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Original Article

The effects of elevated hearing thresholds on performance in a paintball simulation of individual dismounted combat

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Abstract

Objective: To examine the relationship between hearing acuity and operational performance in simulated dismounted combat. *Design*: Individuals wearing hearing loss simulation systems competed in a paintball-based exercise where the objective was to be the last player remaining. Four hearing loss profiles were tested in each round (no hearing loss, mild, moderate and severe) and four rounds were played to make up a match. This allowed counterbalancing of simulated hearing loss across participants. *Study sample*: Forty-three participants across two data collection sites (Fort Detrick, Maryland and the United States Military Academy, New York). All participants self-reported normal hearing except for two who reported mild hearing loss. *Results*: Impaired hearing had a greater impact on the offensive capabilities of participants than it did on their ''survival'', likely due to the tendency for individuals with simulated impairment to adopt a more conservative behavioural strategy than those with normal hearing. *Conclusions*: These preliminary results provide valuable insights into the impact of impaired hearing on combat effectiveness, with implications for the development of improved auditory fitness-for-duty standards, the establishment of performance requirements for hearing protection technologies, and the refinement of strategies to train military personnel on how to use hearing protection in combat environments.

Keywords: Psychoacoustics/hearing science, hearing conservation, noise, instrumentation

Introduction

Hearing is an essential sense in dismounted (i.e. on foot) combat operations. It aids greatly in the ability to communicate with confederates, to detect the enemy and to maintain adequate acoustic stealth. Unfortunately, hearing acuity can be compromised during combat operations in a number of ways, including temporary or permanent noise-induced hearing loss and/or by wearing hearing protection. However, the relationship between the degree of hearing impairment and its impact on objective measures of operational performance is largely unknown. The purpose of this experiment was to objectively examine the impact that elevated auditory detection thresholds have on the performance of military personnel in a simulated combat environment.

The traditional approach to determining the functional impacts of hearing impairment on military operations has been to break down the military mission into distinct, easily controllable components and test those components individually. For example, one previous study examined how well listeners with hearing impairment and/or wearing hearing protection would be able to detect combat-related sounds, such as the footsteps of a booted soldier, the action of a rifle bolt and the movement of equipment and personnel in a tactical environment (Price & Hodge, 1976). Clasing and Casali (2014) performed a similar study examining the minimum distance required to detect and identify militarily relevant signals by soldiers on foot patrol while wearing different types of hearing protection. The logarithmic nature of human detection thresholds means that even relatively modest hearing impairments (20 dB) can lead to very large (10-fold) changes in the minimum detection distances of these sounds. These dramatic changes in detection distance can be misleading, as there is no way to know which sounds are likely to be most critical to detect in the successful execution of dismounted combat, or what the impact on mission success might be if a soldier fails to hear a particular signal like a footstep at a particular distance.

An alternative method of studying the impact of impaired hearing on operational tasks is to have listeners perform more realistic but less-controlled tasks, while their hearing is

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systematically impaired to increasing degrees with a real-time hearing loss simulator. One classic example is the study by Peters and Garinther (1990), which used interruption as a way to simulate impaired speech intelligibility in an M1A1 Tank Simulator. That study found combat effectiveness to be significantly degraded when hearing was impaired, including reductions in the number of enemy targets destroyed and an increase in the number of tank crews killed. In a more recent study, Casali et al, (2009) had teams of ROTC cadets perform a series of simulated combat tasks where hearing ability was systematically manipulated by the use of different hearing protection devices. Various hearing-critical tasks were integrated into the scenario, and the results showed that the use of hearing protection had a significant effect on performance in these staged auditory detection tasks (in fact, the hearing protection devices in some cases improved performance when they provided some amplification to the listener). However, the tasks were not designed to evaluate combat-related outcomes, such as survivability or lethality, so it is difficult to know what impact these changes in signal detection would have on actual mission success.

In this study, we attempted to measure the impact of hearing acuity on performance in a more realistic field environment that required listeners to perform integrated combat tasks similar to those they would perform in actual combat environments without making any attempt to control the specific auditory signals that were required to complete the mission. This was accomplished by having groups of individual participants engage in simulated paintball combat in a rural, wooded environment while wearing immersive hearing loss simulation systems. By ensuring that each participant within a group completed one round of combat with each of four levels of simulated hearing loss, we were able to balance for differences in individual aptitude in the paintball task across the participants and focus on the impact that the hearing loss had on operational performance. It was hypothesised that overall combat effectiveness would systematically degrade with decreasing hearing acuity.

Methods

The data reported are compiled from experiments spanning two research protocols and two data collection sites at Ft. Detrick, MD and the United States Military Academy (USMA) at West Point, NY. The experiments conducted at USMA were part of a series of student capstone projects in the Department of Behavioural Sciences and Leadership over the course of three consecutive academic years. Each experiment followed the same core methodology and used the same primary measurements, with only some minor variations in the secondary measurements collected.

Participants

Forty-three participants participated in the experiment. Twenty-nine participants were members of the USMA Close Combat Team with experience playing similar paintball scenarios on the same course where data collection occurred (18–22 years of age, one female), 10 were active-duty U.S. Army personnel from the National Capital Region (25–40 years of age, one female), and the remaining four were civilians from a pilot experiment (32–39 years of age, all male). All participants self-reported normal hearing except for two who reported mild hearing loss. Eleven participants played in two matches of the scenario and one played in three matches. All others played in just one match.

Study design

Electronic hearing loss simulation systems (HL Sims) were used to systematically vary the effective hearing acuity of the participants while conducting a paintball-based simulated combat scenario. The scenario was based on a common competitive paintball format known as single-elimination or last man standing, in which four to eight players participated at a time in a heavily wooded playing area, each wearing an HL Sim programmed to a different hearing loss profile. The mission objectives in each round were to eliminate all opposing players by marking them with paint and to be the last player remaining. Four rounds were played to make up a match and four hearing loss profiles were tested in each round (no hearing loss, mild, moderate and severe; Figure 1).

The no hearing loss condition was a passthrough condition that maintained the original hearing acuity of the participants and served as our baseline condition. The thresholds for the mild hearing loss condition were deliberately chosen to simulate a soldier classified with an H2 hearing profile, but who would be on the cusp of being classified as an H3 profile according to Army Medical Fitness Regulation 40–501 if their threshold were just 5 dB higher at any one frequency. Currently, a soldier in the Army with an H1 or H2 profile would be deemed fit for duty, whereas an H3 profile would require further testing of speech recognition in noise which, combined with years of service, would be used to determine recommendations for retention or separation. Thus, this is an important condition because it is near the current borderline for being deemed medically fit for duty. Similarly, the moderate hearing loss condition was chosen to reflect the 90th percentile threshold for all H3s in the Army over a period of a few years leading up to the study, meaning that only 10% of H3s in the Army had thresholds greater than these values. Lastly, the severe hearing loss condition was set to the maximum possible threshold that the HL Sim could simulate at each frequency. A soldier with this audiogram would almost certainly be separated from service.

If there were more than four participants in a match, then some participants were assigned the same loss in a given round (e.g. two players might be programmed with mild loss). Hearing loss assignments were switched between rounds in a pseudorandom fashion such that a given participant experienced a different hearing

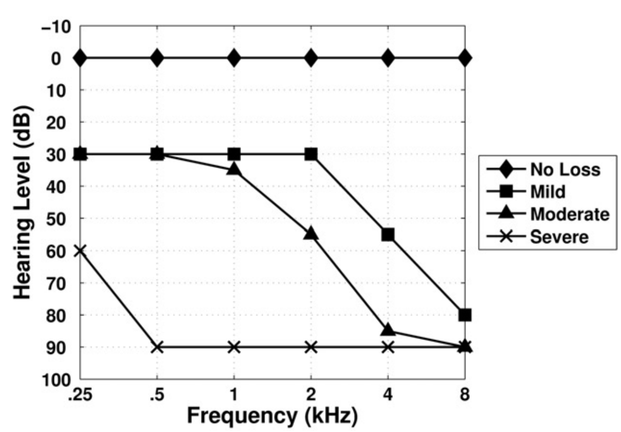

Figure 1. Hearing loss simulation profiles used in the experiment. Note that the ''No Loss'' condition was a passthrough condition that maintained the original hearing acuity of the participants; it does not mean that participants assigned to this condition had thresholds of 0 dB HL.

loss profile in every round (Table 1). This allowed counterbalancing of simulated hearing loss across participants and helped control for differences in individual aptitude in the paintball task. In addition to overall winning percentage, participants were scored on their lethality (number of opponents eliminated) and survivability (order of elimination and survival time). The study design allowed the participants to conduct their missions in a safe and relatively unconstrained way and provided measures of overall performance that were closely related to the most critical parameters that determine military success on the battlefield.

In total, 40 rounds of the scenario were conducted across the two sites with 224 observations spanning the four hearing profiles. During one round of the exercise, a player assigned with the severe loss condition was wearing an HL Sim that was accidentally powered off before the round began, so the data from this round were omitted, leaving 216 total observations reported. Also, in the first four rounds of the scenario at USMA, the moderate loss condition was replaced with an open ear condition, in which the participants played while wearing the hearing loss simulation systems with the insert earphones removed (see ''Equipment''). No differences were observed between this open ear condition and the no loss condition, so it was included in the no loss results. Therefore, there are 58 observations reported for the no loss condition, 50 observations for the moderate condition and 54 for the mild and severe conditions.

Table 1. Example hearing loss profile assignments for a match with four participants.

Round	*Participant 1*	*Participant 2*	*Participant 3*	*Participant 4*
1	No Loss	Mild	Moderate	Severe
2	Mild	Moderate	Severe	No loss
3	Moderate	Severe	No loss	Mild
4	Severe	No loss	Mild	Moderate

Note that the actual assignments were pseudorandomised and did not necessarily exhibit the pattern that is shown here for clarity.

Equipment

The participants conducted the experiment while wearing the custom immersive hearing loss simulation system shown in Figure 2 (Sensimetrics Corp., Malden, MA). Each system consists of a helmet-mountable, battery-powered digital signal processor and a pair of ER-2 insert earphones (Etymotic Research, Inc., Elk Grove Village, IL), where both earphones have been adapted to hold an ambient-sound pick-up microphone (FG-23742, Knowles, Itasca, IL). Each system also includes I/O controls, a USB interface and a microSD card reader for system control, programming and log file recording. The software architecture that handles system programming and real-time audio processing is based on the commercially available HeLPS headset (Zurek & Desloge, 2007). The algorithm for simulating hearing loss allows sounds to pass through from the microphones at certain frequencies and utilises a combination of attenuation from the earphones and additive masking noise to elevate the absolute detection thresholds (i.e. hearing levels) for other frequencies, depending on the audiogram being simulated. It is also designed to produce for the listener the sensation of loudness recruitment (i.e. abnormally rapid growth in perceived loudness) that is associated with a specified hearing loss. In this manner, sounds that are below the specified threshold at a particular frequency are no longer audible. However, sounds well above the threshold are perceived as having the same loudness as they would for an unimpaired listener. The validity of a hearing loss simulation that incorporates threshold shift and recruitment is supported by other studies that have used similar noise-masking simulations (e.g. Zurek & Delhorne, 1987; Humes et al, 1987; Dubno & Dirks, 1992).

Most participants used Tippmann 98 custom paintball markers (Tippmann Sports, LLC, Fort Wayne, IN) set to a velocity of 290 feet per second (10 below the maximum threshold for most recreational paintball venues). The markers were loaded with one hopper of paint (~200 paintballs) prior to each round. No spare ammunition pods were allowed and participants wore Army Combat Uniforms (ACUs) whenever possible. All participants were equipped with a synchronised watch and participants at

Figure 2. Hearing loss simulator (HL Sim) shown in close-up (left) and when mounted on top of a participant's helmet/mask (right). The knob on the front of the HL Sim was used to select between the preloaded hearing loss simulation profiles. Note the wooded and hilly terrain behind the soldier, which is a view of the playing area near the centre staging zone at the US Military Academy site.

USMA were also equipped with a Qstarz BT-Q1300ST Nano Keychain GPS in their ACU shoulder pocket to track their movement during the scenario.

Procedure

At the USMA, data collection took place in a section of the Close Combat Team's woodsball training course, approximately 250 m by 100 m. This was a heavily wooded mountainous area that was familiar to participants. At Ft. Detrick, data collection took place on a course approximately 150 by 50 m in a heavily wooded but relatively flat terrain that was unfamiliar to the participants. Prior to the experiment at both sites, the participants were walked around the perimeter of the course to indicate the boundaries, which were marked by natural features such as ravines, tree lines or dirt roads. In the centre of the course was a safe/staging zone where the experimenters and equipment were stationed. Participants were provided with a synchronised watch and outfitted with a helmet-mounted HL Sim system and facemask. Each participant was assigned one of eight colours (red, yellow, orange, green, blue, pink, white or black) and their assigned colour was indicated by wrapping strips of coloured duct tape around both biceps. Each participant's HL Sim was set to the no loss condition while the experimenters provided instructions and answered any questions that the participants might have about the experiment. This served both to ensure that the HL Sims were functioning properly and to allow the participants some practice listening through the device before the experiment.

A compass in the staging area (either drawn on the ground or indicated by cardinal directions affixed to nearby trees) was used to indicate starting directions for the participants. Similar to the hearing condition, starting directions were assigned in a pseudo-random fashion such that any given participant was assigned to a different direction in every round. Participants were instructed to choose a starting location in the path of their assigned direction, out of sight from all other participants. Immediately prior to the first round and each subsequent round, participants were notified of their starting directions and the time that the round was scheduled to begin. The participants were then switched into their assigned hearing condition on the HL Sim. Participants were not told their hearing loss assignment nor were they physically able to see the setting of their HL Sim; however, the masking noise of the simulator gave the participants a relative indication of their hearing condition, which was unavoidable. Participants were given a few minutes to get to their starting locations and were instructed to wait until the scheduled start time before beginning play. An air horn was used to indicate the beginning of a round. In case participants with severe degrees of hearing loss were unable to hear the air horn, they were instructed to use their watches to determine when to start. At the sound of the air horn, a single-elimination, free for all scenario commenced where participants were eliminated from play as soon as they were marked by an opponent's paintball marker. Participants were instructed that, once marked, they were to return to base and report which opponent eliminated them and the time at which it occurred. Additional safety-marked experimenters were stationed throughout the course to verify accurate scoring when eliminations occurred within their line of sight. These experimenters were generally blinded to the hearing loss condition of the participants. Once all but one player was eliminated, the round ended and the winning player was notified to return to base. If a winner had not been decided after 15 min of play in a given round and the remaining players were not close to an engagement, the round was ended. Only two rounds ended this way, and in these instances, the two players remaining were given the same elimination order and neither player was credited with a win.

A total of four rounds were played with each set of participants, with the hearing loss assignments and starting locations switched between rounds. Players were given a short rest between rounds while the hearing loss profiles were switched and scoring was recorded. A typical round with four players took approximately 10 min with a typical match lasting about 60–80 min including breaks.

During two of the matches at USMA, participants were asked to rate the decrease in situational awareness caused by the hearing loss simulator relative to what their situational awareness would be without wearing the HL Sim. This question was asked after every round and was measured using a 10-point Likert scale where 1 represented no decrease in situational awareness and 10 represented an extreme decrease in situational awareness. There were 8 and 6 players in each of these two matches, respectively. Thus, 14 data points were collected for each of the four hearing loss profiles tested.

Data analysis

Due to the nature of the exercise, the last player remaining, order of elimination and lethality data observed in every round were not independent measures (i.e. each was a zero-sum game). Thus, a traditional analysis of variance (ANOVA) was not appropriate. Instead, statistical analyses were conducted using a 100,000-trial Monte Carlo simulation, which matched the 216 observations across the four hearing loss profiles with the same number of players and hearing loss profiles in every round of the actual data set with the null hypothesis that the order of elimination in each round was determined completely by chance. The maximum differences between conditions that could be expected to occur more than 5% of the time by chance (i.e. equivalent to statistical significance at the $p < 0.05$ level) were determined and any differences greater than this were deemed statistically significant.

For the subjective data, the relationship between hearing loss profile and perceived decrease in situational awareness was measured using a logistic regression on individual trials. Each response was coded by player and hearing loss profile and a Pearson chi-squared value was calculated with a significance level of $p < 0.05$.

Results

Objective results are shown in Figures 3–5. Each of these figures looks at a different aspect of performance in the paintball task. Figure 3 shows the mean percentage of opponents eliminated (i.e. lethality) across the four hearing loss conditions. A downward trend in lethality was observed with increasing levels of hearing loss, such that participants were approximately half as lethal in the severe loss condition as in the normal hearing condition.

The Monte Carlo simulations indicated that differences in lethality greater than 9.1% between conditions were significant (Bonferroni corrected for six comparisons). Thus, significant differences in lethality were observed for the severe hearing loss condition relative to both the no loss (9.9% difference) and mild loss conditions (10.4% difference). The simulation also indicated that the lowest level of lethality expected by chance was 13.4%

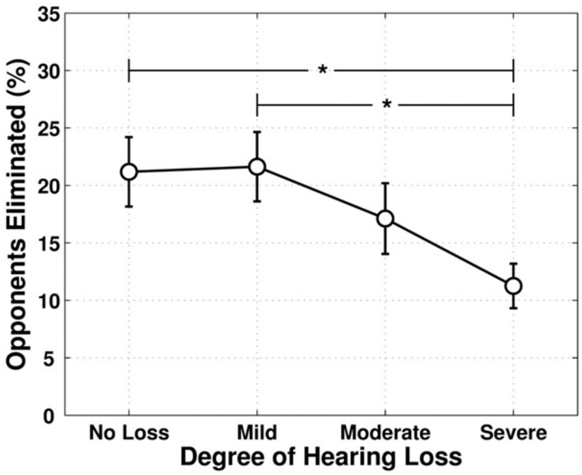

Figure 3. Mean lethality as a function of simulated hearing loss. Error bars represent 95%confidence intervals. Stars indicate statistically significant differences between conditions in a Monte Carlo simulation.

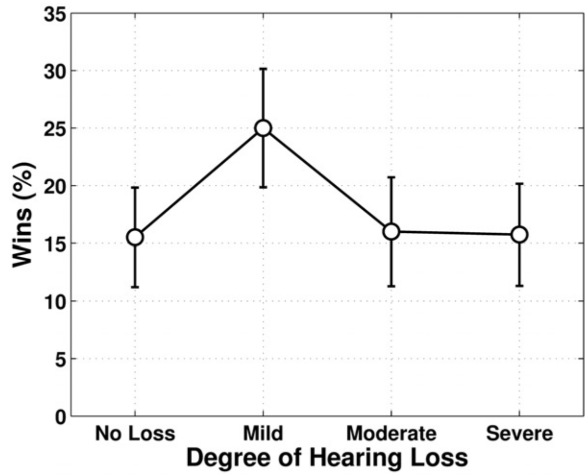

Figure 5. Mean percentage of wins determined by the last player remaining as a function of simulated hearing loss. Error bars represent 95% confidence intervals.

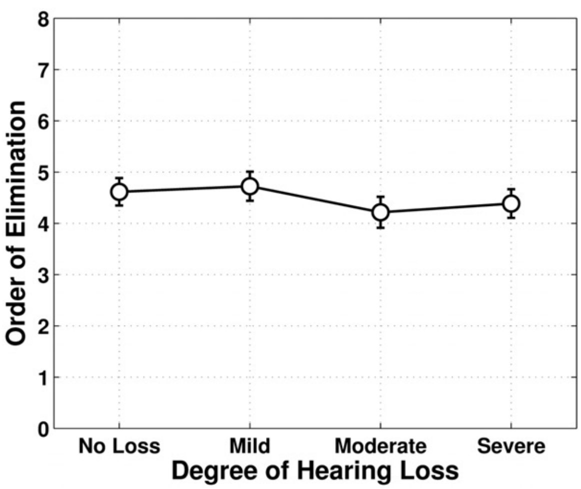

Figure 4. Mean survivability determined by order of elimination as a function of simulated hearing loss. Error bars represent 95% confidence intervals. Order of elimination was normalised to a scale of 1 to 8 for all rounds. Low and high numbers on the scale indicate earlier and later elimination in the round, respectively.

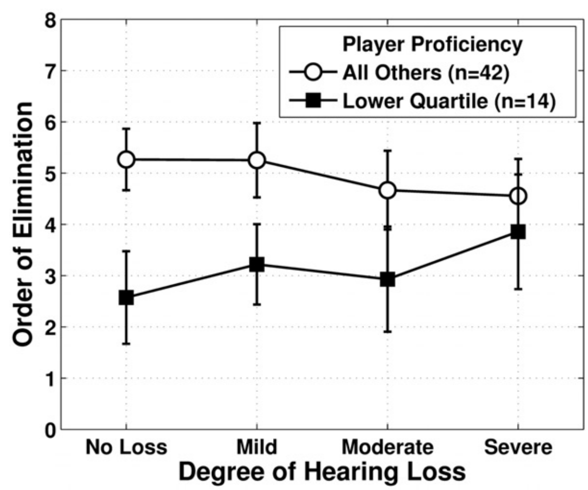

Figure 6. Mean order of elimination as a function of simulated hearing loss for players in the lower quartile of overall performance versus the players in the middle and upper quartiles.

(Bonferroni corrected for four conditions) and that it was extremely unlikely ($p < 0.001$) that the very low percentage observed for the severe loss condition (11.3%) occurred by chance.

Contrary to the results for lethality, a significant effect of hearing loss was not observed for survivability (mean order of elimination (Figure 4)) and no clear trends were observed. Figure 5 displays the mean percentage of rounds in which a participant assigned with each of the four hearing loss conditions was the last player remaining (i.e. winning percentage). Overall, there were no significant differences in the winning percentage across the four hearing loss conditions tested in the experiment, although there was a trend towards better performance in the mild hearing loss condition.

At the outset of the study, a scoring rubric was developed to measure success in the mission aside from being the last player remaining. This composite score simply awarded two points for every opponent that a player eliminated and one point for every opponent that a player outlasted. This scoring system was told to the participants prior to the match, but they were not explicitly given feedback of their performance after every round. However, this composite score, which is essentially a combined measure of lethality and survivability, was used *post hoc* to evaluate the overall skill of each player by calculating their mean composite score across all four hearing conditions. The participants were then rank ordered by composite score and separated into quartiles. Figure 6 shows the mean order of elimination for players in the bottom quartile (25th percentile composite score) versus the players in the middle and upper quartiles as a function of hearing loss. A downward trend in survivability can be observed for the better

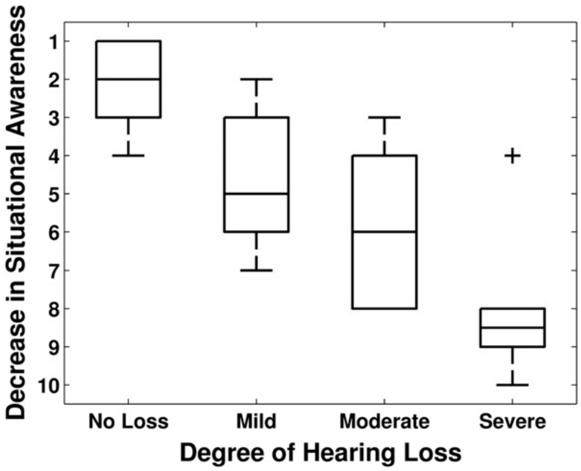

Figure 7. Perceived decrease in situational awareness as a function of simulated hearing loss, where 1 represents no decrease in situational awareness and 10 represents an extreme decrease in situational awareness. The central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the most extreme data points not considered outliers, and outliers are plotted individually.

performing players as hearing loss increased, whereas the lower performing players demonstrated the opposite trend. Unpaired *t*-tests with Bonferroni correction were used to examine the difference between these two groups in each hearing condition. Significant differences were observed between the groups in the no loss ($p < 0.001$) and mild loss conditions ($p < 0.05$), but not in the moderate ($p = 0.065$) or severe loss conditions ($p = 1.0$). These data show that there was something that the higher performing teams were doing better to maintain survivability when they could hear normally that went away as hearing loss increased.

The subjective results are shown in Figure 7, which plots the perceived decrease in situational awareness on a scale of 1 to 10 for each of the four hearing loss profiles. A significant relationship was observed between hearing loss profile and decrease in situational awareness ($\chi^2 = 79.6$, $p < 0.001$).

Discussion

The most striking aspect of the results of this experiment was that, while hearing loss clearly resulted in a significant decrease in situational awareness of the queried participants and had a negative impact on lethality, even the most severe hearing losses had little or no impact either on survivability or on the probability the participant would win a round by being the last player remaining. The most likely explanation for this result is that participants experiencing higher levels of hearing impairment may have made a conscious decision to switch to a more passive or defensive mode in order to maintain survival at the cost of lethality. In other words, they may have adopted a strategy to play more cautiously or to hide to increase their chances of survival. Some participants did report to the experimenters that they had employed a strategy when they were assigned the higher levels of hearing loss to stay hidden until most of the other players had eliminated one another and/or until an opponent came into their field of view.

From the perspective of an individual combatant in this simulated combat environment (for whom survival would likely be of paramount importance even at the expense of lethality), this would be a reasonable strategy to adopt. However, it does have its limitations, as it is impossible to win a round without eliminating at least one other opponent. In a real combat environment where fighting is done as a team rather than as an individual, a systematic shift towards a more timid offensive posture by those members of a unit with impaired hearing could have a devastating impact on unit cohesion and overall mission capability. On the other hand, it is unclear whether individuals would adopt this same strategy in a team environment.

Although the more conservative strategies adopted by the participants with hearing loss had relatively little impact on survivability or on the probability of being the last person remaining (which was nominally the victory condition in this scenario), the reduction in lethality could have significant implications for overall military effectiveness. The results of this experiment provide compelling evidence that the ability to engage and eliminate opponents in dismounted combat is negatively impacted for individuals with more than a moderate hearing loss. In part, this is likely due to the conservative strategy used by these participants; however, it is highly likely that the loss of tactical information provided by auditory cues from footsteps and from the sounds of other opponents engaging one another on the battlefield also played a direct role.

A change in strategy might also explain the slightly elevated (though non-significant) level of performance seen in winning percentage for the mild hearing loss condition (Figure 5). It is possible that participants, when in the mild hearing loss condition, adopted a balanced strategy of aggression combined with some caution that was more effective relative to the other conditions. Whereas participants operating in the no loss condition may have overestimated their advantage relative to the hearing-impaired listeners and adopted a more aggressive but less effective strategy than the participants in the mild hearing loss condition.

The importance of skill in selecting a strategy that was appropriate for a particular hearing loss condition is highlighted in Figure 6, which shows that hearing impairment had a much different impact on survivability performance (order of elimination) for the lowest performance quartile of players than it did for the more skilled players in the experiment. In the no loss and mild loss conditions, the less skilled players tended to be eliminated much more quickly than the more skilled players, probably because they were lured into adopting a strategy that was overly aggressive in these rounds of the experiment. By contrast, the more skilled players tended to survive much longer in the rounds with no or mild hearing loss, presumably because they were using a more balanced strategy where they used audio cues both to engage and avoid enemy contact as appropriate. In the severe loss conditions, the skilled and unskilled players were both forced into essentially the same strategy (hiding) where level of skill had less impact on the outcome and both the good and bad players essentially performed the same. This result highlights the important role that experience and training may play in allowing military personnel to know what to do with auditory information they may receive on the battlefield. If they use this information incorrectly, it may lead to a worse outcome than if they don’t receive it at all.

Another notable result of the experiment is that the effects of hearing impairment were relatively modest until the simulated hearing loss increased to the severe condition. This probably reflected the individually-focussed nature of the last player standing scenario. In a team scenario, speech understanding would have likely been impacted in all hearing loss conditions due to a loss of audibility at the higher frequencies, although non-verbal communication (e.g. hand signals) may help compensate for this to some degree. The current scenario did not involve communication. Instead, success depended on the ability to detect and locate the enemy. Previous research has shown that low-frequency interaural time delay cues below 1 kHz are sufficient for localising sound sources (Wightman & Kistler, 1992), particularly when exploratory head motion cues are available. These low-frequency sounds also tend to propagate further than high-frequency sounds, since low-frequency sounds are less subject to atmospheric absorption and interference by foliage and other obstacles. In this experiment, all hearing profiles except for the severe loss had relatively low thresholds (<35 dB HL) at or below 1 kHz. If participants were able to use the low-frequency components to detect and visually orient towards sounds in the environment, they may have been able to maintain sufficient situational awareness even without having access to high-frequency cues.

Although the paradigm used in this study has higher face validity than most other measures of performance in simulations of dismounted combat, the paintball-based scenario tested in this initial study has some inherent limitations that need to be taken into consideration when extending the results to real-world military combat environments. First and foremost, the scenario purposefully lacked a need for communication and/or teamwork, as discussed previously. Instead, it was designed to isolate the impact that a loss of non-verbal auditory cues (e.g. footsteps, localisation of gunfire) would have on mission success. But the design also encouraged a more conservative strategy to be adopted when hearing was impaired to maximise the probability of survival due to the individualised nature of the scenario and the emphasis of playing only for one's own survival. Had teamwork been necessary, which is almost always the case in actual combat, participants might have been less inclined or perhaps even less able to adopt such a strategy. A second limitation of the study is that the range and accuracy of a paintball marker are much worse than those of an M4 assault rifle. This means that participants needed to get much closer to an opponent prior to engagement than they might under normal circumstances. And in the instances when a player did successfully track and surprise an opponent, unless one of the first few shots fired made a mark, the opponent would be alerted and the advantage of surprise would be lost, simply because of the limited accuracy of the paintball markers. Also, the acoustic signature of a paintball marker firing is quite different (e.g. much quieter) than that of the weapons typically carried in dismounted combat, which may have impacted the results. Another consideration is that a situation in which only one player has normal hearing in each round is rather unrealistic in combat. The study design maximised data collection efficiency by testing/comparing all four hearing loss conditions at once, but the differences between hearing conditions may have been more pronounced if all but one player in each round had normal hearing and the remaining player was assigned one of the other three hearing conditions. However, this would have required a great deal more time and effort to achieve the same statistical power.

Despite these limitations, we believe that this study has successfully demonstrated the feasibility of the overall approach of using real-time, wearable hearing loss simulation systems to measure the impact that impaired hearing has on performance in complex operational tasks like simulated dismounted combat. Our current efforts are focussed on extending the paintball-based research paradigm to include increasing levels of realism, including the integration of team tasks that require communication, and examining different levels of hearing loss to determine the point at which operational performance starts to degrade. Eventually, we anticipate that the results of this experiment and other similar studies will allow us to make better-informed decisions in the development of fitness for duty standards for hearing-impaired personnel (Tufts et al. 2009) and the establishment of performance-based requirements for tactical hearing protection systems (Lee & Casali, this issue).

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