# Effects of Secondary Tasks on Auditory Detection and Crossing Thresholds in Relation to Approaching Vehicle Noises

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**Authorization to Submit Thesis**

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## Abstract

Auditory perception is important in the pedestrian environment. Recent research suggests an association between distracting environmental sound stimuli and poorer performance in detection and localization of approaching vehicles. The present study investigated the effects of secondary tasks (holding naturalistic vocal and texting cell phone conversations) on participants' detection of approaching vehicles and crossing thresholds. Ninety-nine adults were randomly assigned to conditions of vocal conversation, texting conversation, or a control group and completed an auditory vehicle detection task. Vehicle detection distances were significantly smaller in the vocal cell phone conversation group than in the control group, an effect that became stronger as the level of speed increased. Crossing thresholds were not affected by the concurrence of a secondary task. Implications for future research and injury prevention are discussed.

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## Dedication

Dedicated to my mother and father: Ria and Phillip Davis.

# Table of Contents

Authorization to Submit Thesis ........ ii

Abstract ........ iii

Acknowledgments ........ iv

Dedication ........ v

Table of Contents ........ vi

List of Figures ........ viii

List of Tables ........ ix

Chapter 1: Introduction ........ 1

Auditory Cues in the Pedestrian Task ........ 2

Summary ........ 5

Cell Phone-Induced Distraction ........ 5

Aims & Hypotheses ........ 8

Chapter 2: Method ........ 10

Sample ........ 10

Measures and Procedure ........ 10

Demographic questionnaire ........ 10

Auditory stimuli ........ 10

Vehicle detection task ........ 12

Cell phone conversation ........ 13

Procedure ........ 14

Analyses ........ 15

Chapter 3: Results ........ 16

Sex Differences and Descriptive Statistics ........ 16
Data Quality ........ 16
Vehicle Type ........ 16
Detection Distance ........ 17
Crossing Threshold ........ 18
Misses and Prompts ........ 18
Chapter 4: Discussion ........ 19
Detection Distance ........ 19
Vehicle speed ........ 19
Vocal conversation ........ 20
Texting conversation ........ 21
Speed × secondary task interaction ........ 22
Crossing Threshold ........ 23
Limitations ........ 24
Conclusions and Future Directions ........ 25
References ........ 28
Appendix 1: IRB Form ........ 37
Appendix 2: Naturalistic Cell Phone Conversation Script ........ 38

# List of Figures

Figure 1. Plot of speed by secondary task condition for detection distance ............................35

Figure 2. Plot of speed by secondary task condition for crossing threshold............................36

## List of Tables

Table 1. Overall means, standard deviations, and variances for distance judgments ...............33

Table 2. Distance judgment statistics for each level of speed and secondary task ...................34

# Chapter 1: Introduction

Approximately 1200 pedestrians aged 18-35 died and more than 55,000 endured medically attended injuries in the United States in 2013 (National Center for Injury Prevention and Control, 2016). Research has identified several intrapersonal risk factors for pedestrian safety. For example, personality factors have been found to play a role (Schwebel, Stavrinos, & Kongable, 2009). Individuals high in attentional control were typically more patient, while those who preferred intense experiences were more likely to be involved in an injury event. Attitudes and perceived behavioral control also are related to distracted street crossing (Barton, Kologi, & Siron. 2016). Research examining visually-impaired pedestrians also demonstrated the importance of auditory cues. Specifically, individuals with visual impairments can use auditory cues to inform their crossing decisions but are impeded by their inability to nonverbally communicate with drivers (Ashmead et al., 2005).

Environmental factors also are related to pedestrian injury risk. For example higher traffic volume is related to greater risk (Lascala, Gerber, & Gruenewald, 1999). The risk for pedestrian injury increases with traffic volume for both sighted and visually impaired individuals (Guth, Ashmead, Long, Wall, & Ponchillia, 2005). Additionally, pedestrian injury rates are particularly likely to occur in areas with high population density, a high proportion of males, a low proportion of children, a high degree of unemployment, a low proportion of well-educated residents, and/or a high density of bars (Lascala, Gerber, & Gruenewald, 1999). Areas with obstructed visibility (due to bends in the roadway, parked cars, etc.) are also associated with greater pedestrian risk due to a heightened reliance on auditory cues and diminished visual information about oncoming traffic (Ampofo-Boateng & Thompson, 1989; Roberts, Norton, Jackson, Dunn, & Hassall, 1995).

Auditory cues are an emerging area of empirical inquiry. Research has examined factors such as speed and direction of vehicle approach, masking effects of vehicle noise, age differences, and some relations with cognitive development (e.g. Barton, Ulrich, & Lew, 2012; Ulrich, Barton, & Lew, 2014). One factor yet to receive attention is the impact of auditory distraction on detecting and localizing approaching vehicles noises. The present study examined auditory detection and localization of approaching vehicles in the context of a secondary task, specifically a concurrent cell phone conversation.

**Auditory Cues in the Pedestrian Task**

Both visual and auditory perceptual skills are necessary for safe pedestrian navigation. Critical tasks in the pedestrian traffic environment include orienting attention to salient stimuli, judging approaching vehicle distances, determining approaching vehicle speeds, estimating time to vehicular contact, and make judgments of gaps between vehicles (Demetre et al., 1992; Lee, Young, & McLaughlin, 1984). Visual perception plays a vital role in orienting towards the external environment and has received much attention in literature concerning pedestrian safety (e.g. Barton, 2006). Such studies have investigated traffic gap decisions (Demetre et al., 1992) and vehicle approach time estimations (Hoffman et al., 1980).

Most research in pedestrian safety and navigation has been dedicated to examining visual perception in the pedestrian traffic environment, but many pedestrian injuries occur in locations where visibility is obstructed such as bends in the roadway, crossroads, crests of hills, streets with large volumes of parked cars, and streets with higher traffic volume (Ampofo-Boateng & Thompson, 1989; LaScala, Gerber, & Gruenewald, 2000; Roberts et al., 1995). An estimated 40-70% of children's and 20% of teenagers' accidents when crossing the street involve visual occlusion by a parked vehicle (van der Molen, 1981). In situations with obstructed visibility and/or high environmental demands, auditory perception becomes more important in detecting approaching vehicles and making crossing decisions. However, research suggests pedestrians have significant difficulty making decisions when relying on auditory perception (Emerson & Sauerburger, 2008; Guth et al., 2005), underscoring the need for research examining the auditory perceptual skills necessary for detecting and locating approaching vehicles in the pedestrian traffic environment.

A recently emerging line of research examined the role of auditory cues (vehicle sounds) in pedestrian safety. Initial research found vehicle speed was significantly related to pedestrians' performance in detecting and localizing approaching vehicles (Barton, Ulrich, & Lew, 2012). Generally, detection distance was positively correlated with vehicle speed. Slower moving vehicles were detectable only at a short distance from the participant while faster moving vehicles were detectable at significantly greater distances. The authors attributed the observed variation in detection distance by speed to changes in the sound signatures emitted by the engine, tires, and wind resistance, in addition to variations in sound intensity.

Whereas Barton, Ulrich, and Lew (2012) investigated adults' detection and localization of approaching vehicles, a follow-up study investigated developmental differences in auditory vehicle detection and localization (Barton, Lew, Kovesdi, Cottrell, & Ulrich, 2013). Compared to young children ages 6-9, adults and older children detected approaching vehicles more quickly and were more accurate in determining direction of approach and arrival of the vehicle at their location. The safety implications of young children's poorer performance in auditory vehicle detection and localization demonstrate a clear need for more research investigating pedestrian auditory perception.

A study examining detection and localization of approaching vehicles in the context of competing noise from a second vehicle, a common situation on busy streets, extended the line of research (Ulrich, Barton, & Lew, 2014). Auditory vehicle detection performance in the presence of a secondary vehicle was significantly worse than when no secondary vehicle was present. Put differently, lack of a secondary vehicle was associated with greater detection distances and more accurate localizations. The masking effect from auditory interference from a second vehicle results in heightened risk for pedestrians, highlighting the need to investigate whether other types of auditory stimuli can act as sources of interference.

In addition to the heightened risk posed by competing vehicles, research suggests ambient background noise interferes with pedestrians' ability to detect approaching vehicles at a safe distance (Emerson & Sauerburger, 2008). Additionally, background traffic noise impedes pedestrians' ability to determine the travel path of a vehicle (Ashmead et al., 2012). However, a literature review revealed no studies which have examined auditory detection of approaching vehicles in the context of a competing sound stimulus with associated cognitive demand.

Most recently, research compared younger adults aged 18-30 with older adults aged 60 and above (Barton, Heath, & Lew, 2015). Researchers examined indices of auditory detection distance, direction of approach, and minimum acceptable distance (vehicle's distance in feet when the participant indicated crossing was no longer safe; i.e. a threshold for safe crossing). Detection distance and minimum acceptable distance varied significantly according to age, but not judgments of approach directionality. Specifically, older adults detected vehicles at greater distances than younger adults and were more conservative with their determination of unacceptable distance for crossing.

## Summary

An emerging body of research concerning the role of auditory cues in pedestrian safety adds to existing literature focusing on visual cues. Factors such as vehicle speed, direction of vehicle approach, age, and competing sound stimuli have been found to influence vehicle detection and localization. However, a gap in the literature exists regarding the possible effects of a secondary task on navigation in the pedestrian traffic environment. Ecologically valid examples of such a task are cell phone conversations in auditory and visual modalities (i.e. talking and texting), the distractive potential of which have been demonstrated in contexts such as driving (e.g. Strayer, Watson, & Drews, 2011).

## Cell Phone-Induced Distraction

Approximately 303 million individuals in the United States subscribe to a cell phone service (CTIA-The Wireless Association, 2011). Despite the convenience of communication afforded by cell phones, the distractive potential of cell phones is well documented. For example, Kuznekoff and Titsworth (2013) examined the impact of cell phone use on university students’ performance when learning and taking notes. Students who did not use cell phones to text or comment on social media posts during a video lecture took more notes, demonstrated greater recall, and scored higher on a multiple-choice test than students who did use their phones.

Cell phones and other electronic devices are pervasive in today’s workplace and are related to safety concerns. For example, a survey of 15,000 working-age adults showed the use of cell phones was associated with as much as 4.5% of narrowly avoided workplace accidents and 0.4% of actual workplace accidents within a 12-month period (Korpinen & Pääkkönen, 2012). Cell phone-related accidents and narrowly avoided accidents were more prevalent among men and young adults compared to other demographics, as well as among those suffering from minor aches and pains and sleep disturbances.

Researchers have also examined the distractive potential of cell phones in hazardous situations and tasks such as driving. One such study investigated the impact of cell phone use on automobile drivers' visual perception, noting cell phones to present a source of cognitive distraction for drivers and significantly increase the risk of an accident (Strayer, Watson, & Drews, 2011). Specifically, concurrently holding a vocal cell phone conversation while driving can induce a form of inattention blindness whereby the driver fails to notice salient information in their line of sight. Further, this attentional deficit cannot be practiced away and is not observed when the conversation is held with an actual passenger rather than via cell phone.

In contrast to the impact of cell phone use while driving, less is known about the primary mechanisms by which cell phone use interferes with pedestrian navigation and decision making (Schwebel, Stavrinos, Byington, Davis, O'Neal, & Jong, 2012). Some research suggests cell phone use may elicit inattention blindness not only in drivers (as in Strayer, Watson, & Drews, 2011) but also in pedestrians. Specifically, an observational study found people walking in a plaza while using cell phones to exhibit behaviors characteristic of inattention blindness (Hyman, Boss, Wise, McKenzie, & Caggiano, 2009). Compared to people walking with a friend or portable music player (or neither), those holding a cell phone conversation walked more slowly, changed directions more frequently, and were less likely to acknowledge other people or notice a clown on a unicycle along their route.

Some studies have utilized street-crossing tasks in virtual environments to ascertain the impact of cell phone use on pedestrian safety. For example, one study assessed the virtual street-crossing behaviors of participants under conditions of no distraction, a hands-free cell phone conversation, and listening to music on a portable player (Neider, McCarley, Crowell, Kaczmarski, & Kramer, 2010). Participants holding a vocal cell phone conversation took more time to cross the street and were less likely to successfully do so as compared to the other two conditions, suggesting that cell phone use impedes a pedestrian's ability to notice and subsequently act on crossing opportunities.

A similar study examined the behavior of participants in a virtual pedestrian environment across two within-subjects experiments (Stavrinos, Byington, & Schwebel, 2011). The first experiment compared participants' performance under no distraction with performance holding a naturalistic cell phone conversation. The second experiment compared participants' performance holding a naturalistic phone conversation, holding a verbally complex phone conversation, and holding an arithmetically complex phone conversation. Four variables were of interest: time to spare before the next vehicle arrived at the participant's location, missed opportunities (the number of safe crossing gaps the participant did not accept), attention to traffic (the number of times the participant looked left and right before crossing the street divided by average time waiting to cross), and hits and close calls (instances when the participant either would have gotten hit by a vehicle or narrowly avoided getting hit by a 1 second gap). For all variables, participants' performance was worse when holding a cell phone conversation regardless of subject matter with one exception: Attention to traffic seemed to be inhibited more by cognitively complex conversations than naturalistic conversations.

Results of studies suggesting a significant impact of cell phone use on pedestrian safety contrast with other research. In recent research participants completed a virtual street-crossing task while texting, listening to music, and holding a vocal cell phone conversation (Schwebel, Stavrinos, Byington, Davis, O'Neal, & Jong, 2012). Pedestrians texting or listening to music while crossing a virtual street were significantly more likely to be hit by vehicles than participants either undistracted or holding a vocal cell phone conversation. However, all three types of distractors were associated with pedestrians looking away from the virtual street more often than undistracted pedestrians. The authors speculatively attributed these findings to the cognitive demands and constant auditory disruption presented by texting and listening to music respectively. A clear need exists for more research examining the effects of distractors on pedestrian perceptual skills.

**Aims & Hypotheses**

Previous research examined detection and localization of approaching vehicles alone as well as in the context of noise produced by a second vehicle. In contrast to previous work, the primary aim of the present study was to examine the impact of a concurrent secondary task on vehicle detection and crossing thresholds. Naturalistic cell phone conversations in the auditory and visual modalities served as distracting secondary tasks.

The introduction of a secondary task in either modality (talking or texting) was expected to be associated with differences in detection and crossing threshold of approaching vehicles. Specifically, for both talking and texting modalities the concurrence of a cell phone conversation was hypothesized to result in shorter detection distances and crossing thresholds at all speeds compared to not holding a cell phone conversation. Furthermore, holding a cell phone conversation in either modality was hypothesized to result in more failures to indicate vehicle detection and crossing threshold. Finally, the concurrence of a vocal cell phone conversation was hypothesized to result in more interrogative statements from the researcher to the participant than a texting conversation.

# Chapter 2: Method

## Sample

A sample of 99 young adults was recruited from the undergraduate population at a university in the Pacific Northwest (*M* = 19.49 years, range 18-27, *SD* = 1.93, 37.40% male). Participants received one half-hour of credit as compensation for their participation. Adults are generally experienced pedestrians whose cognitive and physical abilities are unlikely to interfere with pedestrian tasks, as opposed to children and the elderly who exhibit poorer performance in auditory vehicle perception (Barton, Lew, Kovesdi, Cottrell, & Ulrich, 2013; Barton, Heath, & Lew, 2015). The sample was representative of the local population: 80% Caucasian, 9% Latino, 5% Asian, 4% African American, and 2% Middle Eastern. The study was approved by the university's Institutional Review Board.

## Measures and Procedure

First, participants completed a demographic questionnaire. Next participants completed a vehicle detection task during which a naturalistic cell phone conversation took place for those participants assigned to perform a secondary task.

**Demographic questionnaire.** Each participant was administered a questionnaire to collect basic demographic information. Specifically, age, sex, and ethnicity were recorded. A fourth question requested at least three topics in which the participant was interested and comfortable discussing casually. Potential conversation topics identified by the questionnaire were then used to generate dialogue in the main experiment's naturalistic cell phone conversation.

**Auditory stimuli.** Vehicular sound stimuli were those used in previous research (Barton, Ulrich, & Lew, 2012). A tripod-mounted Edirol R-09HR digital stereo field recorder was used to collect recordings of a 2009 Nissan Altima, 2008 Toyota Camry, 2001 Pontiac Grand AM, 2001 Subaru Legacy, and a 1999 BMW 323i in real pedestrian settings. In order to produce recordings free of any noise except tire, wind resistance, and engine sounds, the vehicles were driven at night on a road free of snow, ice, rain, or loose gravel. Each sound stimulus comprised the vehicle passing the recorder's location from the left at three speeds: 5 mph, 12 mph, and 25 mph. Vehicle speeds were chosen to simulate three vehicle noise conditions pedestrians may encounter in American cities. Vehicle sounds at 5 mph comprise mostly engine noises, which are difficult to detect at low speeds. Twelve mph was chosen to represent the speed at which research suggests engine noises begin to blend together with tire noises (Japanese Automobile Standards International Centre, 2009). At 25 mph risk for severe injury is significantly higher, and noises generated by tires and wind resistance reach a level that may mask engine noise (Barton, Ulrich, & Lew, 2012).

Each sound file was recorded and presented in .wav format and shared the following characteristics. Three seconds elapsed at the beginning of the file before the vehicle became detectable. Once detectable, the sound of the vehicle gradually grew louder until arriving at the listener's position, followed by 5 seconds of travelling away from the observer's position. In other words, each sound file possessed natural vehicle sound cues and preserved the Doppler Effect. Sound files varied in length due to speed-related differences in the amount of detectable vehicle noise in each file. For example, vehicles travelling at 5 mph emitted less noise and were closer to the observer before becoming detectable. Sound files were the following lengths for each speed condition: 5 mph (15 seconds; 3 seconds lead, 7 seconds approach, 5 seconds moving away), 12 mph (20 seconds; 3 seconds lead, 12 seconds approach, 5 seconds moving away), and 25 mph (25 seconds; 3 seconds lead, 17 seconds approach, 5 seconds moving away).

**Vehicle detection task.** Auditory stimuli were presented in a 4 × 4 foot insulated sound chamber equipped with a pair of KRK ROKIT 5 studio monitors (45Hz – 35kHz frequency response) placed four feet apart and mounted in the walls of the sound chamber, facing each other parallel to the back wall of the sound chamber. The sound chamber was 8 feet tall, equipped with a door, and insulated to provide noise attenuation. Based on real-world sound samples, the studio monitor volume levels were adjusted so that stimuli peaked at 75 dBA. Ambient noise inside the sound chamber was approximately 35 dBA. Participants each completed 45 trials in a vehicle (5) × speed (5 mph, 12 mph, 25 mph) design. Participants also completed 10 practice trials to gain familiarity with the vehicle detection task. Participants were allowed additional practice trials on request; none were requested. Each trial contained a vehicle of one of five types approaching from the left, as in previous research (Ulrich, Barton, & Lew, 2014), at one of the three speeds. Presentation of sound files in a randomized order across participants was accomplished with specialized software (Peirce, 2007). The software also computed and recorded the detection distance and crossing threshold variables for each trial.

After software initialization by the research assistant, trials progressed automatically with five-second breaks between. Participants responded to each vehicle sound stimulus with a set of Lemo PC USB foot pedals. Specifically, during each trial, participants stepped on the first foot pedal to indicate detection of a vehicle, and stepped on the second foot pedal to indicate when they thought the vehicle too close for them to safely cross. The first pedal press yielded a *detection distance* index, representing the vehicle’s distance in feet from the observer at the moment of the pedal press. The second pedal press yielded a *crossing threshold* index, representing the vehicle's distance in feet when the observer deemed the situation unsafe to cross.

In addition to detection distance and crossing threshold, the numbers of *detection misses* and *threshold misses* were recorded. Detection misses were defined as instances in which the participant failed to press the first foot pedal before the car reached their position and thus did not record a detection distance for the trial (likewise for crossing thresholds).

Previous studies used a keyboard key press procedure for participant input (Barton, Heath, & Lew, 2015; Barton, Ulrich, & Lew, 2012). The mode of input was changed from key presses to foot pedal presses in the present study for two reasons. First, the nature of the secondary tasks necessitated the participants' hands being free in order to hold the cell phone. Second, the foot pedals were believed to serve as an interface metaphor (Sutcliffe, 2012) allowing participants to more intuitively grasp the response procedure than with a hand-operated keyboard. Other studies in the realm of pedestrian safety (e.g., Schwebel et al., 2012) using foot-operated input methods have not reported complications.

**Cell phone conversation.** Throughout the vehicle detection task, participants in either of the secondary task groups engaged in a naturalistic (i.e., casual and lifelike) conversation, comprised of open-ended questions about topics of interest, with a research assistant. Both parties used an LG Optimus Exceed 2 cell phone running the Android 4.4 "KitKat" mobile operating system. Participants in the vocal cell phone conversation group were asked to hold the phone to their right ear in order to maintain a constancy of the left ear being reserved for detecting vehicle stimuli. In order to expedite responses to text messages, the research assistant used an AmazonBasics Bluetooth wireless keyboard to type responses to the participant. For both conditions the research assistant's number of prompts for information, defined as interrogative statements toward the participant, was recorded with a handheld mechanical tally device.

The cell phone conversation took place via either talking or texting depending on whether the participant was assigned to the vocal or texting conversation group. The participant and the research assistant discussed topics identified in the demographic questionnaire as topics of interest, beginning with the first listed topic and progressing to subsequent topics as needed. For each topic the research assistant followed a general script, beginning with questions about the participant's history with the topic (e.g., "when did you first become interested in Star Trek?") and following up with more in-depth questions (e.g., "what are some advanced aspects you've learned about motorcycle repair?"). Appendix A presents the general script followed (adapted from Strayer, Drews, & Johnston, 2003). The participant was not pressured to answer questions quickly. Brief conversational tangents initiated by the participant were allowed, but the research assistant steered the conversation back toward the predetermined topics and script.

**Procedure**. Participation comprised five steps. First, each participant was assigned to one of the three groups by a dice roll on arrival. Specifically, a 1 or 2 corresponded to assignment to the vocal conversation group, 3 or 4 to the texting conversation group, and 5 or 6 to the control group. Second, the informed consent process began. Third, the participant was screened for hearing difficulties inside the 4 × 4 foot square sound chamber. Single-channel pure tones at 100 Hz, 250 Hz, 440 Hz, 1 kHz, and 10 kHz were played through the studio monitors individually and the participant was asked to simply indicate which side (left or right) from which they heard the tone. No participants exhibited hearing difficulties, or reported having hearing deficits, requiring them to be excluded from the study. Fourth, the participant completed the demographic questionnaire. Fifth, the participant completed the vehicle detection task. Pilot testing was conducted with a sample of five participants in order to identify potential issues with the research protocol. No problems arose during pilot testing.

**Analyses**

Analyses proceeded in several steps. First, descriptive statistics and sex differences were examined. Second, data normality was assessed via Q-Q plots. Third, a series of repeated-measures ANOVAs was used to examine main effects and interactions for speed and secondary task in relation to detection distance and crossing threshold.

# Chapter 3: Results

## Sex Differences and Descriptive Statistics

Sex differences were examined in detection distances, crossing thresholds, misses, and prompts in a series of ANOVAs. No statistically significant differences were found. Sex was excluded from all subsequent analyses. Descriptive statistics for overall detection distances and crossing thresholds are presented in Table 1.

## Data Quality

Data normality was checked with a series of Q-Q plots. A number of detection distance variables exhibited significant negative skew, but skewness did not appear to be associated with a particular vehicle speed or vehicle type. A square root transformation was conducted to correct negative skewness. However, results of the following analyses remained the same pre- and post-transformation. Results below are from raw data. Crossing threshold variables did not exhibit unusual distributional characteristics.

## Vehicle Type

Detection distances and crossing thresholds were examined in a secondary task (3) × vehicle type (5) repeated-measures ANOVA. Significant main effects of vehicle type was found for detection distance, $F$ (4, 384) = 218.49, $p < .01$, and for crossing threshold, $F$ (4, 384) = 72.27, $p < .01$. Neither detection distance nor crossing threshold significantly interacted with secondary task. Bonferroni follow-up tests indicated significant differences in both detection distance and crossing threshold for every pairwise vehicle comparison, with two exceptions. The Grand Am and Subaru did not significantly differ in mean detection distance, and the Camry and Grand Am did not significantly differ in mean crossing threshold.

**Detection Distance**

Detection distances were examined in a secondary task (3) × speed (3) repeated-measures ANOVA. A significant main effect of secondary task was found, $F$ (2, 96) = 7.21, $p < .01$, partial $\eta^2 = .13$. Bonferroni follow-up tests indicated detection distances for the vocal conversation condition (*M* = 218.26, *SE* = 8.13) were significantly smaller than in the control condition (*M* = 260.03, *SE* = 7.42). Detection distances in the texting conversation condition (*M* = 239.52, *SE* = 7.75) fell between vocal conversation and control conditions but were not significantly different from either. A significant main effect of speed was found, $F$ (2, 142) = 2860.87, $p < .01$, partial $\eta^2 = .97$. Bonferroni follow-up tests indicated detection distances significantly increased at each level of speed (see Table 1).

A significant speed × secondary task interaction was found (see Figure 1), $F$ (4, 192) = 6.23, $p < .01$, partial $\eta^2 = .12$. The first half of Table 2 presents descriptive statistics for detection distances at each level of speed and secondary task. Figure 1 presents follow-up paired-sample t-tests conducted to compare average detection distances between levels of speed within each secondary task condition; Bonferroni correction of .05/3. Average detection distance increased significantly at each level of speed within each secondary task condition. An ANOVA with Bonferroni follow-ups compared average detection distances between secondary task groups within each level of speed. Participants in the control condition had significantly greater average detection distances than participants in the vocal conversation condition for all levels of speed, and greater average detection distances than participants in the texting conversation condition only for the 5 mph speed condition. The differences between groups increased with speed (i.e., greatest in the 25 mph speed condition).

**Crossing Threshold**

Crossing thresholds were examined in a secondary task (3) × speed (3) repeated-measures ANOVA. The second half of Table 2 presents descriptive statistics for crossing thresholds at each level of speed and secondary task. No main effect of secondary task was found. A significant main effect of speed was found, $F$ (2, 142) = 652.11, $p < .01$, partial $\eta^2$ = .90. Crossing thresholds significantly increased with speed. No significant interaction was found between speed and secondary task for crossing thresholds (see Figure 2).

**Misses and Prompts**

Detection misses, crossing threshold misses, and numbers of prompts for information were examined next. Neither detection misses nor crossing threshold misses varied significantly in frequency by condition. The number of prompts for information (i.e., interrogative statements from the research assistant to the participant) was significantly greater in the vocal conversation condition ($M$ = 17.60, $SD$ = 3.58) than in the texting condition ($M$ = 9.94, $SD$ = 2.05), $t$ (61) = 10.55, $p < .01$.

# Chapter 4: Discussion

The primary aim of this study was to investigate the effects of secondary tasks (i.e., vocal and texting cell phone conversations) on adults' detection distances and crossing thresholds of approaching vehicles. Detection distances were significantly shorter in the concurrence of a vocal cell phone conversation than in the absence of a secondary task, partially supporting the initial hypotheses. However, crossing thresholds were unaffected by the concurrence of a secondary task. The following sections discuss the results, limitations, and conclusions of the present study in the context of other literature and implications for pedestrian safety.

## Detection Distance

**Vehicle speed.** Detection distance judgments increased with vehicle speed, a finding consistent with previous studies (e.g., Barton, Ulrich, & Lew, 2012; Ulrich, Barton, & Lew, 2014). In general, faster-moving vehicles are more easily detected than slower-moving vehicles, likely due to faster vehicles generating more noise (Japanese Automobile Standards International Centre, 2009). The effect of vehicle speed was present across secondary task conditions. A review of epidemiological literature concerning the association between vehicle speed and injury risk highlights a general trend whereby risk increases monotonically with vehicle speed (Rosén, Stigson, & Sander, 2011). However, the authors noted that the degree of risk is commonly overestimated due to disproportionately high quantities of reported injuries compared to national statistics. In light of the association between vehicle speed and injury risk, the finding that faster-moving vehicles are more easily detected than slower-moving vehicles is reassuring.

**Vocal conversation.** Previous research found vocal cell phone conversations to be a source of distraction for drivers and pedestrians alike (e.g. Hyman et al., 2009; Strayer et al., 2011). As expected, detection distance judgments were significantly shorter for participants in the vocal cell phone condition compared to those who did not have to contend with a secondary task. Further, differences in detection distance judgments between vocal and control conditions increased with speed. The present results suggest a vocal conversation may create a masking effect in a manner reminiscent of the competing vehicle in Ulrich, Barton, and Lew's (2014) study, ambient background noise as in Emerson and Sauerburger's (2008) study, and background traffic noise as in Ashmead et al. (2012). As a result the pedestrian is less likely to detect an approaching vehicle until the vehicle is relatively close to their position. The vehicle may even be detected at a distance that is too close to qualify as an acceptable margin of safety.

Maintaining a cell phone conversation interfered with participants' ability to attend to vehicle noises. Nasar, Hecht, and Wener (2008) conducted two studies, one experimental and one observational, which examined pedestrian distraction through cell phone use and iPod use. Overall, pedestrians holding a cell phone conversation performed more poorly than undistracted pedestrians and iPod listeners on an object recall task and exhibited more unsafe crossing behaviors as well. While a small sample size for the iPod condition in study two precluded the researchers from drawing any conclusions, they postulated that cell phone use is a source of cognitive distraction, impeding situation awareness and placing pedestrians at greater risk for injury. However, the present study utilized casual, naturalistic conversations which were intended to present minimal cognitive demand. Driving safety literature suggests a driver's ability to monitor their speed and maneuver safely decreases as conversation complexity increases (Qu, Zhang, Du, & Zhang, 2014). Therefore, the distractive effects observed for participants in the vocal cell phone condition may not have been substantially cognitive in nature.

**Texting conversation.** Detection distance judgments of participants holding a texting conversation were significantly different neither from those holding a vocal conversation nor from those in the control group (except at 5 mph for the latter). The different rates of information exchange inherent to talking and texting may help explain why only a vocal cell phone conversation elicited significantly shorter detection distance judgments at all speeds. Specifically, vocal conversations convey a greater amount of information given the same period of time. The greater rate of information exchange inherent to vocal conversations is evidenced by the observation of a significantly greater average number of prompts for information in the vocal condition than in the texting condition. With a greater rate of information exchange, participants holding vocal conversations may have been afforded fewer opportunities to attend to the vehicle sound stimuli rather than the phone conversation. In other words, the slower pace of texting conversations may have facilitated greater vigilance in attending to approaching vehicle noises due to the relatively long pauses compared to vocal conversations.

Deficits in vehicle detection in the concurrence of a vocal cell phone conversation but not a texting conversation may also be explained by the modality of the stimuli and secondary task. Schwebel et al. (2012) found texting and listening to music to produce more errors than holding a vocal conversation in a virtual street-crossing task, but the street-crossing task in their study was visual rather than auditory. Since the present study did not produce similar results, the distractive potential of a secondary task may depend on the modality of the primary task, as predicted by Multiple Resource Theory (Wickens, 2002). According to Multiple Resource Theory, attentional resources can be classified along four dichotomous dimensions: processing stage (perception/cognition and response selection/execution), perceptual modality (auditory and visual), visual channels (focal/foveal and ambient/peripheral), and processing codes (spatial and verbal). Multiple Resource Theory predicts that when two tasks compete for resources at the same dimension and level, the performance of one or both tasks suffers. In the context of the present study, a vocal conversation competed with the vehicle sound stimuli for auditory perceptual resources, resulting in shorter detection distances. A texting conversation, on the other hand, utilized visual perceptual resources and therefore did not significantly compete with the auditory vehicle stimuli.

**Speed × secondary task interaction.** Previous studies as well as the present study have demonstrated the importance of vehicle speed when attempting to understand how pedestrians use auditory cues to detect approaching vehicles. The present study found the concurrence of a secondary task to also be an important factor. Therefore, examining speed and secondary task in the context of each other constitutes a critical step in furthering scientific understanding of pedestrian auditory perceptual skills.

The interaction between levels of speed and secondary task conditions produced a “fanning” pattern whereby differences in detection distance judgments between conditions became greater as speed increased. Specifically, a vocal or texting conversation seemingly modulates the effect of vehicle speed on the distance at which pedestrians detect and localize an approaching vehicle. The effect is stronger with a vocal conversation, implying an auditory distractor affects modulates the greater noise signatures of faster cars more than a visual distractor does. Ulrich, Barton, and Lew (2014) found a similar interaction between speed and the presence of a competing vehicle noise signature; like the secondary tasks in the present study, the effect of a competing vehicle in terms of detection distance deficits increased with vehicle speed. The similarity of results between studies utilizing environmental and intrapersonal distractors may lend support to the notion that distractors affect the pedestrian street crossing task through a masking effect modulated by vehicle speed.

**Crossing Threshold**

Crossing thresholds increased with vehicle speed, consistent with the findings of Barton, Heath, and Lew (2015). The effect of speed, observed across secondary task conditions, is not particularly surprising since a pedestrian would want more time and space to cross in front of a faster vehicle.

Contrary to expectations, crossing thresholds were not affected by the concurrence of either type of secondary task. Therefore, the distractive effects of a cell phone conversation appear to manifest in the auditory domain primarily as deficits in vehicle detection rather than affecting crossing thresholds. One possible explanation is that a pedestrian’s attention will not easily divert away from a detected vehicle, meaning a judgment of safe crossing threshold will not suffer as long as detection occurs before the vehicle reaches that threshold. Multiple Resource Theory (Wickens, 2002) may also offer an explanation. Making a judgment of a safe crossing threshold, unlike initially detecting a vehicle, can be considered as drawing resources from the response selection/execution level of the processing stage dimension rather than the perception/cognition level. As a result, the secondary tasks used in the present study, which relied heavily on perception, did not compete as strongly with judgments of crossing threshold as with detection distance.

**Limitations**

Several limitations must be mentioned. First, the set of vehicle sound stimuli this study used was comprised only of five different vehicles and cannot be considered a representative sample of all vehicles one might encounter on American roadways. Electric vehicles, motorcycles, and commercial trucks were not included in the present study's vehicle sound stimuli.

Second, pedestrians in real-world scenarios are subject to a myriad of sounds and potential distractions other than vehicles and phone conversations. The sound stimuli used in the present study were collected in a quiet environment devoid of noises produced by other vehicles, other pedestrians, birds, etc. Eliminating other sources of noise was necessary for laboratory experimental control, but in doing so the present study sacrificed some ecological validity. More research is needed to understand pedestrian auditory perceptual skills in the contexts of other sources of noise, especially from traffic travelling parallel to the direction of crossing.

Third, the sample was comprised entirely of young adults from a university community and was not representative of the national population, precluding any broad generalizations. Future studies should include broader samples of participants if possible.

Finally, while the research assistant endeavored to mitigate conversational lulls by maintaining a steady conversation, participants may have used lulls as a compensation strategy. Such a possibility cannot be ruled out based on the collected data. Future studies should address this limitation by recording audio of vocal conversations and measuring characters per minute of texting conversations in order to check for consistent conversational pace.

**Conclusions and Future Directions**

Research on the auditory perceptual skills salient for pedestrian navigation has focused on the detection and localization of vehicles with and without secondary distractor sounds (Barton, Ulrich, & Lew, 2012; Ulrich, Barton, & Lew, 2014). However, there has been a lack of research examining how safety can be affected by a concurrent secondary task. The present study took steps to fill a gap in the literature by assessing adults' ability to detect approaching vehicle sounds and make judgments of safe crossing thresholds while maintaining a naturalistic phone conversation in auditory and visual modalities (talking and texting respectively).

The present study demonstrated a secondary task, especially a vocal cell phone conversation, can significantly impede a pedestrian's ability to use auditory cues to detect an approaching vehicle. Holding a vocal cell phone conversation produces a time compression effect whereby vehicles are detected closer to the pedestrian's location, putting the pedestrian at increased risk for injury. In other words, since the vehicle is detected closer to the pedestrian's location, the pedestrian has less time to react to the vehicle's presence, which can lead to serious injury if the pedestrian has already stepped into the roadway. However, most pedestrians have the ability to perceive visual cues, and in many cases visual cues are readily available, so the effect of a primarily auditory secondary task on vehicle detection may be tempered by the redundancy afforded by visual cues. Future research should investigate the effects of auditory and visual secondary tasks in situations where both auditory and visual cues are available as well as when only visual cues are available.

Crosswalks in areas with visually obstructed roadways can be particularly hazardous for pedestrians due to diminished visual cues and a heightened reliance on auditory cues (Ampofo-Boateng & Thompson, 1989; Roberts, Norton, Jackson, Dunn, & Hassall, 1995). Vehicular auditory cues are susceptible to interference not only from competing vehicles (Ulrich, Barton, & Lew, 2014) but from secondary tasks as well, warranting injury prevention efforts in multiple domains. First, public education efforts should discourage the use of cell phones at crosswalks, emphasizing that cell phones can be as dangerous to pedestrians as they are to drivers. Second, smartphone application developers should explore the possibility of developing applications that automatically modulate call volume and screen brightness when GPS data indicates the user is at a crosswalk. Finally, from a traffic engineering perspective, the installation of curb extensions at potentially hazardous crosswalks and intersections would shorten crossing distances and mitigate the problem of obstructed visibility caused by parked vehicles.

Pedestrians rely on auditory cues to detect vehicles when visual cues are unavailable or otherwise diminished (Ampofo-Boateng & Thompson, 1989; Roberts, Norton, Jackson, Dunn, & Hassall, 1995). The results of the present study demonstrated that the concurrence of a cell phone conversation can result in poorer performance in detecting an approaching vehicle using auditory cues. Vehicles with low noise emissions may also pose a risk to pedestrians in scenarios where visibility is obstructed. Electric vehicles in particular are significantly quieter than internal combustion engine vehicles at low speeds (Garay-Vega, L., Hastings, A., Pollard, J. K., Zuschlag, M., & Stearns, M. D., 2010). Therefore, research is needed to investigate methods of mitigating the distractive potential of a secondary task, which may be compounded by the difficulty of detecting vehicles with low noise emissions.

A study using visually impaired participants found adding an artificial alert sound increased a hybrid vehicle's detectability (Kim, Emerson, Naghshineh, Pliskow, & Myers, 2012). While the artificial alert sound did not improve participants' ability to determine the path of the vehicle, the improvement in detection distance is promising.

The present study investigated the effects of secondary tasks on auditory vehicle detection and localization, extending a line of research which has found factors such as age and the presence of a competing vehicle to be important factors in understanding pedestrian auditory perception (Barton, Heath, & Lew, 2015; Ulrich, Barton, & Lew, 2014). Naturalistic cell phone conversations in both texting and vocal modalities, but especially the latter, resulted in poorer performance in detecting approaching vehicles using auditory cues. Several potential avenues for future research exist; for example, research is needed to investigate the potential interaction between intrapersonal distractors (e.g., a cell phone conversation) and environmental distractors (e.g., a competing vehicle). Future studies should also use Multiple Resource Theory (Wickens, 2002) as a foundation to describe the distractive potential of secondary tasks in terms of processing stage and perceptual modality.

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Table 1

*Overall means, standard deviations, and variances for distance judgments.*

| Detection distances in feet | | | |
|---|---|---|---|
| Speed (mph) | *M* | *SD* | *Variance* |
| 5 | 50.20 | 9.48 | 89.90 |
| 12 | 172.05 | 40.28 | 1622.86 |
| 25 | 499.35 | 95.19 | 9062.07 |
| Crossing thresholds in feet | | | |
| Speed (mph) | *M* | *SD* | *Variance* |
| 5 | 17.71 | 8.60 | 73.90 |
| 12 | 61.82 | 27.17 | 738.33 |
| 25 | 200.14 | 80.39 | 6462.07 |

*Note*. *N* = 99.

Table 2

*Distance judgment statistics for each level of speed and secondary task.*

| | Detection distances in feet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 5 mph | | | 12 mph | | | 25 mph | | |
| Condition | *M* | *SD* | *Variance* | *M* | *SD* | *Variance* | *M* | *SD* | *Variance* |
| Vocal | 45.77 | 11.04 | 121.80 | 153.89 | 46.36 | 2148.83 | 455.11 | 108.92 | 11862.58 |
| Texting | 48.89 | 9.03 | 81.51 | 172.00 | 35.32 | 1247.71 | 497.67 | 83.34 | 6945.47 |
| Control | 55.10 | 5.76 | 33.14 | 187.24 | 33.21 | 1102.85 | 537.75 | 77.45 | 5997.94 |
| | Crossing thresholds in feet | | | | | | | | |
| | 5 mph | | | 12 mph | | | 25 mph | | |
| Condition | *M* | *SD* | *Variance* | *M* | *SD* | *Variance* | *M* | *SD* | *Variance* |
| Vocal | 15.18 | 8.74 | 76.30 | 55.28 | 29.62 | 877.17 | 198.13 | 92.87 | 8625.31 |
| Texting | 16.51 | 8.16 | 66.60 | 61.23 | 26.25 | 689.12 | 192.36 | 72.20 | 5213.22 |
| Control | 20.92 | 8.09 | 65.39 | 67.80 | 25.23 | 636.62 | 208.96 | 77.72 | 6040.31 |

*Note*. *N* = 99.

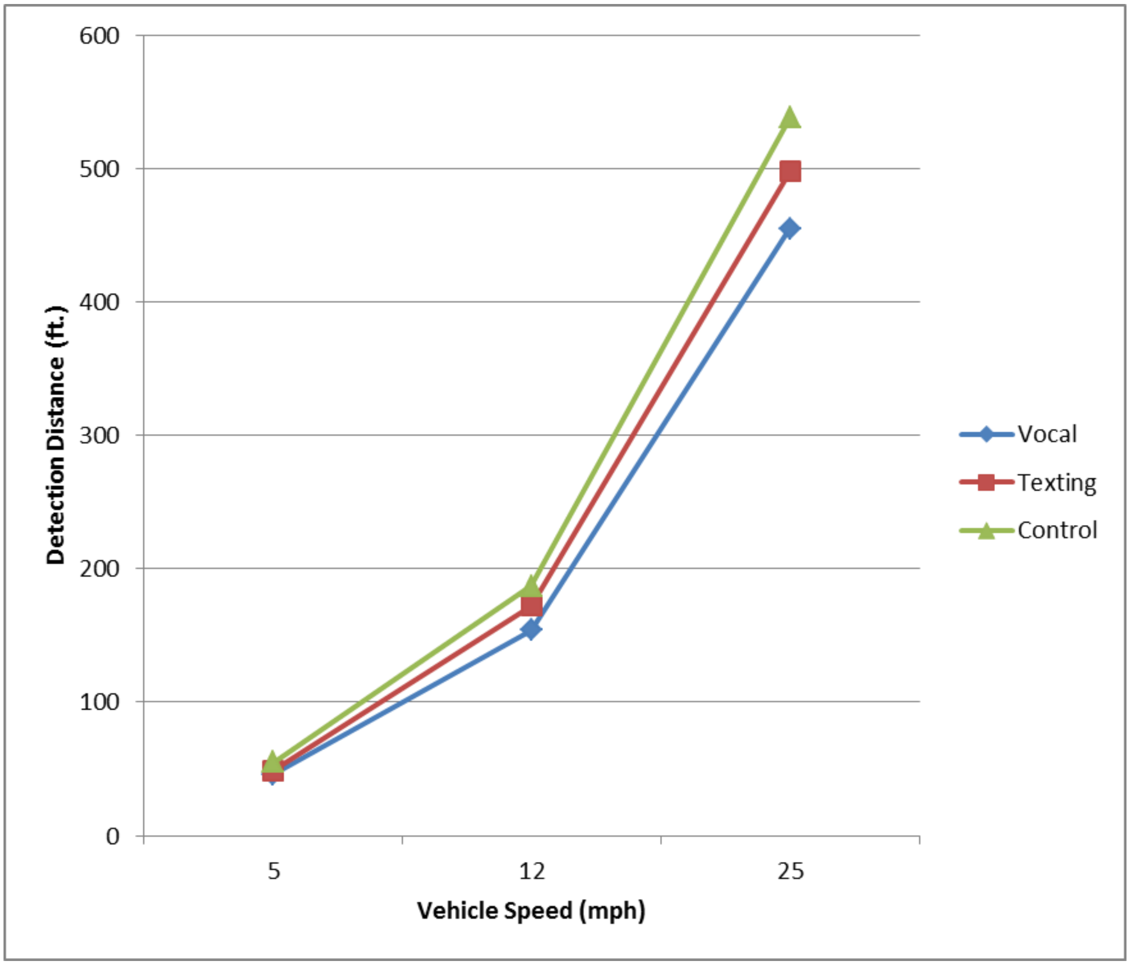


*Figure 1*. Plot of speed by secondary task condition for detection distance.

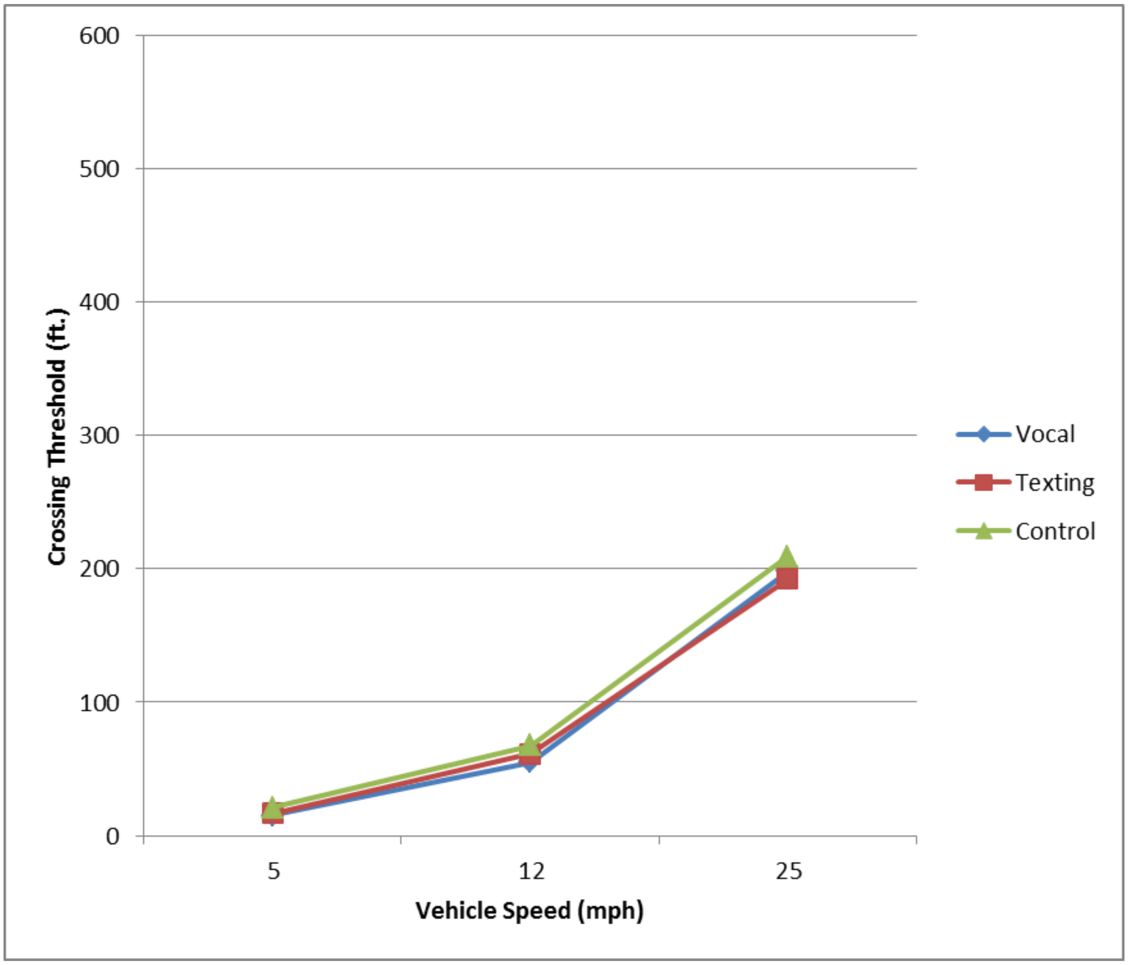


*Figure 2.* Plot of speed by secondary task condition for crossing threshold.

## Appendix 1: IRB Form

University *of* Idaho
Office of Research Assurances
Institutional Review Board
875 Perimeter Drive, MS 3010
Moscow ID 83844-3010
Phone: 208-885-6162
Fax: 208-885-5752
irb@uidaho.edu

To: Benjamin Barton

From: Jennifer Walker
Chair, University of Idaho Institutional Review Board
University Research Office
Moscow, ID 83844-3010

Date: 5/15/2015 4:34:41 PM

Title: Effects of Secondary Tasks on Auditory Detection and Localization of Approaching Vehicle Noises

Project: 15-709
Approved: May 15, 2015
Renewal: May 14, 2016

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On behalf of the Institutional Review Board at the University of Idaho, I am pleased to inform you that the protocol for the above-named research project is approved as offering no significant risk to human subjects.

This study may be conducted according to the protocol described in the application without further review by the IRB. Every effort should be made to ensure that the project is conducted in a manner consistent with the three fundamental principles identified in the Belmont Report: respect for persons; beneficence; and justice.

This IRB approval is not to be construed as authorization to recruit participants or conduct research in schools or other institutions, including on Native Reserved lands or within Native Institutions, which have their own policies that require approvals before Human Participants Research Projects can begin. This authorization must be obtained from the appropriate Tribal Government (or equivalent) and/or Institutional Administration. This may include independent review by a tribal or institutional IRB or equivalent. It is the investigator's responsibility to obtain all such necessary approvals and provide copies of these approvals to ORA, in order to allow the IRB to maintain current records.

As Principal Investigator, you are responsible for ensuring compliance with all applicable FERPA regulations, University of Idaho policies, state and federal regulations.

This approval is valid until May 14, 2016.

Should there be significant changes in the protocol for this project, it will be necessary for you to submit an amendment to this protocol for review by the Committee using the Portal. If you have any additional questions about this process, please contact me through the portal's messaging system by clicking the 'Reply' button at the top of this message.

Jennifer Walker

**Appendix 2: Naturalistic Cell Phone Conversation Script**

*When did you become interested in ________?*

*What do you like most about ________?*

*How much time do you dedicate to ________?*

*Is there anything you dislike about ________?*

*Why do you dislike that aspect of ________?*

*Where did you learn about ________?*

*What are the basics of ________?*

*What are some advanced aspects you've learned about ________?*

*If you were trying to persuade someone to learn more about ________, what would you tell them?*

*Tell me about any different types of ________?*

*How does ________ affect your social life?*