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The Effect of Distracted Driving on the Conspicuity of Pedestrians at Night

Ellen Campbell Szubski
Clemson University, ellen.szubski@outlook.com

THE EFFECT OF DISTRACTED DRIVING ON THE CONSPICUITY OF PEDESTRIANS AT NIGHT

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Ellen Campbell Szubski
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Dr. Richard Tyrrell, Committee Chair
Dr. Patrick Rosopa
Dr. Lee Gugerty

ABSTRACT

Between 2008 and 2018, pedestrian fatalities have increased 35 percent in the United States and nighttime fatalities are responsible for a substantial portion of this increase. There are two significant problems that limit drivers' ability to respond to pedestrians at night: the degradation of drivers' visual abilities due to low illumination and the low contrast of pedestrians against the background. Pedestrians can make themselves more visible to nighttime drivers by strategically placing retroreflective material on the major joints of the body to highlight their biological motion (biomotion). However, past research on pedestrian conspicuity has largely focused on drivers who are not distracted. Distracted driving is the one of most common causal factor of vehicle crashes and is increasing with advancements in technology. The purpose of this project was to assess the effect of driver distraction on the effectiveness of biomotion to enhance the conspicuity of pedestrians at night. Participants were driven along a predetermined route and asked to respond to all pedestrians they encountered. A test pedestrian was either walking or standing in place while wearing retroreflective biomotion markings. Approximately half of the participants were distracted by a secondary task that demanded cognitive, visual, and manual resources. Although highlighting the pedestrian's biomotion maximized conspicuity, there was no evidence that biomotion mitigated the detrimental effects of distraction. Important limitations with the study, including the possibility that the standing pedestrian was too inconspicuous to allow for a strong test of the hypothesis, are discussed.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

INTRODUCTION

Pedestrian fatalities have been dramatically increasing in recent years. Since 2008, there has been an alarming 35 percent increase in pedestrian fatalities resulting in an estimated 6,227 pedestrians killed nationwide in 2018 (Retting, 2019). Seventy-five percent of all pedestrian fatalities occurred in the low illumination conditions of nighttime in the United States in 2016, resulting in a one percent increase in nighttime pedestrian fatalities from the previous year (NHTSA, 2018; NHTSA, 2017). Even when controlling for driver fatigue and alcohol consumption, pedestrian fatalities increase when ambient illumination decreases (e.g., Owens & Sivak, 1996) suggesting that the degraded visual abilities of drivers and the low contrast of pedestrians are two significant problems that affect the conspicuity of pedestrians at night (Borzendowski, Sewall, Fekety, & Tyrrell, 2014). Numerous studies have examined the benefits of outfitting a pedestrian's extremities with retroreflective material to their conspicuity (See Tyrrell, Wood, Owens, Whetsel-Borzendowski, & Stafford-Sewall, 2016 for a review) however, to our knowledge, there is limited research exploring the robustness of the conspicuity benefits of biological motion to driver distraction. A study was conducted to determine the strength of highlighting biological motion in enhancing conspicuity among distracted drivers and its's robustness to driver distraction.

Pedestrians can wear visibility aids to increase their contrast and therefore their visibility, however, increasing a pedestrian's visibility doesn't necessarily enhance their conspicuity (see Tyrrell et al., 2016 for review). Visibility is defined as when is object is visible or distinguishable from the back ground (Langham & Moberly, 2003).

Conspicuity differs from visibility such that a conspicuous object is defined as one that 'grabs' the observer's attention with minimal visual search and is easily recognizable as that object (Langham & Moberly, 2003; Tyrrell et al., 2016). While typical visibility aids increase pedestrian's visibility via the use of retroreflective material, fluorescent material, or a combination of both, their effect on pedestrian conspicuity depends on how the material is configured on the pedestrian. For, example, retroreflective material is best utilized in low illumination conditions during which headlamps are used, while fluorescent material is best used in daylight conditions. In the context of nighttime driving, the light emitting from the vehicle's headlights are reflected from the retroreflective material back towards the vehicle driver. Because these materials capitalize on forward lighting from vehicles, and because the user need not carry a power source, retroreflective materials are an inexpensive and convenient means of enhancing contrast at night. The placement of the visibility aid on the body of the pedestrian is equally as important as the visibility aid used in increasing pedestrian conspicuity. Here, the concept of biological motion (or biomotion) is critical.

Johansson discovered in 1973 that humans are able to perceive other humans based on their patterns of movement (biological motion) even if the actor's major joints are the only available visual information (Johansson, 1973). Biological motion or "biomotion" is perceived in a specific and specialized area of the brain: the posterior superior-temporal sulcus (posterior STS) and is more dominate in the right hemisphere for most observers (Grossman et al., 2000; Grossman & Blake, 2001). Attention regulates the perception of biological motion in human-beings, particularly when the information is degraded by poor visual conditions or surrounded by visual clutter (Thompson & Parasuraman, 2012). Visually salient information captures the visual attention of humans, especially if the information is behaviorally relevant, as in with biological motion (Corbetta & Shulman, 2002). Downing, Bray, Rogers, and Childs (2004) conducted a study in which they examined how biological and mechanical stimulus captures the attention of participants as they are performing a visual primary task. Participants were tasked to view a black and white cross on a computer screen and judge if the vertical or horizontal line of the cross was longer. Then, a figure would appear in which the participants had to answer which of the four quadrants the figure appeared in and what the figure was. The figure was either an object or biological in nature. They found that participants were better able to recognize body of a human than an object suggesting that biological information captures the attention of the observer and that human biological information is prioritized for attentional selection (Downing et al., 2004). This idea was expanded upon in a study conducted by Shi, Weng, He, and Jiang (2010), in which they found that the biological motion of other upright human beings automatically captured the participant's visuospatial attention, whereas inanimate motion did not. This is observed in humans as young as ten hours old who have been shown to prefer biological motion point-light displays in comparison to random or chaotic point-light displays (Bardi, Regolin, & Simion, 2011; Simion, Regolin, & Bulf, 2007; Fox & McDaniel, 1982). The perception of biological motion is strongly moderated by selective attention especially if there are two or more objects in the visual field that are competing for attention (Safford, 2012). Responses to a stimulus displaying biological motion will be reduced if the attention is directed away from the stimulus (as in with distraction) (Safford, 2012). From point light displays that show the biological motion of an actor, humans are able to recognize themselves and friends (Cutting & Kozlowski, 1977). Humans are also able to identify the specific action the actor is performing such as walking or running and the sex of the actor (Johansson, 1973; Kozlowki, & Cutting, 1977). Performance of recognizing biological motion is robust across foveal and periphery vision (up to twelve degrees) if the stimulus is appropriately scaled for size in the periphery and in the absence of noise (Gibson, Sadr, Troje, & Nakayama, 2005; Ikeda et al., 2005; Thompson, Hansen, Hess, & Troje, 2007). Taken together, this past research suggest that humans are perceptually sensitive to the movement of other human beings, such that when a biological stimulus is moving, a human's visual attention will be automatically oriented to it above any other type of movement.

Given our perceptual sensitivity to biomotion, past research has examined the effects of highlighting pedestrian's biological motion with retroreflective material at night (See Tyrrell et al., 2016 for review). One of the first studies to examine this was conducted by Blomberg, Hale, and Preusser (1986). These researchers examined the effect various visibility aids designed to enhance the conspicuity of pedestrians at night. They found that pedestrians wearing retroreflective ankle, head, and belt bands were recognized at a distance of 133 meters (436 feet) before the driver overcame the pedestrian whereas pedestrians wearing non-reflective clothing were recognized at the closer and more dangerous distance of 32 meter (105 feet). They also found that pedestrians that were wearing retroreflective "dangle tags" or retroreflective disks attached near the waist of the pedestrian, were recognized at much shorter distances (44 meters/ 144 feet) than the pedestrians wearing the retroreflective ankle, head, and belt band (133 meters/436 feet) (Blomberg et al., 1986) highlighting the importance of specific body placement of retroreflective material. Participants reported seeing the dangle tags from greater distances but said that the stimulus was too ambiguous to identify the stimuli (Blomberg et al., 1986). With the correct placement of visibility aids such as retroreflective material, the object can become not only more visible but conspicuous. The more conspicuous an object is, the easier it is for the vehicle driver to estimate its location in space and predict future movements.

Owens, Antonoff, and Francis (1994) were the first to make the connection between pedestrian safety and highlighting biological motion. In their study, participants viewed a video which featured a jogger wearing various retroreflective markings from the driver of a vehicle's point of view (Owens et al., 1994). While watching the stimulus videos, participants were tasked to press a 'brake' pedal, simulated with a gaming pedal, upon recognizing that a jogger was present in the scene (Owens et al., 1994). They found that participants recognized the jogger in the biomotion retroreflective marking configuration significantly sooner than the jogger in without retroreflective markings (Owens et al., 1994).

Wood, Tyrrell, and Carberry (2005) conducted a closed road study in which they quantified the conspicuity of pedestrians at night. Twenty participants—half young and half older—drove a test vehicle multiple times around a closed road test route where they encountered pedestrians wearing one of four clothing conditions. The test pedestrians walking in place that were dressed in either all black, all white, retroreflective material located on the chest (vest configuration) or retroreflective material located on the wrists, elbows, shoulders, waist, knees, and ankles (biomotion configuration). The retroreflective material was kept at a constant surface area between the vest and the biomotion configurations. For half of the laps, participants drove with their high beams while they drove the other half with their low beams on. Collapsing across age, participants recognized the pedestrian the biomotion configuration at a mean distance of 148.2 meters (approximately 486 feet) in comparison to recognizing the pedestrian in the vest configuration at 43.4 meters (approximately 142 feet), the pedestrian in the white configuration at 40.3 meters (approximately 132 feet), and the pedestrian in the black configuration at just 5.6 meters (approximately18 feet). Wood et al., (2005) found that highlighting a pedestrian's biomotion is essential to enhancing pedestrian conspicuity, while increasing a pedestrian's contrast, as in the vest configuration, is not.

Similarly, but on an open road, Balk, Tyrrell, Brooks, & Carpenter (2008) conducted a study exploring the conspicuity of pedestrians at night. Participants were driven past a test pedestrian wearing either black clothing or 302 cm^2 of retroreflective markings situated on the chest, ankles, ankles and wrist (full biological motion) of the test pedestrian and either walked in place or stood still. The surface area of the retroreflective material was kept constant across all test conditions so that the sole effect of highlighting biological motion could be explored rather than the effect of surface area facing the test vehicle. Participants were tasked to respond when they recognized a pedestrian was present in the roadway. Balk et al., (2008) found that the response distance was overall, 2.9 times greater within each configuration when the pedestrian was walking in comparison to when standing still. Configurations in which the retroreflective material was located on the pedestrian's limbs (ankles, ankles and wrist, and full biomotion) and had the pedestrian walking in place, had significantly greater response distances than the walking black control and walking vest configurations (Balk et al., 2008). The full biomotion configuration had the greatest response distance, followed by the ankles and wrist configuration, then the ankle configuration, suggesting that highlighting biomotion, therefore offering more information about the pedestrian's movement is critical to enhancing pedestrian conspicuity rather than simply increasing the pedestrians contrast in the scene (Balk et al., 2008). Balk et al., (2008) found that highlighting the pedestrian's biological motion, especially when the retroreflective material is located toward the pedestrian's extremities, is more effective at increasing conspicuity than simply increasing the pedestrian's contrast or surface area of the retroreflective material.

Another study had similar findings. Wood et al., (2011) examined how biological motion can enhance the conspicuity of roadway workers at night. They had four roadway workers at two separate worksites—one suburban and one freeway—wearing four clothing configurations. Each of the four roadway workers walked in place and wore one of the following configurations: standard roadworker night vest, standard vest with additional retroreflective strips on thighs, standard vest with retroreflective strips on the ankles and knees or a standard vest with retroreflective strips located on eight moveable joints (full biomotion configuration) on the body (Wood et al., 2011). Participants rated the relative conspicuity of the road workers while located in a stationary vehicle from there different distances (Wood et al., 2011). Wood et al., (2011) found that across both sites, the clothing configuration which highlighted the full biomotion configuration was ranked as the most conspicuous road worker, closely followed by the ankle and knee configuration. The vest configuration was rated at being the least conspicuous configuration especially at the freeway site, while the thigh configuration was rated as marginally more conspicuous than the vest configuration across both sites (Wood et al., 2011). The findings from this study suggest that highlighting a pedestrian's extremities is maximally beneficial in increasing a pedestrian's conspicuity instead of just increasing their contrast.

Past research demonstrates that conspicuity benefit of highlighting biomotion is robust at increasing pedestrian conspicuity even with mild visual impairments such as cataracts, refractive blur, or among visual clutter (Wood, Chaparro, Carberry, & Chu, 2010; Tyrrell et al., 2009). Wood et al., (2010) had participants drive along a closed road route at night with wearing visual googles that simulated mild visual impairment such as refractive blur and cataracts. They found that despite the refractive blur and the simulated cataracts reducing the drivers' visual acuity to the same level, the simulated cataracts had a greater negative effect on participants' ability to recognize the pedestrian. When comparing the ability of the drivers to recognize the pedestrian in the control (test pedestrian wearing all black clothing) and biomotion configurations, participants in the cataract condition recognized the test pedestrian zero percent of the time in the control configuration, while they recognized the pedestrian eighty percent of the time in the biomotion configuration. For the participants that experienced no visual impairment, participants recognized the pedestrian in black clothing approximately thirty-five percent of the time and the pedestrian in the biomotion condition one hundred percent of the time (Wood et al., 2010). Tyrrell et al., (2009) examined the effect of biomotion among clutter. On a closed road, drivers were tasked with pressing a button as soon as they encountered one of two test pedestrians wearing various retroreflective clothing configurations (Tyrrell et al., 2009). Both test pedestrians wore clothing configurations in which there was either no retroreflective material present (control), or retroreflective material was located on the vest, ankle, or ankles and wrists of the test pedestrian. One of the test pedestrians was walking in place and was either surrounded by visual clutter or was not, while the other test pedestrian was always surrounded by visual clutter and was either standing or walking in place. They found that drivers were only able recognize that control pedestrian was present in the roadway twenty-one percent of the time, while they were able to recognize that the biomotion pedestrian was present in the roadway ninety-four percent of the time (Tyrrell et al., 2009).

The results of these past studies demonstrate that highlighting a pedestrian's biomotion is essential to increasing their conspicuity. However, these past studies have examined ways to increase pedestrian conspicuity in the ideal conditions of having a driver who is fully attending to the task. Distracted driving accounts for approximately twenty-five percent of all vehicle crashes reported by the police, making it one of the most commonly cited causal factors of vehicle collisions (Ranney, Mazzae, Garrott, & Goodman, 2000; Wang, Knipling, & Goodman, 1996). It is estimated that 55.5 percent of drivers who were involved in a crash as the result of distracted driving had the source of distraction come from inside of the vehicle such as phone, adjusting the radio, or interacting with a passenger (Wierwille & Tijerina, 1996). The use of distracting in-vehicle systems, such as GPS devices and cell phones, are increasing and adding to drivers' attentional demands (Regan, 2004).

There have been numerous studies conducted exploring the connection between a cognitive distraction and its effect on driving performance. Harbluk, Noy, Trbovich, and Eizenman (2007) examined the eye movements of drivers navigating an urban environment while engaging in a distraction task. In this task, participants were verbally presented with double digit mathematical equations that required carry-over and asked to mentally solve them. Participants drove along a planned route in city traffic while simultaneously completing this cognitive task of mental double-digit addition with carryover (thus demanding cognitive but not visual or manual resources). Harbluk et al., (2007) found that the drivers had significant changes in their visual search behavior in comparison to the participants who did not perform a secondary task. Their visual search behavior changed to spending more time looking directly ahead of the vehicle and less time scanning the periphery. Participants in the cognitive task made significantly fewer glances to traffic lights and their vehicle mirrors with some participants not even making any glances outside of the test vehicle at all (Harbluk et al., 2007). Thus Harbluk et al., (2007) found that this cognitive task is distracting enough to significantly change visual search behavior by concentrating eye movements to straight-ahead. Similar to Harbluk et al., (2007), Victor, Harbluk, and Engström, (2005) examined the link between driver distraction and performance but in the visual and auditory modalities. Victor et al., (2005) conducted a study in which participants drove along both open roadways and in a driving simulator while completing an auditory and visual task. For the visual task, participants were tasked, as they were driving, to find a target among distractors on a screen situated next to the driving wheel and to verbally indicate whether the target was present or absent. The visual task had three levels of difficulty ranging from a simple single-feature task to a conjunctive search. They found that as the visual task increased in difficulty (from simple single-feature search to conjunctive search), participants spent less time looking at the road in front of them and more time was spent looking at the visual display.

Liang and Lee (2009) demonstrated the detrimental effects of a distraction task in the visual and cognitive attentional channels. Liang and Lee (2009) measured drivers' ability to detect hazards by having participants driving a simulator while completing a visual, cognitive, or combination (visual and cognitive) distraction task. In the visual task, participants viewed a four by four matrix of arrows presented on a display and were tasked to match the orientation of the target to one of the four arrows in the matrix. In the cognitive task, participants listened to a recording of a person's path and tasked to identify which direction the person is facing at the end of the path. In the combination task, participants listened to similar recordings used in the cognitive task and then answered the orientation of the person on a touch-screen display. They found that participants in the visual and combined distraction condition both had significant impairments in their ability to detect hazards, with the greater impairment in the visual distraction task. While the cognitive task negatively affected steering, it surprisingly improved the participant's ability to maintain lane position. Participants in the visual and combination task condition also had longer and more frequent off-road glances. They also concluded that most of the negative effect on visual behavior while driving is from the visual aspect of the combination distraction task. The finding that the visual task is more detrimental to visual performance than the combination task is most likely due to the visual aspect of the task using more of the finite attentional resources than the cognitive distraction task when searching for a visual target. According to Wickens' (2002) Attentional Resource Model because the visual task of detecting hazards in the roadway and the cognitive distraction task occupies two different modalities, attentional resources can be effectively shared between them. However, when the distraction task occupies the same modality, therefore competing for the same attentional resources (when participants had to match arrows to a target while searching for hazards in the roadway) there is a decrease in the performance of both the primary and secondary visual tasks. Liang and Lee (2009) attribute the detrimental effects of the visual and combination distraction task on detecting a hazard in the roadway on both tasks occupying the same modality.

In a meta-analysis of distracted driving research, Atchley, Tran, and Salehinejad (2017) examined 342 distracted driving studies and the various auditory, cognitive, visual, manual, and combination distraction tasks used. They found that overwhelmingly these tasks produced significant negative effects on various aspects of driving performance. Cognitive distractions such as talking on a hands-free cell phone, solving riddles, mentally solving mathematical summations, or talking to a passenger, were found to degrade driving performance such as peripheral detection of targets. This is especially relevant to the current study, such that participants will most likely have their attention captured by the test pedestrian in the periphery, and then orient their attention to the test pedestrian. If the participant's ability to detect a pedestrian in the periphery is degraded, they will be more likely to have a shorter response distance to the test participant. Though cognitive distractions are detrimental to performance, combination tasks which distract the participant cognitively, visually, and manually, such as text messaging, are particularly detrimental to performance (Atchley et al., 2017). Klauer et al., (2006) conducted a naturalistic study in which 100 cars were outfitted with sensors to capture the driver's state during vehicle crashes, near-crashes, and incidents. They found that drivers displaying inattention due to participating in a visual, manual, or combination task were three times more likely to experience a near-crash or crash than attentive drivers (Klauer et al., 2006). The driver's chances of being in a crash increases if an unanticipated event, such as a pedestrian walking into the roadway, occurs at the same time as the distracted driving event (i.e., talking on a phone, eating, or adjusting the radio) the driver's chances of participating in a crash increases (Ranney et al., 2000; Klauer et al., 2006).

A large part of the past distracted driving research examined the impacts of using a cell phone while driving and has confirmed that phone-related distraction is harmful to driving performance (See McCartt, Hellinga & Bratiman, 2006 for review). Using a phone while driving increases the driver's chance of being in a collision four-fold (Redelmeier & Tibshirani, 1997). Numerous studies found that both hands-free and hand-held phones are detrimental to driving performance and safety (See McCartt et al., 2006 for review). Caird, Johnston, Willness, Asbridge, and Steel (2014) conducted a meta-analysis of the vast amount of literature examining the effect of text messaging has on driver performance. They examined twenty-eight studies and found that texting adversely affects multiple measures of driving performance including making longer and more frequent glances away from the road, missing more targets, reacting more slowly to hazards, having more crashes, and having a harder time staying within the driving lane (Caird et al., 2014). In this meta-analysis, Caird et al. (2014) found the largest decrements in behavior resulted from eye movements during typing and reading a message. Text messaging while driving is both a visual, cognitive, and manual distraction task resulting in less time spent looking at the road and less control of the vehicle. If a vehicle is driving at 64.4 kilometers per hour (forty miles per hour) and the driver takes five seconds to read and send a text message, the vehicle has traveled approximately 89.6 meters (98 yards) without the driver attending to the road or hazards outside of the vehicle.

The purpose of the current study is to determine how a distracting secondary task that combines visual, manual, and cognitive demands affects participants' ability to respond to the presence of a pedestrian at night and to determine whether the presence of biomotion makes pedestrians somewhat robust to participant distraction at night. There are two independent variables in this study—distraction group and biomotion presence. Each independent variable had two levels which created four unique groups—attentive/standing, attentive/walking, distracted/standing, and distracted/walking. The distance at which the participant responded to a test pedestrian was measured for each of the groups, with longer response distances representing better pedestrian recognition performance. I hypothesized that participants would have the longer mean response distance when the pedestrian was walking than when he was standing still. Overall, I hypothesized that attentive participants would have longer response distances than distracted participants. I hypothesized an interaction between the level of distraction and pedestrian motion such that biomotion would be robust to distraction, meaning that distracted participants viewing the walking pedestrian would have a smaller response distance in comparison to attentive participants, however, the difference in response distances between the attentive and distracted participants would be more pronounced for the participants viewing the standing pedestrian (no biomotion) than the walking pedestrian(biomotion).

As found in past research, where a distraction task that involves the manual, visual, and cognitive components decreases driving performance, I predicted that participants who provide a higher percentage of correct responses on the distraction task would respond to the pedestrian from shorter distances than those participants who provided fewer correct responses on the distraction task (Atchley et al., 2017; Liang and Lee, 2009). I hypothesized that a measure of the workload associated with the secondary (math) task would be positively correlated with the percentage of correct responses on the math task. I also predicted that the workload scores will be negatively correlated with response distance.

METHOD

Design

There are two independent variables: distraction group and pedestrian motion. Each has two levels. Participants were sorted into one of two distraction groups: attentive or distracted, with the constraint of maintaining relatively equal sample sizes in each group. Participants were driven along an open road route at night where they encountered a test pedestrian who was either walking in place or standing still. In all trials, the test pedestrian was outfitted in all black clothing with retroreflective (Scotchlite beaded fabric) markings on the major joints of the body (wrists, elbows, shoulders, hip, knees, and ankles; see Figure 1). The total surface area of retroreflective material that faced oncoming traffic was 228.6 cm^2 and held constant across conditions. This configuration of retroreflective material was chosen as it maximally capitalizes on the pedestrian's biomotion and has been repeatedly found to be an effective configuration resulting in long response distances when the pedestrian is walking in place (e.g., Owens et al., 1994; Balk et al., 2008; Wood, et al., 2011; Wood et al., 2005). The standing pedestrian, outfitted in the same retroreflective configuration as the walking group, stood still and served as a control in which biomotion was absent. The primary dependent variable was response distance – the distance at which the participant responded to the pedestrian by pressing a button on a hard keypad.

Each night of data collection was randomly assigned to test one of the four groups: distracted participant searching for a walking pedestrian, distracted participant searching for a standing pedestrian, attentive participant searching for a walking pedestrian, and attentive participant searching for a standing pedestrian, with the constraint that each of the four groups contained approximately equal sample sizes.

Figure 1. Retroreflective strips were placed on the test pedestrian's major joints. In the biomotion configuration, the pedestrians walked in place, while the pedestrian stood still in the standing condition. In all conditions the pedestrian was positioned on a sidewalk immediately to the right of the test vehicle's lane of travel, facing the oncoming test vehicle.

Participants were unaware of the conditions being tested during the night they participated.

Measures

Four demographic and visual performance items were measured in addition to response distance (see Appendix A). These items included participant's age, gender, visual acuity (measured by the Bailey-Lovie acuity chart; see Appendix B), and contrast sensitivity (measured by the Pelli-Robson Contrast Sensitivity chart; see Appendix C).

The participant's response to the test pedestrian was measured with a key press at the moment that they "first become reasonably confident that a pedestrian is present." The button press triggered a measurement of the time interval that separated the participant's button press from the moment the front of the test vehicle reached the pedestrian. The distance that separated the vehicle from the pedestrian at the moment the participant pressed the button was calculated by multiplying the response interval by speed of the test vehicle (40 miles per hour; 17.9 m/s).

After each participant passed the test pedestrian, participants quantified their workload by completing the NASA-TLX by using their smartphone to access an online survey (see Appendix D). The NASA-TLX is the most-cited survey in current published studies for measuring workload, has been translated into dozens of languages, and has been used in various workload tasks such as driving a car and completing a visual search task (e.g., Hart, 2006; Grier, 2015). When completing the NASA-TLX, participants rate their subjective workload from 1 to 100 on six separate subscales (Mental, Physical, Temporal Demands, Frustration, Effort, and Performance) (Grier, 2015). Then participants answer fifteen paired comparisons of all possible combinations of the six subscales in which they choose which subscale weighs more heavily on their subject workload of the task (Grier, 2015). With the participant's weights, a global score workload score is calculated (Grier, 2015). Hart and Staveland (1988) compared the NASA-TLX against other survey-based workload measures such as the Subjective Workload Assessment Technique (SWAT) and Overall Workload survey (OW) and found that the NASA-TLX is highly correlated with SWAT and OW in accurately measuring workload, and it was found to be more sensitive. These finding have been confirmed by other researchers, and the NASA-TLX is shown to be widely validated (Hill et al., 1992; Byers, Bittner, Hill, Zaklad, & Christ, 1988). Other methods of analyzing the NASA-TLX such as the Raw NASA-TLX can be used to measure workload. The raw NASA-TLX (RTLX) or unweighted score differs from the original weighted workload score (WWL) in that the six subscales are averaged without consideration to the participant's subscale weights (Hart, 2006). Noyes & Bruneau (2007) compared the computer version of the NASA-TLX to a paper version of the survey. They also compared the WWL and the RTLX ways of analyzing the survey. They found that though the computer version had significant differences in workload in comparison to the paper version, both the computer and paper version of the RTLX ratings of workload were highly correlated to the WWL ratings of workload (Noyes & Bruneau, 2007). Other studies have also found a high correlation between the weighted and unweighted scoring of the NASA-TLX (Moroney, Biers, & Eggemeier, 1995; Moroney, Bier, Eggemeier, & Mitchell, 1992). The RTLX was used in the current study because it is faster to complete, easier to score, and highly correlated to the weighted version of the NASA-TLX (See Appendix D).

Procedure

The participants were greeted in the lab, heard an explanation of the procedures, and read and signed an informed consent. Participants also completed visual screening and a double-digit addition ability assessment while in the lab. In this addition assessment, participants were asked to solve a series of double-digit mental addition problems presented on their personal cell phone through a Qualtrics survey. Each of these mental addition problems were sufficiently complex to require the carrying-over of digits (e.g. 36 + 27; see Harbluk et al., 2007). ("Carry-over" here refers to the fact that the sum of at least one column – either the two most right digits or the two most left digits – is at least 10 and thus requires the carrying over of a digit to the next adjacent left column). Participants completed this assessment while performing no other task.

Once the participant demonstrated normal visual acuity and contrast sensitivity, they were walked to the test vehicle and driven around a pre-determined open road route (see Figure 2). Up to two participants could be tested during a session as participants sat in either the front passenger seat or – if a second participant was present – the driver's side of the back seat of the vehicle. The participant in the back seat was instructed to adjust their body position so that they had a maximal view of the vehicle front windshield. This method has been successfully used in past studies (Fekety, Edewaard, Stafford-Sewall, & Tyrrell, 2016; Fekety, Edewaard, Szubski, Tyrrell, & Moore, 2017; Edewaard, 2017).

Before the drive began, the participants were read the following instructions: “We are going on a 10-15 minute drive around and near campus. Your task is to look for pedestrians in or near the roadway. A pedestrian is defined as any person in or near the roadway. Please press this button on the keypad as soon as you are reasonably confident that you are looking at a pedestrian. You don’t have to be 100 percent confident, but we do want you to be mostly confident you are looking at a pedestrian. I will tell you when to begin.” Participants in the distracted group were also read the following instructions: “Please use your phone to scan this QR code. The QR code will take you to an online survey in which you will be asked to solve a series of mathematical problems while also looking for a pedestrian in or near the roadway. Solve these problems, in your head, as quickly and as accurately as possible and type your answer on your cellphone. The hand that you use to hold your phone should rest against your lap for the duration of the experiment.” Additionally, participants in the distracted group were told to prioritize the task of looking for a pedestrian over the addition task, as missing a pedestrian has more dire real-life consequences. After instructions, participants were driven along a predetermined route (see Figure 2) through and near Clemson University campus, where they encountered a test pedestrian (an experimenter) along a straight flat roadway (speed limit of 40 mph or 64.4 km/hr) roughly 620 meters (34.0 sec) after completing a sharp right curve. The pedestrian was positioned on the sidewalk to the right of the test vehicle’s travel lane and was either walking or standing in place while facing the approaching test vehicle such that the pedestrian’s right shoulder was nearest the road. After the test vehicle and participant passed the pedestrian, the experimenter explained

Figure 2. Experimental driving route near and around Clemson University. "S" indicated the starting and end point. The pedestrian sign indicated where the participant encountered the test pedestrian.

that the participant(s) could stop looking for pedestrians and performing the addition task (if applicable). The participant(s) then answered a series of verbal questions such as "What did you see?" and "What about the pedestrian attracted your attention?" (see Appendix E). Additionally, participants were asked to specify the make and model of their smartphone and how long they had been using their phone. In a free response question, the participant was also asked if they are using a keyboard other than the standard keyboard issued for their model of cell phone, and if so, to specify the keyboard model. Then, while still in the test vehicle, the participant completed the raw NASA-TLX as described earlier. Once this was completed, participants were driven back to the starting point and then released.

In the distraction group, participants were tasked to search for pedestrians while simultaneously solving a series of double-digit mental addition problems (see Appendix F). The double-digit mathematical problems were identical in presentation but varied in specific problems, such as participants were asked to solve different addition problems between the practice task taken in the lab and the distraction task taken in the test vehicle (See Appendix G for specific questions asked in the lab and in the vehicle). The difference between the distraction task taken in the lab and the distraction task taken in-vehicle was that for the in-vehicle distraction task, participants solved the addition problems while also searching for a pedestrian, while the addition assessment taken in the lab was the only task participants were required to do.

Participants accessed the survey by scanning a QR code. The participant was instructed to hold their phone to rest comfortably in their lap for the duration of the experiment. This was enforced by the experimenter. The participant had to mentally solve the problems and type in an answer using their phone's keyboard. Once the participant entered an answer, they saw one of two screens — one that indicated the participant correctly solved the mathematical problem or one that notified the participant of an incorrect response. Each mathematical problem was presented for a maximum of 15 seconds and each feedback screen was presented for 1 second. If the participant failed to respond within the 15 seconds that the problem was presented, the participant's response was treated as being incorrect and the next problem was presented. Performance on the secondary task of mathematical summation was measured by the percent of math problems correctly solved. Through using a task that combines methods from Harbluk et al., (2007), Victor et al., (2005), Liang and Lee (2009), and Atchley et al., (2017), participants were distracted by a task that required them to make frequent glances at the cellphone in their lap, therefore further decreasing the overall amount of time spent searching for pedestrians. Though Liang & Lee (2009) found that the visual distraction task was more detrimental to performance than a combination task of both a visual and cognitive distraction, I used a combination task that also includes a manual component to simulate the more realistic and likely distraction that drivers face today when they interact with their phones. To ensure that the mathematical summation task with a manual component is an effective distraction task, participants rated their workload of this task using the NASA-TLX shortly after the test vehicle passes the test pedestrian. Participants in the attentive group did not experience the secondary task. There was no extraneous talking in the test vehicle to limit confounding variables in both the attentive and distracted groups

RESULTS

A power analysis was conducted before data collection started resulting in the need of 128 participants (four groups total with approximately 32 participants per group) to obtain a power of .80 with a medium effect size of .25 (calculated using G*Power; Faul, Erdfelder, Lang, & Buchner, 2007). 174 undergraduate students participated in this study and received research credits in their psychology class in exchange for their participation. Nine participants never made it to the test vehicle because they either failed to meet visual requirements (N = 6) or weather issues appeared (N = 2) or the participant did not have a smartphone (N = 1). All remaining participants met the vision requirement of 20/40 or better binocular visual acuity (Bailey-Lovie acuity chart) and a log contrast sensitivity score of 1.65 or better (Pelli-Robson Letter Sensitivity chart) while using their presenting optical correction. Data from an additional 25 participants were excluded due to issues that arose during the driving portion of the study, including extraneous vehicles obstructing the view of the test pedestrian (N=4), extraneous pedestrians being present (N=5), failure to follow instructions (N=4), previous knowledge of the location of our pedestrian (N=1),or issues such as the surveys not working, or a missed signal to the test pedestrian (N=11). Lastly, two participants were excluded due to being more than three standard deviations from the mean response distance. The final data set was analyzed using the 138 participants (M= 19.3 years, SD=1.3 years; 85 female and 53 male), surpassing the minimum number of participants needed for adequate power. Of the participants who viewed the standing pedestrian, 34 were in the attentive group and 35 were in the distracted group. Of the participants who viewed the walking pedestrian, 34 were in the attentive group and 35 were in the distracted group (See Table 1).

Table 1: Number of participants in each group

	Attentive	Distracted	Total
Standing	34	35	69
Walking	34	35	69
Total	70	70	138

A manipulation check tested the effectiveness of the distraction math task. For this check, performance was calculated as the rate of double-digit math problems attempted per minute. Each problem for each participant was coded as an attempt if they clicked on the page on which the problem was presented. A paired samples t-test was conducted and found to be significant, t (69) = 9.91, $p < .001$, suggesting that there is a significant difference between performance on the math task in the lab (mean = 8.73 problems attempted / minute) and the performance in the vehicle (mean = 6.78 problems attempted/ minute) suggesting that participants attempted significantly fewer problems when in the test vehicle (and searching for the test pedestrian) than when in the laboratory (with no other secondary task; see Figure 3). Participants also had a higher accuracy on the addition task when in the laboratory (mean = 86.0% correct) than when in the vehicle (mean = 80.0% correct), $t(69) = 3.09$, $p = .003$, confirming that participants performed the addition task less accurately when they were simultaneously searching for pedestrians (see Figure 4). There was also a significant difference between their number of correct problems per minute while in the lab (M = 7.83 correct problems per minute) than in the car (M=5.52 correct problems per minute), $t(69) = -8.703$, $p <.001$, suggesting that participants were less accurate and moved slower when simultaneously looking for pedestrians than in the lab with no other secondary task.

In order to assess the speed-accuracy tradeoff in the participants' math data, correlations were calculated between the problems attempted per minute (speed) and the accuracy on the distraction task for the in-lab and in-vehicle task. A Pearson's product moment correlation revealed a significant positive relationship between participants speed and accuracy while completing the distraction task in the lab, r=.56, N=70, p<.001, R^2=.32 (See Figure 5). Participants that attempted more problems per minute also tended to have higher accuracy on the distraction task in the lab. A similar relationship was found for the in-vehicle distraction task. Participants that attempted more problems per minute tended to have higher accuracy on the distraction task in the vehicle (while also searching for pedestrians), r=.40, N=70, p=.001, R^2=.16. In the lab, 57% of the variance in speed was accounted for by accuracy, whereas in the vehicle, only 16% of the variance in speed was accounted for by accuracy. The positive relationship between speed and accuracy for both the in-lab and the in-vehicle math task suggest that participants did not have a significant trade-off between speed and accuracy while in either the lab or the vehicle.

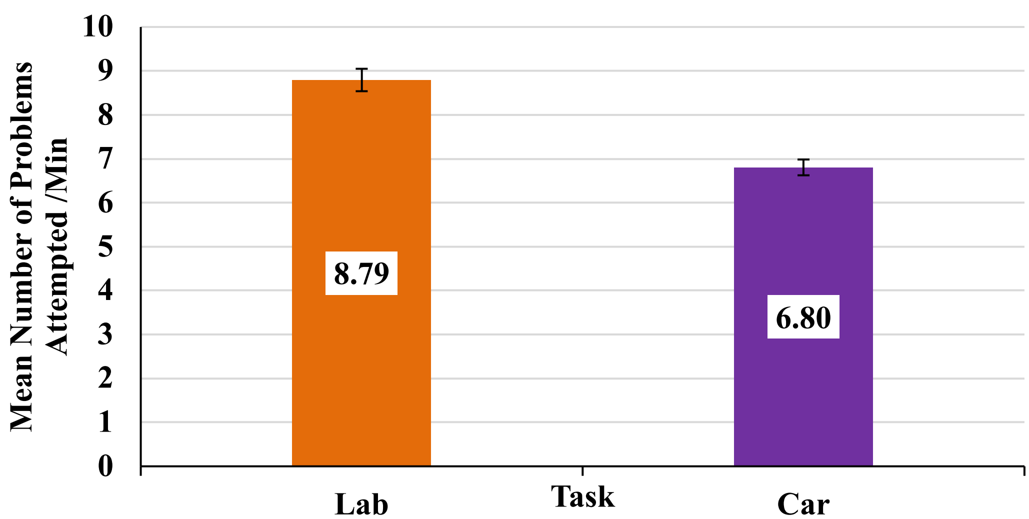


Figure 3. Mean number of problems attempted per minute for the distracted participants in the lab (no other secondary task) and the distracted participants in the car (while also searching for pedestrians). Error bars represent +/-1 standard error of the mean.

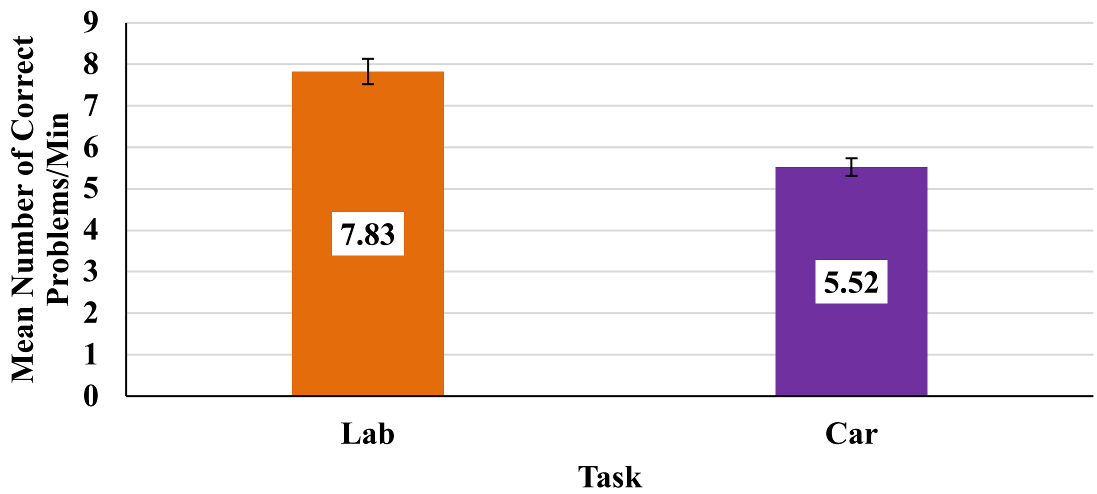


Figure 4. Mean proportion of correctly solved problems for the lab math task and the car math task. Error bars represent +/-1 standard error of the mean problems.

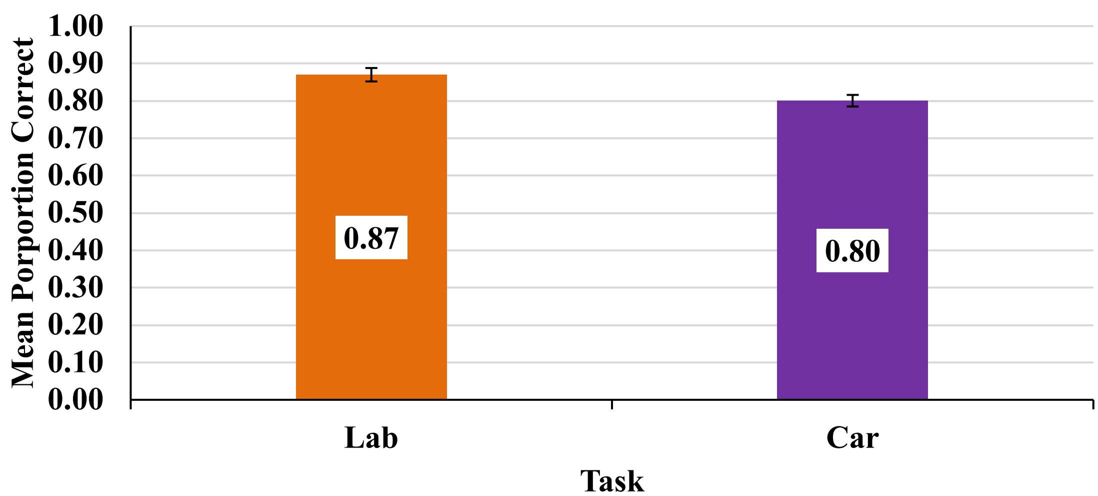


Figure 5. Mean number of correctly solved math problems per min (+/-1 standard error of the mean) for the distracted participants in the lab (no other secondary task) and in the car (while also searching for pedestrians).

Correlations between workload, response distance, and performance on the addition task were also calculated to ascertain the effectiveness of the addition task as a distraction task. All assumptions of a Pearson's correlation were satisfied, with the exception that the response distances were positively skewed. (Normality issues with the response distance data are explored in depth later). Data transformations were explored but none met the assumption of normality to test for the association between two continuous variables Beversdorf and Sa (2011) recommend using Spearman's rank-order correlation when dealing with non-normal data with larger samples. Accordingly, Spearman's rank-order correlation assessed the relationship between workload and response distance. No significant relationship was found between these variables, r_s (136) = -.066, p = .44. When including data only from the participants in the distracted group, the relationship between percentage of correct responses on the distraction task and response distance was explored using a Spearman's rank-order correlation. There was no significant relationship between these variables, r_s (68) = -.103, p= .40. There was also not a significant relationship between workload and the percent of correct responses on the math task, r_s (68) = -.227, p= .06. There was also a non-significant relationship between response distance and the number of correctly answered problems per minute, r_s (68) = -.196, p= .10.

The primary dependent measure was the response distance that was measured once from each participant. As mentioned previously, the response distance data exhibited positive skewness such that there is a high frequency cluster of short response distances and a long, low frequency tail of longer response distances. The positive skewness to the response distance data were a result of 42 (30.4%) participants having a response distance of 0.0 meters as a result of either not pressing their response button or pressing it after the test vehicle had passed the test pedestrian (see Figures 6 and 7). When examined by group, 50.0 percent of attentive participants missed the presence of a pedestrian standing in place, 5.9 percent of attentive participants missed the pedestrian walking in place, 25.7 percent of distracted participant missed the pedestrian walking in place, and 68.6 percent of distracted participants missed the pedestrian standing still.

Confronted with the strong positive skewness, multiple transformations were tried, including logarithm, cube root, natural log, square root, reciprocal, and weighted least squares transformations (both with adding small constants and without adding small constants). Even after multiple transformations were explored, the distribution of these response distances still did not meet normality assumptions.

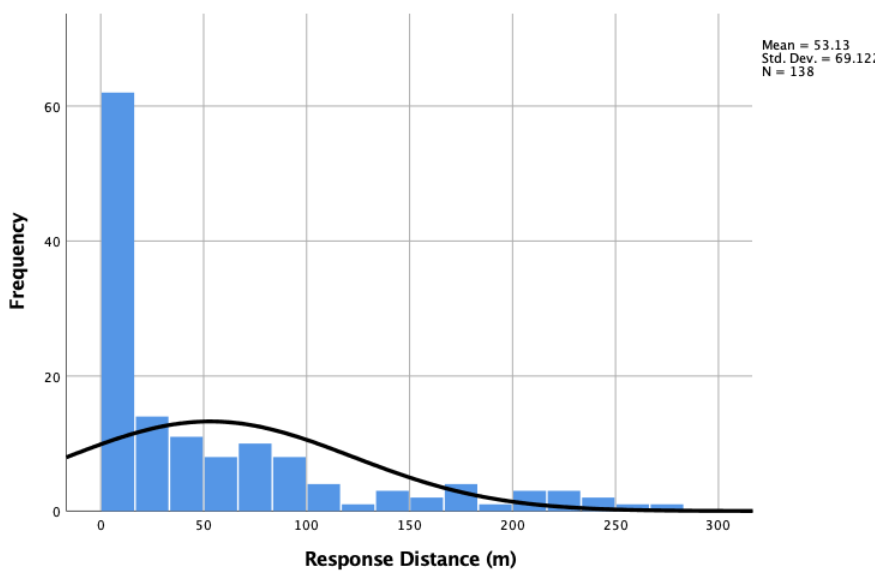


Figure 6. Distribution of response distances (meters) from the full sample of 138 participants.

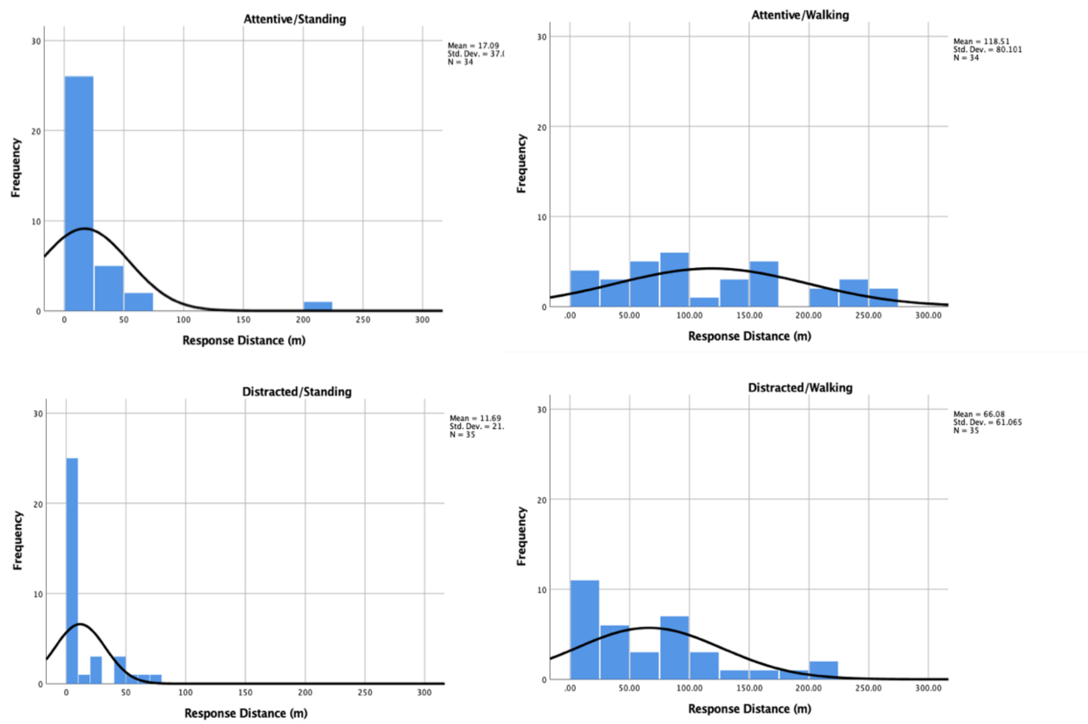


Figure 7. Distribution of response distances (meters) within each of the four groups.

In order to meet the normality assumption of an analysis of covariance (ANCOVA), a generalized linear model with the assumption of an underlying gamma distribution was used to model the data instead of the traditional general linear model which assumes an underlying normal distribution. This method is frequently used in positive continuous data with a severe positive skew, such as reaction times and insurance claims (Fu and Moncher, 2004; McGill, 1963). Because the gamma distribution requires all data to be greater than zero, a small constant of 0.05 m was added to each response distance. The overall model with the predictors of biomotion (2 levels) and distraction (2 levels) and the covariate of seat position was found to be significant indicating that the model is significantly better than the intercept-only model, χ^2 (4) = 37.39, $p < .001$, φ=.52. There was a main effect of biomotion, χ^2 (1) = 14.19, $p < .001$, φ=.32, indicating that, when averaged across the two distraction groups, participants responded to the test pedestrian from a mean distance that was significantly longer when the test pedestrian walked in place (91.9 m) than when the pedestrian stood still (14.4 m). There was not a significant main effect of distraction on response distances, indicating that, when averaged across standing and walking, participants who were distracted did not have a significantly different mean response distance (38.9 m) than the participants who were in the attentive group, (67.8 m), χ^2 (1) = 1.97, $p = .16$, φ=.12. Lastly, there was not a significant interaction between distraction and biomotion, χ^2 (1) = 1.08, $p = .30$, φ = .09(See Figure 8 for the untransformed response distances).

There was a significant effect of the covariate of seat position, χ^2 (1) = 6.28, $p < .01$, φ=.21. This significant effect is a surprising finding because it contradicts the lack of a significant effect of seat position in studies that used similar methods (e.g., Fekety, Edewaard, Stafford-Sewall, & Tyrrell, 2016; Fekety, Edewaard, Szubski, Tyrrell, & Moore, 2017; Edewaard, 2017, Balk et al, 2008). The study was specifically designed to position participants in both the front seat and in the back in order to maximize the sample size while minimizing the number of driving trials. To maintain consistency, participants seated in the back were instructed to lean towards the middle of the vehicle in such a way that their view of the front windshield was maximized. It is possible that the participants seated in the back did not fully comply with the instructions over the

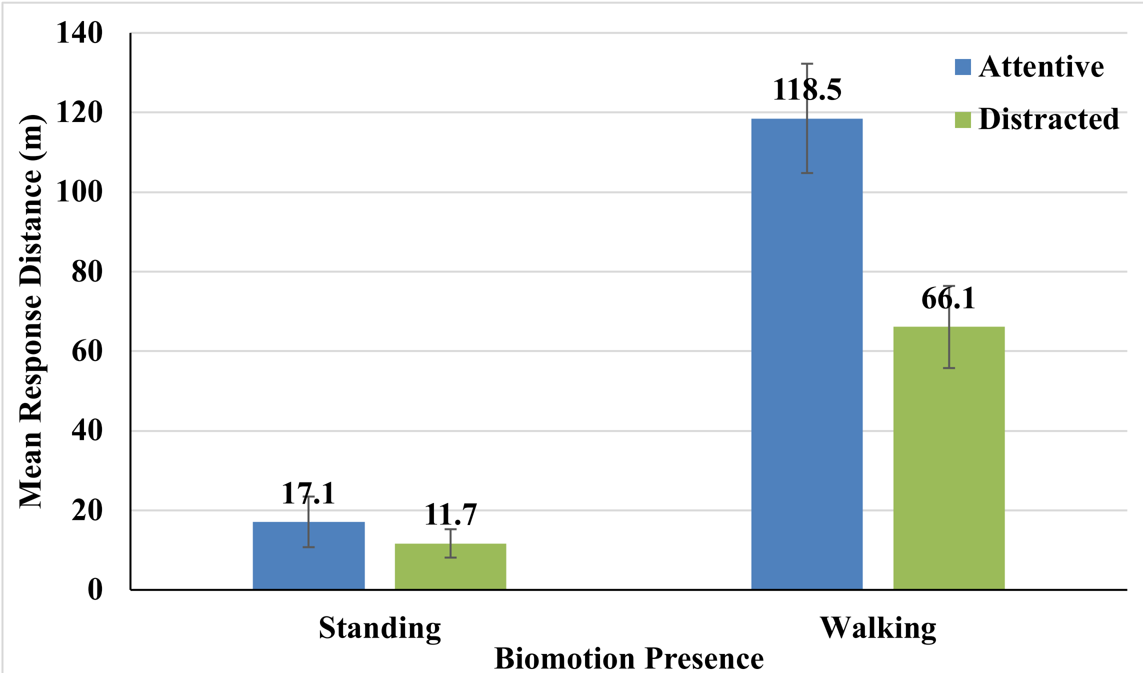


Figure 8. Mean (+/-1 standard error of the mean) response distance as a function of the four groups.

duration of the drive, thus limiting their ability to respond to the test pedestrian. The front seat participants responded from a mean response distance of 54.9 m (SD = 68.0 m), while the back-seat participants responded from a mean of 44.8 meters (SD = 69.1 m). Because seat position was treated as a covariate it did not distort the results of the ANCOVA. To ensure the lack of distortion, a separate ANOVA was used to test the effect of biomotion and distraction on the participants' response distances who were seated in the front of the vehicle and similar results were found to the model that included both front and back seated participants. The overall model with the predictors of biomotion (2 levels) and distraction (2 levels) of only the participants that were seated in the front of the test vehicle was found to be significant indicating that the model is significantly better than the intercept-only model, χ^2 (3) = 23.04, p < .001, φ=.41. Like before, there was a main effect of biomotion, χ^2 (1) = 9.68, p =.002, φ=.26, indicating that participants responded to the test pedestrian from a mean distance that was significantly longer when the test pedestrian walked in place (97.3 m) than when the pedestrian stood still (17.1 m). There was not a significant main effect of distraction on response distances, χ^2 (1) = 1.82, *p* = .18, φ=.11, or a signification interaction of distraction and biomotion, χ^2 (1) = 1.37, *p* = .24, φ=.10. Participants who were distracted did not have a significantly different mean response distance (39.8 m) than the participants who were in the attentive group (74.6m).

Because 42 participants (30.4% of 138 participants) failed to respond to the presence of a pedestrian, especially those in the distracted / standing group (68.6% of the 35 distracted participants who viewed the standing pedestrian), a secondary analysis was conducted in which the response distances were converted to a binary variable. Thus "response type" was coded as either 0 for misses (when response distance = 0.0 m) or correct detections (when response distance was > 0.0 m). Participants who failed to respond to the pedestrian generally indicated (in the post-task interview) that they either didn't respond to the test pedestrian (i.e. they reported that they never saw the pedestrian) or they responded *after* the test vehicle had passed the location of the test pedestrian.

A three-way loglinear analysis tested the relationship between biomotion presence, distraction group, and response type. This three-way loglinear analysis produced a final model that retained all effects except the three-way interaction (biomotion presence * distraction group * response type). The three-way interaction was not significant, $\chi^2\,(1) = 1.00$, $p = .33$, $\varphi = .09$. However, the next highest order interaction (the two-way interactions) were found to have a significant effect, $\chi^2\,(3) = 36.02$, $p < .001$, $\varphi = .51$ (See Figure 9). Separate chi-squared tests were performed, determining that interaction between response type and distraction group was significant, $\chi^2\,(1) = 5.67$, $p = .02$, $\varphi = .20$, indicating that participants were significantly more likely to miss the pedestrian if distracted than when attentive. The interaction between response type and biomotion presence was also significant, $\chi^2\,(1) = 29.11$, $p < .001$, $\varphi = .46$, suggesting that participants were more likely to have a correct detection to the walking pedestrian than

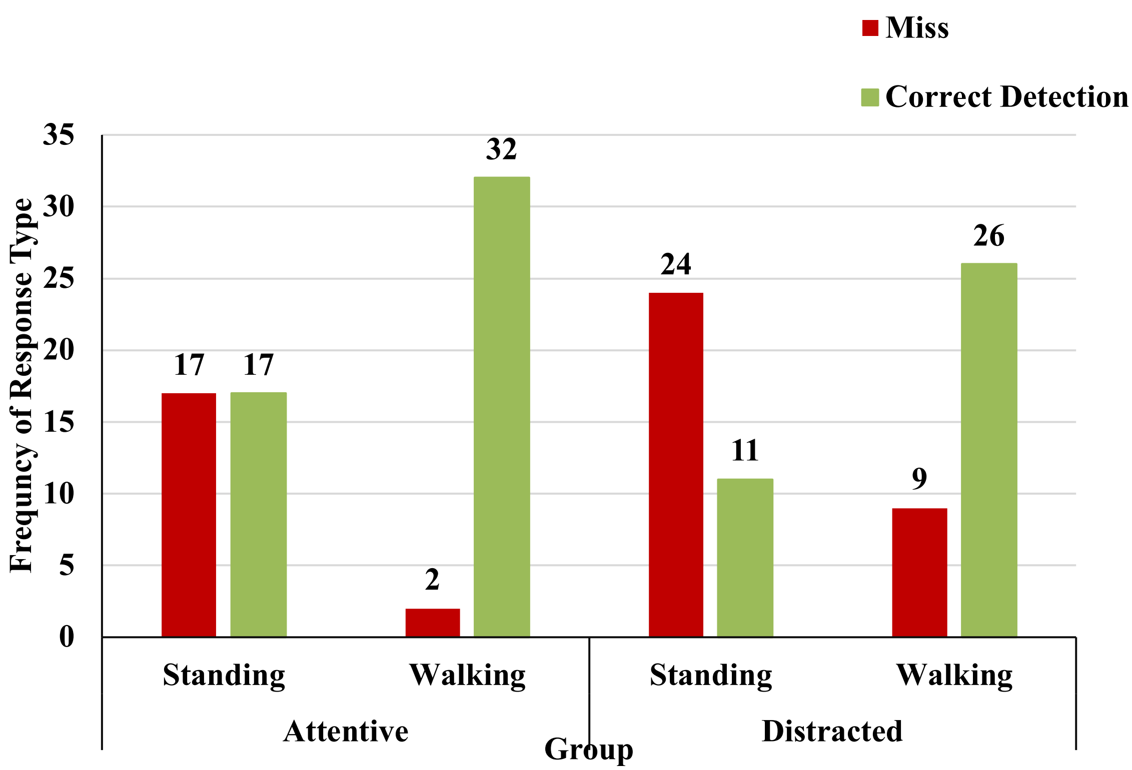


Figure 9. Frequency of the Response Type between each of the four groups. “Miss” refers to any response distance of 0 m, while “correct detection” refers to a response distance that is greater than 0 m.

the standing still pedestrian. The two-way interaction between biomotion and distraction was not found to be significant, $\chi^2(1) = 1.44$, $p = .23$, $\varphi=.10$

Odds ratios indicate that attentive participants were 1.88 times more likely to have a correct detection to the pedestrian that is walking in place than standing still and were 8.5 times more likely to miss the standing pedestrian than the walking pedestrian. Distracted participants were 2.36 times more likely to correctly detect the presence of the walking pedestrian than the pedestrian standing still, and 2.67 times more likely to miss the pedestrian standing still than the walking pedestrian. This analysis reveals that participants are more likely to have a correct detection to the pedestrian that is walking in place rather than the pedestrian standing in place, indicating an effect of biomotion. It also shows that participants were more likely have a correct response to the pedestrian when attentive than when distracted. Odds ratios for the standing pedestrian indicate, participants were 1.4 times more likely to miss the pedestrian if distracted and were 1.55 more times likely to have a correct response to the pedestrian if attentive. For the walking pedestrian, participants were 1.23 times more likely to have a correct response to the pedestrian if attentive and 4.5 times more likely to have a miss response if distracted (See Table 2).

Table 2: Contingency Table between Distraction Level and Response Type and Biomotion Presence

Biomotion Presence				Response Type: Miss	Response Type: Correct Detection	Total
Standing	Distraction Group	Attentive	Count	17	17	34
			% within Distraction Level	50.0%	50.0%	100.0%
			% within Response Type	32.7%	19.8%	24.6%
			% of Total	12.3%	12.3%	24.6%
		Distracted	Count	24	11	35
			% within Distraction Level	68.6%	31.4%	100.0%
			% within Response Type	46.2%	12.8%	25.4%
			% of Total	17.4%	8.0%	25.4%
Walking	Distraction Group	Attentive	Count	2	32	34
			% within Distraction Level	5.9%	94.1%	100.0%
			% within Response Type	3.8%	37.2%	24.6%
			% of Total	1.4%	23.2%	24.6%
		Distracted	Count	9	26	35
			% within Distraction Level	25.7%	74.3%	100.0%
			% within Response Type	17.3%	30.2%	25.4%
			% of Total	6.5%	18.8%	25.4%
Total			Count	52	86	138
			% within Distraction Level	30.4%	62.3%	100.0%
			% within Response Type	100.0%	100.0%	100.0%
			% of Total	37.7%	62.3%	100.0%

DISCUSSION

It has been well documented that drivers who are distracted as a result of using their smartphones are less able to perceive and respond to the presence of hazards such as pedestrians. It has also been established that biomotion enhances the nighttime conspicuity of pedestrians to approaching drivers. This study was conducted to examine the extent to which biomotion increases the nighttime conspicuity of a pedestrian who is encountered by distracted participants. Participants were tasked with responding to pedestrians while being driven along an open road route and tasked with responding to pedestrians. Roughly half of the participants were distracted by a cellphone task during the drive. Unfortunately, the fact that 30.4 percent of the participants had a response distance of 0 m (varying from 5.9% in attentive walking group to 68.6% in distracted standing group) prevented this experiment from providing a strong test of the primary hypothesis that biomotion mitigates the detrimental effect of distraction on response distance to a pedestrian.

The tasks participants were asked to complete in this study were difficult and resulted in a large frequency of missed responses. The distraction level in this experiment was either none ("attentive") or a challenging task in which participants were tasked with double digit mental addition ("distracted") while being driven. Similarly, the conspicuity of the test pedestrian was maximal (walking in a full biomotion configuration) or minimal (standing still; no biomotion). Because the participants in the distracted group were required to alternate their fixation between their phone (in their lap) and the road, they faced a serious visual challenge. When the pedestrian recognition task was made even harder by the pedestrian's lack of biomotion these participants were least likely to perceive and respond to the pedestrian. The fact that 47.1 percent of the participants in the distracted group (27.2% distracted / walking; 72.8 % distracted / standing) did not respond to the test pedestrian created a floor effect that severely limited the variability in the response distance measure and contributed to the difficulty in analyzing the differences in each unique group. This floor effect may have contributed to the lack of support for the hypothesis that biomotion mitigates the detrimental effect of distraction when the response distance variable was used to measure pedestrian recognition. The poor recognition performance of the attentive / standing group left little room for the distracted / standing group to do worse. Further contributing to the lack of variability in the response distance data, the floor effect was greater for participants viewing the standing pedestrian (55.1% misses) than for participants that viewed the walking pedestrian (15.9% misses).

To help eliminate this floor effect in future studies, the pedestrian configurations need to vary in conspicuity. The study included a test pedestrian who was either optimally conspicuous, as in the walking configuration in which the biomotion of the pedestrian was fully highlighted, or not conspicuous as in the standing configuration in which biomotion was not present. A way to vary the conspicuity of the test pedestrian would be to include configurations in which the pedestrian was walking in place and outfitted with retroreflective material highlighting the movement of either the ankles, the ankles and knees, the lower body(ankles, knees, and hips), or entire body (ankles, knees, hip, wrist, elbows, and shoulder). Another method of increasing the recognizability of the test pedestrian would be to reduce the difficulty of the distraction task through changing the addition problems to single digit without carry-over. The distraction task was either extremely demanding as it occupied the visual, cognitive and manual modalities (Atchley et al., 2017; Harbluk et al., 2006; Laing and Lee, 2009), or absent in which participants did not have a secondary task. The extremes in the difficulty of the distraction task contributed to a lack of variability in which 47.1 percent of distracted participants failed to recognize the presence of a pedestrian. This effect was compounded when distracted participants were tasked to respond to the pedestrian that was standing in place.

In addition, the position of the cellphone during the distraction task may have contributed to the large frequency of missed responses. Participants were instructed to hold the cellphone in their lap, therefore forcing participants to repeatedly alternate their fixation between their laps (to read and solve the addition problems) and outside of the vehicle (to search for pedestrians). Because these gaze deviations were approximately 40-50 degrees, a participant looking at their phone would be unable to recognize the test pedestrian in their periphery (Ikeda et al., 2005; Wittmann et al., 2006). Past research indicates that the ability to detect stimuli decreases with increases in retinal eccentricity, especially as cognitive load increases due to a secondary task (Williams, 1982; Chan and Courtney, 1993; Recarte and Nunes, 2003). Therefore, it would have been extremely difficult for the biomotion of the test pedestrian to capture the attention of the participant as originally hypothesized. A few participants mentioned that when they use their phone while driving, they position their phone in their line of sight while driving instead on in their lap in order to minimize the distance between looking at the road and their phone as shown in past research to increase driving performance (Wittman et al., 2006). It would be interesting in future research to test a phone position that reduced the retinal eccentricity of the test pedestrian.

The addition of different levels of pedestrian conspicuity and levels of difficulty in the distraction task would contribute to more variability in participants' response distances. Participants recognized the presence of the pedestrian walking in place in 84.1 percent of the trials, whereas the pedestrian that was standing in place was only recognized on 40.6 percent of the trials. When examining the relationship between distraction level and response type, there was weaker but significant relationship. Participants were more likely to completely miss the pedestrian if they were in the distracted group than those who were in the attentive group; overall, 72.1 percent of the attentive participants responded to the pedestrian but only 52.8 percent of the participants who were using their phones to perform the math task responded to the pedestrian. Participants that were distracted were more likely to fail to recognize the presence of the pedestrian regardless if the pedestrian was standing or walking. This in in accordance with previous research that demonstrations that distraction is detrimental to perceiving hazards such as pedestrians (Harbluk, et al., 2007; Victor et al., 2005; Liang & Lee, 2009; Atchley et al., 2017; Klauer et al., 2006).

In order to further combat this floor effect, future research should also include a preliminary descriptive analysis of pilot data in order to ensure that the combination of the two tasks do not result in a floor effect for pedestrian recognition performance. The tasks within the manipulations in this study were, despite fairly extensive pilot testing, too difficult to perform which resulted in many participants failing to perceive the pedestrian at all. The distraction task should have been designed so that the task was difficult, but not so difficult that many participants failed to perceive the pedestrian.

Despite the frequency of misses in the response data and the challenges that presented in analysis, there was still a significant advantage of biomotion indicating that participants recognized the presence of the test pedestrian from significantly longer response distances when that pedestrian was walking in place rather than standing in place. Averaged across the attentive and distracted groups, participants' mean response distance was 6.4 times longer to the walking pedestrian than to the pedestrian who stood still. From the response type data, participants were more likely to have a correct response to the walking pedestrian than to the pedestrian who stood still. This is consistent with other findings of the nighttime conspicuity enhancements of highlighting a pedestrian's biological motion with retroreflective material (see the Tyrrell et al., 2016, review). Consistent with past research, participants were also more likely to miss the test pedestrian if they were distracted indicating that the distraction task did negatively affect the participant's ability to recognize the presence of a pedestrian (Harbluk et al., 2007; Liang and Lee, 2009; Atchley et al., 2017; McCartt et al., 2006)

Lastly, there were two limitations to the external validity of this study. The first limitation was that participants were passengers who were not actually driving the test vehicle. It is likely that the participants' ability to respond to the presence of the test pedestrian would have been even worse had the participants been driving the vehicle. Further, to maintain experimental control and accurate measurements of response distances, the test pedestrian walked in place during all walking trials. Some participants remarked that the test pedestrian had “robotic” and “marching” movements suggesting that experimenters may not have been adequately trained in how to make walking in place appear as natural gait. In addition, some participants did remark that the pedestrian’s movement “looked funny” because the pedestrian seemed like they were walking but “not going anywhere.” It is unknown if the strangeness of the pedestrian movement in combination with the lack of lateral movement influenced participants’ responses.

As found in this and past studies, driving while distracted is detrimental to performance and the perception of roadway hazards. Additionally, the findings of this study confirm that highlighting biological motion maximizes pedestrian conspicuity. However, due to the surprising frequency of participants failing to respond the presence of the test pedestrian, this experiment unfortunately did not provide a strong test of the primary hypothesis that biomotion would reduce the harmful effects of distraction on pedestrian conspicuity. Future research is needed to provide a solid answer to this important question.

Appendix A

Demographics

Age: ________________

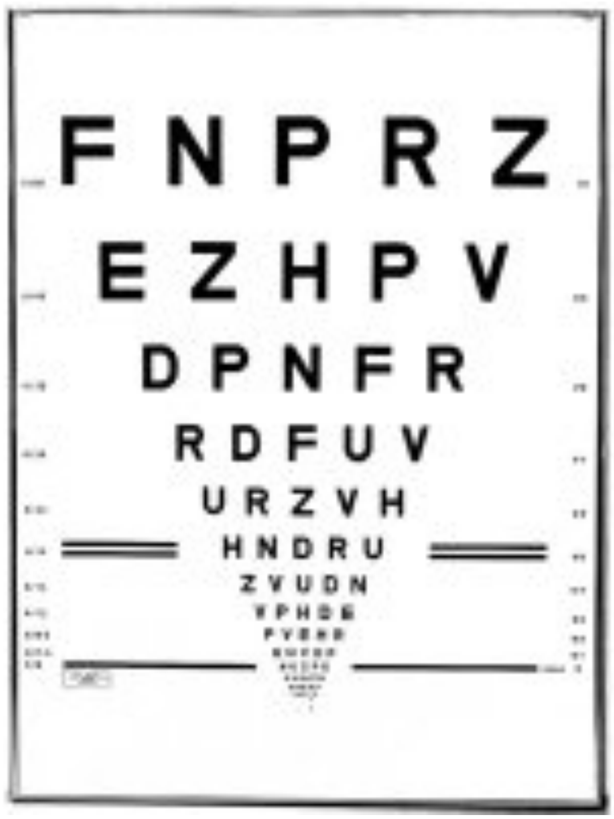
Gender (circle one): Male Female

Visual Acuity score: _________________

Contrast Sensitivity score: ____________

Appendix B

Bailey-Lovie Visual Acuity Chart



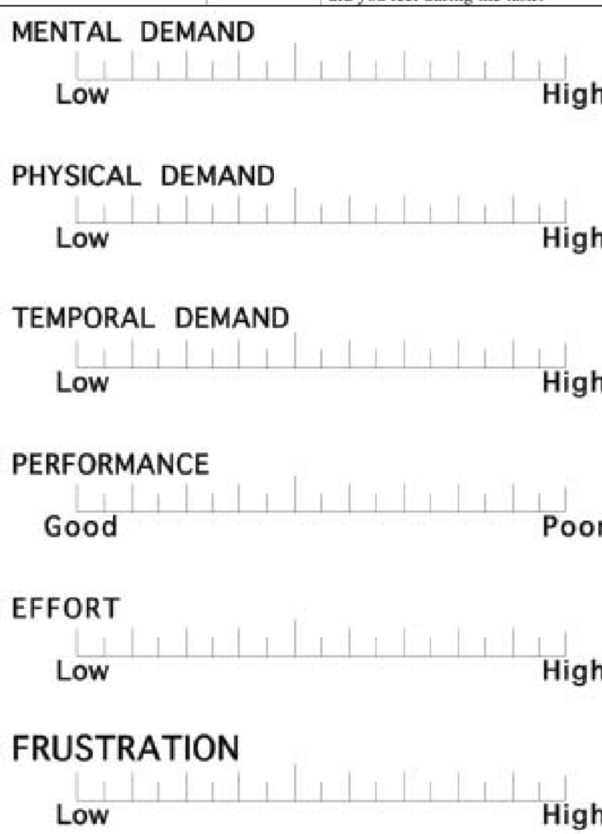
Appendix C

Pelli-Robson Contrast Sensitivity Chart

Appendix D

NASA-TLX (Task Load Index) (Hart, 2006)

RATING SCALE DEFINITIONS		
Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	*Good/Poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?



Appendix E

Post Pedestrian Questionnaire (Not necessarily in this order)

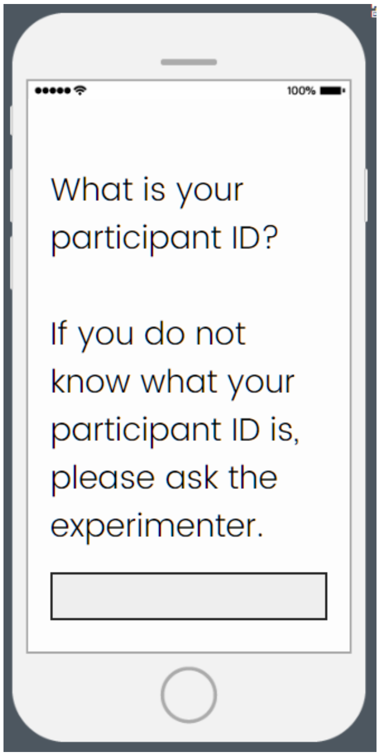
How many pedestrians did you see?
Describe to me what the last pedestrian looked like.
What about the pedestrian made you press your button?
At the moment that you pressed your button, how confident were you on a scale from 0-100% were you that you were responding to person?
Describe to me what was going on in your head as we approached the last pedestrian.
Did you hesitate to press your button? If so, what made you hesitate.
Have you ever seen a pedestrian that looked like the pedestrian you just saw? Did it remind you of anything?
Any questions about the experiment?

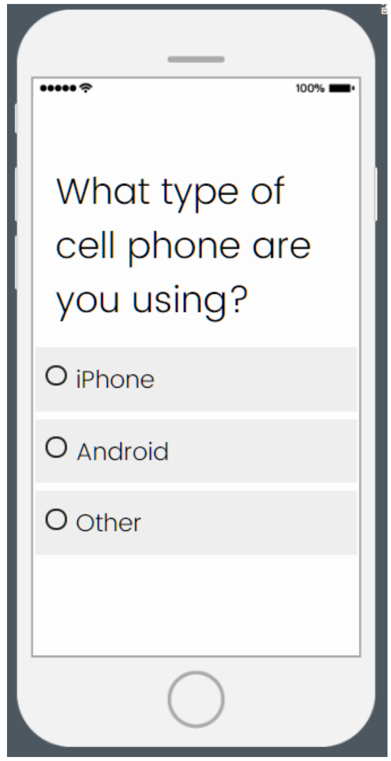
Additional questions if in the distracted group

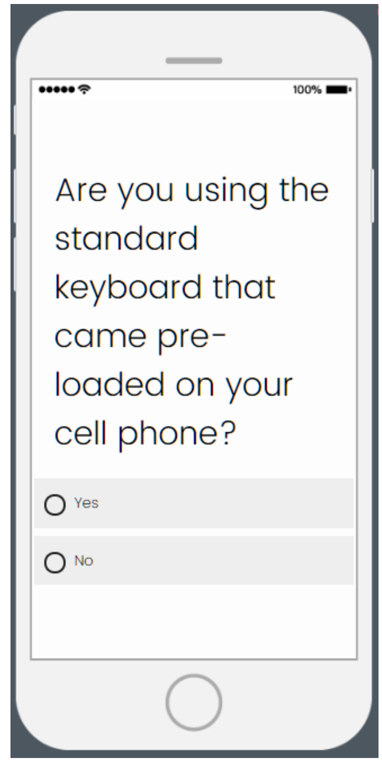
You were tasked with doing two things at one time---the addition task and searching for pedestrians. How do you think you did on both of those tasks?
Did you favor one task over the other?
Why do you think you favored that task over the other one?
How much time did you spend looking at your phone verses looking in the environment?

Appendix F

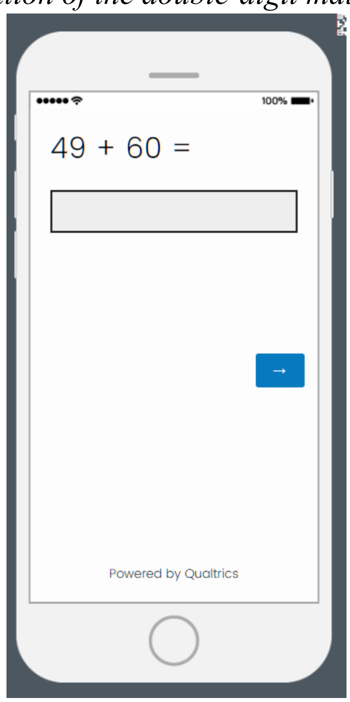
Mathematical Survey







Example of the presentation of the double-digit mathematical problems



Appendix G

Full battery of double-digit mathematical problems taken while in the lab.

28 + 62=	60 + 79 =	77 + 99 =
46 + 81 =	37 + 98 =	30 + 86 =
61 + 98 =	91 + 98 =	29 + 92 =
71 + 91 =	52 + 59 =	57 + 93 =
50 + 95 =	37 + 45 =	42 + 86 =
84 + 90 =	34 + 64 =	53 + 99 =
81 + 94 =	24 + 28 =	

Fully Battery of double-digit mathematical problems taken while in the vehicle.

49 + 50 =	35 + 65 =	67 + 80 =
79 + 82 =	43 + 99 =	70 + 79 =
39 + 71 =	56 + 78 =	43 + 63 =
19 + 54 =	62 + 91 =	70 + 77 =
20 + 95 =	27 + 33 =	58 + 99 =
42 + 69 =	46 + 64 =	69 + 81 =
57 + 73 =	27 + 98 =	77 + 89 =
56 + 75 =	64 + 75 =	64 + 85 =
59 + 91 =	32 + 88 =	34 + 72 =
51 + 67 =	44 + 65 =	69 + 93 =
45 + 83 =	19 + 92 =	28 + 66 =
36 + 81 =	64 + 88 =	73 + 78 =
50 + 51 =	47 + 85 =	26 + 98 =
83 + 99 =	82 + 99 =	21 + 87 =
26 + 46 =	54 + 71 =	42 + 84 =
61 + 69 =	33 + 94 =	31 + 87 =
54 + 79 =	73 + 91 =	46 + 59 =
44 + 46 =	50 + 53 =	73 + 85 =
40 + 74 =	76 + 81 =	32 + 38 =
68 + 96 =	50 + 88 =	26 + 59 =
75 + 76 =	42 + 62 =	21 + 69 =
36 + 77 =	49 + 70 =	51 + 94 =
27 + 65 =	49 + 81 =	40 + 86 =
68 + 97 =	72 + 85 =	59 + 92 =
61 + 79 =	25 + 97 =	90 + 91 =

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