Detection and Localization of Approaching Vehicle Noises among Older Adults

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Abstract

The present study examined detection and localization of auditory cues from a pedestrian environment among a sample of older and younger adults. Past research suggested normal aging may be associated with declines in physical, cognitive, and perceptual abilities. Relatively few studies have examined the impact of such developmental changes on pedestrian safety among older adults. The present study explored developmental differences in relation to auditory detection and localization of sound stimuli collected from a real pedestrian environment. Results by speed condition were similar to past research and age differences were found on two of the three indices of detection and localization. Meaningful interactions were also discovered between age levels and speed conditions. The inclusion of a new score for unacceptable distance offered new insight into pedestrians' use of auditory information. Results are discussed in the context of past research and with regard to informing future injury prevention efforts.

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Chapter 1: Detection and Localization of Approaching Vehicle Noises among Older Adults

Approximately 4,500 pedestrians die annually in the United States, with more than 75,000 injuries requiring medical treatment (National Center for Injury Prevention and Control, 2014). Walking is one of the most dangerous modes of transportation, accounting for approximately twelve percent of traffic deaths (Ernst & McCann, 2002). Pedestrian injury is also costly to the individual and to society in general. Lost income, increased medical expenses, and possible increased insurance premiums are among potential outcomes following pedestrian injury. Recent information indicated the cost associated with medical care and productivity losses in pedestrian injuries exceeded $99 billion and is forecasted to continue to rise (National Center for Injury Prevention and Control, 2014).

The problem of pedestrian injury is multifaceted. Patterns of injury differ depending on a number of factors including developmental differences, gender, and socioeconomic status (Chakravarthy, Vaca, Loftipour, & Bradley, 2007). Particularly vulnerable populations include children aged 4-15 years and older adults aged 60 years and older (Lobjois & Cavallo, 2007). Prior research has pointed out several age-related changes in street crossing behavior, for instance, slower decision making, increased attentional errors, reduced walking speed, greater difficulty in selecting safe gaps, and selection of adequate safety margins. As adults age, there is a steady reduction of hearing, vision, skeletal reflexes, and cognitive processing, all of which are key for executing safe street crossings. Only a limited amount of research has focused on developmental differences for older adults. The present study will explore factors relevant to understanding developmental differences in use of auditory cues among older adults in a simulated pedestrian scenario. We must first, however, understand the nature of the street crossing as a task.

The Nature of the Street Crossing Task

Stimulus detection and judgment of affordances form the core of the street crossing task. While crossing a street is a rather mundane chore for the average adult, the task can actually be quite taxing (Oxley, Fildes, & Dewar, 1999). A pedestrian must detect approaching vehicles, determine direction of approach, and make some judgment of speed and distance; a task accomplished through integration of information from visual and auditory sensory input. Next, this information must be integrated with physical ability in order to arrive at a perceived estimate of risk. Ultimately, the pedestrian must accept an available gap and cross the road within that specific gap or choose to reject the available gap and continue to wait at the curb. Once committed to a crossing, physically walking across the street requires pedestrians to adapt their movements and behaviors to accommodate the continuous perceptions of the dynamic oncoming traffic. Older adults, along with young children, are among those who often have great difficulty in crossing tasks because of the global change or degeneration associated with aging (Lobjois & Cavallo, 2007; Tom, Auberlet, & Bremond, 2007).

The Importance of Auditory Cues

Safe navigation of a pedestrian through a traffic environment requires visual and auditory perceptual skills. Adjusting one’s attention to relevant stimuli, judging approaching vehicle distances, determining approaching vehicle speeds, estimating time to contact, and judging affordances all are important for safe crossing (Demetre, Lee, Pitcairn, Grieve, Thomson, & Ampofo-Boateng, 1992; Lee, Young, & McLaughlin, 1984). Visual perception plays an important role in pedestrians' orientation in the external environment and has received attention for some time (e.g., Barton, 2006). Studies examining the role of visual perception have used investigations into estimation of vehicle approach times (Hoffmann, Payne, & Prescott, 1980), and decisions about traffic gaps (Demetre et al., 1992).

Though visual perception has been the dominant topic of interest for detecting approaching vehicles, the role of auditory perception also is important. The locations of pedestrian injuries often comprise visual occlusions of approaching traffic such as curves in the roadway, crossroads, crests of hills, and streets with large volumes of parked cars (Ampofo-Boateng & Thompson, 1990; Roberts, Norton, Jackson, Dunn, & Hassall, 1995). When visibility is obstructed pedestrians compensate by using their auditory system to make judgments about where and when to cross the street. Despite the strong tendency for injuries to occur at locations where visibility is obstructed, little research has been done on the relevant auditory perceptual skills required for detecting approaching vehicles in the traffic environment.

A number of important auditory perceptual skills are necessary for detecting approaching vehicles in the traffic environment. Auditory perceptual skills used for detecting approaching vehicles are analogous to some of the perceptual skills required for visual detection of approaching vehicles. Very similar to how attention must be directed towards visual stimuli, auditory attention must be directed towards a specific approaching vehicle to allow for more complex cognitive processing of the stimuli.

One of the cognitive processes necessary for making accurate street crossing decisions is the ability to localize the sound of an approaching vehicle. Sound localization requires a number of psychophysical calculations to generate a full three-dimensional spatial representation of the acoustic landscape from a particular place in space. Sound localization uses interaural level and interaural time differences to determine the direction of the sound source (Hartmann, 1983). The interaural level difference (ILD) is the comparison between the intensity of the sound entering the left and the right ear expressed as a decibel ratio. The human auditory system can use ILD's sufficiently to localize a sound source at frequencies above 500 Hz (Hartmann, 1983). To localize sounds below 500 Hz, the auditory system relies on interaural time differences (ITD), between sound entering the left and the right ear (Hartmann, 1983). As sound waves travel towards the pedestrian's head, the head acts as a barrier and diffracts the sound wave, which causes the sound wave to reach one ear before the other. By cognitively calculating this time difference, the auditory system is able to localize sound at low frequencies in a three dimensional spatial representation. Both ILD and ITD can be used in concurrence. However, each is specialized depending on the frequency range of the sound stimuli. The pedestrian environment contains sounds at both high and low frequencies, demanding the utilization of both ILDs and ITDs when detecting and localizing approaching vehicles.

Several studies have explored the role of auditory perception in the pedestrian environment among adults. The use of auditory cues among visually-impaired adults has been one area of exploration. One study examined gap selections while listening to real traffic at roundabouts, but not actually crossing through traffic (Guth, Ashmead, Long, Wall, & Ponchillia, 2013). Results signify that visually impaired pedestrians are able to use auditory cues to make crossing decisions, but the usefulness of these cues is dependent on environmental factors. For example, gap selection varied by road configuration and traffic volume. Another study involved crossings through real traffic at roundabouts (Guth, Ashmead, Long, Wall, & Ponchillia, 2013). Visually impaired adults were able to successfully complete crossings using only auditory information, but were disadvantaged by their inability to rely on non-verbal visual communication with drivers. Visually impaired participants waited longer to cross than sighted participants, but were unable to take advantage of opportunities to cross when drivers yielded to them. A third study examined the importance of auditory cues within the larger context of other environmental factors, as well as visually-impaired pedestrians' use of traffic noise when aligning themselves with a crosswalk (Guth, Hill, & Rieser, 1989). Traffic sounds were found to be useful for aligning themselves when readying for a street crossing, but did not guarantee success, indicating sound localization in the pedestrian setting is imperfect even for many adults.

Another line of recent research has examined detection and localization of approaching vehicle sounds beginning with basic questions and incorporating some developmental hypotheses. Barton, Ulrich, and Lew (2012) recently examined auditory detection and localization of approaching vehicles in adults. The results of the study showed adults were able to more easily detect and localize vehicles moving at higher speeds, but had more difficulty determining the time of arrival of a faster moving vehicle. Other recent research explored localization and detection among children and young adults (Barton, Lew, Kovesdi, Cottrell, & Ulrich, 2012). Results pointed to developmental differences existing in auditory detection and localization of pedestrian stimuli, and highlighted the importance of understanding children's and adults' use of auditory cues for pedestrian safety.

Further research (Ulrich, Barton, & Lew, 2013) examined auditory detection and localization of sounds of approaching target vehicles while also in the presence of competing noise from a second vehicle. Auditory perception of approaching vehicles suffered significantly when more than one vehicle is approaching the pedestrian. Results suggested that the presence of competing vehicle sounds will lead to greater judgment errors at roadside.

Detecting and localizing sounds is important for safely crossing the street even when vision is also available. For example, in recent research (Rodrigues, Pinto, Dommes, Cavallo, & Vienne, 2012), the use of auditory cues is important for pedestrians who have declining visual acuity, because the auditory system can serve as compensation for declining visual acuity. Older adult pedestrians could benefit from the presence of auditory information to compensate for visual and other cognitive degeneration.

Cognitive Factors in Street Crossing

The street crossing task can be mundane, but taxing on cognitive abilities. Information Processing Theory provides a useful framework within which to understand the demands inherent in the pedestrian street crossing task (Barton, 2006). Normal age-related declines of cognitive and executive function generally includes mild deterioration in memory performance, speed of cognitive processing, and executive functions (particularly divided and selective attention), and capabilities which are particularly relevant to pedestrian safety (Dunbar, Holland, & Maylor, 2004; Oxley, Ihsen, Fildes, Charlton, & Day, 2005). The age-complexity effect refers to the well-established finding that the magnitude of cognitive age differences increases as the task becomes increasingly complex (Salthouse, 1991). The age-complexity effect is attributed to deficiencies in information processing resources, highlighting two aspects of information processing as particularly important for older pedestrians: speed of processing and various types of attention.

Speed of Processing. As noted above, a critically important aspect of information processing is speed. Cognitive processing speed refers to how quickly a person can perceive, think, and act on information in the environment. Processing speed is frequently measured using reaction time tasks. Numerous studies have found that the processing speed of older adults is slower than that of young adults on a broad range of timed decision-making tasks (Birren, Riegal, & Morrison, 1962). Furthermore, Salthouse and colleagues (1991) suggest that the effects of slower cognitive processing can be detrimental to performance on any type of timed task. Older adults experience increased accuracy when time is not a factor during decision making, similar to young adults (Kutas, McCarthy, & Donchin, 1977). Nevertheless, RT is a relevant measurement for understanding information processing speed in street crossing tasks (Bashore, Ridderinkhof, & van der Molen, 1997). Reduced information processing speed may render older adult pedestrians less efficient at concurrently processing incoming information from the complex traffic environment, hindering their ability to make a safe street crossing decision. Oxley and colleagues (1999) found, in comparison to younger adults, older pedestrians' increased reaction and decision times result in a smaller safety margin in which to correct misguided actions in response to possible hazards.

Another factor influenced by the reduction in information processing speed is cognitive flexibility. Cognitive flexibility refers to the ability to shift streams of thought and actions in order to perceive, process, and respond to situations in different ways (Langevin, Dommes, Cavallo, Oxley, & Vienne, 2011), and is an important ability to have as traffic environments are constantly changing. Older adults have reduced cognitive flexibility, especially in complex situations such as a street crossing (Oxley et. al., 2005). Lack of flexibility and reduced processing speed may encumber older adult's ability to react effectively to rapidly changing events, such as the unexpected movement of a vehicle.

Attention. Attention is the allocation of processing resources, and is a resource that can only accommodate and maintain a limited amount of information from the environment (Norman, 1969). Information processing is concerned with both internal attention (streams of thoughts) and external attention (stimuli attended to in the environment) and the integration of both. Attention is often disrupted due to injury, age, or both. Salthouse (1991) reported that processing resources are more limited for older than for younger adults and that they diminish with increasing age.

Attention comprises several specific functions. Selective attention, for example, brings goal-oriented information into consciousness, while simultaneously disregarding or inhibiting other information. The ability to selectively attend to information affords goal-oriented behaviors to be carried out. Distraction and inability to attend to appropriate information result in errors when shifting attention between stimuli. In a pedestrian street crossing situation, the implication of attending to appropriate and relevant stimuli is crucial for safety (Barton, 2006). Older individuals experience more difficulty than younger adults in selectively attending to the most important stimuli (Salthouse, 1991), which by extension will likely hinder performance during the complex task of crossing the street.

Another function of attention is divided attention. Divided attention shares the spotlight with multiple goal-oriented tasks or sources of information (Dunbar, Holland, & Maylor, 2004). For pedestrian safety, divided attention is frequently calculated using dual-task studies where a pedestrian is required to walk and also do a separate task, thereby using cognitive resources concurrently. Although walking is generally thought of as automatic, walking does in fact consume attentional resources and imposes increasing attentional demands with age (Neider, Gasper, McCarley, Crowell, Kaczmarski, & Kramer, 2011). Attentional resources diminish with age, leaving fewer total resources to be distributed across competing tasks, such as walking, continuous scanning, and processing of information, which causes older adults to experience disproportionate dual-task costs in goal-oriented performance (Neider et al., 2011).

Summary. The implications of cognitive development (or developmental decline) for pedestrian safety are multifaceted. As Birren et al. (1962) explain, generalized slowing of information processing is not just a peripheral performance issue, but rather an integral determinant of overall cognitive ability for older adults, which shows the interwoven nature of among various factors. Inattention and deficiencies in information processing are key factors that have been attributed to the overrepresentation of older adults in pedestrian collisions (Oxley, Fildes, and Dewar, 1999). Accurate cognitive performance is fundamental in street crossing tasks, incorporating recognizing and attending to a stimulus, and integration of information.

Physical Factors Influencing Street Crossing

Motor abilities, such as walking speed, agility and balance also are important for executing a safe crossing. Previous research has shown that declines in physical abilities play an important role in the high percentage of pedestrian collision involving older adults (Dunbar, Holland, & Maylor, 2004). For example, walking speed has been found to be predictive of unsafe street crossing decisions (Lobjois & Cavallo, 2007).

Indeed, the relation of physical declines to walking speed among older adults has been noted (Oxley, 2002). Generally older adults walk more slowly and often experience difficulty whether crossing the street at signaled crosswalks (Oxley, Fildes, and Dewar, 1999) or at streets with no traffic control (Emerson & Sauerburger, 2008). Good motor performance depends on the ability to coordinate movements while interacting with information-rich dynamic environments (Oxley, 2002). Older pedestrian's compromised balance and weakened skeletal muscles can reduce agility. In turn, loss of agility can dampen one's ability to respond efficiently to changes in the physical street environment. Older people with balance difficulties are less likely to be able to cope when the sensory information used to maintain balance is restricted (Oxley, Fildes, and Dewar, 1999). In general, the complex nature of traffic environments tax multiple resources, which can lead to confusion, lack of coordination, and risky pedestrian behavior.

Aims and Hypotheses

The current study had two aims. First, older adults' detection and localization of noises of approaching vehicles were to be examined in comparison to those of young adults. Older adult pedestrians are expected to perform more poorly than younger adults during the auditory detection and localization task. Second, older adults' performance on a detection and localization task was examined in relation to cognitive performance and a self-report of physical abilities among older adults. Cognitive declines are expected to be predictive of decreased performance among older adult pedestrians. Specifically, older pedestrians are expected to take longer to detect the sound of an approaching vehicle, to be less accurate in determining direction of approach, and to generally be more conservative in their assessment of sound cues for crossing than the younger adult pedestrians.

Chapter 2: Method

Sample

Seventy participants were recruited: 35 younger adults (ages 18 to 26; *m* = 20.17, *sd* = 2.12, median = 20, mode = 18, 15 male, 20 female) and 35 older adults (ages 60 to 86, *m* = 66.77, *sd* = 4.94, median = 66, mode = 67, 17 male, 18 female). The young adult sample's age range was selected to include of adult aged (18+) to adults who are aged 30 years. In many developed countries 40 is considered middle age (Gorman, 2000) and the current study's aim was to look at younger adults not middle aged adults. The age of 60 to 65, is roughly equivalent to retirement ages in most developed countries, is said to be the beginning of old age (Gorman, 2000). Efforts were made equalize participants in each age group sex. Efforts also were made to ensure the ethnic composition of the sample will be representative of the surrounding population. People aged 60 and older comprise an especially vulnerable pedestrian population (Oxley et al., 1999). The younger, comparison group was recruited from the university population. Older participants were recruited through cooperation with organizations such as senior centers. The protocol was approved by the University of Idaho Institutional Review Board.

Measures and Procedure

Participants first report age, sex, and any experiences being injured as a pedestrian or involvement of any narrowly avoided collision also known as a "near miss" on a short demographic form. Physical measures were collected next, including walking speed time and a short self-report of physical activities. Third, participants completed cognitive measures. Finally, participants completed the auditory detection and localization task.

Physical. Physical abilities were measured in two ways. First, participants completed a self-report of any physical activities they are involved with. Second, a measure of walking speed time was recorded across a 20 foot course. The average walking time score was input later into the auditory task to determine if each participant would have safely made it across the street. Each participant stood on a marker and was instructed to "walk to the other end of the course at your usual speed, just as if you were walking down the street or going to the store." The participants completed the task three times, after which the average of the three trials was calculated to represent each participant's walking speed, or time taken to complete the course (Oxley et al., 2005).

Cognitive The Pattern Comparison Test (PCT) measure (Salthouse & Babcock, 1991) will be the first of two cognitive measures. The PCT primarily was used to assess processing speed. The Pattern Comparison test requires the participant to visually scan two adjacent sets of line patterns composed of three, six, or nine line segments and write an "S" if the pattern was the same as the box before, and a "D" if the pattern is different than the box before. The two-page test form comprises two columns of 15 pattern pairs, each with a blank line between the line patterns. The number of correct responses and the number of incorrect responses produced within 30 seconds will serve as the measure of processing speed. The score is calculated by the sum of the total number of correct comparisons in the allotted time.

Participants next completed the Contingency Naming Test. The CNT taps multiple aspects of cognition, including selective attention and working memory (CNT; Anderson, Anderson, Northam, & Taylor, 2000). The CNT progresses through a series of four subtests centering on correct identification of combinations of 27 colors and shapes presented on a stimulus card. As rules and conditions are added, each subset becomes more cognitively demanding than the previous one. After completing each subtest, the participant's time taken to complete the test, their uncorrected errors, self-corrected errors, and number correct were recorded by the researcher.

The CNT yields several scores. One score used in previous research was a total cognitive efficiency score, calculated as the sum of efficiency scores across the four subtests to yield a total efficiency score that penalizes long completion times and errors. Scores for speed of processing, self-regulation, self-corrective behavior, and errors also can be calculated from performance on the CNT. Each of these scores is positively related to better cognitive performance, with the exception of errors having a negative correlation. In the present study, the most useful measure was a simple time taken to complete the CNT test, which functioned as an indicator of speed of processing.

Auditory task and vehicle detection Similar to previous research, participants completed a detection and localization task using the sounds of approaching vehicles recorded in a naturalistic setting (Barton, Ulrich, & Lew, 2012; Barton, Lew, Kovesdi, Cottrell, & Ulrich, 2013). The interested reader may refer to previous research for a more detailed description of the rationale and creation of sound stimuli. Stereo recordings of sound stimuli were collected from real pedestrian settings, under controlled conditions of speed and direction. The position of the vehicle emitting each sound is known and entered into the software presenting the stimuli, allowing key press reactions to be used to derive several measures. Inclusion of distracter noises sets the present study apart from previous research. The distracter sound stimuli are intended to be similar to what a pedestrian would potentially hear as a pedestrian common within a pedestrian setting. Distracter sounds included in the auditory task included vehicle horns, a siren from an emergency vehicle, screeching brakes, etc. The distracter sounds were presented during each trial for approximately 10 seconds beginning and concluding randomly within the trial. The randomization was done with the use of a randomization equation within the auditory task's program. Inclusion of extraneous noises is designed to add complexity and realism to the detection and localization task beyond that used in previous studies.

The vehicle stimulus was presented through a pair of studio monitors and Dell XPS M1330 laptop speakers. Participants were screened for hearing difficulties prior to presentation of the vehicle stimuli by presentation of pure tones at 100Hz, 250Hz, 440Hz, 1 kHz, and 10 kHz played through the monitor speakers and the laptop speakers, which were set up in a half circle array around the participant. See Figure 1 for layout arrangement. Participants simply were asked to indicate if the tones were audible. No participants were excluded due to hearing difficulties.

Participants were then presented with sounds of five different approaching vehicles, in a format used in previous research (Barton, Ulrich, & Lew, 2012). Sounds were presented in a 5 (vehicle type) X 4 (speed: 5, 12, 25, and 35 mph) X 2 (left vs. right approach) design. Participants listened to a total of 50 vehicle trials, ten of which were practice trials.

In each trial, participants responded to detection and localization of the vehicle through a series of key presses on a computer keyboard. Participants were required to complete 10 practice trials in order to familiarize themselves with the key press procedure. Additional trials were allowed, if necessary, to ensure participants understood the procedure.

Three dependent or outcome variables were of interest for examining auditory detection and localization of the approaching vehicle was derived from key presses. First, participants were asked to indicate when they were certain they had detected a vehicle approaching by pressing the “down” arrow key. A *detection distance* variable was recorded as the vehicle’s distance in feet from the listener when he/she has indicated a vehicle was present. Since the listener’s position (i.e., the recorder location) was known, distance measures relative to the vehicle can be calculated. Second, participants were asked to indicate when they were certain of the direction from which the vehicle is approaching. Participants pressed the left arrow key to indicate they think the vehicle is approaching from the left, and vice versa for an approach from the right. *Direction accuracy* were scored simply as the percentage of correct direction decisions. The percentage of correct direction accuracy was calculated for each participant. Finally, and differing from previous research in order to collect a new measure, participants were be asked to press the “up” arrow key to indicate when they think the vehicle is too close to allow a safe crossing. The last key press yielded an *unacceptable distance* recorded as the vehicle’s distance in feet from the listener. The time of arrival and speed of the vehicle in each trial are known variables within the software, which will allow calculation of distances in relation to participants’ key presses. Taken together, these variables provide indices of detection of the approaching vehicle (detection distance), localization (direction of approach), and participants’ indication of when they would no longer cross.

Pilot Testing

Data were collected from three participants in each age category in order to identify any problems with the research protocol to be edited prior to full data collection. The key press procedure to be used in the auditory detection task has been separately pilot tested (see Barton, Lew, Kovesdi, Cottrell, & Ulrich, 2013). Pilot participants in the present study reported no problems with the key press procedure.

Analyses

Analyses proceeded in four steps. First, descriptive statistics and sex differences were examined. Second, age differences in measures of physical ability and speed of processing were examined in a series of mean comparisons. Third, the three indices of auditory detection and localization were examined in separate repeated-measures ANOVAs. In each ANOVA, main effects for speed and age were assessed, as well as speed X age interactions. Finally, Pearson correlations and a series of hierarchical regressions were used to examine relations of speed of processing to the three indices of detection and localization.

Chapter 3: Results

Descriptive Statistics and Sex Differences

Descriptive statistics are reported in Table 1. Speed of processing measures, detection distance, direction accuracy, and unacceptable distance were examined for sex differences. No significant sex differences were found and thus sex was excluded from subsequent analyses. We should note sex differences were not expected, but preliminary analysis was important as sex differences are somewhat common in behavioral pedestrian literature (LaScala, Gerber, & Gruenewald, 2000).

Age Differences in Physical Activity

Age differences were examined for two indices of physical activity. Average walking time (in seconds) was significantly shorter for younger participants ($m = 5.43$; $sd = .40$) than older participants ($m = 6.27$; $sd = .57$), $F\ (1, 68) = 51.07$, $p < .01$. Self-reported physical activity on a given day did not differ significantly between younger ($m = 3.34$; $sd = .76$) and older ($m = 3.26$; $sd = .85$) participants, $F\ (1, 68) = .20$, $p > .05$.

Age Differences in Speed of Processing

Age differences were examined for two indices of speed of processing. The number of items correct prior to the 30-second mark on the PCT was significantly greater for younger participants (m = 39.51; sd = 5.89) than older participants (m = 30.23; sd = 4.85), F (1, 68) = 51.85, $p < .01$. On the CNT younger participants (m = 124.44; sd = 12.90) completed the test in a significantly shorter amount of time than older participants (m = 183.37; sd = 51.67) participants, F (1, 68) = 42.86, $p < .05$. Overall, results indicated speed of processing among younger participants was significantly better than among older participants.

Differences in Auditory Detection and Localization

Detection distance. Detection distances (i.e., the vehicle's distance in feet from the listener when he/she indicated a vehicle was present) were examined in a repeated-measures ANOVA speed (4) X direction (2) X age (2). A significant main effect was found for speed, F (3, 204) =3266.81, $p < .01$, $\eta^2 = .98$. Bonferroni post-hoc tests indicated average detection distances were significantly different from one another at all levels of speed (see Table 1), and average detection distance increased significantly at each level of speed. A significant main effect also was found for direction of approach, F (1, 68) =114.15, $p < .01$, $\eta^2 = .63$. Average detection distance was significantly greater when the vehicle approached from the right versus the left. Finally, a significant main effect was found for age group, F (1, 68) = 9.15, $p < .01$, $\eta^2 = .12$, with detection distance being significantly greater for older versus younger participants.

A significant speed X age interaction was found (see Figure 1), F (3, 204) = 7.59, $p < .01$, $\eta^2 = .10$. Follow-up paired-samples t-tests were performed comparing average detection distance between levels of speed within each level of age, with a Bonferroni correction of

.05/6 applied. Results indicated average detection distance was significantly different at all levels of speed within each level of age, and increased significantly with level of speed. Follow-up independent-samples t-tests were performed comparing average detection distance between levels of age within each level of speed, with a Bonferroni correction of .05/4 applied. Results indicated average detection distance was significantly greater for older participants at each level of speed with the exception of the 5 mph condition, and the difference by age grew larger as speed increased. Indeed, the difference appeared to be strongest in the 35 mph condition, in which older participants more often detected approaching vehicle noise equivalent to a distance of 1000 feet or more (66%) versus younger participants (31%).

Direction Accuracy. Direction accuracy (the percentage of correct decisions about whether the vehicle was approaching from the left or right) were examined in a repeated-measures ANOVA speed (4) X direction (2) X age (2). Again, means and standard deviations are presented in Table 1. Direction accuracy did not differ by speed, F (3, 204) = .43, p > .05, $\eta^2 = .00$. Direction accuracy did not differ significantly by direction of vehicle travel, F (1, 68) = .14, $p > .05$, $\eta^2 = .01$. No main effect was also found for age group, F (1, 68) = .22, $p > .05$, $\eta^2 = .00$. Thus, the percentage of times participants were correct about the direction from which vehicles were approaching did not differ significantly by speed, direction of approach, or age. Participants correctly determined the direction from which vehicles were approaching on average 70% of the time ($m = .70$, $sd = .20$).

Unacceptable Distance. Unacceptable distance (the vehicle's distance in feet from the listener when they would no longer step out in front of the approaching vehicle) was examined in a repeated-measures ANOVA speed (4) X direction (2) X age (2). A significant main effect was found for speed, *F* (3, 168) =562.53, $p < .01$, $\eta^2 = .91$. Bonferroni post-hoc tests indicated unacceptable distance was significantly different from one another at all levels of speed (see Table 1); unacceptable distance increased significantly at each level of speed. A significant main effect also was found for direction of approach, *F* (1, 56) = 34.97, $p < .01$, $\eta^2 = .38$. Unacceptable distances were significantly greater when vehicles approached from the right. Finally, a significant main effect was found for age group, *F* (1, 56) = 6.92, $p < .05$, $\eta^2 = .11$, with unacceptable distance being significantly greater for older versus younger participants.

A significant speed X age interaction was found (see Figure 3), *F* (3, 168) = 9.48, $p < .01$, $\eta^2 = .15$. Follow-up paired sample t-tests were performed comparing average unacceptable distance between levels of speed within each level of age, with a Bonferroni correction of .05/6 applied. Results indicated average unacceptable distance was significantly different at all levels of speed within each level of age, and increased significantly with level of speed. Follow-up independent-samples t-tests were performed comparing the average unacceptable distance between levels of age within each level of speed, with a Bonferroni correction of .05/4 applied. Results indicated average unacceptable distance was significantly greater for older participants only in the 25 mph and 35 mph conditions; i.e., the difference by age grew larger as speed increased.

Relations between Speed of Processing and Auditory Detection

Relations between speed of processing and indices of auditory detection were examined in a series of hierarchical multiple regression analyses. Prior to beginning analyses, the two indices of speed of processing were aggregated in a series of steps. First, PCT scores were centered and reversed, as higher raw PCT scores indicated faster speed of processing whereas higher raw CNT time scores indicated slower speed of processing. Next, both PCT and CNT scores were standardized. Finally, scores from both measures were averaged together. The resulting scores functioned as an aggregate index of speed of processing such that higher scores indicated more problems with speed of processing.

Three hierarchical multiple regression analyses were then performed. In each analysis an index of auditory detection or localization was regressed onto walking time and physical activity in the first step, and walking time, physical activity, and speed of processing in the second step. Relations between predictor and dependent variables are shown in Table 2. Results of each regression analysis are shown in Tables 3-5. Speed of processing did not contribute significantly above and beyond variance in detection distance accounted for by indices of physical activity, which together explained 11% of the variance (see Table 3). Similarly, no significant results were found in the model tested for correct decisions about direction of vehicle approach (i.e., Table 4). However, in the final analysis the addition of speed of processing accounted for a significant increase in variance explained in unacceptable distance, offering evidence that cognition indeed plays at least a small role in auditory detection and localization. In this final analysis, slower speed of processing was predictive of larger unacceptable distance.

Chapter 4: Discussion

The current study examined detection and localization of approaching vehicle sounds among younger and older adults, and whether such factors were related to speed of processing. Similar to previous research, significant results were found for speed, age, and speed by age interactions. Results for detection and localization, as well as speed of processing will be discussed separately below.

Auditory Detection and Localization

Age Differences. Age differences were found between younger and older participants for detection distance and unacceptable distance, but not direction accuracy. Older adults detected approaching vehicle noise from significantly greater distances than the younger adults. One explanation for this result may be that older participants focused more intently on the task of detecting vehicle noise. Older participants in a real environment, for example, may be faced with a task in which they have less room for error (e.g., the need for greater walking time) and therefore would want to detect a vehicle as early as possible to allow more walking time.

Unacceptable distance showed older adults would no longer cross the street in front of the approaching vehicle at greater distances than younger adults. Perhaps older adults carried behavioral tendencies into the laboratory that they would normally use in a real pedestrian setting. A possible explanation for choosing greater minimum acceptable distances among older adults may have been compensation for limits in physical and/ or cognitive resources (e.g., Oxley et al., 2005). Thus greater unacceptable distances would translate to older adults having more crossing time than younger adult participants.

Detection Distance. Detection distances followed a pattern found in previous research (Barton et al., 2012; Ulrich et al., in press): participants were able to detect approaching vehicles at greater distances as speed increased. Results in the present study were most similar to those found in (Barton et al., 2012), in which participants were able to detect approaching vehicles above an average of 700 feet away. Overall, the present study offers additional evidence that detection of approaching vehicles varies by vehicle speed.

However, exactly why faster moving vehicles can be detected at increasing distances remains to be explored.

Detection distances also were greater in the present study than in past studies. Some participants (more often older ones) detected vehicles more than 1000 feet away. Again, a possible explanation for this finding could be the introduction of distracter noises. While some additional noises could occlude the vehicle noise (e.g., Ulrich et al., in press), noises added in the present study may have actually had the unintended effect of increasing participants' focus of attention on the noise of approaching vehicles. In other words, participants may have simply listened more carefully because of the presence of a distracter. Another explanation could be that when a pedestrian is attending/listening to approaching vehicle noise the distinctive sound "fingerprint" may be fundamentally different at various speeds. Examination of the sound characteristics themselves was beyond the scope of the present study, but one cannot rule out the possibility of a combined effect of distracters, qualitative differences in sounds across levels of speed, and use of a different methodology (i.e., speakers).

Direction Accuracy. Direction accuracy did not follow the pattern found in previous studies. Previous work found significant differences by age groups (although comparisons were with children), significant difference between left and right approach, and performance overall was more accurate (Barton et al., 2012; Barton et al., 2013; Ulrich et al., in press). At least two explanations can be offered. First, participants in the present study had to contend with distracter noises, which could have forced focus to be greater on detection. Alternatively, addition of distracter noises added realism to the study and could have made determining direction accuracy was more difficult. Second, use of new methodology (i.e., speakers) could have made the simulation more realistic and yielded performance scores that were more indicative of performance in a real environment.

Our results are rather interesting for several reasons in spite of, and in part because of, being non-significant. First, unlike detection distance and unacceptable distance, direction accuracy did not differ significantly across speed. One possibility for this lack of significance could be the ages of participants. In previous work using a young adult sample (Barton et al., 2012), direction accuracy was more accurate when vehicles were travelling faster and when vehicles were approaching from the left. In our data, older participants showed no real difference in accuracy across speeds and directions of approach, whereas a trend was emerging among younger participants to be more accurate as speed increased and approach was from the right. Thus, perhaps differences in direction accuracy could be confined to younger participants in general. Furthermore, no significant main effects were found for age, which is different from past studies in which adult participants were more accurate than young children (Barton et al., 2013). One possible reason could be that in the present study two groups of adults were being compared, rather than adults compared to children. Perhaps once individuals reach adulthood, certain aspects of auditory detection and localization plateau and others continue to show age differences. Second, participants were correct only about 70% of the time when determining direction. Accuracy of 70% is much lower than in past studies, in which adults had approximately 90% or greater accuracy in determining direction (Barton et al., 2013) and young children’s accuracy was approximately 60%. Third, younger and older adults may not have differed significantly in direction accuracy, but could have made decisions while vehicles were at different distances. Although examination of such differences were not possible within the current data, further inquiry into the possibility of such differences would be interesting.

Unacceptable Distance. The current study included a new participant response concerning unacceptable distance for crossing. Unacceptable distance has not been examined in past studies and offers new insight into pedestrians' use of auditory cues, and a hypothetical extension to implications for safety. Results were intriguing. First, average unacceptable distance increased significantly at each level of speed, which is not entirely surprising as pedestrians would want more time to cross in front of a faster moving vehicle. Pedestrians may recognize the greater potential for catastrophic injury with increasing vehicle speed, although that realization was not assessed in the present study. Second, average unacceptable distance was significantly greater for older adults. One potential explanation could be older adults were compensating for declines in physical and perceptual abilities, so increasing their unacceptable distance would allow them greater time to make a street crossing. Older adults did indeed have greater walking time in the present study, although self-reported physical activity did not differ significantly between age groups. However, whether compensatory strategies were being used remains to be explored in future research.

Interactions. Results from this and previous studies show that speed and age are important when attempting to understand pedestrians' use of auditory cues. However, one cannot understand the importance of speed without taking into account the age of the listener. Likewise, the importance of age cannot be understood without taking into account the various speeds related to the approaching vehicle noise with which they were working. For example, when an older adult is making a decision to cross the street their predicted performance cannot be understood without knowledge of the traffic environment at hand, and more specifically at what speeds are the vehicles moving at per hour.

Unique to the current study, two different adult age groups were compared. Previous research conducted by Barton et al. (2013) also found a speed X age interaction, with adults performing better than children. The present study showed, while adults performed better than children in previous work, adult-level performance is not constant and developmental differences may persist across the lifespan. However, important to note is that the present study did not focus on why age differences occurred between younger and older participants, but at least one explanation can be offered: perhaps with increasing age comes life experience, which assists older individuals with making wiser and more cautious decisions, especially in the context of physical ability.

Speed of Processing and Auditory Detection and Localization

Relation of developmentally changing cognitive skills to detection and localization has a logical extension to other aspects of the pedestrian task. Notably, age-related physical, cognitive, and perceptual limitations in older pedestrians would increase the likelihood of making a risky decision when crossing the street (Langevin, et al., 2011). Decisions to cross are based on perception and processing of information, and thus any lack of efficiency in processing information that functions as safety cues in the pedestrian setting should result in less accurate decision making. In the pedestrian context, less accuracy in decision making results in increased risk of injury. For example, older pedestrians may fail to detect oncoming vehicles and, in conjunction with deteriorating physical abilities, be unable to adjust their travel and cross the road quickly enough to dodge oncoming traffic.

Analysis of speed of processing in regards to auditory detection distance lacked significant results, nonetheless a trend emerged between speed of processing and detection distance. Specifically, the more problems that occurred with processing, the greater the average detection distance. This trend emerged in correlations, but not in later regression analyses. On the other hand significant results were found for unacceptable distance, which showed speed of processing is indeed relevant and is relevant above and beyond a person's physical activity level. The more problems with speed of processing, the greater the average minimum acceptable distance participants chose. Older adults tended to have greater average unacceptable distances, which mean that they would indicate earlier, and at greater distances, than younger adults. The findings show that older adults in general wanted more time to allow for a safe street crossing.

Several possible explanations exist for the general lack of significant results for speed of processing and detection and localization. One reason could have been the effect size of the relationship between cognition and auditory detection is small, and would require obtaining a much larger sample. In fact, other studies have suggested relations between cognition and pedestrian skills could be difficult to detect (Kovesdi & Barton, 2013). A second explanation could be the wrong aspect of cognition was examined. A third reason could be that cognition simply does not play a large role in auditory detection and could be more relevant to use of visual cues.

Limitations

As with any study, some limitations exist. First, the present study lacked some mundane realism, which limits ability to generalize to everyday pedestrian settings. However, the study was done in a controlled lab setting, which will allow for a clearer identification of variables in question. A second limitation is our results are not indices of human ability. That is, readers should use caution when interpreting data in terms of the actual capability of adult pedestrians when using auditory information. Third, our sound stimuli included only five vehicles. Although sound stimuli included vehicles common on American roadways, future work could include sounds from larger commercial vehicles or from smaller vehicles such as motorcycles. Different patterns of localization and detection could occur in response to other vehicles with various body types and/ or engine types. While testing of such relationships was beyond the scope of the present study, knowledge of pedestrians' responses to sounds of larger vehicles is an important factor to consider in future research in order to better understand the full scope of factors at play in the pedestrian setting. Fourth, the present study used a cross-sectional design. In any cross-sectional design, one must consider the potential for cohort effects in any study including participants from various generations. Fifth, a limited number of distracter stimuli were used in the present study. In any pedestrian environment, a wide variety of additional stimuli could be present. However, our intention was to simply include several stimuli that would be common to many pedestrian settings rather than attempting to encompass all types of stimuli.

Conclusion and Future Directions

The current study adds to the growing knowledge of use of auditory cues in pedestrian settings. A large portion of what adult pedestrians attend to and process in the traffic environment are visual, however hearing is another modality in which pedestrians obtain information from the environment. Accordingly, examination of how pedestrians use auditory information and what capabilities pedestrians have is of great importance for understanding and preventing pedestrian injuries and fatalities.

Differences between older and younger adults' performance on our auditory detection and localization task raise new questions and open new avenues of exploration. Although we found limited results for the role of cognitive ability in detection and localization, our results should not be taken to mean cognitive ability does not play a role. Researchers should further explore whether older adults' performance is based on cognitive ability in order to determine whether other aspects of cognition may be more relevant, or whether cognition overall may impact use of auditory cues in very specific ways. Future research should also examine whether older adults engage in strategies of compensation to allow themselves more time to cross, especially in conditions of high speed, high traffic volume environments with a high degree of auditory distraction, or in environments that include visual occlusions (e.g., curves) requiring auditory information to be used in decision making.

Injury prevention efforts could include design changes for older adult pedestrians' declining abilities. Including redundancy triggered by a distance threshold, for example, for the approaching vehicle during street crossings is one way this could be accomplished. For example, if a street crossing is situated near, or within, a curve in the roadway vehicle sounds could be occluded by the curve. The result would be a shorter detection distance with which the pedestrian has to work, which will lead to an unintentional or uninformed decision to cross the street. Traffic engineering could include installation of an alarm triggered by approaching vehicles crossing a threshold, thus allowing pedestrians more information on which to base their crossing decision. Other solutions may include customization of the approach signal to pedestrians' walking speeds, recorded as they approach the crossing location, to allow pedestrians more time to cross. Overall, the results of the present study afford researchers, public health professionals, engineers, and community planners more information about older pedestrians' abilities around which they may implement solutions for injury prevention.

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Table 1

Means and (standard deviations) for detection and localization variables by speed and direction

	Detection Distance	Direction Accuracy	Unacceptable Distance
Left – to – Right 5mph	45.36 (13.55)	.69 (.24)	10.21 (9.05)
Older	47.89 (13.54)	.66 (.22)	10.17 (8.65)
Younger	45.83 (13.28)	.72 (.25)	10.25 (9.56)
Left – to – Right 12mph	166.01 (41.12)	.72 (.22)	55.10 (25.72)
Older	182.60 (37.17)	.74 (.22)	59.27 (23.38)
Younger	149.42 (38.52)	.70 (.24)	50.93 (27.56)
Left – to – Right 25mph	503.52 (88.58)	.69 (.23)	203.11 (78.32)
Older	531.61(78.48)	.72 (.21)	222.81 (77.70)
Younger	475.43 (90.21)	.66 (.24)	183.41 (74.92)
Left – to – Right 35mph	926.78 (163.87)	.68 (.24)	387.84 (155.45)
Older	982.61 (130.42)	.71 (.25)	450.45 (146.99)
Younger	870.95 (176.26)	.65 (.23)	325.25 (139.14)

Note. *N* = 50. Units for detection distance and unacceptable distance are in feet. Direction accuracy is the percentage of correct responses.

Table 1 continued

Means and (standard deviations) for detection and localization variables by speed and direction

	Detection Distance	Direction Accuracy	Unacceptable Distance
Right – to – Left 5mph	47.81 (13.07)	.69 (.25)	13.59 (10.35)
Older	51.25 (12.40)	.68 (.27)	12/29 (11.53
Younger	44.38 (12.99)	.70 (.23)	14.89 (9.01)
Right – to – Left 12mph	182.36 (41.95)	.71 (.24)	63.52 (27.70)
Older	197.02 (38.18)	.68 (.25)	70.89 (25.93)
Younger	167.70 (40.88)	.73 (.23)	56.14 (27.79)
Right – to – Left 25mph	559.92 (100.21)	.71 (.27)	238.45 (85.44)
Older	590.41 (87.89)	.67 (.27)	268.57 (76.31)
Younger	529.45 (103.65)	.77 (.25)	208.33 (84.40)
Right – to – Left 35mph	993.62 (143.18)	.72 (.27)	434.60 (167.93)
Older	1036.03 (123.57)	.68 (.30)	495.16 (152.40)
Younger	951.21 (150.44)	.75 (.23)	374.04 (162.65)

Note. *N* = 50. Units for detection distance and unacceptable distance are in feet. Direction accuracy is the percentage of correct responses.

Table 2

Means (Standard Deviations) and Correlations between physical ability, speed of processing, and indices of auditory detection and localization

Variables	Mean	2	3	4	5	6
1. Walking time	5.85 (0.64)	-.20	.64**	.31**	-.07	.13
2. Physical activity	3.30 (0.81	—	-.19	-.18	-.01	-.26*
3. Speed of processing	0.00 (0.89)		—	.36**	-.04	.30*
4. Detection distance	428.21 (71.15)			—	.04	.49**
5. Direction of Accuracy	.70 (.15)				—	-.06
6. Unacceptable Distance	175.92 (64.17)					—

Note. $N = 70$. * $p < .05$. ** $p < .01$.

Table 3

Linear Regression Predicting Detection Distance

Predictors	*B*	*SE*	β	R^2	Δ R^2
Step 1					
Walking time	31.55	13.00	.28*		
Physical activity	-10.61	10.43	-.12	.11*	
Step 2					
Walking time	12.71	16.46	.12		
Physical activity	-9.03	10.27	-.10		
Speed of processing	21.63	11.91	.27	.15	.04

Note. $N = 70$. * $p < .05$. ** $p < .01$.

Table 4

Linear Regression Predicting Direction Accuracy

Predictors	*B*	*SE*	β	R^2	ΔR^2
Step 1					
Walking time	-.00	.02	-.02		
Physical activity	-.02	.03	-.08	.01	
Step 2					
Walking time	-.00	.02	-.02		
Physical activity	-.02	.04	-.08		
Speed of processing	.00	.03	.01	.01	.00

Note. $N = 70$. * $p < .05$. ** $p < .01$.

Table 5

Linear Regression Predicting Unacceptable Distance

Predictors	*B*	*SE*	β	R^2	Δ R^2
Step 1					
Walking time	7.94	11.98	.08		
Physical activity	-19.07	9.58	-.24	.07	
Step 2					
Walking time	-13.44	14.96	-.14		
Physical activity	-17.28	9.33	-.22		
Speed of processing	24.55	10.82	.34*	.14*	.07*

Note. $N = 70$. * $p < .05$. ** $p < .01$.

Figure 1

Auditory Speaker Arrangement

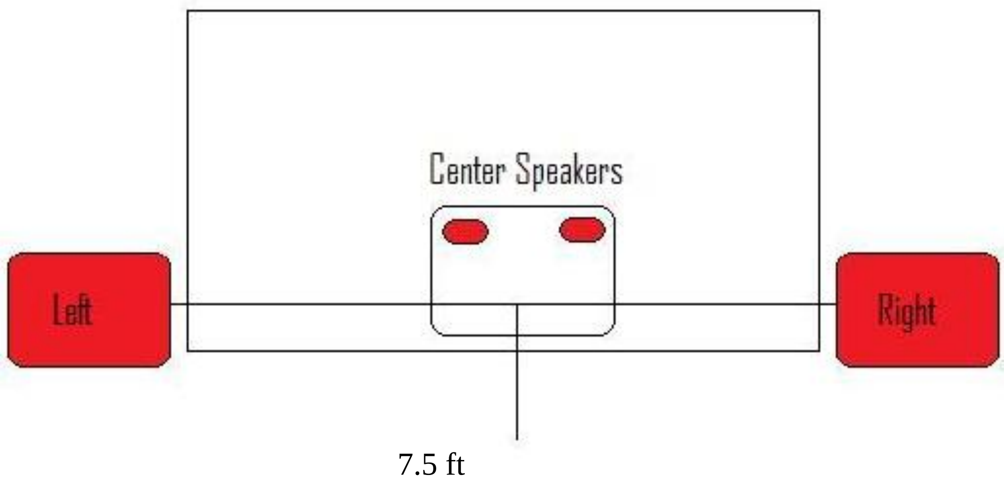

Figure 2

Speed X Age Interaction for Detection Distance (in feet)

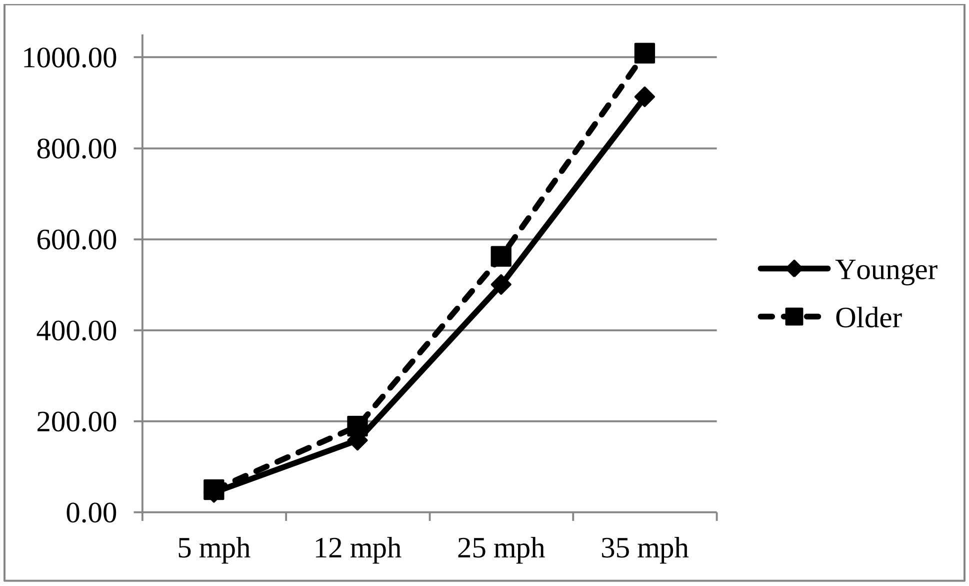

Figure 3

Speed X Age Interaction for Direction Accuracy (Percentage of correct direction selections)

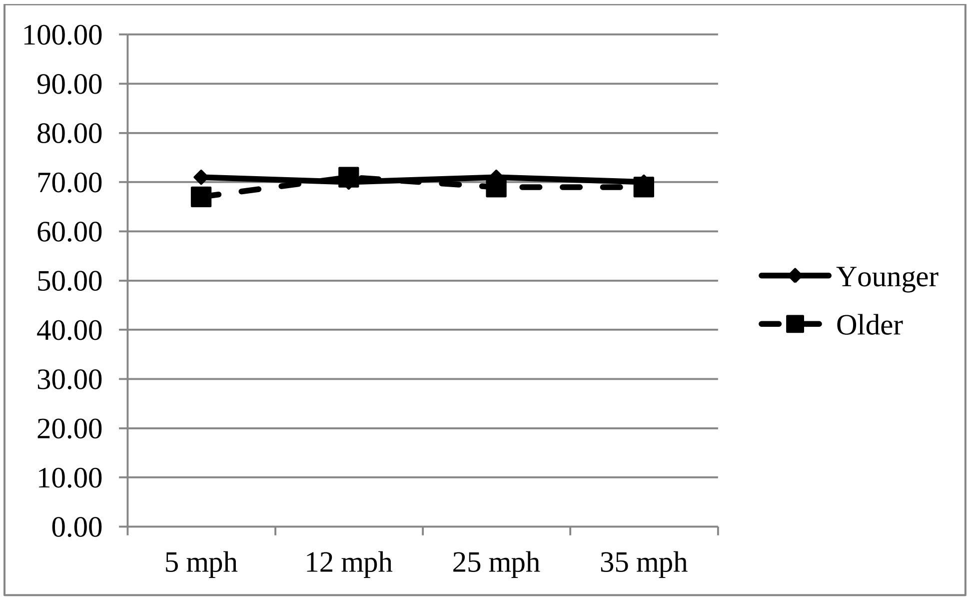

Figure 4

Speed X Age Interaction for Unacceptable Distance (in feet)