participants when they stopped the car at the end of the roadway was a Walgreens. The entire course was 975 m long.

In the voicemail condition, driving the car triggered a tone 50 m before the S-curve and a car honk 15 m before the stop sign. Participants were instructed that the tone signaled them to start talking about the voicemail prompt topic and that the car honk signaled them to stop talking. The car honk also signaled that participants were approaching the end of the course. In the silent condition, participants were only instructed that the car honk signaled the end of the course.

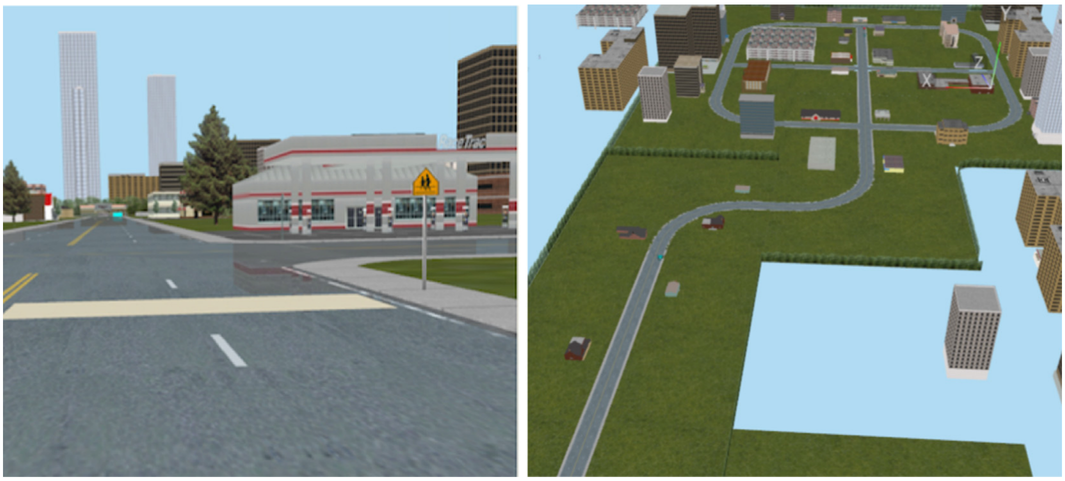

Fig. 2. Realtime Technologies Inc. Driving simulator view of one of the crosswalks (top picture) and aerial view of the driving course (bottom picture). Each run began in the bottom left corner of the bottom picture. Participants drove down the middle road and did not turn at any of the intersections.

During the two practice runs, no pedestrians appeared in the virtual environment. Starting with the first experimental run, pedestrians could be seen walking along the sidewalks. In addition, there was one male pedestrian standing on the sidewalk at the first crosswalk and two male pedestrians standing on the sidewalk at the second crosswalk. These male pedestrians never entered the roadway and never changed locations across runs. For one of the crosswalks, a female pedestrian in a white shirt walked into the crosswalk as the driver approached the crosswalk. The female pedestrian walked straight into the crosswalk without looking right or left. The pedestrian was triggered to start crossing the street when the driver crossed an invisible marker placed 37 m before the start of the crosswalk. Therefore, *if drivers did not slow down to the crosswalk and maintained the requested speed* of 35 MPH, the pedestrian would begin entering the crosswalk about 2.4 s before the car entered the crosswalk. In the "Crosswalk 1 probable" condition, the female pedestrian crossed at the first crosswalk for Runs 1 through 3. On Run 4, the female pedestrian was at Crosswalk 2 and crossed the street as the driver approached Crosswalk 2 (the female pedestrian was no longer present at the first crosswalk). For the "Crosswalk 2" condition, this pattern was reversed for the first and second crosswalk (the female pedestrian crossing the street was at the second crosswalk for Runs 1–3 and the first crosswalk for Run 4).

The crosswalk signs and pedestrians were visible from approximately 75 m before the crosswalk. The painted crosswalks on the street were first visible at a distance of approximately 45 m before the crosswalks.

2.4. Procedure

Participants presented a valid state-issued driver's license and provided informed consent before being familiarized with the driving simulator. All instructions were read aloud to the participants. The first set of instructions familiarized the participants with the simulator by pointing out the car's features and set-up. All participants were informed that they could not use the radio while driving. The participants were informed that they would be driving the car six times and that there will be time for a brake between each run. Participants were also informed that the driving simulator can cause motion sickness and that they are able to withdraw at any point. Next, participants were instructed to enter the car and notice the red button that would allow them to end the simulator immediately at any point. The experimenter addressed any questions before instructing the participant to adjust the seat to match how they normally drive a car. In the voicemail condition, after the participant adjusted their seat, the participant was instructed to put on the headset.

Following being familiarized with the car, participants completed two practice runs. During the practice runs no pedestrians appeared on the sidewalks and no pedestrians crossed the street. None of the participants left a voicemail during the first practice run. On the second practice run, participants in the voicemail condition practiced the voicemail task.

Before the first practice run, participants were informed they would be driving through the virtual environment to familiarize themselves with how the car functions. The participants were instructed to drive in the right-hand lane and maintain the car's speed between 30 and 35 miles per hour. A warning was given that they should start to decelerate once they approach the flagpole (signaling the end of the run), to stop at the stop sign, and to put the car in park. The same instructions were given before the second practice run, except participants in the voicemail condition were also informed that they were going to practice leaving a voicemail while driving.

In the voicemail condition, instructions were as follows regarding how to leave a voicemail while driving. Participants were instructed to imagine they have just called their friend, mom, or whomever they are most likely to talk on the phone and that there was no answer, so they leave a voicemail message. They were given one of five topics to talk about on each run (Practice #2 and Runs 1–4) and were told to talk as much as possible about the given topic. To help participants have enough to talk about for the whole run, they were told to talk about anything they could think of that related to the topic and were given some suggestions, and they were told that when they could not think of anything else to say to start talking about another instance that matched the topic. Participants were reminded again that they would be leaving a voicemail for each run and to maintain their speed between 30 and 35 miles per hour (MPH) and stay in the right lane. Finally, participants were asked, "Before we start, what is the topic you will be discussing on the voicemail message?" to be sure that they remembered the instructed topic.

One of five different topics was discussed on each run through the environment. On each run, participants were asked to discuss either (1) social activities with family and friends, (2) places they want to travel and why, (3) something recently read on social media, blogs or watched on YouTube or video blog, (4) courses currently enrolled, and (5) recent movies or TV shows or books. The prompt orders were counterbalanced across participants, so each prompt was used once in each position in the order.

The only difference for the silent condition instructions is that participants were never told to leave a voicemail while driving. After completing all four experimental runs, all participants were asked to list (free recall) as many landmarks as they could remember from the environment.

3. Results

Velocity was defined as miles per hour (mph) within 15.5-meter stretches of roadway, and steering deviation was defined as the standard deviation in the angle of steering within 15.5-meter stretches of roadway. Using 15.5-meter bins allowed for equal partitioning of the roadway between the two crosswalks.

3.1. The impact of leaving a voicemail message on driving performance

To examine the effect of leaving a voicemail message on velocity and steering deviation, we examined velocity (mph) and standard deviation in steering over the four runs for the 124-meter section (averaged across 8 bins of 15.5 m) of the roadway between the two crosswalks and intersections. This is a straight section of roadway with no crosswalks or other local targets relevant to the driving tasks (traffic signs, etc). We also examined the proportion of 27 bins (15.5 m each) in which average velocity exceeded the speed limit (35 mph). The first 15.5-meter bin of this 418.5-meter section of the roadway began just after the S-curve (88 m before the start of the first crosswalk) and ended 67 m after the start of the second crosswalk. The mixed model ANOVAs included run (1, 2, 3, 4) as a within subject variable and voicemail (voicemail or no voicemail) as a between subject factor.

3.1.1. Velocity

For the 124-meter stretch of roadway between the two crosswalks, there was a main effect of voicemail, $F(1, 73) = 20.88$, $p < .001$, $\eta_p^2 = 0.222$, due to faster velocity when leaving a voicemail message (M = 33.94 mph) than when not leaving a voicemail message (M = 31.37 mph). There was no main effect of run, $F(2.34, 171.11) = 0.93$, $p = .41$, $\eta_p^2 = 0.013$, and no voicemail × run interaction, $F(2.34, 171.11) = 0.22$, $p = .84$, $\eta_p^2 = 0.003$ (see Fig. 3).

For the proportion of bins with an average mph above the speed limit (35 mph), there was a main effect of voicemail, $F(1, 73) = 24.5$, $p < .001$, $\eta_p^2 = 0.49$, due to a higher proportion of bins with an average mph above 35 mph when leaving a voicemail message (M = 0.24) than when not leaving a voicemail message (M = 0.06). There was also a main effect of run, $F(2.34, 170.92) = 4.66$, $p = .004$, $\eta_p^2 = 0.06$, due to the proportion of bins above 35 mph decreasing from Run 1 (M = 0.20) to Run 2 (M = 0.12), $t(74) = 3.18$, $p = .002$. There was not a significant voicemail × run interaction, $F(2.34, 170.92) = 0.92$, $p = .43$, $\eta_p^2 = 0.012$ (see Fig. 3).

3.1.2. Steering deviation

For the 124-meter stretch of roadway between the two crosswalks, there was a main effect of voicemail, $F(1, 73) = 15.29$, $p < .001$, $\eta_p^2 = 0.173$, due to greater deviation in steering when leaving a voicemail message (M = 0.52) than when not leaving a voicemail message (M = 0.31). There was no main effect of run, $F(2.35, 171.43) = 1.03$, $p = .37$, $\eta_p^2 = 0.014$, and no voicemail × run interaction, $F(2.35, 171.43) = 1.25$, $p = .29$, $\eta_p^2 = 0.017$ (see Fig. 3).

Overall, leaving a voicemail message lead to faster driving, more instances of exceeding the speed limit and greater steering deviation. These effects did not decline or increase as familiarity with the environment increased.

3.2. The impact of leaving a voicemail message at crosswalks with and without pedestrians

In order to examine the effects of leaving a voicemail message on driving performance near critical targets (crosswalks and pedestrians entering the roadway), we selected roadway segments for each crosswalk and a no-crosswalk segment of the roadway. For velocity, we compared velocity from single 15.5-meter bins that contained the crosswalks (these bins started 10.5 m before the beginning of the crosswalk and ended 5 m after the start of the crosswalk) and a 15.5-meter bin between the two crosswalks (no-crosswalk). We also calculated the change in velocity and change in steering deviation as participants approached the crosswalks. In order to calculate the change in velocity and the change in steering standard deviation, we took the average value from the 15.5-meter bin that began 57 m before the start of each crosswalk and subtracted the average value from the bin containing the crosswalk. This gave a value that represented the amount of change in velocity and change in steering standard deviation as drivers approached the crosswalks. This was calculated for both crosswalks and for a segment of road between the two crosswalks that did not contain a crosswalk (no-crosswalk control).

See Appendix A for omnibus 3 × 4 × 2 × 2 mixed model ANOVAs for *velocity*, *velocity change, and steering deviation change* that include roadway segment (Crosswalk 1, Crosswalk 2, no-crosswalk) and run (1, 2, 3, 4) as within-subject factors and probable pedestrian crosswalk (Crosswalk 1 probable, Crosswalk 2 probable) and voicemail (voicemail, no voicemail) as between subject factors. There were main effects of probable pedestrian crosswalk, interactions between road segment and probable pedestrian crosswalk, and three-way interactions between run, road segment, and probable pedestrian crosswalk for velocity, change in velocity and change in steering deviation. These effects were due to a slower velocity, more change in velocity, and more change in steering deviation when there was a pedestrian in the roadway. In order to further examine the effects of run, pedestrian location, and voicemail at each crosswalk, 4 × 2 × 2 mixed model ANOVAs were conducted separately for each road segment with run, probable pedestrian crosswalk, and voicemail as variables.

3.2.1. Velocity

There was a significant three-way interaction between run, pedestrian probable crosswalk, and voicemail for Crosswalk 1, $F(2.16, 153.6) = 4.75$, $p = .003$, $\eta_p^2 = 0.063$, and for Crosswalk 2, $F(2.10, 148.99) = 3.10$, $p = .045$, $\eta_p^2 = 0.042$. These were followed up with 2x2 (probable pedestrian crosswalk × voicemail) ANOVAs at each run for each crosswalk (see Fig. 4). All runs for both crosswalks revealed significant main effects for pedestrian probable crosswalk (see Table 1). When there was a pedestrian that entered the roadway at the crosswalk, participants drove slower. There were significant effects of voicemail at Crosswalk 1 for Runs 1, 2, and 4 and at Crosswalk 2 for Runs 1, 2, and 3 due to faster speeds when leaving a voicemail message. There were significant pedestrian probable crosswalk × voicemail interactions for Crosswalk 1 at Run 2 and for

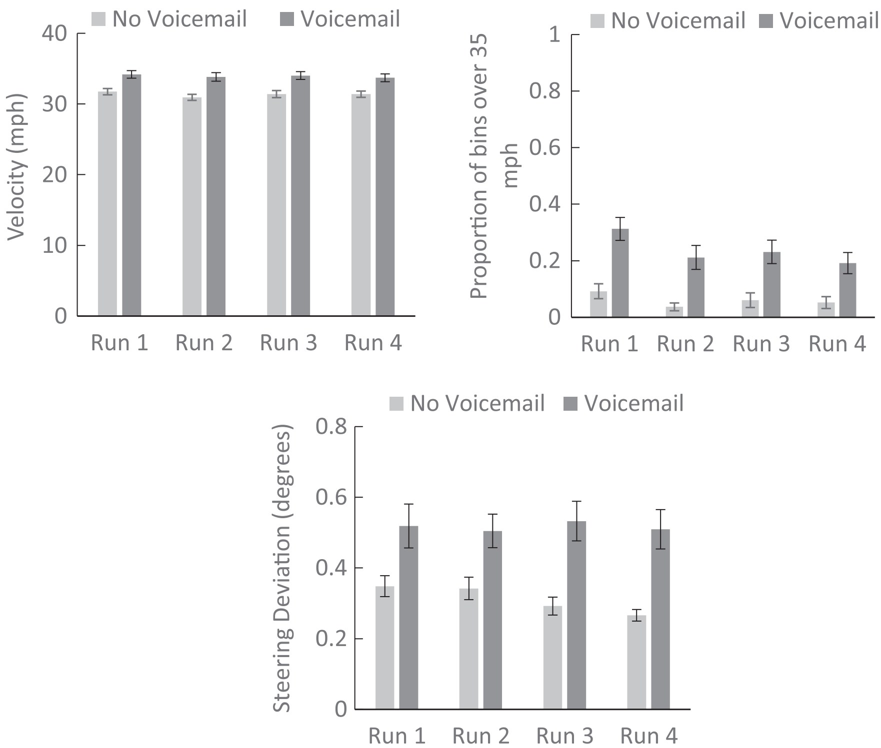

Fig. 3. Top left: Driving speed between the two crosswalks. Top right: The proportion of bins exceeding the speed limit. Bottom: Steering deviation between the two crosswalks. Error bars represent the standard error of the mean.

Crosswalk 2 at Run 2 (see Table 1). These interactions were consistent with the interaction between pedestrian probable and voicemail found in the 3 × 4 × 2 × 2 ANOVA (see Appendix A), and were due to effects of leaving a voicemail message when there was not a pedestrian in roadway, but no effect of leaving a voicemail message when there was a pedestrian present in the roadway (see Fig. 4). That is, when no pedestrian enters the roadway, drivers who were leaving a voicemail message drove faster than drivers who were not leaving a voicemail message. However, this effect was not present if there was a pedestrian in the roadway.

3.2.2. Change in velocity

Mixed model ANOVAs for each road segment revealed a significant three-way interaction between pedestrian probable crosswalk, run, and voicemail for Crosswalk 1, $F(2.17, 153.73) = 5.61$, $p = .004$, $\eta_p^2 = 0.073$, and for Crosswalk 2, $F(2.33, 165.36) = 4.16$, $p = .013$, $\eta_p^2 = 0.055$. These effects were followed up with 2 × 2 ANOVAs at each run for each crosswalk (see Fig. 5). All runs for both crosswalks revealed significant main effects for pedestrian probable crosswalk (see Table 2). When there was a pedestrian that entered the roadway at the crosswalk, participants slowed down more. There were also significant pedestrian probable crosswalk × voicemail interactions for Crosswalk 1 at Runs 1, 2, and 4 (but not for Run 3), and for Crosswalk 2 at Run 2 only (see Table 2). These interactions were due to a pedestrian in the roadway resulting in a larger difference in the amount of deceleration for the voicemail conditions than in the no voicemail conditions. That is, for the voicemail condition, the difference in the amount of deceleration when there was a pedestrian in the crosswalk versus when there was not a pedestrian in the crosswalk was larger as compared to the no voicemail condition. Drivers who were leaving a voicemail had a faster speed when no pedestrian was present, therefore, they must decelerate more to accommodate the pedestrian in the roadway. Furthermore, drivers leaving a voicemail decelerated less than silent drivers when there was no pedestrian in the roadway.

3.2.3. Change in steering standard deviation

In order to assess the effects of run and pedestrian at each crosswalk, mixed model ANOVAs were conducted separately for Crosswalks 1 and 2. The three-way interaction between pedestrian location, run, and voicemail was not significant for either Crosswalk 1, $F(2.52, 178.61) = 1.06$, $p = .36$, $\eta_p^2 = 0.015$, or Crosswalk 2, $F(2.52, 178.71) = 1.09$, $p = .35$, $\eta_p^2 = 0.015$. However, there were significant two-way interactions between pedestrian location and run for Crosswalk 1, $F(2.52, 178.61) = 4.05$, $p = .012$, $\eta_p^2 = 0.054$, and for Crosswalk 2, $F(2.52, 178.71) = 6.19$, $p = .001$, $\eta_p^2 = 0.08$.

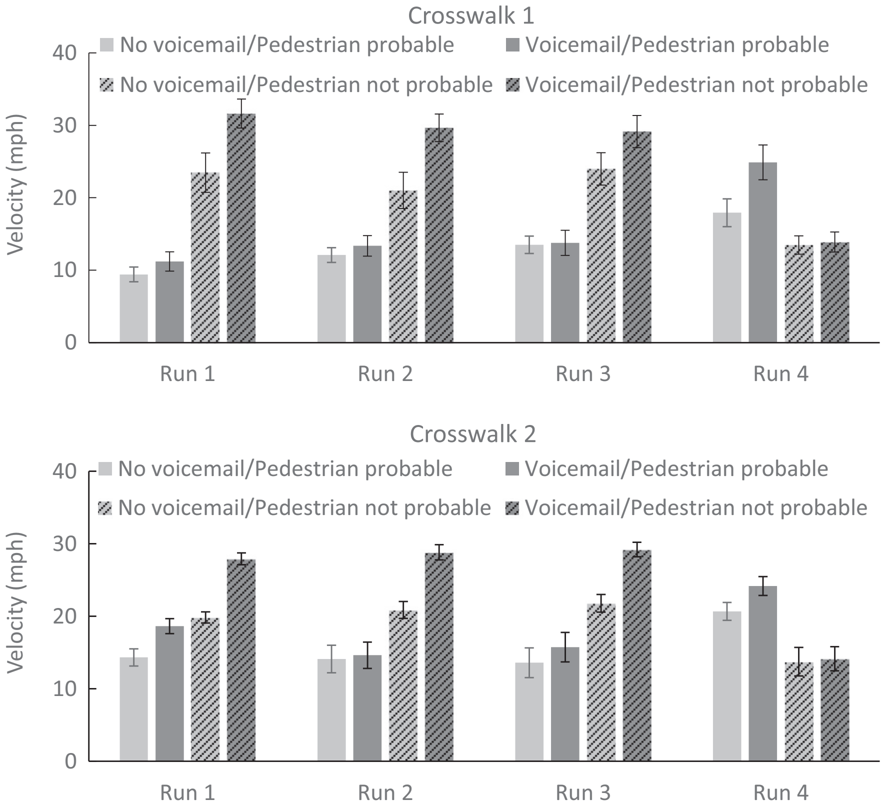

Fig. 4. Average velocity from single 15.5-meter bins that contained the crosswalks at each run for voicemail and no voicemail conditions. When a pedestrian was probable, a pedestrian entered the roadway for runs 1, 2 and 3. When a pedestrian was not probable, the pedestrian only entered the road for the 4th run. Error bars represent standard error of the mean.

Table 1
Velocity 2x2 (probable pedestrian location × voicemail) repeated measures ANOVAs at each run for each crosswalk.

		Crosswalk 1				Crosswalk 2			
		Run 1	Run 2	Run 3	Run 4	Run 1	Run 2	Run 3	Run 4
Voicemail	*F*	7.20	7.80	2.07	4.13	11.62	7.49	8.34	1.59
	P	0.009	0.007	0.155	0.046	0.001	0.008	0.005	0.211
	η_p^2	0.092	0.099	0.028	0.055	0.141	0.095	0.105	0.022
Pedestrian	*F*	86.28	50.54	46.73	18.30	16.54	46.07	42.80	29.59
	P	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	η_p^2	0.549	0.416	0.397	0.205	0.189	0.393	0.376	0.294
Voicemail xPedestrian	*F*	2.92	4.34	1.68	3.25	1.08	5.77	2.53	0.998
	P	0.092	0.**041**	0.199	0.076	0.303	**0.019**	0.116	0.321
	η_p^2	0.039	0.058	0.023	0.044	0.015	0.075	0.034	0.014

Note: DF = (1,71).

This was followed up with 2x2 ANOVAs at each run for each crosswalk (see Fig. 6). There were significant main effects for pedestrian location for Runs 1 and 2 at Crosswalk 1 and for Runs 2, 3 and 4 for Crosswalk 2 (see Table 3). In all of these cases, the effect was caused by a greater increase in steering deviation when there was a pedestrian in the roadway than when there was no pedestrian in the roadway.

In summary, when there was a pedestrian in the crosswalk, drivers drove slower, slowed down more and, on some runs, also deviated their steering more. In addition, there were consistent interactions between probable pedestrian crosswalk and voicemail (3 × 4 × 2 × 2 mixed model ANOVA and 2 × 2 ANOVA for Run 2) for velocity. These interactions were driven by an effect of leaving a voicemail message only when the pedestrian was not present in the crosswalk. Overall, the effect of leaving a voicemail message is larger when there is no pedestrian in the crosswalk. When there was a pedestrian in the crosswalk, driver's reactions (speed, decrease in speed, and steering deviation) were minimally affected by leaving a voicemail message. Finally, familiarity with the driving environment had a minimal impact on the effects of leaving a voicemail message while driving.

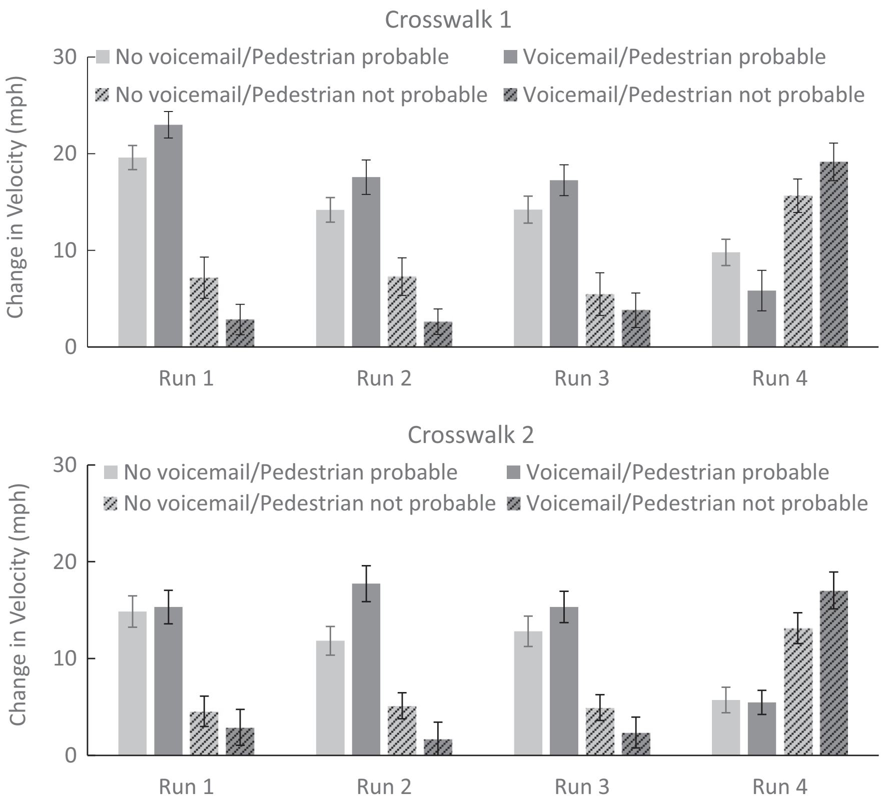

Fig. 5. Change in velocity at each run for voicemail and no voicemail conditions. When a pedestrian was probable, a pedestrian entered the roadway for runs 1, 2 and 3. When a pedestrian was not probable, the pedestrian only entered the road for the 4th run. Error bars represent standard error of the mean.

Table 2
Change in velocity 2 × 2 (pedestrian location × voicemail) repeated measures ANOVAs at each run for each crosswalk.

		Crosswalk 1				Crosswalk 2			
		Run 1	Run 2	Run 3	Run 4	Run 1	Run 2	Run 3	Run 4
Voicemail	*F*	0.084	0.161	0.153	0.017	0.122	0.588	<0.001	1.39
	p	0.77	0.69	0.70	0.90	0.728	0.446	0.99	0.242
	η_p^2	0.001	0.002	0.002	<0.001	0.002	0.008	<0.001	0.019
Pedestrian	*F*	103.92	46.81	39.75	28.13	44.63	49.43	46.4	37.87
	p	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
	η_p^2	0.594	0.397	0.359	0.284	0.386	0.410	0.395	0.348
Voicemail xPedestrian	*F*	5.84	6.37	1.79	4.26	0.387	8.31	2.78	1.81
	p	**0.018**	0.**014**	0.185	0.**043**	0.536	**0.005**	0.10	0.183
	η_p^2	0.076	0.082	0.025	0.057	0.005	0.105	0.038	0.025

Note: DF = (1,71).

3.2.4. Braking

Although drivers slowed for pedestrians in the crosswalk to a similar speed when they were leaving a voicemail message as when they were not leaving a voicemail message, if and when drivers braked for crosswalks with and without pedestrians may have been affected by leaving a voicemail message. We examined the 15.5-meter crosswalk bin and the five 15.5 m bins before the crosswalks to see if and when participants began braking to slow down for the crosswalk. The crosswalk bin is the same bin used in the velocity analysis above that started 10.5 m before the beginning of the crosswalk and ended five meters after the start of the crosswalk. First, we counted how many participants did not brake as approaching the crosswalks. If there was a pedestrian in the crosswalk, participants always braked (except for one participant in the voicemail/ probable pedestrian at Crosswalk 2 condition during Run 4 at Crosswalk 1). Therefore, we examined the number of participants who braked for the crosswalks without pedestrians and how many bins prior to the crosswalk bin they braked for crosswalks with pedestrians.

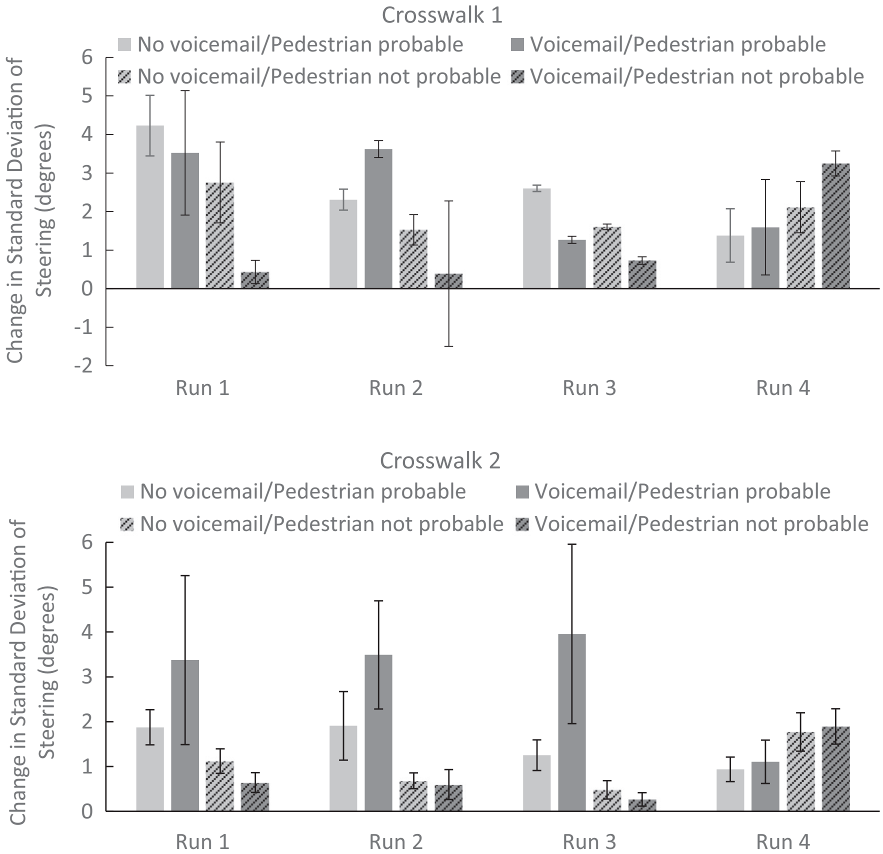

Fig. 6. Change in steering deviation at each run for voicemail and no voicemail conditions. When a pedestrian was probable, a pedestrian entered the roadway for runs 1, 2 and 3. When a pedestrian was not probable, the pedestrian only entered the road for the 4th run. Error bars represent standard error of the mean.

Table 3
Change in steering deviation 2 × 2 (pedestrian location × voicemail) repeated measures ANOVAs at each run for each crosswalk.

		Crosswalk 1				Crosswalk 2			
		Run 1	Run 2	Run 3	Run 4	Run 1	Run 2	Run 3	Run 4
Voicemail	F	2.08	0.012	3.72	0.501	0.267	1.03	1.45	0.131
	p	0.154	0.913	0.058	0.481	0.607	0.315	0.233	0.718
	η_p^2	0.028	<0.001	0.05	0.007	0.004	0.014	0.02	0.002
Pedestrian	F	4.72	6.25	1.8	1.57	3.1	7.8	4.63	4.03
	p	0.**033**	0.**015**	0.184	0.214	0.083	0.**007**	**0.035**	0.**049**
	η_p^2	0.062	0.081	0.025	0.022	0.042	0.099	0.061	0.054
Voicemail xPedestrian	F	0.592	2.33	0.164	0.232	0.999	1.28	1.99	0.003
	p	0.444	0.131	0.687	0.632	0.321	0.262	0.163	0.957
	η_p^2	0.008	0.032	0.002	0.003	0.014	0.018	0.027	<0.001

Note: DF = (1,71).

If there was no pedestrian at the crosswalk, participants were more likely to brake before the crosswalk if they were not leaving a voicemail message than if they were leaving a voicemail message for Runs 1–3 (see Fig. 7) (Run 1: $X^2(1) = 5.87$, $p = .015$, Run 2: $X^2(1) = 8.35$, $p = .004$, Run 3: $X^2(1) = 9.71$, $p = .002$). In Run 4, when the pedestrian location changed from the crosswalk with a pedestrian in the first three runs to the other crosswalk, rates of not braking when the pedestrian was not in the crosswalk were not different between the not leaving a voicemail message and leaving a voicemail message conditions, $X^2(1) = 2.43$, $p = .12$. The expectation of a pedestrian in the crosswalk, based on what had happened on the previous three runs, increased the number of participants braking from Run 3 to Run 4 for the voicemail condition, $X^2(1) = 10.32$, $p = .001$, but not for the no voicemail condition, $X^2(1) = 2.64$, $p = .10$. Therefore, leaving a voicemail message while driving decreased the likelihood of braking to a crosswalk without a pedestrian in the roadway unless there was an expectation based on previous experience for a pedestrian to enter the roadway.

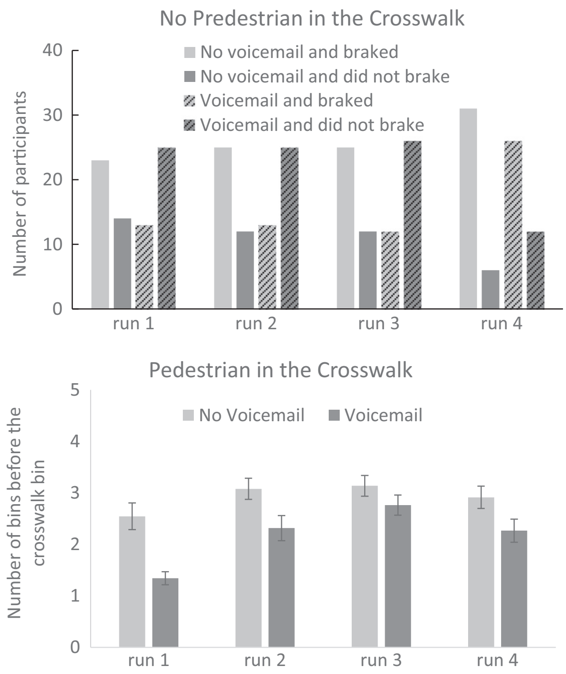

Fig. 7. Top: Number of participants braking and not braking to crosswalks without pedestrians in the roadway for each run. Bottom: Number of 15.5-meter bins before the crosswalk bin when braking began if there was a pedestrian in the roadway. Error bars represent standard error of the mean.

For the crosswalks with pedestrians in the roadway, the onset of braking was calculated as the number of bins prior to the crosswalk bin in which braking started (see Fig. 7). If the bin that included the crosswalk was the first bin with braking, this was coded as a "zero". If braking started one bin before the crosswalk bin, this was coded as a "one". This process continued up to five bins before the crosswalk bin. The 5th bin before the crosswalk is the bin in which the crosswalk and the pedestrians first became visible (approximately 75 m before the crosswalk) and the 2nd bin before the crosswalk is the bin in which the pedestrian began entering the roadway. A 4 $\times$ 2 mixed model ANOVA with run (1, 2, 3, 4) as a within subjects variable and voicemail (voicemail, no voicemail) as a between subjects variable revealed a main effect of voicemail, $F(1, 72) = 10.84$, $p = .002$, $\eta_p^2 = 0.131$, and a main effect of run, $F(2.46, 177.09) = 13.23$, $p < .001$, $\eta_p^2 = 0.155$, but no interaction $F(2.46, 177.09) = 2.06$, $p = .12$, $\eta_p^2 = 0.028$. That is, braking occurred in bins further from the crosswalk bin in the silent condition (*M* = 2.9 bins before the crosswalk) than in the voicemail condition (*M* = 2.2 bins before the crosswalk).

3.3. Memory for the driving environment

We examined participants' memory for the items along the roadway. First, we calculated the number of any environment feature (Blockbuster, KFC, Walgreens, post office, grocery store, gas station, houses, office buildings, trees, black clouds, pedestrians in crosswalk, people, flag pole, crosswalk/crosswalk signs, stop sign) participants accurately recalled on the free recall test that was completed at the end of the experiment. Participants in the silent condition recalled more items (*M* = 3.18, *SE* = 0.18) than participants in the voicemail condition (*M* = 2.18, *SE* = 0.17), $t(75) = 4.04$, $p < .001$. Second, we calculated the number of salient and specific landmarks (Blockbuster video store, KFC restaurant, Walgreens, post office, grocery store, gas station) participants accurately recalled. Participants in the silent condition recalled more salient landmarks (*M* = 1.45, *SE* = 0.16) than participants in the voicemail condition (*M* = 0.67, *SE* = 0.1), $t(75) = 4.11$, $p < .001$. Next, we calculated the number of participants that listed the most salient landmarks that were within the voicemail range of the driving route, the Blockbuster, the KFC, and the gas station. More participants in the no voicemail condition (27 out of 38) recalled the Block Buster than in the voicemail condition (10 out of 39), $X^2(1) = 15.90$, $p < .001$. Also, more participants in the no voicemail condition (13 out of 38) recalled the KFC than in the voicemail condition (4 out of 39), $X^2(1) = 6.42$, $p = .011$. Very few participants noticed the gas station (9 out of 75), which occurred right after the first crosswalk, and there was no difference in the number who remembered the gas station between the no voicemail (5 out of 38) and voicemail (4 out of 39) conditions, $X^2(1) = 0.098$, $p > .05$. The Walgreens and the Post Office were at the very end of the route where drivers stopped driving. More participants in the no voicemail condition (27 out of 38) recalled the Walgreens than in the voicemail condition (16 out of 39), $X^2(1) = 5.74$, $p = .017$. More participants in the no voicemail condition (8 out of 38) also recalled the Post Office than in the voicemail condition (0 out of 39), $p < .05$ (Fisher's exact test).

3.4. Vocal characteristics

To ensure that participants were vocalizing similarly across runs, we analyzed various vocal characteristics across the four runs. Repeated measures ANOVAs suggested that neither vocal production nor vocal variability changed across the runs. For vocal production, participants were recorded, on average, for 61.33 s (*SD* = 5.88 s) on each run. Participants were consistently speaking for the vast majority of this time. They produced speech (vocal production) for approximately 82.23 (*SD* = 3.87) percent of the trial, with an average pause time of 649.05 ms (SD = 202.70 ms). Only 5.6% of the recordings contained pauses greater than five seconds in length. The percentage of time producing speech did not vary across runs, $F(3,148) = 0.53$, $p = 0.66$, $\eta_p^2 = 0.01$. Participants averaged 39.21 (*SD* = 9.85) utterances, which each averaged 816.59 ms (*SD* = 327 ms). The number of utterances did not change across runs, $F(3, 148) = 1.46$, $p = 0.23$, $\eta_p^2 = 03$. Vocal variability, in terms of mean/standard deviation of fundamental frequency or intensity, also did not change across runs (Fs(3, 148) < 1.46, ps > 0.23, η_p^2s < 03).

4. Discussion

Overall, leaving a voicemail message while driving led to faster driving, more instances of exceeding the speed limit, and greater steering deviation. Importantly, drivers who were leaving a voicemail message drove faster than drivers who were not leaving a voicemail message, even when approaching and driving across a crosswalk that had pedestrians on the roadside that did not enter the roadway. Although drivers leaving a voicemail message did decelerate for pedestrians entering the roadway to a similar speed as drivers not leaving a voicemail message, drivers leaving a voicemail message were delayed in braking compared to drivers not leaving a voicemail message. Drivers leaving a voicemail message also had worse memory for landmarks along the roadway than the drivers not leaving a voicemail message. These effects were relatively stable across several runs through the same driving environment, suggesting that familiarity and practice with driving in a given environment had a minimal impact on the effects of leaving a voicemail message while driving. Overall, these results suggest that leaving a voicemail message reduces attention to the driving task and environment; participants are less able to monitor their speed and steering, slower to react to local targets, and are less likely to remember landmarks along the roadway.

4.1. Risks of talking while driving

Previous research shows that listening to speech while driving impairs driving performance (Murphy & Greene, 2017a) and a recent meta-analysis suggests a negative impact of talking while driving (see Caird, Simmons, Wiley, & Johnston, 2018). Consistent with this previous research and research showing that producing speech requires attentional resources (Atchley & Dressel, 2004; Drews, Pasupathi, & Strayer, 2008; Stayer & Drews, 2007), we found that leaving a voicemail while driving led to faster speeds and more steering deviation. Also consistent with previous research (Atchley et al., 2014), we found that memory for the driving environment was reduced after leaving a voicemail message while driving. This suggests that critical resources needed for the driving task (e.g., visual attention and executive attention) were used when leaving a voicemail message, reducing processing of the driving environment.

Drivers leaving a voicemail message were also delayed in responding to crosswalks with pedestrians in the roadway. Specifically, drivers leaving a voicemail message initiated the brake response closer to the crosswalk than drivers not leaving a voicemail message, suggesting that they were delayed in detecting the crosswalk and pedestrian. This is consistent with previous research showing that engaging in a conversation increases the likelihood of hitting a pedestrian (Kass, Cole, & Stanny, 2007) and slows braking time (Yoshizawa & Iwasaki, 2015). It is suggested that drivers can respond to road hazards in about 1.5 s depending on many factors including urgency, age, and expectation (Green, 2000) or up to 2.5 s (Triggs & Harris, 1982). On average, participants were driving at 32 MPH in the bin where the pedestrians became visible (5 bins before the crosswalk). That is 14.31 m per second. So in the 1.5 s needed to respond, the driver has traveled 21.46 m and is in the 4th bin before the crosswalk and in 2.5 s the driver is the 3rd bin before the crosswalk if maintaining a speed of about 32 mph. Drivers not leaving a voicemail message began braking on average 2.9 bins before the crosswalk, but drivers leaving a voicemail message did not begin braking until 2.2 bins before the crosswalk. Delayed braking could be problematic because drivers leaving a voicemail message drive faster and so they need to decelerate more to stop at a crosswalk. Therefore, although only one driver failed to brake for a pedestrian in a crosswalk in the current study, this study shows that the risk for delayed braking is greater when leaving a voicemail message. Because drivers leaving a voicemail message are taking longer to initiate braking to pedestrians in crosswalks, the risk of not having enough time to decelerate is increased.

Delayed braking for drivers leaving a voicemail message may be related to reduced memory for the driving environment. If expectations can influence the perception-reaction time (Green, 2000), and poorer memory for the environment impairs the ability to expect the crosswalk, then this could contribute to the delay in braking when leaving a voicemail message. In support of this possibility, previous research has indicated that talking while driving can lead to a decrease in situational awareness when driving (Heenan et al., 2014).

Given that drivers leaving a voicemail message were able to slow to similar speeds as drivers not leaving a voicemail message at crosswalks with pedestrians in the roadway, the effects of leaving a voicemail message were not universally detrimental in the current study. This is consistent with other research showing that talking while driving does not universally lead to negative effects on driving performance (Atchley et al., 2014). In the current study, although drivers leaving a voicemail message initiated the brake response closer to the crosswalk than drivers not leaving a voicemail message, they were able to slow to a similar speed as drivers not leaving a voicemail message and only one of the drivers leaving a voicemail message failed to brake to pedestrians in the roadway. Furthermore, increases in steering deviation for all drivers (those leaving a voicemail and those not leaving a voicemail) could be a compensation for less slowing as the drivers may have swerved to prevent hitting the pedestrian. This suggests that although the drivers leaving a voicemail message were delayed in detecting the pedestrian due to the voicemail task using resources necessary for detecting visual targets while driving, they were generally able to compensate adequately.

Importantly, talking is a complex ability that is variable with respect to its cognitive demands in any given moment. A broad range of factors related to speech (e.g., topic novelty, automaticity of language, syntactic complexity) can affect the resources required to produce it (Ding, et al., 2016). Further, the current experiment used a voicemail task rather than a conversation task, which may impact the cognitive resources need for the task. Hence, participants may have strategically allocated their cognitive resources from speaking to driving in a given moment, in effect, by deliberately manipulating the demands of their speech. This could be accomplished through pausing, producing clichéd or relatively automatic language, using language fillers (e.g., "uh"), repeating previously spoken language, reducing syntactical complexity, or a myriad of other strategies. If this is the case, a task requiring more consistently heavy cognitive resources may lead to more deleterious effects on driving performance.

The way in which data was collected for this study prevents full assessment of the risks associated with talking and driving. First, the study was designed to focus on locations within the driving environment rather than time to reach a driving hazard. In research assessing risks in driving, time to respond to a risk is generally used as the main variable of measurement (Green, 2000; Triggs & Harris, 1982). The use of binned data across road segments in the current study prevented a similar time to respond risk assessment. Second, the voice data collected in this study was not time-locked to driving performance with sufficient resolution to meaningfully explore their relationship. Nonetheless, it is likely that talking is not universally negative on driving behavior. Explicitly developing regulation strategies, such that drivers know when and where they should be actively allocating their cognitive resources, may be a useful component for driver education.

4.2. Familiarity with the driving environment

Increased familiarity with the driving environment had a minimal impact on the negative effects of leaving a voicemail message while driving. Most of the dependent variables measured were not affected by familiarity. This is surprising given that the predictability of the environment was higher than it would be in the real world. That is, on runs 2 and 3 was 100% because the runs were identical to the first run. However, there is evidence to suggest that drivers leaving a voicemail message did learn about predictable events in the environment and were not sensitive to changes in this predictability. During the fourth run in the environment, the location of the pedestrian entering the roadway changed to the other crosswalk, which had never previously had a pedestrian enter the roadway. For the first three runs, drivers leaving a voicemail message were less likely than drivers not leaving a voicemail message to brake for the crosswalk without a pedestrian in the roadway. However, on the fourth run, when there was an expectation of a pedestrian (but none present), drivers leaving a voicemail and not leaving a voicemail both braked similarly. That is, drivers leaving a voicemail message increased their rate of braking to that of the drivers not leaving a voicemail message. This suggests that they had learned to expect a pedestrian in the roadway but were not actively exploring the environment to see if the expectation would be fulfilled. Coincidentally, expectations based on prior driving experience had the effect of removing the negative consequence of leaving a voicemail message when approaching a crosswalk without a pedestrian. Drivers leaving a voicemail message were less likely to brake if there was not a pedestrian, but if drivers expected a pedestrian based on previous experience (Run 4 of the pedestrian probable condition), they were as likely to brake as drivers not leaving a voicemail message. Overall, the data suggest that drivers leaving a voicemail message braked based on their expectations for a pedestrian, built up from previous runs in the environment, rather than based on current available information in the driving environment. This support previous research showing a decrease in visual exploration of the driving environment with increased familiarity (Martens & Fox, 2007a).

Experience with a driving environment can lead to more automatized driving such that the driving task will require fewer resources (Charlton & Starkey, 2011; Martens & Fox, 2007a; Yanko & Spalek, 2013). Although previous studies have found effects of driving familiarity by the 4th run in a driving environment, we did not find similar effects in the current study. It is important to remember that drivers completed two practice runs prior to the four experimental runs that were included in the analyses. Therefore, there should have been enough runs in the environment to find familiarity effects. Although it is possible that more runs through the environment would be necessary to observe familiarity effects. There are some examples of effects that were trending toward significant interactions with the number of runs in the environment. For example, in the braking analysis for the number of bins prior to the crosswalk when drivers braked to a pedestrian in the roadway, drivers leaving a voicemail message appear to brake sooner with more experience with the driving environment (from Run 1 to Run 3, see Fig. 7). Although, the interaction between run and voicemail was not significant ($p = 0.12$), more runs in the environment may have revealed an effect of familiarity with the environment on reactions to pedestrians in the roadway. Future research should further examine the possibility of experience with the driving environment reducing the negative effects of talking while driving.

Drivers leaving a voicemail message did expect pedestrians in the probable crosswalk location and braked to these crosswalks even when the pedestrian was not present (Run 4) demonstrating the presence of this expectation. However, when a pedestrian was not present and not expected, drivers leaving a voicemail message were less likely to brake. This does not bode well for situations where drivers are leaving a voicemail message while driving and a pedestrian enters the roadway unexpectedly. It is important to note that the salient cues to predict a pedestrian were present (a crosswalk sign and crosswalk lines on the roadway), so the pedestrian is unexpected only in the sense that one has not entered the roadway in that location previously. This highlights a situation under which leaving a voicemail message while driving may be especially problematic. That is, leaving a voicemail message may be particularly detrimental in situations where more attentional resources need to be directed to the environment to monitor for critical driving targets (pedestrians) because previous knowledge about the driving location is unreliable.

5. Conclusion

The current study demonstrates that leaving a voicemail message while driving impacts driving performance. Drivers that were leaving a voicemail message drove faster and have more deviations in steering. Furthermore, drivers slowed and increased steering deviation at crosswalks with and without pedestrians. Interestingly, Drivers that were leaving a voicemail message had worse driving performance at crosswalks without pedestrians but were minimally affected at crosswalks with pedestrians. Although drivers that were leaving a voicemail message waited longer to initiate braking to pedestrians in crosswalks, they did not fail to brake and were able to decelerate to the same speed as silent drivers. Drivers that were leaving a voicemail message did build up expectations within the driving environment based on previous experience, but the effects of this driving behavior were minimal.

These findings can be used to (1) guide driving laws, specifically laws about talking on cell phones while driving, (2) improve training and education about the risks of talking while driving and (3) design of safety alerts on cell phones and vehicles. Education efforts (public service advertisements, sections added to driver education courses, remedial driving courses) that alert drivers to the increased risks of leaving a voicemail message while driving could be implemented. Furthermore, drivers could be made more aware that familiarity with a driving environment is not likely to significantly decrease the risk of leaving a voicemail message while driving.

6. Ethics approval and consent to participate

The current study was approved by the Louisiana State University Institutional Review Board (#E6049). All participants read and signed a consent form prior to participation in the study.

7. Consent for publication

Not Applicable.

8. Availability of data and materials

The datasets supporting the conclusions of this article are available on request.

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Authors' contributions

MRB contributed to the study design, data analysis, and writing the paper. RRG and KCM contributed to the study design, data collection and analysis and paper editing. ASC contributed to the study design, data analysis, and paper editing. BW contributed driving simulator access and programing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

A 3 × 4 × 2 × 2 mixed model ANOVA was conducted on *velocity*, *velocity change, and steering deviation change*. Roadway segment (Crosswalk 1, Crosswalk 2, no-crosswalk) and run (1, 2, 3, 4) were included as within-subject factors and probable pedestrian crosswalk (Crosswalk 1 probable, Crosswalk 2 probable) and voicemail (voicemail, no voicemail) were included as between subject factors (see supplemental information). Table 1 lists all main effects and interactions from the ANOVA. Main effects of roadway segments demonstrate that the crosswalks affected driving behavior. Participants drove slower, decelerated more and had greater steering deviation at the crosswalks. This demonstrates that, the crosswalks were critical driving targets that impacted driving behavior.

Main Effects of Roadway Segments: Velocity. Crosswalk 1 and Crosswalk 2 bins both had slower velocity than the no-crosswalk bin (M = 33.04 mph, SE = 0.32), $t(74) = 18.68$, $p < .001$ and $t(74) = 12.08$, $p < .001$, respectively. The velocity at Crosswalk 1 (M = 18.88 mph, SE = 0.86) was the same as at Crosswalk 2 (M = 19.56 mph, SE = 0.71), $t(74) = 0.71$, $p = .48$.

Main Effects of Roadway Segments: Change in Velocity. The change in velocity variable also revealed a main effect for roadway segment. The decrease in velocity as approaching Crosswalk 1 (M = 11.63, SE = 0.67) was greater than when approaching Crosswalk 2 (M = 9.41, SE = 0.63), $t(74) = 2.36$, $p = .021$. Crosswalk 1 and Crosswalk 2 both had a greater decrease in velocity than the no-crosswalk road segment (M = -0.30, SE = 0.133), $t(74) = 16.48$, $p < .001$ and $t(74) = 8.41$, $p < .001$, respectively.

Main Effects of Roadway Segments: Steering Deviation. Participants' steering deviation varied more at the crosswalks. There was also a main effect of roadway segment for the steering deviation variable. Participants increased the amount of steering deviation as they approached crosswalks. The amount of increase in steering deviation as approaching Crosswalk 1 (M = 2.08, SE = 0.27) and as approaching Crosswalk 2 (M = 1.59, SE = 0.34) did not differ ($t(74) = 1.4$, $p = .17$), but both had a greater increase in steering deviation than the no-crosswalk road segment, which had a slight decrease in steering deviation (M = -0.09, SE = 0.02), $t(74) = 7.99$, $p < .001$ and $t(74) = 4.9$, $p < .001$, respectively.

The effects of leaving a voicemail on driving behavior for the three dependent variables appear to not differ between crosswalk and no-crosswalk segments of the roadway. The interactions between road segment and voicemail were not significant for any of the dependent variables (see Table below). This suggests the effects of leaving a voicemail on driving behavior are similar for roadway sections with and without crosswalks.

3 × 4 × 3 × 2 mixed model ANOVAs	*Velocity*	*Change in Velocity*	*Change Steering*
segment	$F(1.83, 130.12) = 22.96$, $p < .001$, $\eta_p^2 = 0.24$.	$F(2, 142) = 258.11$, $p < .001$, $\eta_p^2 = 0.78$.	$F(2, 142) = 26.79$, $p < .001$, $\eta_p^2 = 0.27$.
run	$F(2.1, 149.05) < 1$, $p = .664$, $\eta_p^2 = 0.01$.	$F(2.54, 180.7) = 5.05$, $p = .004$, $\eta_p^2 = 0.066$.	$F(2.66, 189.04) = 1.95$, $p = .13$, $\eta_p^2 = 0.03$.
voicemail	$F(1, 71) = 17.81$, $p < .001$, $\eta_p^2 = 0.20$.	$F(1, 71) < 1$, $p = .848$, $\eta_p^2 = 0.001$.	$F(1, 71) < 1$, $p = .870$, $\eta_p^2 < 0.001$.
pedestrian	$F(1, 71) = 3.93$, $p = .051$, $\eta_p^2 = 0.052$.	$F(1, 71) < 1$, $p = .629$, $\eta_p^2 = 0.003$.	$F(1, 71) < 1$, $p = .715$, $\eta_p^2 = 0.002$.

(*continued on next page*)

3 × 4 × 3 × 2 mixed model ANOVAs	Velocity	Change in Velocity	Change Steering
run × voicemail	$F(2.1, 149.05) = 1.46$, $p = .235$, $\eta_p^2 = 0.02$.	$F(2.54, 180.7) < 1$, $p = .772$, $\eta_p^2 = 0.005$.	$F(2.66, 189.04) = 1.05$, $p = .368$, $\eta_p^2 = 0.01$.
run x pedestrian	$F(2.1, 149.05) = 50.16$, $p < .001$, $\eta_p^2 = 0.41$.	$F(2.54, 180.7) = 2.29$, $p = .90$, $\eta_p^2 = 0.03$.	$F(2.66, 189.04) = 1$, $p = .386$, $\eta_p^2 = 0.01$.
segment × voicemail	$F(1.83, 130.12) = 2.80$, $p = .069$, $\eta_p^2 = 0.04$.	$F(2, 142) < 1$, $p = .742$, $\eta_p^2 = 0.004$.	$F(2, 142) = 1.67$, $p = .192$, $\eta_p^2 = 0.02$.
segment × pedestrian	$F(1.83, 130.12) = 49.34$, $p < .001$, $\eta_p^2 = 0.41$.	$F(2, 142) = 69.68$, $p < .001$, $\eta_p^2 = 0.49$.	$F(2, 142) = 6.7$, $p = .002$, $\eta_p^2 = 0.09$.
segment x run	$F(3.48, 247.05) = 197.45$, $p < .001$, $\eta_p^2 = 0.74$.	$F(2.46, 174.63) = 1.84$, $p = .152$, $\eta_p^2 = 0.02$.	$F(3.25, 230.8) < 1$, $p = .505$, $\eta_p^2 = 0.01$.
voicemail x pedestrian	$F(1, 71) < 1$, $p = .875$, $\eta_p^2 < 0.001$.	$F(1, 71) < 1$, $p = .995$, $\eta_p^2 < 0.001$.	$F(1, 71) < 1$, $p = .596$, $\eta_p^2 = 0.004$.
run × voicemail × pedestrian	$F(2.01, 149.05) = 2.3$, $p = .101$, $\eta_p^2 = 0.03$.	$F(2.54, 180.7) = 1.36$, $p = .26$, $\eta_p^2 = 0.02$.	$F(2.66, 189.04) < 1$, $p = .392$, $\eta_p^2 = 0.01$.
segment × voicemail × pedestrian	$F(1.83, 130.12) = 3.03$, $p = .056$, $\eta_p^2 = 0.041$.	$F(2, 142) = 4.08$, $p = .019$, $\eta_p^2 = 0.05$.	$F(2, 142) = 1.81$, $p = .167$, $\eta_p^2 = 0.02$.
run × segment × voicemail	$F(3.48, 247.05) < 1$, $p = .605$, $\eta_p^2 = 0.01$.	$F(2.46, 174.63) < 1$, $p = .720$, $\eta_p^2 = 0.005$.	$F(3.25, 230.8) = 1.41$, $p = .238$, $\eta_p^2 = 0.02$.
run × segment × pedestrian	$F(3.48, 247.05) = 63.36$, $p < .001$, $\eta_p^2 = 0.47$.	$F(2.46, 174.63) = 66.61$, $p < .001$, $\eta_p^2 = 0.48$.	$F(3.25, 230.8) = 6.11$, $p < .001$, $\eta_p^2 = 0.08$.
run × segment × pedestrian × voicemail	$F(3.48, 247.05) = 4.99$, $p = .001$, $\eta_p^2 = 0.07$.	$F(2.46, 174.63) = 5.72$, $p = .002$, $\eta_p^2 = 0.07$.	$F(3.25, 230.8) = 1.08$, $p = .354$, $\eta_p^2 = 0.01$.

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