

The Effects of Simulated Hearing Loss on Simultaneous Speech Recognition and Walking Navigation Tasks

by Paul Fedele, Rachel Weatherless, Kathy Kehring, and Tomasz Letowski

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Human Research Engineering Directorate, ARL

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14. ABSTRACT This study assessed whether a concurrent but independent navigation task exacerbates effects of hearing loss on speech recognition and whether hearing loss degrades performance of the navigation task when performed during the independent listening task. Previous studies showed that vehicle operation performance decreases when crew instruction communication is impaired, but it remains unknown how performance would be affected if the vehicle operation were independent of this communication process. Participants performed a listening task by responding to Callsign Acquisition Test (CAT) stimuli at three simulated hearing levels. For each hearing level, the participant performed one trial while stationary and another trial while navigating a path in a virtual environment using a hand-held map. Additionally, participants navigated a path with no CAT. The proportion of correctly repeated callsigns was used to measure speech recognition performance. The total walking time measured performance on the walking navigation task. CAT scores showed an expected negative effect of hearing loss. Concurrent navigation produced an even larger decrease in CAT scores. Hearing loss caused an insignificant decrease in navigation task performance. These results demonstrate that, while walking, a person with hearing loss may communicate less effectively than predicted from hearing loss alone. Conclusions and recommendations are given.				
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Summary

Hearing losses, temporary and permanent, are significant problems in military combat; however, the impact of hearing loss on the task performance of Soldiers remains uncertain. Hearing loss naturally leads to decreased speech intelligibility. Previous Army studies have evaluated how decreased speech intelligibility degrades task performance for fighting vehicle crews. These studies did not determine if the degraded task performance was due to failures in communicating task variables, or to a decreased availability of attentional resources needed for successful task execution. More recent research studies have demonstrated degradation of walking task performance when listening, speech, and other mental tasks are performed at the same time. Multiple resource theory indicates that this degradation is due to reduced of attention applied to the walking task because some attention was usurped in performing the listening, speech, and other mental tasks.

The study presented in this report addressed the question of whether hearing loss, which may cause a further increase in attentional requirements over listening without hearing loss, can cause further decreases in the performance of concurrent, non-hearing related tasks. To address this question, participants walked along a path in a virtual reality environment; the path was given to them on a paper map, just before they began walking. While walking, they were required to listen and respond verbally to a Callsign Acquisition Test (CAT) task, which was presented to them at three filtered levels simulating how the CAT stimuli would sound if the listener had various levels of hearing loss.

Analyses of CAT and walking performance were used to determine if walking performance degradation increases with the levels of increasing hearing loss with which the CAT stimuli were presented. The simple navigation task used in this study had a significant adverse influence on the speech-recognition task performance when a simulated hearing loss was applied. This implies that hearing loss caused an increase in resources needed to perform speech communication and walking tasks simultaneously. This influence may be important not only in the case of a permanent threshold shift but even for a temporary threshold shift, which a Soldier may experience on the battlefield. This implies that, if a Soldier were to experience hearing loss, their speech recognition ability could decrease further if the Soldier was moving about.

Although multiple resource theory includes a multiple task interaction capable of reducing walking performance due to an increased demand for attention caused by listening difficulty associated with hearing loss, the magnitude of this interaction depends on details of the specific tasks. If both tasks are easy, the interaction can be small. We observed no significant effect of simulated hearing loss on the simple navigation task performance. This may be a result of the relatively easy navigation task. This also may have occurred because, as the overall workload increased, the listening task was given less attention, allowing performance of the navigation

task to remain unperturbed. In contrast to our conclusion that hearing loss causes the walking task to produce a significant adverse impact on the hearing task, we conclude that, hearing loss does not cause the speech-recognition task to produce a significant impact on the walking task. In the context of our specific militarily relevant tasks, we conclude that the effects of speech recognition difficulties on independent walking task performance remain of little concern.

1. Introduction

Loud impulsive and continuous noises produced by weapons and military vehicles cause significant hearing loss among many U.S. service members. Hearing loss is a widespread, severe, and costly problem to many military veterans returning from service. (National Research Council, 2006). Although hearing conservation programs exist and hearing protection devices are available, these measures have limited effectiveness (Saunders and Griest, 2009). The most significant impact of hearing loss is that it degrades the Soldier's ability to understand direct commands and radio messages making it more difficult for the Soldier to operate as a member of a squad and increasing the Soldier's vulnerability. While hearing loss is a significant problem among dismounted infantry veterans (National Research Council, 2006), how hearing loss can effect dismounted operations and the full impact of hearing loss on dismounted operations remain unclear.

1.1 Degraded Military Communication and Secondary Task Performance

The impacts of reduced intelligibility and difficulty of hearing have been demonstrated in simulation studies using combat vehicle and aircraft environments. As intra-crew communication intelligibility decreased, combat performance metrics degraded: the time to identify enemy targets increased, the number of enemy targets destroyed decreased, the number of friendly targets destroyed increased, and the number of casualties (simulated) among vehicle crews increased (Garinther and Peters, 1990; Garinther et al., 1989, 1990, 1994; Peters and Garinther, 1990; Whitaker, 1991). In the case of the aircraft environment, flight characteristics, such as speed and altitude, became more varied and deviations from the prescribed flight path increased under combinations of increased workload, poor communications signal quality, and decreased speech intelligibility (Valimont et al., 2006; Casto and Casali, 2010). In general, as intelligibility of the task-related communications decreased, over ranges achievable by degraded communication systems or hearing loss, the task performance also decreased in an almost linear manner (Garinther and Peters, 1990).

Many studies have demonstrated the impact of decreased communication on the performance of mounted combat vehicle crews, but few similar studies address the impact of hearing difficulty on dismounted Soldier performance. The information and psycho-physical resources required to perform dismounted Soldier activities certainly differ from those needed by vehicle crews in mounted combat vehicle operations. In addition, the environmental threats, threat priorities, threat-induced stresses, and workloads (physiological and cognitive) are different between mounted and dismounted operations. Thus, the impact of communication difficulties on dismounted Soldier performance cannot be assessed from the impact of such difficulties on mounted performance.

1.2 Ways Hearing Loss Can Influence Secondary Task Performance

To fully evaluate the complete impact of hearing loss on dismounted Soldier performance, we must consider the many mechanisms by which hearing loss can impact Soldier performance.

1.2.1 A Failure to Communicate

One way that hearing loss can impact Soldier performance of secondary tasks is by creating a failure to communicate. If critical information needed to properly perform the secondary tasks cannot be fully comprehended, then performance of the secondary tasks is certain to degrade. In Garinther's and Whitaker's studies (Garinther and Peters, 1990; Whitaker, Peters, and Garinther, 1989; 1990), the metric tasks performed were not independent of the information being communicated by the speech and hearing processes. Successful vehicle crew performance depended on information in the compromised speech messages; therefore, when the critical information was not communicated, the secondary task performance had to degrade. A similar inference can be made regarding the data obtained by Whitaker et al. (2003) using a dual-task instruction-driven game playing task. In general, if the secondary task depends on information being communicated under compromised conditions, then performance of the secondary task must degrade as the communication degrades. As Peters and Garinther (1990) showed, the performance degradation of both tasks is nearly linearly related. When communication is 100% effective, the tasks are performed error free, with nearly 100% effectiveness, and when communication is 0% effective, the tasks are performed with no success, or with nearly 0% effectiveness.

To fully consider the operational impact of hearing loss on human performance, we need to consider the possibility of hearing loss effects on concurrent secondary tasks that do not directly rely on information being transferred through a compromised hearing process. We say such secondary tasks are "independent of the listening and hearing tasks" indicating that the secondary task performance is not dependent on information being transferred through the compromised auditory process.

Failure to communicate is a recognized and studied process by which hearing loss can impact secondary task performance. However, it is far from the only way that hearing loss can influence performance.

1.2.2 Attention Overload

Listening to a difficult-to-hear auditory signal can require more attention than listening to an easy-to-hear signal. Attention is a physiological resource that often limits single and dual task performance. We consider attention to be mental concentration on a task or activity. Attention is greater when the concentration is less often interrupted by stimuli from other unrelated tasks or activities. Thus, greater attention is required to increase one's mental receptivity by narrowing the range of perceived stimuli to those associated with the particular task, activity, or process that is the object of the attention.

Dividing attention between multiple tasks involving various modalities produces varied effects on task performance, depending on the number of tasks; their difficulty, interrelation, and relative priorities; and experience and capabilities of the person performing these tasks (Wickens, 2002; Wickens et al., 2003). The complex demands of multitasking are most commonly examined in research involving dual task performance (Damos, 1991). The two concurrent tasks can be discrete, continuous, or combinations of both. Both tasks can be physical or cognitive or one of them can be of each kind. One of the tasks can be the primary task or both tasks can be equally important. In real life scenarios, the relative importance of individual tasks can also shift from one to another and back as the mission progresses.

When both of the tasks are performed concurrently, the performance of each of the tasks usually decreases in comparison to the single-task performance (Wickens, 1991; Horrey and Wickens, 2003). As reported by several authors, attention and training are important factors in ensuring completion of several concurrent time-critical tasks that require divided attention (Bherer et al., 2005; Strayer and Johnston, 2001; Strayer et al., 2003). Hafter et al. (1998) suggested that the primary determinant of cost in dual task activities, which involve signal detection and signal identification processes, is the cognitive processing mode used by the performer. They cite two cognitive processing modes. One is the sensory trace mode, in which signal changes are detected by comparing a signal at one time to the immediately preceding signal. The other is the internal absolute standards mode, where a signal change is identified by comparing its level to a collection of standard levels developed by experience and held in longer-term memory. The authors argued that sensory trace processes do not produce a performance decrement in dual-task activities, while internal absolute standard processes do. In addition, the decrease in dual-task performance has been reported to be a function of aging and degree of similarity between the tasks involved (e.g., Hartley and Little, 1999; Holtzer et al., 2005; McDowd and Shaw, 2000; Navon and Miller, 1987; Verhaeghen and Cerella, 2002).

The mechanisms underlying performance decrements resulting from dual-task activities have been conceptually described by multiple resource theory (Wickens, 1991). However, while dual-task activities have been studied extensively, it is still unclear whether dual-task performance is limited by certain centrally shared attentional resources, a single channel capacity level that operates on one of the tasks at a time (the bottleneck theory), or processing crosstalk (Pashler and Johnston, 1998). It is clear, though, that decrements in dual-task performance depend on many uncertain psychological, cognitive, and physical factors, as well as detailed aspects of the specific tasks (Wickens et al., 2003). Therefore, regardless of the actual mechanisms affecting dual-task performance, empirical experimental evaluation remains invaluable in quantifying performance in dual-task scenarios.

Military activities often involve concurrent performance of several time-critical tasks involving both mental and physical activities. For the dismounted Soldier, an example of such a situation is attending to radio traffic while conducting other tasks frequently unrelated to the radio traffic, such as walking, running, and visually searching for battlefield threats. When hearing is

degraded, additional attention may be required to understand verbal signals and auditory cues. Such increased attention requirements may interfere with motor tasks, even if the motor tasks do not depend on received auditory information. Strayer and Johnston (2001) assessed the effects of cellular phone conversations on simultaneous driving performance and reported a two-fold increase in failures to detect traffic signals and substantial delays in reaction to the signals that were presented and detected. Beauchet and Berrut (2006) observed decreased performance in dual-task activity involving response to verbal messages and walking. Similarly, Hatfield and Murphy (2007) and Nasar et al. (2008) reported the use of a mobile phone caused a decrease in situation awareness and an increase in pedestrian behavior judged unsafe. Certain people with compromised neurological capabilities stop walking when they enter into a conversation (Beauchet et al., 2009; Hyndman and Ashburn, 2004; Lundin-Olsson et al., 1997), indicating that attention required by verbal and auditory processes can decrease walking performance. A dual task study using healthy young adults demonstrated that executive attention requirements increase during performance of increasingly more complex gait tasks (Siu et al., 2008). Thus, reported research findings indicate that the impact of hearing loss may extend well beyond the normal reduction in communication ability.

The results obtained in Garinther's and Whitaker's studies (Garinther and Peters, 1990; Whitaker et al., 1989, 1990) might have involved two different and distinct processes. One process would involve a failure to communicate information needed to properly execute the task. A second different and distinct process might have involved an increase in attention allocated in trying to comprehend the spoken instructions. The increase in required attention might have increased task error rates, even though information transfer was fully successful. In Garinther's and Whitaker's referenced studies, the impact of attention requirements cannot be determined from the reported data and the impact of hearing-related attention requirements in dismounted Soldier operations remains unknown.

1.3 Purpose of the Study

The goal of this study was to determine to what degree hearing loss influences the performance of a listening task and a concurrent navigation task. This task combination is of high relevance to dismounted Soldier operations. Since we already recognize that the performances of dependent tasks will vary together, the listening and navigation tasks performed in this study were designed to be independent. Our test design allowed us to investigate the impact of hearing loss on performance of two concurrent but independent tasks and on each of these tasks in isolation. Our working hypothesis was that the adverse impact of hearing loss will be greater during the simultaneous performance of listening and navigating tasks, than during the performance of the listening task as a single task. We also hypothesized that hearing loss might decrease the navigation task performance, even though the navigation task requires no input from the listening task.

2. Methodology and Procedures

2.1 Participants

A group of 16 Army civilian employees between 20 and 45 years old participated in the study. Nine of the participants were male and seven were female. Although the tasks performed in this study were similar to tasks Soldiers perform during military operations, military training or experience were not required to successfully execute the performed tasks. Participants were required to be in good physical condition and able to walk for up to 2.8 miles on the Human Research and Engineering Directorate's Omni-directional Treadmill (ODT) (MTS Systems Corp., Eden Prairie, MN, and Virtual Space Devices Inc., Bloomington, MI) which is described later in this report.

All participants had normal bilateral hearing defined as 25 dB HL (hearing level, in reference to standard audiometric threshold) or better hearing thresholds measured with pure-tone air conduction audiometry at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. Normal outer ear status and middle ear function was confirmed by otoscopy and ear impedance testing, respectively. Normality of vestibular function was assessed by asking the participants about any cases of chronic vertigo (none) and observing participant behavior during the ODT walking training session. Two potential participants incurred light vertigo during ODT training sessions and were disqualified from the study. Informed consent was obtained from each qualified participant prior to their participation in the research study. All data were collected in compliance with regulations from the Institutional Review Board at the U.S. Army Research Laboratory.

2.2 Instrumentation

Test stimuli. The Callsign Acquisition Test (CAT) (Rao and Letowski, 2006), developed for testing recognition of militarily relevant speech material, was used to measure the speech recognition ability of the participants under all test conditions. We used six pre-recorded CAT stimuli series (versions 1–6), each of which contains 126 callsign items. A single item consists of a word and a number. The word is a two-syllable military alphabet code and the number is a one-syllable number (e.g., alpha 1 or bravo 2). The CAT phrases were played using Sound Forge® software (version 6, Sony Creative Software, Middleton, WI) on a Dell® Desktop Personal Computer Model 620 through a Shure® Wireless Personal Monitor System PSM 200. The participants heard the phrases through a pair of Coby® Sound Isolation Digital Stereo CVE31 Earphones. A Sennheiser® Evolution Wireless Microphone System EW 322 G3 was used to acquire the participants' voiced repetition of the CAT stimuli, which were recorded on a Dell® Laptop Personal Computer Model PP10L.

Simulated hearing loss levels. Military functional capabilities for hearing criteria are profiled as H1 to H4. Condition H1 corresponds to normal or better hearing; conditions H2, H3, and H4 correspond to mild, moderate, and severe hearing impairment, respectively. The specific hearing threshold levels for each hearing profile are specified in Army Regulation 40–501 (Department of the Army, 2008, p. 80). To simulate auditory abilities of people with normal hearing (profile H1) and with two different levels of hearing impairment (profiles H2 and H3), a normal version and two modified versions of the CAT were presented to participants. H4 was not used. To simulate H2 and H3 hearing profiles, two audiometric pure-tone hearing-threshold configurations representative of H2 and H3 types of hearing were used. Hearing loss representative of the H2 hearing profile was simulated by decreasing signal spectrum levels by 15 dB at 500 Hz, 30 dB at 1000 Hz and 2000 Hz, 45 dB at 3000 Hz and 4000 Hz, and 55 dB at 6000 Hz. Hearing loss representative of the H3 hearing profile was simulated by decreasing signal spectrum levels by 20 dB at 500 Hz, 35 dB at 1000 Hz and 2000 Hz, 55 dB at 3000 Hz and 4000 Hz, and 65 dB at 6000 Hz. Both simulated profiles were bilaterally symmetrical. Spectral equalizations as mentioned above are commonly used in audiology to simulate hearing loss for patient education, research, and development of hearing aids (Desloge et al., 2010; Rawool, 2012).

To simulate normal hearing, the CAT items were presented at the participant's selected most comfortable listening level for listening in ODT noise (see The ODT section, paragraph 3, figure 2). All volunteers participating in the study had hearing reflecting individual differences within normal hearing criteria and such small differences can alter the audibility of the test signals. Therefore, to compensate for some of these individual differences, the volunteers were asked to adjust their earphone signal level at the H1 listening condition to match their self-assessed most comfortable listening level and to use this earphone setting at all other hearing level conditions. This adjustment was made prior to data collection by having the participant walk on the ODT with the ODT noise, listen to CAT stimuli presented over their earphone set, and adjust the volume of their earphone set to their most comfortable listening level. The participant was instructed not to change the earphone volume after the most comfortable listening level was set.

The ODT . Walking navigation was conducted using an ODT located in the Immersive Environment Simulator (IES). The IES is a simulator for the dismounted Soldier that combines the ODT with visually immersive virtual environments enabling natural locomotion through the environments. The IES integrates a RAVE II display, the ODT, and a camera-based motion tracking system. The RAVE II (Mechdyne Corp., Marshalltown, IA) is a reconfigurable video display system consisting of four 3.81 m×3.05 m (12.5 ft×10 ft) rear-projected modules. It is used to display a 360 degree field of view of the virtual terrain that the user is traversing. The ODT is a second generation treadmill device that has a 2.44 m×2.44 m (8-ft×8-ft) working surface that allows the user to walk in any direction without leaving the working surface. The maximum speed of the ODT is limited to 1.79 m/s (4 mph). Figure 1 shows a person walking on the ODT in the IES.



Figure 1. Person walking on the ODT in the IES.

A validation study was conducted to compare walking on the ODT to walking over ground for selected biomechanical and physiological variables and to quantify any significant differences (Boynton et al., 2011). Motion capture, gait analysis, and cardiopulmonary measurement techniques were employed to obtain objective measures of temporal -spatial gait parameters, sagittal plane joint kinematics, and metabolic cost for ten subjects walking at two different speeds (1.12 m/s and 1.34 m/s) along a circular course (4.3 m radius) over ground and in the IES along an identical circular course in the simulated environment. The results of the study showed that users walk on the ODT with gait mechanics and joint kinematics similar to those used over ground but expend more energy doing so. The increased metabolic cost may be due to the adoption of a different muscle coordination strategy on the ODT to achieve a natural gait pattern. This difference between over ground and ODT walking needs to be taken into consideration when comparing the results of studies involving prolonged walking where physical fatigue may be an issue; however, it should have little effect when walking for short intervals and at a self selected pace (which tends to be the most energy efficient).

The noise level produced by the ODT depends on the speed of walking and varies slightly as a function of walker direction. Therefore, an additional masking noise of 85 dB A-weighted (measured in the center of the treadmill) was used in the study. Background noise was a pink

noise, which has similar spectral properties to city traffic noise and was, therefore, selected for the study. The noise was produced by a set of four QSC HPR 122i Powered Sound Reinforcement Loudspeakers: one speaker located behind the screens, below the ODT surface on each of the four sides. The spectrum of the combined ODT and pink noise is shown in figure 2, which shows the relative sound energy in decibel 1/3 octave bands.

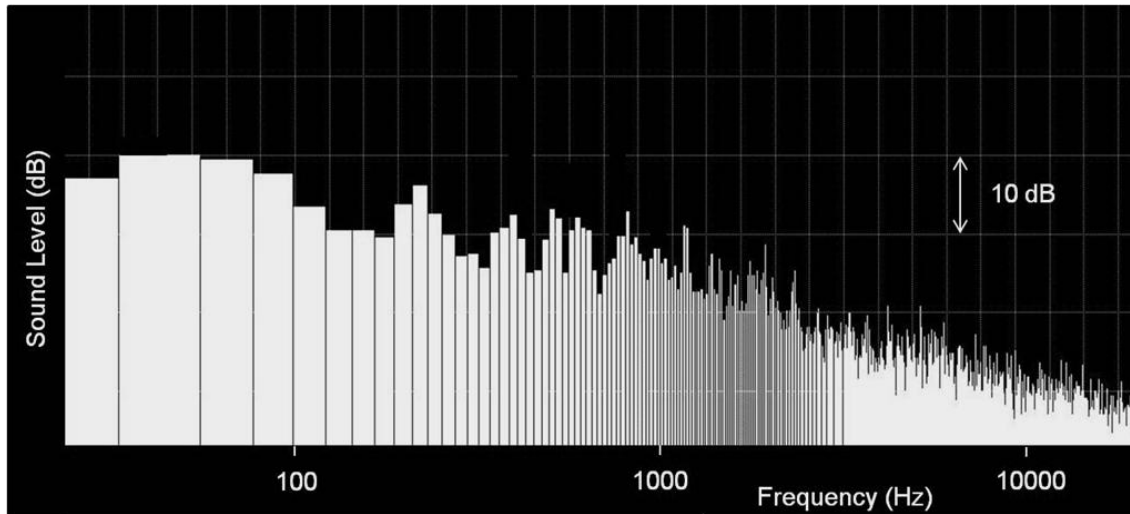


Figure 2. Spectrum (relative levels) of the combined ODT and pink noise.

Walking environment. The participants walked on the ODT in a virtual environment along designated routes. The route to be walked was given to the participant on a map of the simulated environment. Two distinct routes, each approximately 1000 m in length, were used in the study (figure 3). Participants walked each route twice, once in each direction, providing a total of four distinct paths. Path-1 and Path-2 begin at the points marked S1 and S2, and end at the points marked E1 and E2, respectively. A waypoint, marked with a W, is included on each path. In order to maintain approximately the same level of difficulty of all routes, both paths were similar in length; Path-1 was 942 m and Path-2 was 933 m in length. The 9 m difference in path length was expected to influence path walking times by less than 1.7%. To ensure that both paths present the same navigation challenge, the numbers of possible turns were made similar for each of the paths; Path-1 presented a possible 79 turns and Path-2 presented a possible 74 turns. Of the total turns possible, each path involved 14 correct turns, allowing all routes to have a similar level of difficulty determined by the number of possible and correct turns. Both paths were designed so that buildings ultimately limited the participant's ability to cut corners along the path. When the path passed through an open area, the path was always specified as a single straight line across the open area, going directly from the initial access to the open area to the intended exit of the open area. This design minimized the participant's ability to shorten the walking distance by cutting corners along the paths. The time needed to walk along each route was approximately 11 min.



Figure 3. The routes used in this study. Routes start at point S, pass waypoints W, and ends at points E.

A loop was also used for training participants to follow the maps used in the study. The walking practice loop starts and ends at the same point marked S & E in figure 3. The loop passes through a park indicated by the darkened regions in figure 3, which represents grass-covered terrain. The virtual environment simulation allows the participant to walk anywhere across the grass-covered terrain in the park. Thus, unbounded shortcuts could be used in walking about the park.

The assignment of routes to test conditions (No CAT, H1, H2, and H3) was counterbalanced, and each participant walked each route once. This arrangement allowed a participant to walk along a different route in each test condition that involved walking.

2.3 Procedure

The participants received test instruction and training on how to walk and navigate on the ODT before they participated in the study. Participants practiced walking freely in all directions on the ODT until they felt comfortable doing so and they appeared to have no hesitation or issues with their balance. Before participating in the walking and navigation tasks of the study, participants were given a map and asked to walk and navigate a training path that was similar to, but shorter than, the study paths. ODT training was complete after participants indicated familiarity and comfort walking on the ODT and after they successfully navigated the training path without being redirected to the specified path. Participants were also familiarized with the CAT phrases by listening and responding to CAT stimuli in quiet while standing on the ODT.

The goal of the CAT familiarization session was to ensure that all participants could hear and properly pronounce all CAT items correctly when listening to them in quiet. Participants were instructed to repeat the callsign immediately after each callsign was presented. After participants were adequately trained in navigating the path, listening to and repeating callsigns, and doing both tasks concurrently, the experimental trials began.

At the beginning of each test trial the experimenters provided the participants with a map of the path that they were required to traverse. Each path had designated starting and end points. The experimenters oriented the walker at the starting point facing the path direction, prior to the start of each trial. Participants were instructed to move at a fast but safe pace, that is, walk as fast as possible without running, in order to reach the end of the path. The speed of the participant was recorded from the ODT every 20 ms.

As the participants walked, they listened for CAT phrases played through earphones and repeated them aloud. The goal of this task was to assess the participant's ability to recognize speech items under specific test conditions. Listening to radio communications and acknowledging transmitted callsigns while moving is a typical Soldier task during patrolling, search-and-rescue missions, and other similar military operations. If the callsign heard in radio traffic matches the callsign assigned to the specific Soldier, the Soldier responds by repeating the callsign indicating that they are in communication (Department of the Army, 2009).

Each participant wore a wireless microphone system (described previously), and all CAT responses were recorded for further analysis. If the participant made a wrong turn and continued walking, they were immediately verbally redirected by the experimenters to ensure that the participant walked along the designated path. CAT scoring was suspended during redirection, because the participant was getting additional verbal instructions directing them back to the correct location and direction of the path. CAT scoring resumed when the participant returned to the specified route. Participants were told that correctly repeating the CAT callsigns and completing the walking task as well and as quickly as possible, were both equally important tasks.

2.4 Experimental Design

The design of this study was within subjects with two independent variables: CAT presentation with four levels (none, H1, H2, H3) and walking task difficulty with two levels (walking, not walking). The walking task was performed once with no CAT test (control condition), and once with a simultaneous CAT test presented at each level of simulated hearing loss (H1, H2, and H3), for a total of four walking trials per test participant, or a total of 64 walking trials. In addition, at each level of simulated hearing loss, the CAT task was performed once while the test participant was standing stationary on the ODT. In sum, the study consisted of seven trials per test participant.

The dependent variables in this study were measures of speech recognition and walking performance. The speech recognition metric used was the fraction correctly repeated of the presented CAT items. Performance in the walking-navigation task was measured using participant motion data collected from the ODT. When the participant walks away from the center of the ODT, a camera system on the ODT senses the participant's displacement and moves the dual orthogonal belt system of the ODT as needed to return the participant to the center of the ODT. This allows the participant to walk in any direction, without leaving the center of the ODT. The speeds of the dual orthogonal belts are monitored by the ODT control system, and they provide a measure of the speed of the participant. Many variable measurements were considered in evaluating the navigation task performance, including the completion time for each path and the average walking speed of the participant.

The completion time of the walking trial was determined from the time that the ODT motion began, to the time the ODT stopped with the participant at the end of the path. In addition to the completion time and average walking speed, walking performance was evaluated by counting the number of times that a participant was redirected to the designated path after making a wrong turn.

The number of test subjects required was determined by counterbalancing the four CAT presentation conditions (hearing task difficulty levels) with walking tasks on four paths, which required 16 test subjects. The walking trials were counterbalanced to eliminate any influence of continued improvement in ODT walking technique after the ODT training. We counterbalanced walking trials with hearing loss conditions so that each hearing loss condition was presented an equal number of times as the first, second, third and fourth walking trail. Three non-walking trials (conditions H1, H2, and H3) were randomized and interlaced between the walking trials.

3. Results and Data Analysis

3.1 CAT Performance Scores

CAT scores were determined by listening to recordings of the participant's voice as they repeated CAT stimuli during trials. The CAT is administered by playing to the participant one of six pre-recorded lists of callsigns. Recording of the participant's response was started at the same time as the beginning of the CAT stimuli presentation. By following the presentation time for each CAT stimulus and the recording time for each participant response, it was possible to identify the stimuli that were correctly repeated and those that were incorrectly repeated or missed completely. The example in table 1 shows the evaluation of response to the first six callsign stimuli in a trial. By listening to the recorded response of the participant and comparing the response time with the stimulus presentation time, it was found that the participant did not

correctly repeat CAT item numbers 1 and 4, and did correctly repeat CAT item numbers 2, 3, 5, and 6.

Table 1. Example of CAT test performance evaluation process.

CAT Item #	1	2	3	4	5	6
Time of Stimulus (seconds)	0	3.92	7.85	11.78	15.71	19.64
Time of Stimulus (minutes)	0.000	0.065	0.131	0.196	0.262	0.327
Presented Callsign	xray5	alpha4	lima5	delta3	kilo4	delta5
Response Evaluation	0	1	1	0	1	1

A sum of the Response Evaluation row then gave the number of correctly identified stimuli. A count of the number of columns for all callsign stimuli presented in the trial was then used to determine the fraction of callsigns that the participant repeated correctly during the trial. For clarity, table 2 shows the overall results for this example CAT evaluation; the participant correctly repeated 91 CAT stimuli. During the trial, the participant was presented with a total of 159 CAT stimuli. Thus, the fraction of callsigns correctly repeated was 0.57.

Table 2. Example of calculation of the overall callsign fraction correct.

Number Correct	91
Number of Callsigns	159
Fraction Correct	0.57

For all CAT trials, CAT performance was evaluated as the fraction of all presented callsign stimuli correctly repeated. Resulting data for CAT tests for all participant trials are shown in table 3.

Table 3. CAT test data for all participant trials.

Test Plan Participant #	No Walk @ H1	Walk @ H1	No Walk @ H2	No Walk @ H3	Walk @ H2	Walk @ H3
1	1.000	1.000	0.873	0.810	0.763	0.601
2	1.000	0.995	0.795	0.898	0.772	0.131
3	0.937	1.000	0.714	0.937	0.429	0.029
4	1.000	1.000	0.944	0.929	0.821	0.780
5	1.000	0.990	0.841	0.389	0.341	0.155
6	1.000	0.994	0.690	0.778	0.526	0.572
7	1.000	0.992	0.603	0.310	0.146	0.004
8	1.000	1.000	0.213	0.452	0.746	0.005
9	1.000	1.000	0.905	0.857	0.340	0.515
10	1.000	1.000	0.508	0.214	0.250	0.109
11	1.000	1.000	0.841	0.817	0.594	0.225
12	1.000	1.000	0.865	0.660	0.000	0.231
13	1.000	0.972	0.786	0.690	0.564	0.166
14	0.897	0.951	0.579	0.468	0.164	0.079
15	1.000	1.000	0.556	0.616	0.027	0.423
16	1.000	1.000	0.817	0.714	0.730	0.393
Average:	0.990	0.993	0.721	0.659	0.451	0.276

The data listed in table 3 are plotted in figure 4, to provide a more visual indication of how CAT results varied across each test participant, each hearing condition, and each walking condition. In figure 4, CAT data are presented in order of decreasing average performance across walking and not-walking conditions and across simulated hearing levels: H1 (no hearing loss), H2 (moderate hearing loss), and H3 (more severe hearing loss). Although individual differences in performance are evident, the data are plotted from the front row to the back row in order of increasing average performance, to maximize visibility of the data.

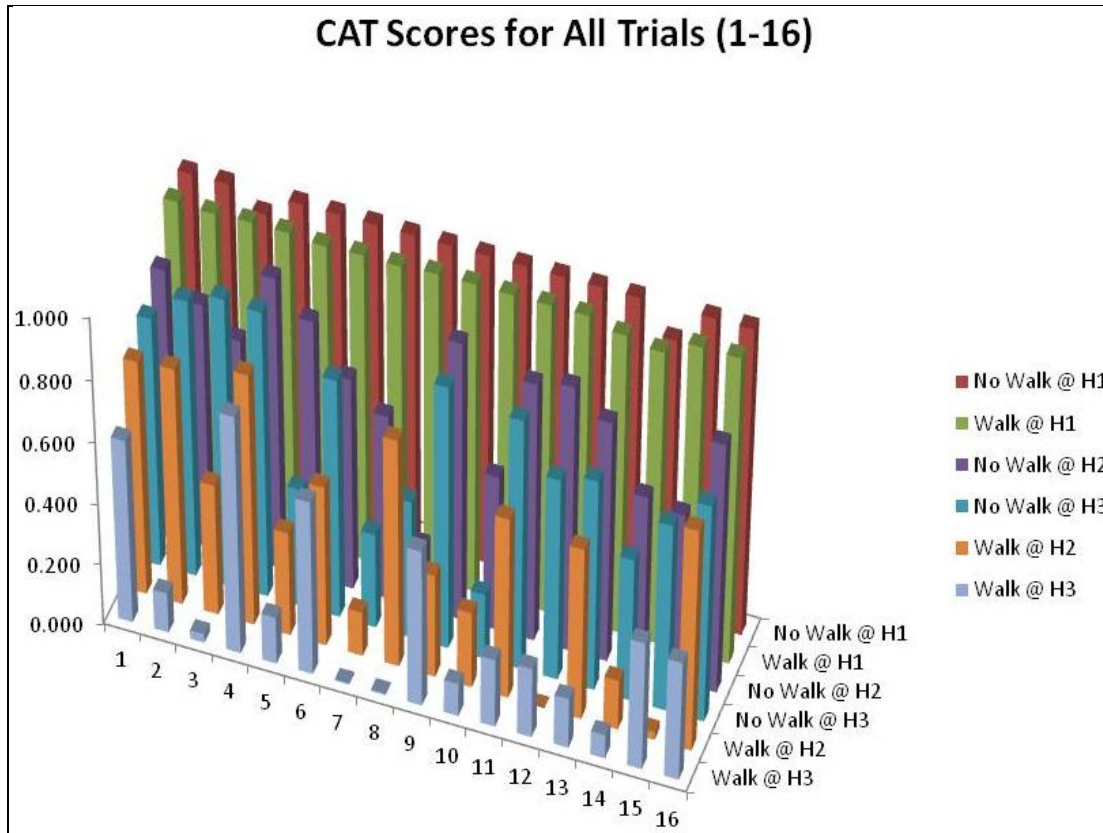


Figure 4. CAT score data are plotted for all trials.

Many of the CAT scores occurred near the highest value in the score range: 1.0, which corresponds to all responses being correct. Our data did not have properties of normal distributions and needed to be normalized for the purpose of statistical analysis of the data. To reduce non-normality in CAT score data, the data were non-linearly transformed to rationalized arcsine units (rau) (Studebaker, 1985). The arcsine transform stretched the domain of proportional values near the maximum and minimum, increasing the normal characteristics of domain-limited distributions. The rationalized arcsine transform adjusts the overall domain to more closely preserve the values of proportions between 0.15 and 0.85, while symmetrizing the enhancement of normality at the upper and lower limits of the proportional domain. Analyses were conducted using transformed CAT scores, which reflected normality, but results are presented by transforming then analyzed values back to fractional CAT scores, for clarity.

Average CAT scores obtained in the study presented as a function of the type of simulated hearing loss are shown in figure 5.

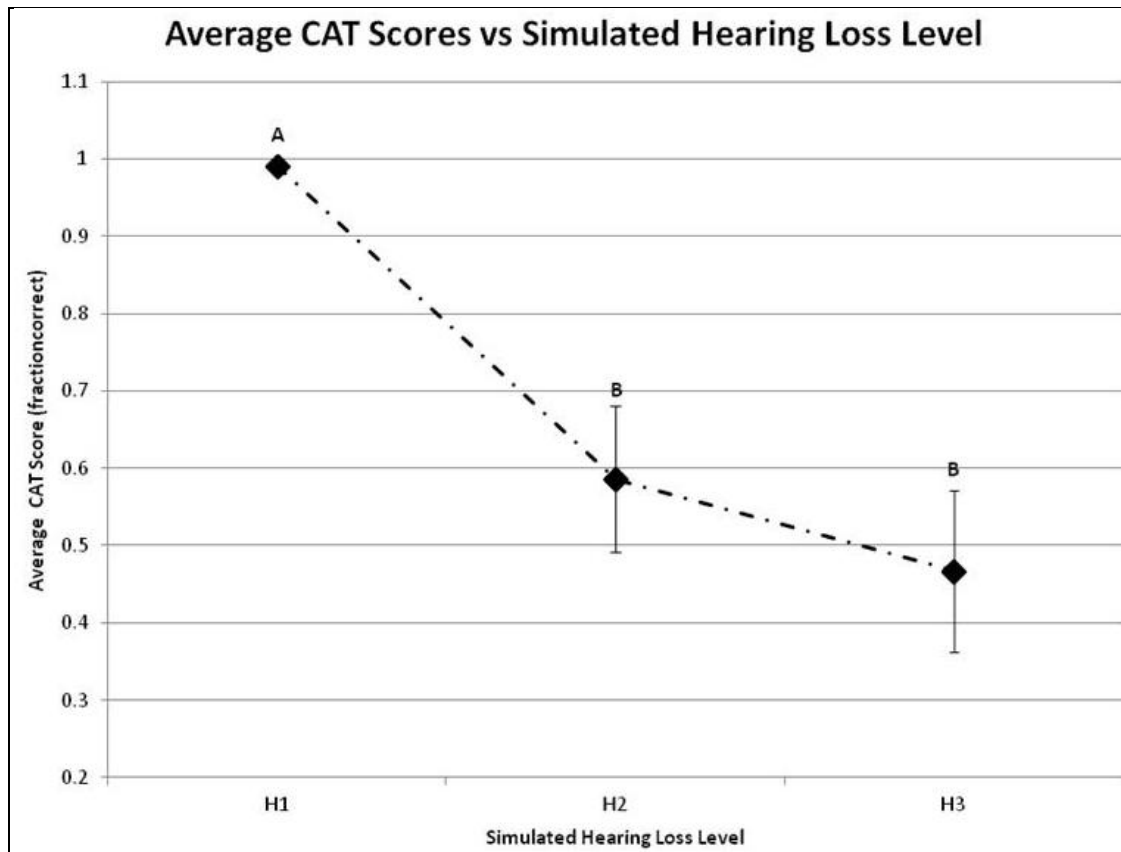


Figure 5. Average CAT Scores versus Simulated Hearing Loss Level.

In figure 5, H1, H2, and H3 correspond to no hearing loss, moderate hearing loss, and severe hearing loss, respectively. Error bars denote 95% Confidence Intervals. Error bars for H1 average CAT score are smaller than the symbol. Points with different letter labels (A, B) are significantly different.

A 2 (walking)×3 (hearing loss) within-subjects analysis of variance (ANOVA) with CAT scores in rau units as the dependent variable showed a significant decrease in CAT scores as the level of simulated hearing loss increased across both walking and not walking trials [$F(1.896, 28.444) = 129.1$, $p < 0.001$]. CAT scores were non-homogeneous, and a Greenhouse-Geisser correction of 0.948 was applied, resulting in the fractional degrees of freedom.

The concurrent walking task also decreased overall CAT scores, [$F(1, 15) = 83.6$, $p < 0.001$]. A comparison between CAT scores with and without concurrent navigation task performance is shown in figure 6. A significant interaction between hearing loss and the walking/not walking was observed, [$F(1.59, 23.84) = 15.07$, $p < 0.001$]. Tukey honestly significant difference (HSD) post-hoc tests showed that CAT scores at the H1 (no hearing loss) level were significantly different from CAT scores at the H2 and the H3 hearing loss levels [$p < 0.001$]. No significant differences were found between walking and not walking CAT scores with no hearing loss, between H2 and H3 CAT scores while not walking, and between H2 and H3 CAT scores while

walking [$p = 0.085$]. In figure 6, CAT scores identified by different letter labels were significantly different.

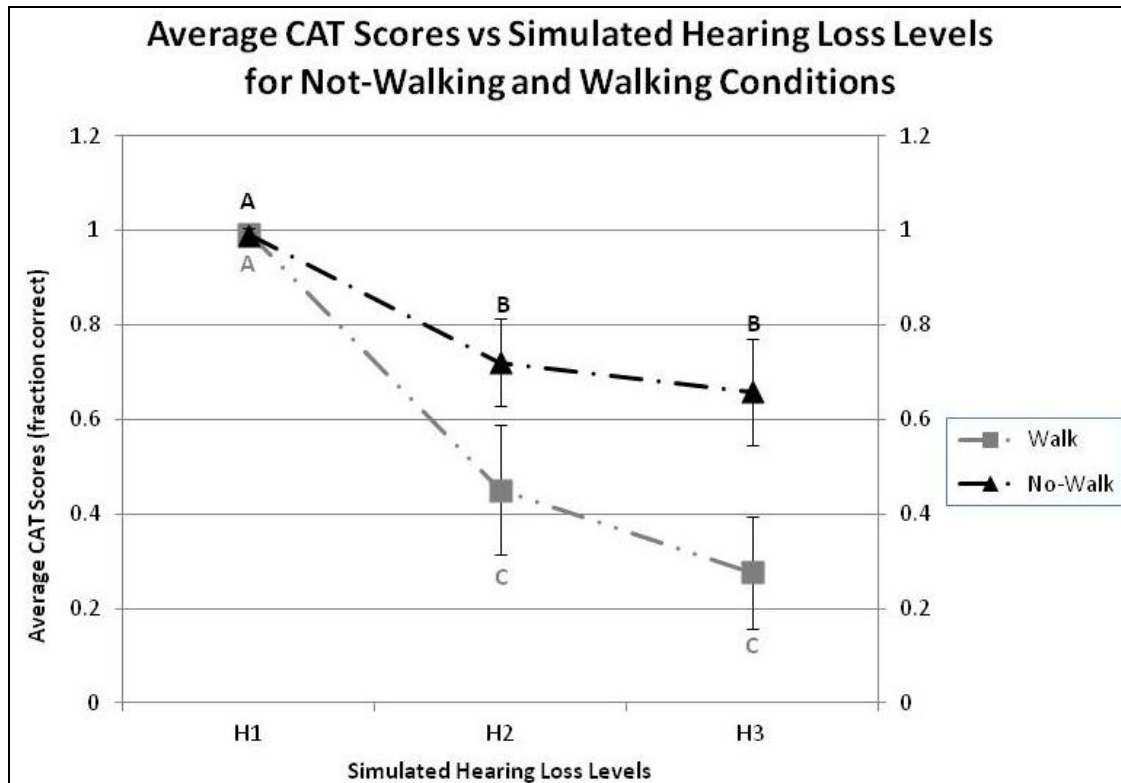


Figure 6. Average CAT Scores versus Simulated Hearing Loss Level.

In figure 6, both not-walking and walking conditions are shown. H1, H2, and H3 correspond to no hearing loss, moderate hearing loss, and severe hearing loss, respectively. Error bars denote 95% confidence intervals. Error bars for H1 average CAT scores are smaller than the symbol. Points with different letter labels (A, B, C) are significantly different.

3.2 Walking Navigation Task Performance

Figure 7 shows average navigation task completion times for all conditions of speech comprehension difficulty used in this study (No CAT, H1, H2, H3). Although the navigation task decreased CAT scores with the increased levels of simulated hearing loss, CAT task performance and simulated hearing loss had no significant influence on the completion time of the simple navigation task used in this study, $F(1, 15) = 2.62$, $p = 0.127$.

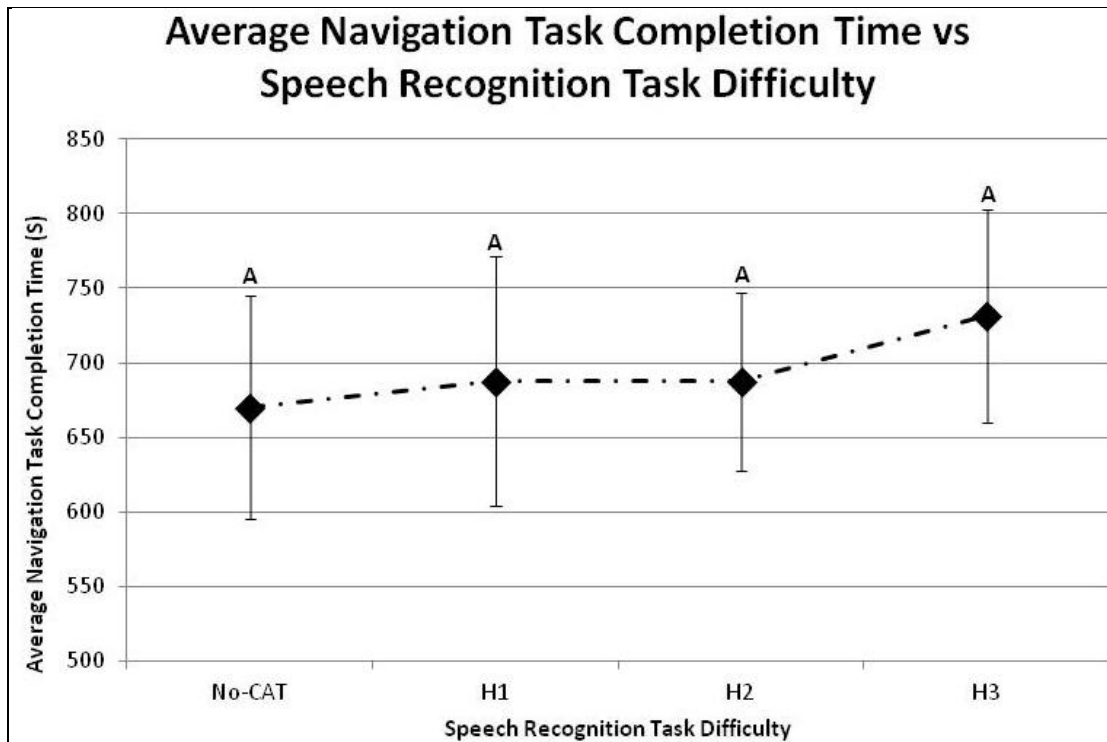


Figure 7. Average Navigation Task Completion Time versus Speech Recognition Task Difficulty.

In figure 7, H1, H2, and H3 correspond to no hearing loss, moderate hearing loss, and severe hearing loss, respectively. Error bars denote 95% confidence intervals. Points with the same letter label (A) are not significantly different by ANOVA

We did not use a solid line between the points in figure 7 because speech recognition task difficulty is not a continuous quantitative variable. Although it was not a continuous variable, we defined speech recognition task difficulty to be monotonically increasing as the overall hearing task became more difficult in each of the test conditions. We assigned a speech recognition task difficulty of zero to the condition when no CAT was performed, a value of 1 when the most-comfortable-listening-level, selected by the participant, was used; a value of 2 when the H2 (moderate) hearing attenuation was applied; a value of 3 when the H3 (most severe) hearing attenuation was applied. To reflect this ordered-pair progression, we have illustrated figure 7 with a dot/dashed line to illustrate the results of this ANOVA.

The overall relationship between the navigation task completion time and CAT score is shown in figure 8. This figure is shown to illustrate the lack of clear differences in participants' CAT data under H2 and H3 simulated conditions. Some of the participants performed better under H2 and some under H3 simulated condition. While similar observations can be inferred from figures 5, 6, and 7, we have included the data plotted in figure 8 to more clearly indicate that profiles H2 and H3 (in contrast to profile H1) are not necessarily good predictors of speech recognition performance. To better illustrate the varied performance under the H2 and H3 hearing

impairment profiles, we have highlighted some specific participant examples for discussions emphasizing the broad range of observed performance variations overall over the H2 and H3 profiles.

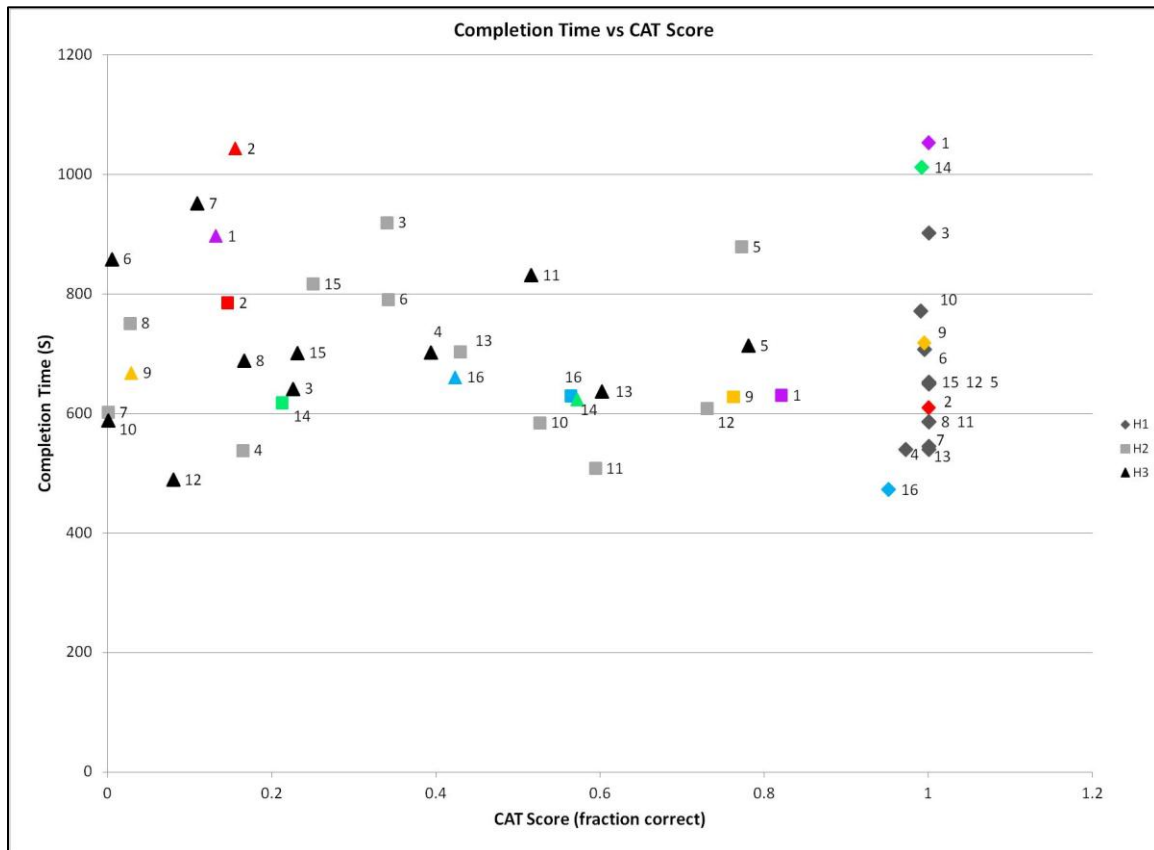


Figure 8. Navigation Task completion time as a function of CAT score.

In figure 8, all participants are identified by number. All three simulated listening conditions H1, H2, and H3 are identified by symbol shapes indicated in the legend. H1, H2, and H3 correspond to no hearing loss, moderate hearing loss, and severe hearing loss, respectively.

Participant 9 (orange data points) experienced a monotonic decrease in CAT performance across the increasing levels of hearing impairment, but the decrease between the H1 and H2 condition was much smaller than the decrease between the H2 and the H3 condition. Participant 9 also experienced a small decrease in completion time from the H1 to the H2 and H3 conditions, indicating that participant 9 actually walked faster at the higher levels of hearing impairment than with no hearing impairment (H1). The improved walking performance may have been facilitated by decreased effort in performance of the CAT at the H3 hearing impairment level.

Participant 1 (purple data points) showed CAT score performance similar to that of participant 9: a small decrease in CAT performance between the H1 and H2 conditions and a large decrease in CAT performance between the H2 and H3 conditions. However, participant 1 experienced much

slower walking performance under the H1 and H3 conditions than under the H2 condition. Thus, participant 1's CAT performance was consistent with the increasing levels of hearing impairment, but the walking performance shows no consistent variation.

Participant 2 (red data points) showed walking task performance that became incrementally slower with each increase in the hearing impairment level. Participant 2's CAT performance showed a large decrease from the H1 condition to the H2 and H3 condition, but remained virtually unchanged between the H2 and H3 hearing impairment levels. For participant 2, the difference between the H2 and H3 hearing impairment levels may have influenced the walking performance, but it caused no change in CAT performance.

Participant 14 (green data points) showed CAT performance that was better at the H3 level than at the H2 level. In addition, participant 14 walked faster at both the H3 and H2 hearing impairment levels than at the H1 (no hearing loss) level. Participant 14 showed no reasonable performance difference between the H2 and the H3 hearing impairment levels.

Participant 16 (blue data points) showed a CAT performance that decreased consistently across levels of increasing hearing impairment, but the difference was small between CAT performance at the H2 and H3 hearing impairment levels. It is interesting to note that participant 16 walked the fastest under the no hearing loss (H1) condition, but also had the lowest CAT score for the H1 condition.

3.3 ODT Speed Recordings and Stride Analysis

The ODT can provide both x- and y-direction velocity components at a significant range of measurement rates. Options on the ODT were selected to record the speed of the participant every 20 ms. We chose this measurement rate because it corresponds to a frequency much higher than human stepping frequency. The ODT velocity magnitude signal contained a small positive DC bias, which corresponded to a velocity magnitude of about 0.04 MPH. This bias was observed when the participant and the ODT were not moving and it corresponds to a speed much smaller than typical human walking speeds. To further reduce potential influence of the noise in the velocity signal, we smoothed the velocity over every two measurements, producing an average speed value at a frequency of 25 Hz, which is still well above the stepping pace of all test participants.

An example of the speed of a participant on the ODT is shown in figure 9.

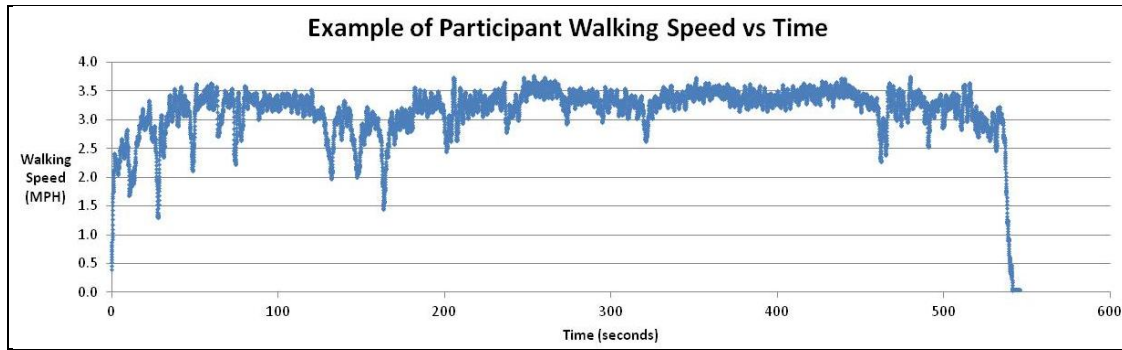


Figure 9. Example of participant walking speed during a trial on the ODT.

On an expanded time-scale, ODT speed data is shown in figure 10.

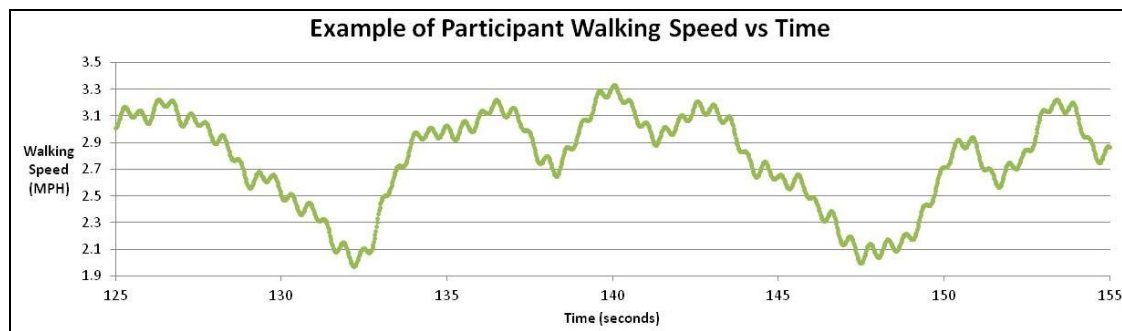


Figure 10. Participant speed plotted on an expanded time scale. .

Figure 10 shows a section of figure 9 between 125 and 155 s. This interval was chosen to include the bottom of the first two of the three major dips in walking speed seen in figure 9 between 100 and 200 s. In each one-second interval, 25 speed measurements are plotted. An oscillatory behavior at 1 cycle per second is visible in these speed measurements. Although the walking speed dips look sharp in figure 9, figure 10 clearly shows that the ODT speed changes quite smoothly between neighboring data points.

Figure 10 shows an oscillating behavior with a period of approximately 1.0 s. We believe this characteristic is produced by the participant's stride, including a complete cycle starting and concluding with the step of the left foot, for example. We believe the oscillating behavior evident in figure 10 indicates characteristics of the stride frequency of the test participant walking on the ODT.

If an experimental condition were to influence the participant's walking performance, an indication of the influence might be observable in the participant's stride frequency. To examine potential hearing loss influences on the participant's walking performance, ODT speed data were analyzed by fast Fourier transform (FFT) to determine characteristics of the participant's stride frequency distribution over each experimental walking trial.

A MATLAB® (version 7.14, release R2007b, The MathWorks, Inc., Natick, MA) application of the FFT was used to produce ODT speed frequency distributions. The magnitudes of the FFT speed data for participant 12's walking trials are shown in figure 11.

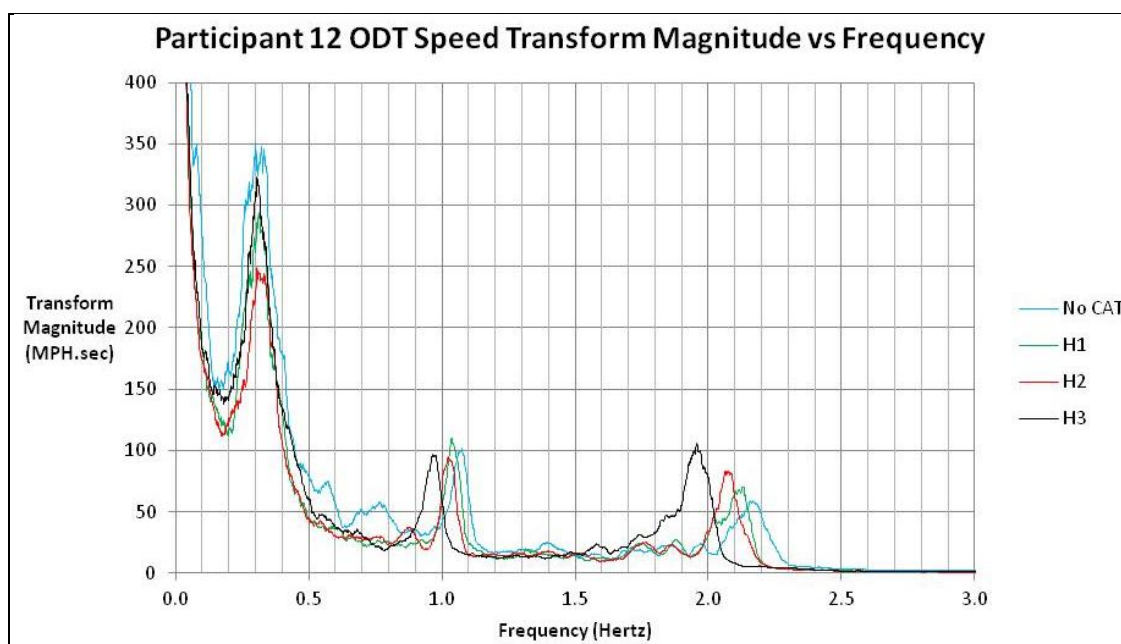


Figure 11. Participant 12 magnitude of FFT ODT speed data.

In figure 11, walking trials are labeled by No CAT and by hearing level: H1, H2, and H3. The group of four peaks near 1 Hz show stride frequency distributions. The group of four peaks at about 2 Hz show step frequency. The step frequency shows how often the participant took individual left and right steps. The frequency location of the highest part of the peak indicates the stride or step frequency most used during the trial. A peak located at a higher frequency indicates a faster stride or step rate than a peak located at a lower frequency.

These peaks also display a characteristic width. We defined the width of these peaks as the width-at-half-height, measured above the apparent background. The widths of these peaks indicate the uniformity of the participant's strides and steps; a wider peak indicates that the participant's stride or step frequency varied over that trial more than it varied over a trial which produced a narrower peak. A narrow peak should indicate a more temporally steady walking frequency, while a broad peak should indicate a less temporally steady, more variable, walking frequency.

For example, the frequency spectra in figure 11 show that this test participant took the slowest steps in the trial labeled H3 (hearing loss level H3) and took the fastest steps in the trial labeled No CAT. Although the stride and step frequencies appear to change with trial, the widths of these distributions do not show significant changes between trials.

All FFT ODT speed data also showed a large zero-frequency (dc) component because the ODT speed was never negative. FFT speed data showed increased background levels at lower frequencies.

A second example of speed frequency distribution is shown for participant 9 in figure 12.

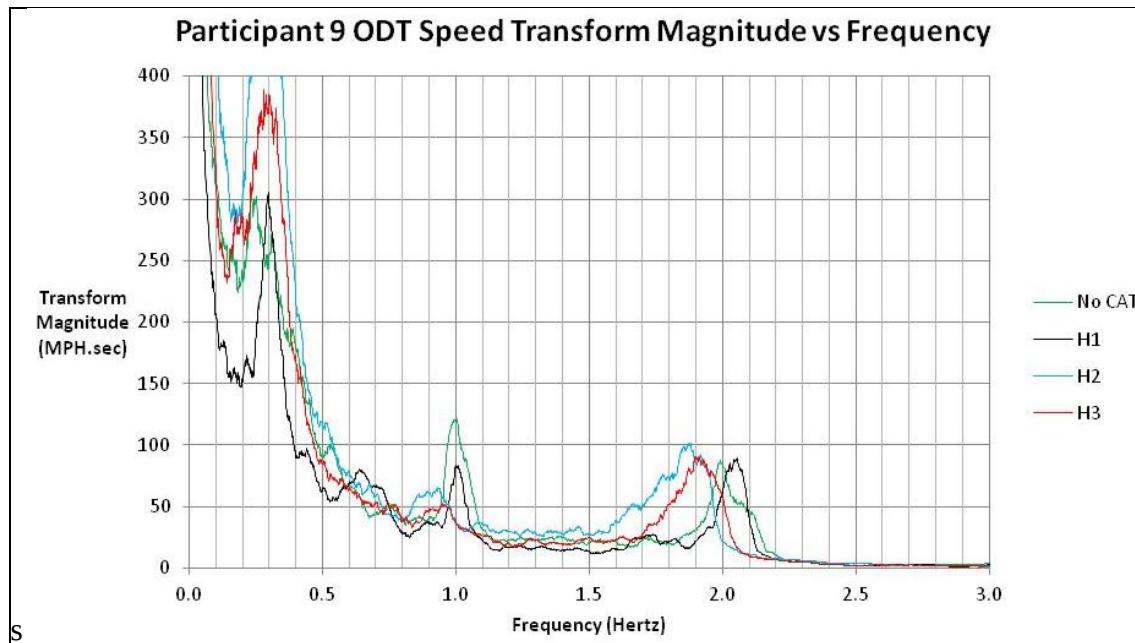


Figure 12. Participant 9 magnitude of FFT ODT speed data..

In figure 12, walking trials are labeled by No CAT and by hearing level: H1, H2, and H3. Speed frequency spectra for test participant 9 show narrow stride and step frequency distributions for the No CAT trial and for the H1 (normal) hearing condition, and wider frequency distributions for the H2 and the H3 hearing conditions. The central stride and step frequencies also have decreased from the No CAT and H1 walking trials to the H2 and H3 walking trials.

A third example of speed frequency distributions is shown for participant 6 in figure 13.

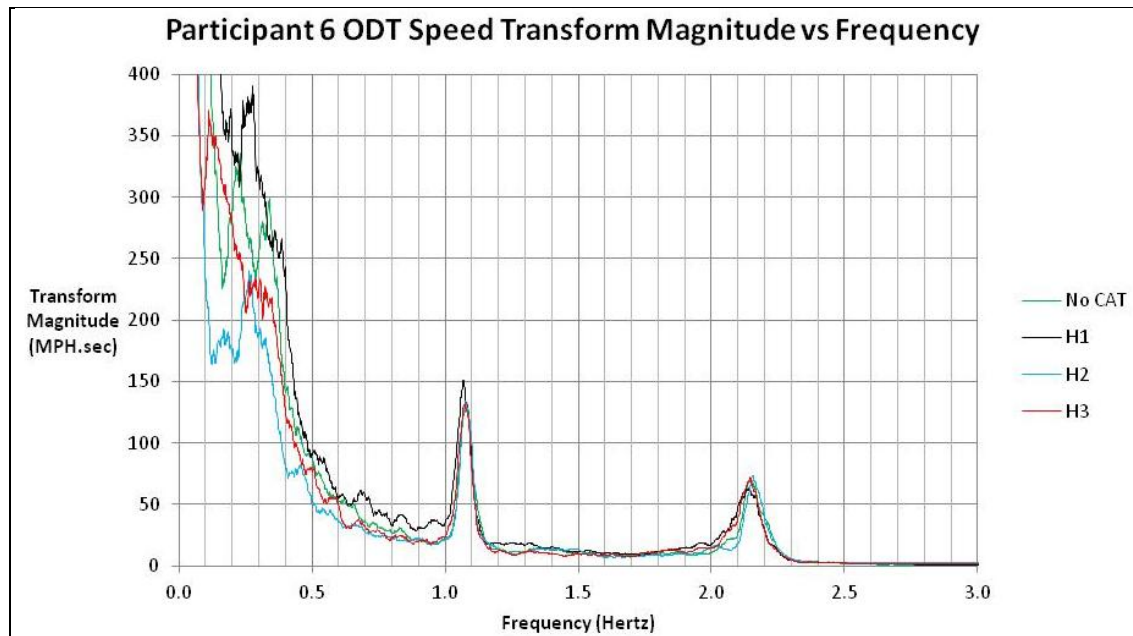


Figure 13. Participant 6 magnitude of FFT ODT speed data.

In figure 13, walking trials are labeled by No CAT and by hearing level: H1, H2, and H3. Participant 6 shows consistent central peak frequency and width for all walking trials, with or without CAT performance, and at all hearing levels. Participant 6's speed frequency spectra also show larger stride magnitudes than step magnitudes, which might indicate a gait asymmetry between left and right strides.

Further understanding of each participant's gait characteristics might be obtainable from frequency spectra of ODT speed recordings. For example, the increase in the stride amplitude of participant 6 might indicate a larger gait asymmetry between participant 6's left and right steps, where as a decreases in the stride amplitude relative to the step frequency amplitude might indicate a more symmetric gait. We also noted transform magnitude variations in the neighborhood of 0.25 Hz on nearly all trials. Although we did not further investigate this observation, we believe that additional information might be obtainable from further analysis of the ODT speed data and various characteristic quantities that describe the FFT magnitudes. Such efforts might be considered in the future, but they are beyond the scope of our present study.

For completeness, we describe one further observation regarding the ODT speed data. Some of the ODT speed data points showed indications that they were digitally corrupted. Gathering speed data points at 50 data points per second produced a very smoothly varying graph of speed as a function of time. It is materially and mechanically impossible to change the ODT speed by more than 1 mph in 0.02 s. Occasionally, in a set of ODT data, the digital ODT speed would change, for just one data point, by an unrealistically large amount. This indicated a digital error in the ODT speed.

When an FFT was performed on speed data containing an impulsive erroneous data point, one that essentially created an impulsive discontinuity in the speed data, the frequency spectrum of the speed data showed the characteristic of white noise; i.e., the amplitude of the FFT did not decrease with increasing frequency. When white noise characteristics were observed in the FFT speed data, the speed data were carefully reviewed, locating all the apparently discontinuous data points. Each erroneous data point was replaced by an interpolation between the immediately preceding and following data points.

Stride and step peak amplitude and frequency, and the width-at-half-amplitude (above estimated baseline) for stride and step peaks were evaluated for each walking trial.

As an example of walking performance characteristics, figure 14 shows the stride frequencies for all trials and levels of hearing task difficulty. The hearing task is least difficult when no CAT is performed during the walking trial. The difficulty is low when the hearing level is the most comfortable (H1, no hearing loss) listening level, which is selected by the participant. Hearing task difficulty is somewhat more difficult under the H2 (moderate hearing loss) profile, and it is most difficult under the H3 (more severe hearing loss) profile.

As with CAT scores, the stride frequencies are plotted from the front row to the back row in order of increasing average performance. Thus in figure 14, stride frequency is layered from the most difficult condition (H3) to the least difficult condition (No CAT) because the average stride frequency decreases as the hearing task difficulty increases. As figure 14 shows, however, individual differences in performance showed much larger variation than the change in average stride frequency across levels of hearing task difficulty. This observation was borne out by statistical analyses.

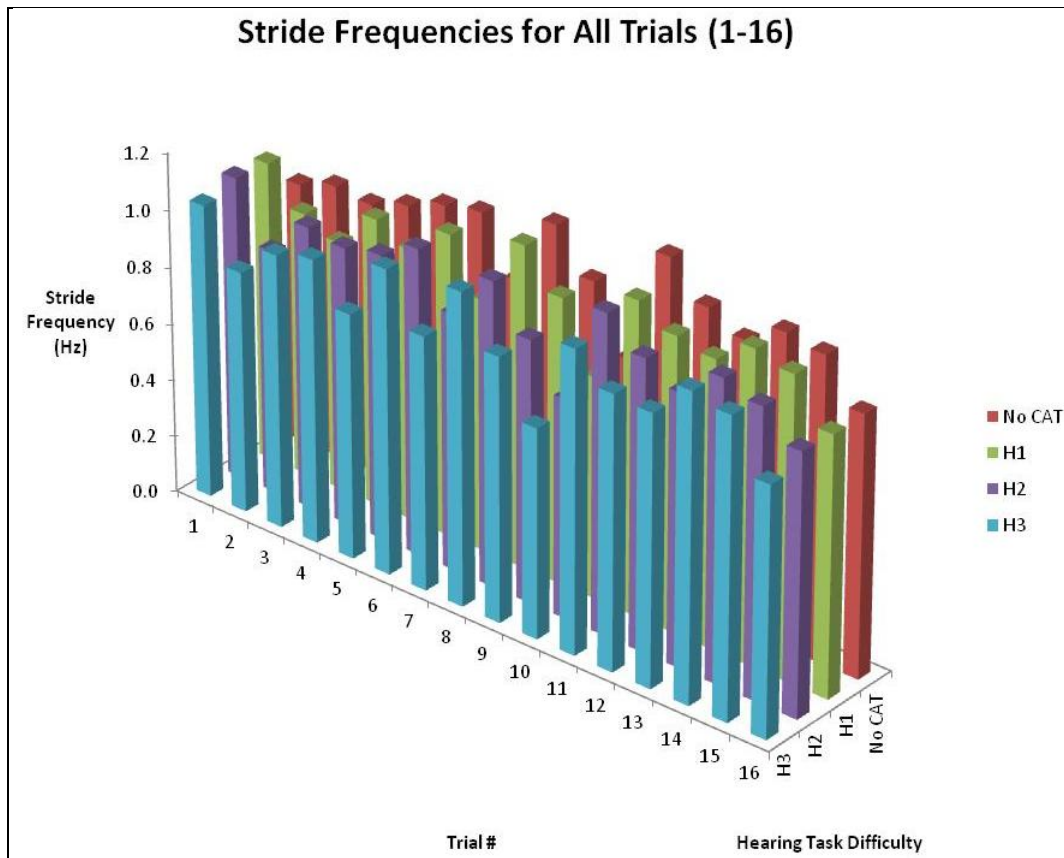


Figure 14. Stride frequencies for all walking trials.

Although a trend is present between increasing hearing task difficulty and decreasing stride frequency, statistical analyses showed that the trend is not significant at the $\alpha = 0.05$ level.

The completion time was chosen as the characteristic for describing the navigation-walking task. It was chosen because it was easily and accurately determined by the starting and stopping time for the ODT. In addition, multiple analyses of the several walking performance measurements indicated that that little information was to be gained by including analyses of more than the single variable to characterize navigation-walking performance.

To test uniformity of the data set across test participants, the participants were labeled in three binary ways, according to the potential secondary variables that could affect the data.

The labels were: participant's gender (male or female), experience with the ODT (yes or no), and experience with the CAT (yes or no). Cluster analysis was performed on all individual CAT scores and navigation task completion time data. The cluster analysis did not show any participants' grouping related to the three binary variables, so the data were combined across all participants in all subsequent analyses. Additional experimental variables also were recorded and examined to determine if any interference effects were introduced by particular CAT

versions or path numbers. Analyses showed that neither the CAT version number nor the path number caused any outlying behavior in CAT score and the completion time.

4. Discussion

The goal of this study was to determine the influence of hearing loss on the performance of a listening task and a concurrent navigation task. We addressed two working hypotheses. We hypothesized that the adverse impact of hearing loss on the listening task would be greater when simultaneously performing the navigation task than when not performing it. We also hypothesized that that hearing loss might decrease the navigation task performance more when performing the listening task with hearing loss than with no hearing loss. We hypothesized this decrease in walking task performance even though the navigation task requires no input from the listening task. Our analyses showed that hearing loss did have a larger negative impact on performance of the listening task when the navigation task was performed simultaneously than when not. Our analysis also showed that the hearing loss failed to produce a significant negative impact on the navigation task. Although the data showed a visible trend in this direction, the trend is not significant at the 5% level.

Average CAT performance showed a significantly greater decrease as a function of simulated hearing loss level for the walking condition as compared to the non-walking condition. Under the normal hearing condition (H1), CAT performance showed no significant decrease associated with the navigation task, indicating that otologically normal adults have sufficient resources to perform the speech recognition task when speech is easily heard while performing the walking navigation task. However, speech recognition (CAT score) significantly decreased with increased hearing loss, especially with the additional navigation task.

Analysis of the completion times showed no significant effect from concurrent performance of the speech communication task, regardless of simulated hearing loss level or hearing task difficulty. Although completions times showed an increasing trend with hearing loss level, the amount of the increase is not significant given the overall spread of the completion times. The navigation task employed in this study was relatively easy. Although the speech communication task and the navigation task both represent realistic tasks performed when a Soldier moves on foot and listens to and communicates over the radio, navigation task performance did not show a significant decrease when performed with the parallel speech communication task regardless of hearing loss. On the basis of the data obtained for these simple tasks, however, we cannot rule out that a more demanding navigation task, or some other physical task that is independent of the information in the listening task, may show significant interaction effects when performed with the degraded listening task. When performed concurrently, both the listening task and the more demanding independent physical task may show decreased performance under decreased hearing capability.

Although multiple resource theory introduces mechanisms that can predict reduced walking performance due to an increased demand for attention caused by listening difficulty from hearing loss (Horrey and Wickens, 2003), multiple resource theory does not *a-priori* specify the magnitude of the interaction effect between the two tasks. Depending on task difficulty and details, the interaction may be small. We observed no significant effect of simulated hearing loss on navigation-walking task performance. As described by Horrey and Wickens (2003), this may be a result of a relatively simple task, which in our case would be the navigation task. The navigation-walking task could be performed by briefly glancing at the map only at individual intersections, or approximately once every minute while walking. This low level of activity might have been easily maintained without any impact from difficulty hearing the CAT stimuli. Walking task performance also may have shown no influence of hearing loss because, as the overall workload increased, less effort was given to the listening task, allowing the listening task performance to fall while allowing performance of the navigation task to remain unperturbed.

Task priority also influences dual task performance (Damos, 1991). In spite of the intent to make both tasks equally important, participants can give one task more attention than another. Walking on the ODT involves some risk of falling (Boynton et al., 2011), and even though participants are tethered to prevent falling, participants may have more readily focused on the walking task to avoid falling, rather than focused on the listening task, which involved no such impending failure consequence.

It is also possible that the effect of a real hearing loss on the navigation task may be greater than that observed for the simulated hearing loss, which was simulated with only a frequency-dependent amplitude reduction and reflected no accompanying decrease in temporal sound resolution. The limitations of the filtering-based simulated hearing have been discussed in the literature (Desloge et al., 2010; Rawool, 2012; Moore, 2007). However, due to problems with simultaneous simulation of all the aspects of hearing loss, simulations limited to signal filtering are common first approximations of hearing loss in simulation studies addressing human auditory performance and not hearing physiology modeling.

Overall, our reported data clearly indicate that constrained filter-based simulation of hearing loss does interact with the walking task, i.e., the effects of hearing loss are exacerbated by walking. Although hearing loss simulated by signal filtering may be insufficient to observe all possible effects of real hearing loss on human performance, since our data clearly show some task performance interaction, it is likely that the lack of an effect of the hearing loss on the walking task performance is related to task requirements and/or priorities, rather than the details of hearing physiology.

Overall, the positive and negative performance differences between the H2 and H3 levels indicate that these hearing impairment profiles are not sufficiently different to cause a unidirectional difference in CAT performance. This result implies that differentiation between

H2 and H3 military hearing profiles may have limited value in application to speech recognition performance.

To our knowledge, the process that we used for estimating step and stride frequency distributions from the FFT of ODT speed has not been previously applied. We believe that this process may provide a useful experimental technique in further studies of walking performance on the ODT. We have described and illustrated this process to provide support for further development of this potentially useful experimental technique.

5. Conclusions

For the particular tasks chosen for this study, the navigation task had a significant adverse influence on the speech recognition task performance when a simulated hearing loss was applied. This indicates that difficulty understanding verbal communications causes an increase in resources needed to perform speech communication and walking tasks simultaneously. This influence may be important not only in the case of a permanent threshold shift but even for a temporary threshold shift which a Soldier may experience on the battlefield. This implies that, if a Soldier were to experience hearing loss, their speech recognition ability could decrease further if the Soldier was moving about. In general, we expect that Soldiers experiencing hearing loss will exhibit performance decrements in understanding verbal communication due to concurrent motor tasks.

As discussed above, different explanations can account for why no influence of hearing loss was seen in our navigation walking task, but because we observe some interaction between the walking and listening tasks, we conclude that task requirements and priorities best account for our observation. Just as a test participant on the ODT must remain focused on movement to avoid a possible fall, a dismounted Soldier must remain focused on their movement through a hostile environment. Therefore, for our specific militarily relevant tasks, we conclude that the effect of speech recognition difficulty on the performance of an independent simple navigation walking task remains of little concern in regard to the variations in navigation walking task performance caused by other environmental factors.

No consistent difference in CAT performance was seen between the H2 and H3 hearing impairment levels. This result indicated that, with regard to speech perception, the H2 and H3 hearing impairment levels simulated by spectrally applied attenuation levels may not adequately differentiate an individual's speech perception capability. Because speech perception is an important life capability, a review of the H2 and H3 hearing profiles may be considered to determine if adjustments might better characterize a decrease in speech perception with increases in the level of hearing impairment.

Further research in this area should address a more concentration -intensive physical task performed with speech communication by participants with actual hearing impairment. Simulated hearing loss accounts for a decrease in hearing sensitivity but it does not account for poorer spectral and temporal resolution typically associated with the hearing loss.

Further research also should examine analysis methods for ODT speed recordings, to determine if the FFT of recorded ODT speeds might provide valuable information about the walking gait and other physical activity of the person on the ODT.

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List of Symbols, Abbreviations, and Acronyms

ANOVA	Analysis of Variance
CAT	Callsign Acquisition Test
FFT	Fast Fourier Transform
HL	Hearing Level
HSD	Honestly significant difference
IES	Immersive Environment Simulator
ODT	Omni-directional Treadmill

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