TOWSON UNIVERSITY

OFFICE OF GRADUATE STUDIES

THE EFFECTS OF HEARING PROTECTION AND EXPERIENCE ON THE ABILITY TO IDENTIFY FIREARMS BY THEIR AUDITORY SIGNATURES

by

Katherine Peitsch

A thesis

presented to the faculty of

Towson University

in partial fulfillment

of the requirement for the degree of

Doctor of Audiology

Department of Audiology, Speech Language Pathology and Deaf Studies

Towson University
Towson, Maryland 21252

May, 2014

TOWSON UNIVERSITY

TOWSON UNIVERSITY
COLLEGE OF GRADUATE STUDIES AND RESEARCH

AUDIOLOGY DOCTORAL THESIS APPROVAL PAGE

This is to certify that the Audiology Doctoral Thesis prepared by Katherine Peitsch entitled: The Effects of Hearing Protection and Experience on the Ability to Identify Firearms by their Auditory Signatures has been approved by his or her committee as satisfactory completion of the Audiology Doctoral Thesis requirement for the degree Doctor of Audiology (Au.D.)

Stephanie Nagle, Ph.D. — Date: 5/3/13
Chair, Audiology Doctoral Thesis Committee

Jeremy Gaston, Ph.D. — Date: 5/13/13
Committee Member

Diana C. Emanuel, Ph.D. — Date: 05/13/13
Committee Member

Janet DeLany, D.Ed. — Date: May 11, 2013
Dean, College of Graduate Studies and Research

ACKNOWLEDGMENTS

I would like to thank those individuals who assisted with this thesis project. I could not have completed this thesis without the support of my thesis chair, Dr. Stephanie Nagle, Ph.D. Her continued supervision and guidance was invaluable in completing this process. Thank you to my thesis committee as well, Dr. Jeremy Gaston, Ph.D., and Dr. Diana Emanuel, Ph.D., for editing this document and providing feedback about the project. Dr. Gaston also provided many of the materials needed to complete the study.

ABSTRACT

THE EFFECTS OF HEARING PROTECTION AND EXPERIENCE ON THE ABILITY TO IDENTIFY FIREARMS BY THEIR AUDITORY SIGNATURES

Katherine Peitsch

Hearing protection devices are used to attenuate loud sounds that could be potentially damaging to the ear and cause hearing loss. The attenuation provided by hearing protection helps to reduce the risk of noise induced hearing loss, but it also attenuates important auditory cues for detection, localization, and identification of sounds. Many soldiers report that they do not wear hearing protection because they believe it compromises their situational awareness. This loss of auditory cues could be detrimental to soldiers who rely on their hearing for awareness of friendly or enemy troops and resources as well as for communication of orders. The purpose of this study was to determine if hearing protection devices had a negative effect on the ability of listeners to identify firearms by their auditory signatures. A secondary purpose was to determine if experience using small arms had an effect on recognition of weapon type as well. Results of this study for one- and three-shot listening conditions suggested that hearing protection does have a detrimental effect on identification abilities; participants scored lower when listening with hearing protection than with an open ear. A significant difference in scores was observed between the hearing protection and open ear listening conditions overall as well as in a one-shot condition. No significant differences were seen between one- and three-shot conditions, nor between the expert and novice experience groups. Based on these findings, hearing protection devices can have a small, but significant negative impact on identification of small arms fire. Despite this negative

effect, it is still important for soldiers to wear hearing protection because noise induced hearing loss can have a greater impact on auditory skills.

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CHAPTER 1

INTRODUCTION

In combat and training situations, soldiers rely on their auditory sense for communication among units, situational awareness, and information about enemy operations. Auditory cues can provide information about enemy location and resources, especially from the sounds of various weapons being fired. The Department of the Army (2008) recognized the importance of good hearing acuity for soldiers to successfully complete their missions and noted that, “unlike visual information, information carried by sound comes to us from all directions, through darkness, and over or through many obstacles to vision” (p. 1-1). Normal hearing is critical for safety on the battlefield as well as successful operations. However, many military personnel are at risk for noise induced hearing loss (NIHL) because of their exposure to loud sounds, including those from machinery and weapons. In 2006, over 55,000 US veterans received compensation for hearing loss as their primary disability, with a cost to the military of over $900 million (Department of the Army, 2008).

NIHL can affect one’s ability to hear specific sounds that are critical for combat readiness and effectiveness. Fortunately, NIHL can be minimized through the use of, and compliance with, hearing conservation programs. While some environmental controls can be put in place to limit the intensity level of sounds coming from loud noise sources, the simplest way to prevent NIHL is to consistently wear hearing protection devices (HPDs), particularly in military settings (Abel, 2008). HPDs are ear level devices recommended to be worn by people in noise that exceeds a specified level, typically 85 to 90 dBA for steady state noise and 140 dB peak SPL for impulse noise (Department of the Army, 1998; National Institute for Occupational Safety and Health, 1998; Occupational Safety and Health Administration, 1981). The consistent use of HPDs is even more critical for soldiers and other military personnel who may be exposed to unexpected damaging impulse noise from weapons or explosives. However, many soldiers do not wear HPDs because they feel that the devices compromise their situational awareness and ability to effectively communicate with their units (Abel, 2008).

Some research has examined the effects of HPDs on detection (Alali & Casali, 2012; Price, Kalb, & Garinther, 1989) and localization (Abel & Hay, 1996; Talcott, Casali, Keady, & Killion, 2012) of various sounds. However, little research has focused on the actual effect that HPDs have on identification of sounds, specifically weapons. The main purpose of this study was to determine if HPDs had an effect on people's ability to identify the type of weapon fired based on their auditory signatures. A secondary purpose was to determine if experience with weapons fire had an effect on the identification of these weapons.

CHAPTER 2

REVIEW OF LITERATURE

Military personnel use auditory cues for localization of enemy forces, for effective communication on the battlefield, and to identify the types of weapons being used by friendly or enemy soldiers. The ability to identify aspects of weapons fire during training and battlefield operations is crucial for the safety and success of the soldiers and their unit. Little research has focused on the auditory cues that allow soldiers to identify various weapons based on the sounds of weapons fire.

Perception of Auditory Signatures

Discrimination. Much research has focused on the auditory cues used for discriminating and processing simple sounds (e.g. tones), often ones created in a laboratory, rather than complex and naturally occurring sounds (e.g. glass breaking). One exception to this lack of research is the discrimination and processing of speech stimuli, which have been studied widely in order to determine the cues used by listeners in the perception of speech sounds (Denes & Pinson, 1993). As early as 1929, the Bell Telephone Laboratories conducted research regarding the cues necessary for intelligible speech when transmitted through telephone lines and later hearing aids (Fletcher, 1929). The goal of their research was to quantify how speech sounds were recognized by listeners to determine what processes were involved in understanding speech. Based on the large body of research regarding auditory cues for speech, multiple cues are important in the identification of speech sounds, including spectral and temporal components (Holt & Lotto, 2006). In their study on auditory cue weighting, Holt and Lotto (2006) demonstrated that listeners use a variety of auditory cues for categorization of complex sounds. The researchers varied the center- and modulation-frequencies of tones to determine what cues are most important in categorizing sounds; results indicated that the center frequency was most important for accurate categorization, even when the center frequency information was modified. The authors suggested the weighting of these auditory cues could be important in second language acquisition as the same cue may be weighted differently in different languages. The authors noted that the phonemes /l/ and /r/ in English are interpreted based upon the third formant of the sound where as the phonemes /w/ and /r/ in Japanese are interpreted upon the second formant of the sound. The weight placed on various cues by listeners may explain why second languages are often difficult to learn. A training program may be effective in teaching listeners to weight various cues and the authors noted that listeners typically use multiple dimensions to categorize acoustic stimuli (Holt & Lotto, 2006). In order to accurately categorize sounds based on auditory input alone, people use temporal and spectral cues to sort sounds into similar classes, such as impulse sounds or speech.

Identification. Identification of complex environmental sounds is similar to speech identification in that it requires multiple auditory cues to accurately identify the sound. Ballas (1993) examined the cues that listeners use to identify “everyday sounds”. Participants were asked to listen to 41 everyday sounds (e.g. stapler, water dripping, telephone ringing, lawn mower) and to rate the sounds based on cues that are also important for speech identification. Three main cues were important for identifying everyday sounds: identifiability, timbre, and familiarity. Sound identifiability was the most important cue and was comprised of being able to create a mental picture of the sound, being able to easily describe the sound, and being able to identify the sound in isolation (Ballas, 1993).

Soldiers need to be able identify broad classes of sounds (e.g. impulse event, speech) related to military operations, as well as to be able to identify subcategories of sounds (e.g. gunshot, explosion). In one of the only studies on recognition of weapons fire, Gaston and Letowski (2012) examined the cues that listeners use to recognize various types of weapons (i.e. large caliber rifle, small caliber rifle, and handgun). Participants were asked to listen to recordings of six weapons being fired and rate the similarity of the pairs of weapons. In general, participants were able to categorize the weapons as handguns or rifles. Analysis using a multi-dimensional scaling solution showed that participants perceived weapons with similar timbre, muzzle velocities, and cartridge sizes as more similar. In the second part of the study, participants were again asked to listen to pairs of recordings of the weapons (one from each category listed above) and then to identify a specific weapon. Similar to the results for the previous study, listeners accurately identified a weapon when it was paired with one from another category (i.e. handgun versus rifle). Participants used temporal, spectral, and intensity cues to differentiate the weapons in this study (Gaston & Letowski, 2012). There are also auditory events specific to gunshots that can be used as auditory cues to identify weapons (Maher, 2006). When a weapon is fired, the gas expanding in the barrel as the cartridge is discharged creates a muzzle blast. A shock wave can also be created as the cartridge leaves the barrel, which travels outward from the path of the bullet. Sound reflections from the surrounding environment will also be created as the muzzle blast and shock wave propagate away from the weapon (Maher, 2006). Soldiers who have experience with various weapons may be better able to use these auditory cues to identify the specific weapons fire, as they are more familiar with the stimulus.

Experience. Ballas (1993) looked at the effects of "ecological frequency" (i.e. how often a sound occurs in an environment) on participants' abilities to identify everyday sounds. He asked participants to record the first sound they heard when a timer sounded throughout the course of a week. The sounds were categorized based on the type and context of the event; many of the sounds that were recorded by participants in this study were also included in the list of 41 everyday sounds (e.g. water running, stapler) that Ballas (1993) asked participants to identify in the first part of this study. Results of this study suggest that the frequency of everyday sounds is significantly negatively correlated with the identification response time and causal uncertainty (i.e. the number of alternative objects that could create that sound). These results demonstrate that the familiarity of the sounds of everyday objects make them more easily identifiable by listeners. The results of this study of everyday sounds would also be applicable to soldiers who have experience listening to weapons fire. Their experience with these sounds may contribute to better identification abilities of weapons fire.

Fluitt, Gaston, Karna, and Letowski (2010) investigated the feasibility of a training program for soldiers to better identify firearms by their auditory signatures. The authors noted that because much research has been done on identification of speech and music, but little on environmental noises, they wanted to determine if a training program could be used by members of the military to better identify weapons. Improved identification of weapons fire would be important as soldiers are exposed to sounds from various firearms in combat. Results of their study indicated that an auditory training program would be helpful for soldiers as the ability to correctly identify firearms improved following auditory training using sound recordings. The training also generalized to a live fire listening condition as participants again demonstrated improved performance (Fluitt et al., 2010). A training program may also be effective for soldiers with hearing loss or for soldiers wearing hearing protection, as many of the auditory cues necessary for weapons identification may not be audible to those with hearing loss or those wearing HPDs.

Noise Induced Hearing Loss

It has been well known since the Industrial Revolution of the 19th century that exposure to loud sounds can cause permanent hearing loss, known as NIHL (Sataloff & Sataloff, 2006). NIHL occurs because the inner ear experiences an acoustic overstimulation or trauma (Sataloff, Sataloff, & Virag, 2006). Spoendlin (1971) demonstrated that exposure to noise damaged the cochlea of guinea pigs; damage was more apparent and widespread with higher intensities and longer durations of noise. In the human cochlea, damage due to noise overexposure is typically seen between the basal and second turn of the cochlea and hearing loss often develops between 3000 and 6000 Hz on the audiogram (i.e. a “noise notch”). The amount of hearing loss caused by noise exposure is related to the duration and intensity of the noise, as well as the rest period before overexposure occurs again (Fligor, Meinke, & Nitzel, 2012; Killion, Monroe, & Drambarean, 2011; Mrena, Ylokoski, Kiukaanniemi, MaKitie, & Savolainen, 2008; Occupational Safety and Health Administration, 2005; Sataloff & Sataloff, 2006; Sataloff et al., 2006).

Given that individuals who use firearms, especially those in the military, are likely exposed to noise well above levels considered safe, it is important for them to use HPDs and be enrolled in a hearing conservation program (HCP) to minimize the risk of NIHL. Hearing loss can have an adverse effect on quality of life, the ability to communicate, and the ability to function in society, especially in the military; NIHL can cause tinnitus, aural fullness, difficulty understanding speech, and increased stress or fatigue (Department of the Army, 1998, Fligor et al., 2012; Mrena et al., 2008; Sataloff & Sataloff, 2006; Sataloff et al., 2006). Hearing loss is particularly detrimental to soldiers as it can affect their combat readiness and impair their ability to "localize snipers, locate patrol members, determine the position, number, and type of friendly and enemy vehicles, or determine types of booby traps" (Department of the Army, 1998, p. 3). Soldiers depend on their hearing to identify enemy troops using environmental sounds, which are often high frequency in nature, and therefore would be most affected by NIHL (Department of the Army, 1998). Communication via radio can be difficult for individuals with normal hearing as military radios have limited bandwidth; the radios do not transmit the entire speech frequency range (i.e. 250-8000 Hz), but rather cut off low and high frequency sounds at either end of the speech range. If a soldier has difficulty hearing and interpreting the already degraded speech signals, he may confuse verbal orders. Finally, the Department of the Army (1998) also recognizes that soldiers with hearing loss will have difficulty identifying different weapons fire. Being able to identify the type of weapon being fired could allow soldiers to determine friendly versus enemy fire as well as determine the level of danger they are encountering.

Noise Exposure and Damage Risk Criteria. Because overexposure to noise can be decreased with the use of hearing protection, noise exposure standards have been developed to allow "safe listening" (Fligor et al., 2012). These standards are based on the noise level that is considered safe to listen to for an 8-hour period. The Occupational Safety and Health Administration (OSHA) standard considers 90 dBA to be safe while the National Institute for Occupational Safety and Healthy (NIOSH) standard allows 85 dBA for an 8-hour day. These standards were designed to protect individuals who are exposed to steady state noise, such as factory workers, and do not necessarily apply to soldiers or to non steady state noise, such as impulse sounds. The OSHA (1981) and NIOSH (1998) standards, as well as the Department of Defense (1997) design criteria standard for hearing conservation, note that workers should not be exposed to unprotected impulse sounds that exceed 140 dB peak SPL. Because much of the research on the damage caused by noise exposure had focused on continuous rather than impulse sounds, Coles, Garinther, Hodge, and Rice (1968) determined damage risk criteria for impulse sounds. The criteria were set such that 75% of people exposed to a certain level of noise for a specific time period would not experience a permanent hearing loss. Using damage risk criteria for steady state noises (i.e. a temporary threshold shift of 10 dB at 1000 Hz, 15 dB at 2000 Hz, and 30 dB at 3000 Hz), the authors extrapolated the permissible exposure level and time for impulse sounds using a 7.62 mm rifle firing as the target sound. The authors suggested that the damage risk criteria should be set at 159 dB (B-duration) for impulse sounds of 5 milliseconds to 150 dB (B-duration) for impulses of 100 milliseconds (Coles et al., 1968). It should be noted that the damage risk criteria from this study are over 40 years old and allowed for some people (i.e. 25%) to be at risk for a permanent hearing loss (Flamme, Wong, Leibe, & Lynd, 2009).

Flamme et al. (2009) tried to determine the damage risk criteria for individuals using civilian firearms without hearing protection based on more modern criteria. The authors were not able to develop a single number to use as damage risk criteria because the intensity of the sound depended upon the firearm used, the type of ammunition used, and the location relative to the weapon. They did note that some firearms could cause a permanent hearing loss if fired even once near an unprotected ear (e.g. .30-06 rifle and .357 caliber handgun loaded with 125 grain .38 caliber ammunition). Flamme et al. (2009) stressed the importance of knowing how loud a particular firearm and ammunition can be, as well as where the greatest sound intensity occurs in order to select appropriate hearing protection. Many modern weapons, especially those used by the military, create impulse sounds well above the limits set by current noise standards as firearms can exceed 160 dB peak SPL and many military weapons can exceed 190 dB peak SPL (Buck, 2009; Fligor et al., 2012). The nature of impulse sounds and variety of weapons used in modern society for recreation and warfare make it difficult to determine one specific intensity level that is safe. Due to the high intensities created by firing weapons in general, hearing protection devices are important in reducing the risk of NIHL.

Hearing Protection Devices

There are many different types of hearing protection devices (HPDs) available to individuals who need to protect their hearing during exposure to noise. The types of HPDs can be broken down into two main categories: active and passive devices (Berger, 2003; OSHA, 2005). Active devices include electronics or amplification systems while passive devices do not include any electronic systems (OSHA, 2005). Active devices contain a microphone, amplifier, and speaker all mounted within the HPD to provide amplification of soft inputs and attenuation of sounds above a predetermined level. The use of active HPDs allows for the attenuation of loud sounds, particularly short duration or impulse sounds, and amplification of softer sounds while wearing the devices. Some active HPDs may also include a noise cancellation system to further reduce noise, which may be ideal when wearers are exposed to continuous noise (Berger, 2003). Passive devices do not contain any electronics, and therefore use mechanical means to attenuate loud and soft sounds (Berger, 2003; OSHA, 2005).

Passive HPDs can be further classified into conventional, uniform/flat, and level dependent/non-linear (Berger, 2003). Conventional HPDs provide attenuation through mechanical processes, but have varying degrees of attenuation based upon the frequency and intensity of the noise. Uniform/flat HPDs provide relatively even attenuation across all frequencies. Passive level-dependent/non-linear HPDs are similar to the active HPDs in that they attenuate loud sounds above a certain intensity, but they attenuate loud sounds through mechanical means and do not contain electronics to amplify soft sounds (Berger, 2003).

Both active and passive HPDs are available in different styles: earplugs and earmuffs (Berger, 2003; OSHA, 2005). Earplugs fit inside the ear canal and are made of materials such as foam, plastic, or silicone and are available in expandable foam and pre-molded styles, or can be custom made to fit an individual's ear. Earmuffs fit around the outside of the ear where a hard ear cup over a flexible cushion seals the ear from external sounds. This device comes in a one size fits most style as it sits on the outside of the head and does not need to be custom made for an individual's ear. HPDs are also available in a helmet style, primarily for military personnel who need to protect their head (e.g. helicopter pilots). The helmets typically contain foam ear cups, which are similar to the earmuffs described above (Berger, 2003; OSHA, 2005).

Though any loud noise can cause NIHL, especially over a prolonged period of time, impulse sounds may be more likely to cause hearing loss than continuous sounds as hearing thresholds do not recover as quickly or efficiently following impulse noise with the same total energy as continuous noise (Clifford & Rogers, 2009). Regular use of hearing protection when using firearms can decrease the incidence of NIHL in military personnel (Mrena et al., 2008). However, the amount of noise reduction and therefore hearing protection provided by these devices, depends upon the type of HPD used (Buck, 2009). Buck (2009) noted that many HPDs are designed for use in industrial settings where noise is typically at a steady level and the peak level of any impulse sound does not exceed 150 dB peak SPL. The noise level in military environments often consists of impulse sounds from weapons, which can range from 150 dB peak SPL to 190 dB peak SPL. Because many HPDs are not intended for military use or with impulse sounds, they are not tested with impulse noise and so the attenuation provided by HPDs may be different in military versus industrial environments (Buck, 2009). In military applications, level dependent/nonlinear HPDs may be the best option as they allow the wearer to have situational awareness for low to moderate level sounds and they provide attenuation against high intensity impulse sounds (Buck, 2009). While the nonlinear HPDs may provide better protection against NIHL in military personnel and improve situational awareness for steady state noises, they may hinder a soldier's ability to identify weapons as they attenuate loud impulse sounds (Clifford & Rogers, 2009). HPDs work to prevent NIHL by attenuating loud sounds, such as steady state noise or impulse sounds, and will potentially attenuate important environmental sounds. The loss of auditory cues can compromise not only the ability of soldiers to identify weapons, but this loss can also affect detection and localization of sounds.

Auditory Abilities and HPDs

Many soldiers do not wear their HPDs as they find them uncomfortable or believe the devices hinder their ability to detect spectral and intensity differences in sounds (Abel, 2008; Clifford & Rogers, 2009). The attenuation provided by HPDs can affect soldiers' ability to hear speech and environmental noises, such as directions from a commander or enemy gunfire (Killion et al., 2011; Price et al., 1989).

Detection. Research has shown that wearing hearing protection can inhibit the wearer's situational awareness, which poses a possible safety hazard for anyone who wears hearing protection, as individuals may not hear a warning sound in their environment in time to remove themselves from the possible danger (Alali & Casali, 2012; Price et al., 1989). In a study on detection of environmental sounds, Alali and Casali (2012) measured the distance at which individuals with normal hearing could first detect a back up alarm on a vehicle while wearing various HPDs. Results of their study indicated that, as predicted, participants could detect the back up alarms at the greatest distance when wearing no hearing protection. When the participants wore the different HPDs, the average distance at which they could first detect the alarm decreased by as much as 500 feet, depending upon the type of HPD worn (Alali & Casali, 2012). This decrease in the distance of detectability with the HPDs as compared to the distance of detectability with the unoccluded ear could put the wearer into a hazardous situation, as the wearer may not have enough time to react to any danger. In a study related to hearing handicap and military applications, Price et al. (1989) calculated the distance at which a soldier could detect speech, non-speech, and equipment sounds when they had a reduction in hearing acuity. Participants had a reduction in hearing acuity due to hearing loss, wearing HPDs, or noise that masked the sound of interest. Results from their calculations show that soldiers with any type of hearing reduction would have more difficulty detecting any type of sound. For soft environmental sounds, a soldier with normal hearing using an unoccluded ear could monitor a space 200 to 400 times larger for enemy sounds, as compared to a soldier with a hearing impairment or a soldier wearing hearing protection. Under some conditions, a soldier with a hearing loss could not hear an enemy approaching at all. A soldier wearing hearing protection could not detect the enemy personnel until he was five steps away, but a soldier with a normal, unoccluded ear could detect the enemy while he was two minutes away in a quiet environment (Price et al., 1989). Based on these studies, HPDs can have a detrimental effect on the ability to detect environmental sounds, particularly soft sounds, which could put individuals at risk of entering hazardous situations.

Localization. In addition to decreasing distance of detection, HPDs can affect localization of sounds (Abel & Hay, 1996; Talcott et al., 2012). Talcott et al. (2012) looked at listeners' abilities to localize firearms in the presence of background noise with an active HPD as compared to an open ear. Participants were placed in a field surrounded by trees in a rural area with ambient background noise of approximately 50 dBA and then with 82 dBA of truck noise. Eight hidden shooter positions were placed in a circle 150 feet from the listeners and the researchers fired blank cartridges at various points around the circle. Listeners were then asked to indicate from which direction they heard the gunshot while wearing four types of HPDs or no HPD (open ear) in both noise conditions. Results of the study showed that listeners performed poorer while wearing active HPDs than with an open ear in both noise conditions. Participants were able to correctly localize a gunshot in background noise in 88% of the trials with an open ear as compared to 43 to 65% of the time while wearing various HPDs (Talcott et al., 2012). This study suggests that if soldiers are using these types of HPDs while on duty, their situational awareness for impulse noises (i.e. gunfire) could be compromised, though NIHL would likely have a greater impact. Abel and Hay (1996) conducted a similar study, in which they assessed the effect of HPDs, hearing loss, and age on localization abilities in adults. Participants were fit with three types of HPDs: passive ear plugs, passive earmuffs, and active earmuffs; they were then asked to localize pure tones in quiet and in 65 dB SPL of white noise. Results of this study indicated again that localization is best with an open ear, as the mean percent correct score across all groups was highest in this condition and poorest with all types of HPDs. In general, when wearing HPDs the participants performed best with the passive earplugs and poorest with the active earmuffs (Abel & Hay, 1996). Results of this study indicate that earmuff style HPDs may affect localization abilities of people with normal hearing as the HPDs cover the pinna; the pinna provides auditory cues that aid in front-back localization. Abel and Paik (2005) conducted a similar study using active earmuff style HPDs. Participants were asked to locate the source of 500 and 4000 Hz tones, and broadband noise presented through speakers arranged in a circle around the participants. Localization abilities decreased by 10 to 40% when wearing the active HPDs as compared to open ear scores. Results of these two studies suggest that hearing protection and hearing loss could impede an individual's ability to localize steady state and impulse sounds (i.e. firearms) in quiet and noisy combat situations (Abel & Hay, 1996; Abel & Paik, 2005).

Identification. Lindley, Palmer, Goldstein, and Pratt (1997) examined participants' abilities to identify various animal sounds while wearing commercially available active HPDs, (designed for hunters and shooters), as compared to the open ear; all participants had normal hearing and no experience in hunting. After being familiarized with the sounds used in this study, the participants were asked to identify seven animals based upon their sounds at four different distances from the participant. At distances of 25, 50, and 75 yards, the participants were able to correctly identify the animals by their sounds in both the open ear and HPD conditions with nearly 100% accuracy. Significant differences were seen between the open ear condition and the two HPD conditions at the 100 yard distance with participants able to correctly identify the animals with about 90% accuracy in the open ear condition compared to about 40% accuracy with the two active HPDs. The authors hypothesized that the HPDs affected the ability to identify sounds as they are essentially mild gain hearing aids which introduced distortion into the signal, thereby degrading the signal to noise ratio, particularly at the 100 yard distance (Lindley et al., 1997).

More recently, Giguere, Laroche, and Vaillancourt (2011) have shown that modern level dependent HPDs used in their active mode settings can provide significant improvement in speech understanding in the presence of military noise. In this study, participants with thresholds ranging from normal hearing sensitivity to severe hearing loss were administered Hearing in Noise Test (HINT) sentences played with simulated military noises at 80-95 dBA. Participants were asked to identify speech in an open ear condition, and while wearing level dependent HPDs used in the active or passive condition. Results of this study indicated that the level dependent HPDs performed similarly to traditional HPDs when used in the passive conditions. No improvement was seen in HINT scores when the HPDs were used in the passive mode, and participants with moderate to severe degrees of hearing loss performed poorer in the passive HPD condition as compared to the open ear condition. When used in the active condition, the level dependent HPDs provided substantial benefit for individuals with hearing loss as increases in HINT scores of up to ~25% were seen when the HPDs were set to the active mode with high gain. The HPDs in the active mode essentially acted like hearing aids for the participants with hearing loss. This advantage of active HPDs did not transfer to individuals with normal hearing as little improvement was seen in this group (Giguere et al., 2011). Though this study shows promise for the use of level dependent HPDs in their active modes, little benefit was seen for individuals with normal hearing, which is a requirement for entering military personnel.

Identification of Weapons Fire

Gaston and Letwoski (2012) examined the abilities of normal hearing listeners to recognize small arms weapons by their auditory signatures in an open ear condition. Listeners were familiarized with recordings of six single shot small arms weapons and asked to rate how similar they perceived the sounds to be. Following the ratings of 300 pairs of stimuli, perceived similarity of the weapon firing sounds was mapped using a multi-dimensional scaling analysis to provide visualization of perceptual similarities of the auditory signatures of each weapon. The results of these similarity rating indicated that handguns were generally distinguishable from small and large rifles, but that the weapons within each of these classes were more difficult to distinguish from each other. In a second part to this study, listeners were presented with a pair of the firearms recordings and asked to judge which interval contained a particular weapon. Results of this part of the study supported those of the first part of the study in that listeners were better able to identify a particular weapon when it was paired with one from another class. For example, the AK-47 recording was most easily identified when paired with the M9 recording and the M4 was also easily recognized when compared with the M9 (Gaston & Letowski, 2012).

Statement of Purpose

Recognizing that hearing loss can affect the safety of the individual soldier and combat units on missions has led the military to attempt to prevent NIHL. In a special text about hearing loss and hearing conservation programs (HCP), the Department of the Army (2008) outlined ways in which to identify hearing loss in its early stages and to prevent further hearing loss to ensure that soldiers had good hearing in order to perform their duties.

> The ability to distinguish the sounds of different weapons, both friendly and enemy, is a combat-critical skill. If the sounds of weapons fire are coming from the next block of buildings, knowing whether it is enemy or friendly, small arms or automatic weapons, small caliber or large caliber, or whether it is a rocket-propelled grenade (RPG) or an antitank weapon determines a Soldier's reaction and is critical information available only with good hearing. (Department of the Army, 2008, p.1-2)

While some research has focused on the effect of HPDs on detection and localization of sounds in life threatening situations, little research has been conducted on the effect of HPDs on identification abilities relevant to life threatening situations (i.e. firearm discharging).

Normal hearing listeners can identify small arms weapons fire based on their auditory signatures with reasonable accuracy with an open ear (Gaston & Letowski, 2012). While an open ear can better identify weapons, it is also more susceptible to NIHL, from temporary or permanent thresholds shifts. HPDs minimize the risk of NIHL from continuous noise and impulse sounds that could damage hearing by attenuating background noise as well as sounds of interest. HPDs have been shown to affect localization (Abel & Hay, 1996; Talcott, Casali, Keady, & Killion, 2012) and the detection (Alali & Casali, 2012; Price, Kalb, & Garinther, 1989) of signals of interest. It stands to reason then that HPDs could also affect individuals' ability to accurately identify sound sources, especially the source of weapons fire based on their auditory signatures alone. The goal of this study was to determine whether HPDs negatively effect the identification of weapons by their auditory signatures as compared to an open ear condition. A secondary purpose to this study was to determine if experience with weapons had an effect on accurate identification of firearms.

In order to determine if HPDs negatively impact accurate identification of weapons fire, participants listened to recordings of an M4 carbine and an AK-47 assault rifle firing one- and three-shot rounds. The task was completed twice, once with an open ear and once while wearing hearing protection. It was hypothesized that the use of HPDs would decrease participants' ability to accurately identify firearms by their auditory signatures. Experience with weapons was hypothesized to improve participants'' ability to accurately identify firearms by their auditory signatures. Finally, participants were hypothesized to perform more accurately on the three-shot listening condition compared to the one-shot condition due to additional temporal cues in the three-shot recordings.

CHAPTER 3

RESEARCH METHODOLOGY

Participants

Thirty adults (17 females, 13 males) between the ages of 20 and 50 years (M= 26.7 years) participated in this study and were recruited from Towson University's Student Veterans Group; the Department of Audiology, Speech Language Pathology, & Deaf Studies; and from the surrounding community. Participants were screened for weapons fire experience based on their responses to a questionnaire regarding use of weapons and military experience developed by the examiner (see Appendix A for the questionnaire). Selected participants did not have any reported neurologic or cognitive deficits that could interfere with their ability to participate in this identification task. Sensorineural hearing loss was not an exclusionary criterion for this study as many individuals who have experience with weapons may also have noise induced hearing loss.

Stimuli

The stimuli used in this identification task were recordings of two weapons, an M4 carbine and an AK-47 assault rifle, fired at a small arms firing range at Aberdeen Proving Ground. Recordings were made using G.R.A.S. Sound & Vibration 40 AF measurement microphones. For each weapon, an experienced shooter fired one or three round bursts of fire and the ballistic sounds were measured from 128 meters in front of the shooter at two different incidence angles from the target line (20 and 30 degrees) for each weapon. Two recordings of each weapon and each incidence angle were made to prevent listeners from using any auditory cues other than the gunfire in identifying each weapon. The basic stimulus set contained sixteen unique pairings of the weapons as two recordings of each weapon at two different incidence angles were made, which created four unique stimuli for each weapon. The peak intensity for the recorded gunfire stimuli was calibrated to 116 dB peak SPL measured with the peak response on the sound level meter.

Materials & Equipment

For the identification task, E-prime (Psychology Software Tools, Inc.) software was used to present pairs of 1-shot and 3-shot stimuli in a 2-alternative, forced choice (2AFC) paradigm. Participants were seated in a comfortable chair in a sound treated audiologic booth with a laptop running the E-prime experiment scripts. All stimuli were presented at intensity levels of 116 dB peak SPL and routed through AKG K701 open reference circumaural headphones connected to a preamp and then to the laptop. For each trial of the 2AFC task, two recordings were presented to participants, with each pair containing one of the M4 carbine tokens and one of the AK-47 assault rifle tokens. The stimuli were presented in the E-prime scripts with a 500 ms silent period prior to the first peak and a 1500 ms silent period following the last peak with a 750 ms interstimulus interval between stimuli.

The HPDs used in this experiment were EP 4 Sonic Defender HPDs (Surefire), which are passive nonlinear HPDs. They have a triple flange design earplug that fits in the ear canal attached to a soft skeleton mold that fit in the concha to provide retention. The HPDs attenuated impulse sounds above 85 dBA by 26 dB up to 35 dB of sound attenuation for a 120 dBA noise (Surefire). The devices also came with a stopper plug to provide attenuation for sounds below 85 dBA; however, this feature was not used in the experiment.

Procedures

All testing took place in a sound treated audiologic booth and pure tone stimuli were delivered through TDH 49 headphones by a GSI 61 audiometer. Air conduction thresholds were obtained for both ears of each participant at 250, 500, 1000, 2000, 3000, 4000, and 8000 Hz and included interoctave frequencies when there was a 20 dB difference in thresholds between adjacent octaves using the modified Hughson-Westlake method of determining pure tone thresholds (Carhart & Jerger, 1959). Degrees of hearing loss were categorized based on degree of poorest threshold and participants were considered to have normal hearing if their pure tone average was 25 dB or less (Goodman, 1965). Bone conduction threshold information was also obtained for any air conduction threshold that fell outside the normal range (i.e. poorer than 25 dB HL) to rule out possible conductive hearing loss.

Participants were familiarized with the task and basic stimulus set in a practice block of 16 trials of stimuli comparisons before completing the experimental block. Each basic stimulus set was presented eight times, for a total of 128 trials in the experimental block. The stimuli order within each trial was counterbalanced and the presentation of pairs for all trials was randomized. The practice and experimental blocks were completed separately for the 1-shot and 3-shot recordings. Following the presentation of each pair of stimuli, participants were asked to indicate which stimulus was the M4 carbine recording by pressing the number 1 or 2 on the laptop keyboard, where 1 represented the first stimulus presented and 2 the second stimulus presented. The response stage terminated when the participant responded, or after 4 seconds. Participants were given feedback about their performance; the software let the participant know if the response was correct or incorrect, as well as the response time. The next trial automatically began after the 1500 ms feedback screen.

The entire experiment (including the one shot and three shot conditions) was completed twice: once with an open ear under headphones and once with EP4 Sonic Defenders Plus hearing protectors under headphones. The examiner inserted the HPDs to prevent user error from affecting results. The earplugs were inserted so that the third flange of the earplug was in the ear canal. Audiometric thresholds were measured prior to and after inserting the HPDs to ensure the earplugs were a good fit. If thresholds shifted by at least 10 dB at 4000 and 8000 Hz, the earplugs were judged to be a good fit. If thresholds did not shift, a different size earplug was used until a threshold shift was seen. The order of experimental blocks was randomized across each participant to control for any possible learning effects. The two HPD listening conditions were completed sequentially to ensure that the earplugs were fit in the ear appropriately for both conditions. The average time of each test session to complete all four practice and experimental blocks was approximately 2 hours.

Statistics

IBM SPSS Statistics 19 software was used to complete statistical analyses. A Repeated Measures General Linear Model was used to determine if there were any significant differences in participant performance for the 1-shot and 3-shot stimuli, the open ear versus the hearing protection conditions, and if experience affected performance, as well as any interactions between these independent variables. Analysis of Variance (ANOVA) measures were used to determine if any order or gender effects occurred. Post hoc tests were done using paired samples t-tests to measure differences in mean attenuation provided by the HPDs between ears. Bivariate Pearson-product correlation tests were completed as well to determine if either frequency of firearms use or length of musical training was correlated with accuracy.

CHAPTER 4

RESULTS

Participants

Participants were categorized as "expert" or "novice" based on their responses to a questionnaire regarding weapons use and military experience. Participants were considered "experts" if they reported that they fired a weapon at least once a year or had previous military experience and "novices" if they had never fired a weapon or did so less than once per year. There were 13 "expert" and 17 "novice" participants in this study. The majority of "expert" participants were occasional users of weapons, as they did not use firearms frequently. Of the "expert" participants, two were police officers, one was a National Guard reservist, and two were military veterans. The other "expert" participants had no professional experience with weapons. Table 1 shows the number of participants in each category used in this study.

Participants' hearing thresholds were measured before and after inserting the HPDs to ensure proper fit of the earplugs. The EP-4 earplugs used in this study provided more high frequency attenuation and Table 2 shows the mean attenuation in decibels for each frequency tested. Paired samples t-tests did not show statistically significant differences in mean attenuation between ears, so right and left ear scores were averaged and reported as one mean score in the table below. The majority of participants had normal hearing sensitivity in both ears. However, four participants (two novice and two expert participants) had thresholds indicative of mild sensorineural hearing loss (i.e. thresholds between 26 and 40 dB HL). One had a mild hearing loss at 4000 Hz in both ears and the other three had a mild hearing loss at 8000 Hz in one ear only.

Table 1

Number of participants and frequency of firearms use per experience level.

	Experience Level	
Frequency of Firearms Use	Novice	Expert
Sample Size	**17**	**13**
Never	13	
Rarely (<1x/Year)	4	
Seldom (1-6x/Year)		5
Sometimes (6+/Year)		4
Often (1+/Month)		2
Frequently (1+/Week)		2
Daily		0
M4 or AK-47 Use		4

Table 2

Mean attenuation provided by EP-4 insert earplugs by audiometric frequency.

Audiometric Frequency (Hz)	Attenuation (dB)	
	Mean	SD
250	2.83	3.42
500	7.58	5.55
1000	14.0	6.56
2000	20.58	6.78
3000	25.25	7.75
4000	24.33	7.28
8000	26.42	7.58

Order and Gender Effects

Scores were compared based on the order in which participants completed each condition to determine if there were any practice effects. Participants tended to perform poorest on the first condition and best on the last condition, with slight improvements during the second and third conditions over previous conditions. An ANOVA was performed and then Bonferroni tests were used to assess differences between specific order conditions. A statistically significant difference, $F(3,116) = 2.59$, $p = .049$, was observed between the first and fourth conditions, but not between any other order conditions. Table 3 shows the mean percent correct scores by order in which conditions were completed.

Table 3

Mean scores by order in which conditions were completed.

Order	Score
1	0.80*
2	0.82
3	0.83
4	0.88*

Note: * Indicates statistically significant differences between mean percent correct scores for the first compared to the last condition. No significant differences were seen between any of the other comparisons.

Scores were also compared between males and females using an ANOVA with gender as a between subject factor with condition (HPD and shot conditions) as within subject factors and percent correct score as the dependent variable to determine if gender played a role in identification abilities. No significant differences were found between scores for male and female participants, for any condition, so data were collapsed for males and females to form expert and novice experience groups.

Effects of Musical Training

The questionnaire used in this study included questions regarding musical training. Bivariate Pearson product-moment correlation tests comparing length of musical training in years and accuracy for each listening condition did not indicate any significant correlation. Table 4 shows the correlation values for each of the four listening conditions.

Table 4

Correlation values for length of musical training and accuracy of scores.

Condition	Correlation (*r*-value)	Significance (*p*-value)
1 Shot HPD	.128	.500
1 Shot Open	.218	.248
3 Shot HPD	.217	.250
3 Shot Open	.074	.698

Effects of Experience

Mean scores were then compared between the "expert" and "novice" participants using a Repeated Measures General Linear Model using experience as a between subjects factor to determine if experience with weapons improved participants' identification abilities. No significant difference was found between groups. Figure 1 depicts the effects of experience on performance in the identification task for each of the four listening conditions. Bivariate Pearson product-moment correlation tests comparing frequency of firearms use and accuracy for each listening condition did not indicate any significant correlation. Table 5 shows the correlation values for each of the four listening conditions.

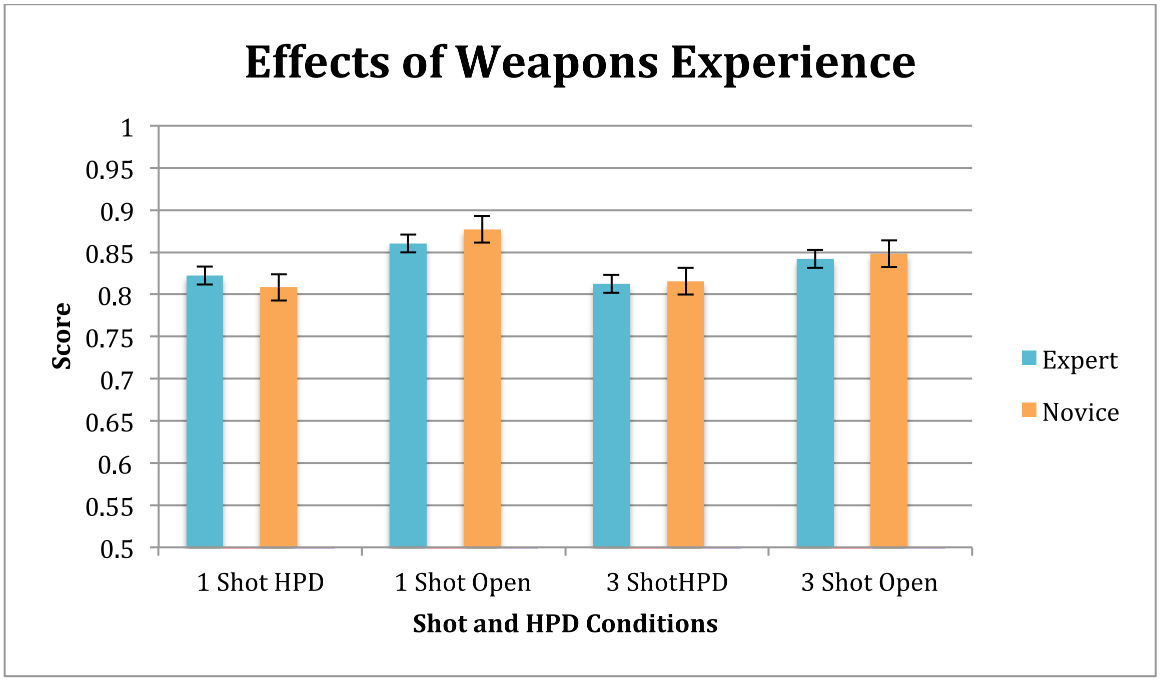


Figure 1. Mean percent correct scores for each shot and hearing protection condition as a function of experience level. Error bars represent one standard error above and below the mean. Note: HPD means hearing protection device.

Table 5

Correlation values for frequency of firearms use and accuracy of scores.

Condition	Correlation (*r*-value)	Significance (*p*-value)
1 Shot HPD	.091	.634
1 Shot Open	-.047	.806
3 Shot HPD	.113	.553
3 Shot Open	-.094	.620

Effects of HPD Condition

Mean scores were calculated for HPD versus open ear conditions and differences in scores between conditions were measured using a Repeated Measures General Linear

Model. A statistically significant difference, $F(1,28) = 8.41$, $p = .007$, was observed between the two conditions for overall scores, with the HPD condition resulting in poorer scores. Post hoc analyses using paired samples t-tests indicated a statistically significant difference $t(29) = 3.14$, $p = .004$, between HPD and open ear scores for the one shot condition, but not for the three-shot condition, $t(29) = 1.38$, $p = 1.78$. Figure 2 shows the effects of HPD condition for both three-shot and one-shot conditions, as well as the overall difference between HPD and open ear conditions.

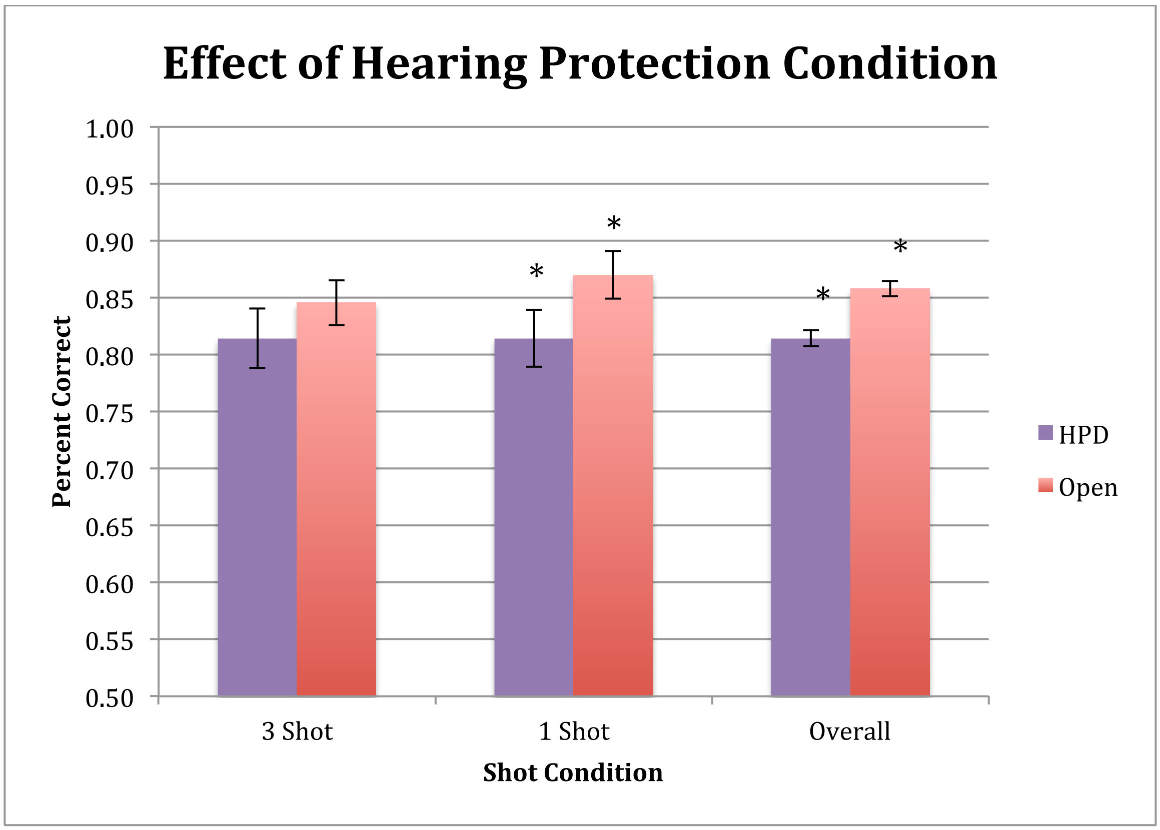


Figure 2. Mean percent correct scores for each hearing protection condition as a function of shot condition. Error bars represent one standard error above and below the mean. Note: HPD means hearing protection device. * Indicates statistically significant (p<.01) difference between scores.

Effects of Shot Condition

Mean scores were also compared by shot condition and participants performed similarly for both the 1-shot and 3-shot recordings. No significant differences were found when scores were compared using a Repeated Measures General Linear Model, $F(1,28) = .80$, $p = .379$. Figure 3 shows the effects of shot condition for both the open ear and HPD conditions.

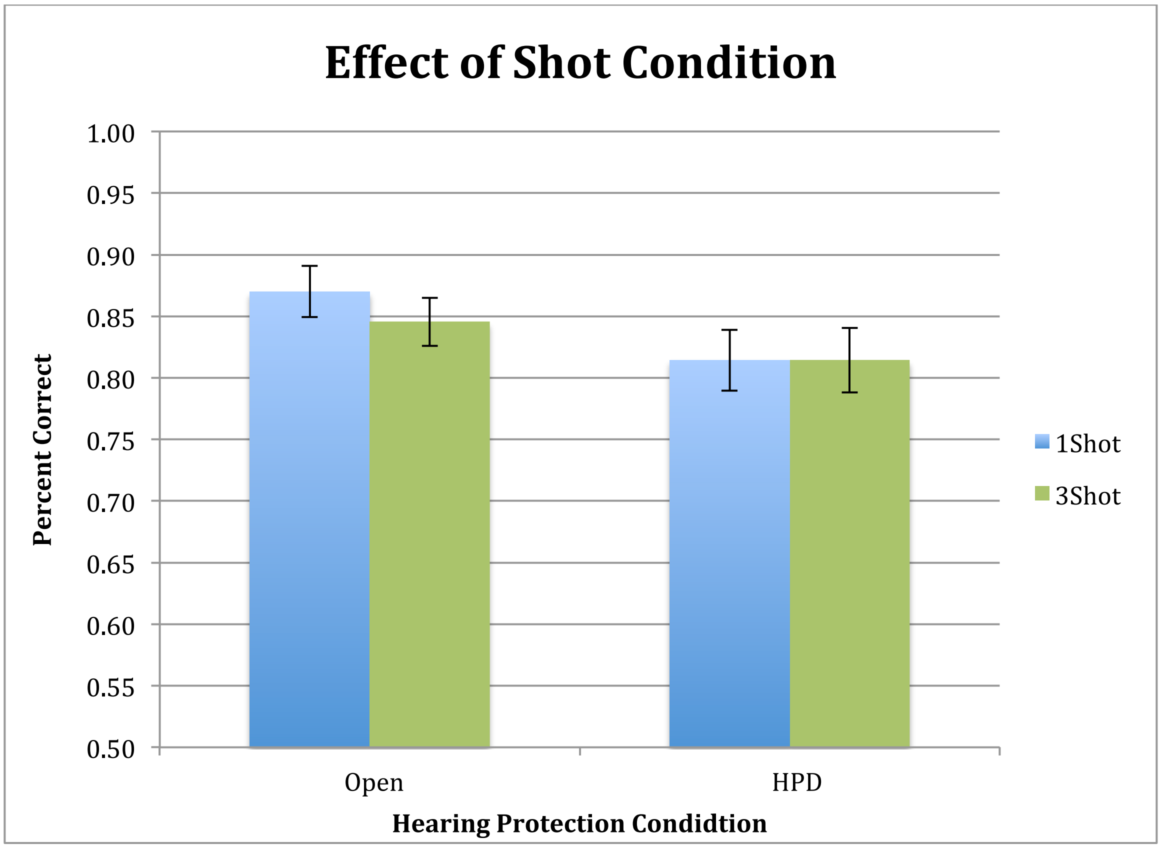


Figure 3. Mean percent correct scores for each shot condition as a function of hearing protection condition. Error bars represent one standard error above and below the mean. Note: HPD means hearing protection device.

No interaction effects were found for HPD condition, shot condition, or experience levels.

CHAPTER 5

DISCUSSION

Many soldiers report that they do not wear HPDs, as they believe the hearing protection decreases their hearing and compromises their situational awareness and communication abilities (Abel, 2008; Clifford & Rogers, 2009). The main purpose of this study was to determine if hearing protection had an effect on participants' ability to identify two weapons, the M4 and AK-47 rifles, by their auditory signatures. Participants listened to recordings of these rifles firing one- and three-shot bursts; with HPDs and with an open ear. Participants were then asked to choose which sound was produced by the M4 rifle. The percent correct scores for each of the four listening conditions were compared to determine if hearing protection conditions and shot conditions had an effect on performance. The results suggest that there is a statistically significant difference in identification abilities when listening with an open ear versus with HPDs as participants scored poorer when listening with HPDs. A significant difference between one- and three-shot conditions was not observed, suggesting that participants relied on various auditory cues for each condition. A secondary purpose of this study was to determine if experience with firearms increased participants' ability to correctly identify the M4 rifle by its sound. No significant differences were observed between "expert" and "novice" participants.

Effects of HPD Condition

The very small, though statistically significant, difference between HPD and open ear conditions seen in this study supports soldiers' claims that HPDs can compromise situational awareness. However, it should be noted that the difference in scores between the open ear and HPD conditions was between 4-6%. Although this difference was statistically significant overall and in the one-shot condition, it is unknown if there is any practical difference in the safety of soldiers based on these accuracy differences. The difference in scores may also become even smaller if soldiers are more familiar with the weapons fire or have training in the perception of small arms fire, as an order effect was seen over the course of the study. Also, NIHL would likely have a greater impact on listeners' ability to accurately identify weapons fire than would the use of HPDs (Abel & Hay, 1996). Results from this study were consistent with results from prior studies that compared HPD and open ear conditions for detection (Alali & Casali, 2012; Price et al., 1989), localization (Abel & Hay, 1996; Talcott et al., 2012), and identification (Giguere et al., 2011; Lindley et al., 1997) of sounds, as these studies also showed decreased auditory abilities in listeners using HPDs compared to an open ear. Abel and Hay (1996) reported that earmuff style HPDs negatively affected participants' abilities to localize sounds as compared to open ear conditions; participants had greater difficulty localizing the 4000 Hz signal as compared to the 500 Hz signal. The authors suggested this difference was due to the greater high frequency attenuation provided by the earmuffs. The nonlinear insert earplugs used in the current study also provided greater attenuation of high frequency sounds. The greater attenuation seen at these higher frequencies was used to judge if the earplugs were fit appropriately in participants' ears. The poorer scores seen with HPDs are likely due to the fact that the HPDs altered high frequency auditory cues necessary for correct identification of the weapons used in this study. The majority of the sound energy in the M4 recordings was located between 1000 and 2500 Hz with additional energy located between 4000 and

6000 Hz, and energy between 7000 and 9000 Hz as well. In the recordings of the AK-47 firing, most of the energy was located between 800 and 1500 Hz with additional energy between 2000 and 3000 Hz. Spectrograms showing sound energy across time for the M4 and AK-47 recordings are located in Appendix B. At the frequencies around the majority of the energy in the M4 and AK-47 recordings, the HPDs provide anywhere from 14.0 to 25.25 dB of attenuation, which likely resulted in the loss of important auditory cues for identification of the weapons fire.

Effects of Shot Condition

There was not a significant effect for the one versus three shot conditions. The three shot condition was expected to result in higher scores because there were more auditory cues available to participants. The cyclical firing rates of the M4 and AK-47 are different, with the M4 firing rate being faster. The difference in firing rate was assumed to provide additional temporal cues for the three-shot listening conditions (Gaston & Letowski, 2012). In the three-shot condition, the three ballistic cracks and muzzle blasts of the M4 overlapped in three of the recordings, such that the ballistic crack of the second and third shots occurred before the muzzle blasts of the previous round. In the last M4 three-shot recording, no overlap of the ballistic crack and muzzle blast occurred; there were inconsistencies between the tokens of the three-shot M4 recordings which could have affected participants' accuracy. There was separation between the muzzle blasts and sound reflections in the AK-47 recordings. Waveforms of the M4 and AK-47 being fired for one- and three-shot bursts are located in Appendix C. This overlap in the M4 recording possibly altered the auditory cues available to listeners so that the additional temporal information in the three shot condition was not as useful to listeners. Some participants subjectively reported that the one shot condition was easier due to the cues of the single ballistic crack and muzzle blast.

Effects of Experience

Experience with firearms was expected to affect performance in identifying weapons. Participants were classified as “expert” or “novice” based on their responses to a weapons use questionnaire developed for this study and were categorized as “expert” if they had previous military service or fired a weapon at least once at year. Fluitt et al. (2010) demonstrated that listeners who were familiarized with the auditory signatures of various small arms weapons through a training program performed better on auditory post-training measures and in a live fire listening condition. In a study on the identification of everyday sounds, Ballas (1993) demonstrated that participants could more easily identify sounds with which they were familiar. This suggests that participants who are familiar with firearms should have better identification abilities of those weapons. Of the expert participants, four reported that they had fired an M4 or AK-47 firearm, but experience with these particular weapons was not significantly correlated with scores. One of the expert participants is currently a police officer who reported that he uses firearms frequently and performed greater than 90% on all four conditions. However, the participant with the highest scores (i.e. 98% or greater) had never fired a weapon. Many of the “novice” participants also performed above 80% despite a lack of firearms experience. The recordings were made in front of the shooter and are comprised of the muzzle blast, ballistic crack, and sound reflections. Even experienced shooters may not be familiar with listening to the sound of gunfire from a position in front of the weapon, which may partially explain why the “expert” participants performed similarly to the “novice” participants. Perhaps there are other auditory cues, such as environmental sounds, in the recordings of the weapons fire that participants used to identify the M4 rifle in this study. While multiple recordings of each weapon were used in this study to attempt to control for this variable, it is difficult to completely eliminate extraneous environmental noise. Many of the participants in this study were recruited from the Towson University Department of Audiology, Speech Language Pathology, and Deaf Studies and may not be representative of the general population as they may have better auditory perception skills. Audiology graduate students may be more aware of temporal, frequency, and intensity cues due to specific training in auditory skills.

Order Effects

A significant difference was seen in mean scores for the first versus the last condition that participants completed. Scores tended to improve with each trial, suggesting that there were learning effects in this study. This result was not surprising due to the training stage of the experiment and repeated nature of the task. Participants were given feedback about their performance following each trial of the task. The test order of HPD and shot conditions was randomized for each participant to attempt to control for any practice effects.

Limitations and Future Research

The greatest limitation of this study was the lack of firearms experience that participants had. Many participants were occasional shooters and only five of the “expert” participants had any professional experience with weapons. This lack of firearms experience may explain why there was no significant difference seen in accuracy between the two experience levels in this study. Future research should include more participants who have professional experience with firearms to determine if experience has an effect on accuracy in identifying weapons fire. Other limitations of this study include the limited number of weapons and HPDs used. Gaston and Letowski (2012) demonstrated that participants perceived the M4 and AK-47 rifles as sounding similar to each other and were more difficult to distinguish as compared to rifle-handgun pairings, so these two weapons were chosen for this study. Future research should include additional weapons that are commonly used in the military to determine if HPDs affect listeners' abilities to identify those weapons as well. Also, only one type of HPD (i.e. EP-4 nonlinear insert earplug) was used in this study. Many styles and models of HPDs are available to soldiers and should be considered in future research as the various types may have different effects. Casali et al. (2011) reported that the earmuff style HPDs used in their study resulted in significantly poorer localization performance as compared to various earplug style HPDs. Future research should include additional HPD styles to determine if various types affect weapons identification. Another limitation to this study is the gender distribution for the "expert" and "novice" groups as there were more males in the "expert" group and more females in the "novice" group, though there was not a significant difference in performance between genders seen in this study.

CHAPTER 6

CONCLUSION

The small, but significant difference seen between the HPD and open ear conditions has implications for soldiers and the military. Many soldiers report that HPDs compromise their ability to hear and therefore situational awareness, which was confirmed by this study. However, the difference in accuracy seen between the open earn and HPD listening conditions was minute. Listeners with NIHL, whether temporary or permanent, would likely perform poorer on identification tasks than listeners with normal hearing using HPDs (Abel & Hay, 1996). Because of the effects of hearing loss on various auditory abilities, the use of HPDs is still important to minimize the risk of NIHL. Soldiers are at high risk of having NIHL due to the high intensity of noise they are exposed to in training and combat situations. Firearms and other military weapons generate impulse sounds, which have high intensity and tremendous sound pressure that can cause acoustic trauma to the ear. Despite the risk of compromising situational awareness, the use of HPDs is essential to minimize the risk of NIHL as hearing loss can also permanently compromise situational awareness and communication abilities (Department of the Army, 2008). Various styles and models of HPDs are available to soldiers and nonlinear models may provide the most benefit as they are designed to protect wearers from loud impulse sounds while allowing softer sounds to be heard. However, even these can contribute to poorer performance as shown in this study. A training program, such as the one used by Fluitt et al. (2010) could be implemented to potentially improve listeners' identification abilities while wearing HPDs. Participants showed a significant improvement in scores over the course of the experiment, about 90 minutes. Training listeners to identify weapons fire while using HPDs would likely overcome the difference seen in accuracy for open ear versus HPD listening conditions seen in this study.

Appendix A

Weapons Use Questionnaire

Do you currently or have you previously served in the military? _____Yes_____No
If Yes, how long did you serve in the military? ___________________
In which branch of military/position did you serve? ___________________
When was your most recent military service? Please list dates

Have ever fired a weapon? _____Yes_____No
How often do you wear HPDs when firing? ___________________
When was the last time you fired a weapon? ___________________
If Yes, how often do you fire a weapon?
_____ Rarely (Less than 1 time per year)
_____ Seldom (1-4 times per year)
_____ Sometimes (6 times or more per year)
_____ Often (1 time or more per month)
_____ Frequently (1 time or more per week)
_____ Daily

Do you own a weapon(s)? _____Yes_____No
If Yes, what type(s) of weapons do you own?

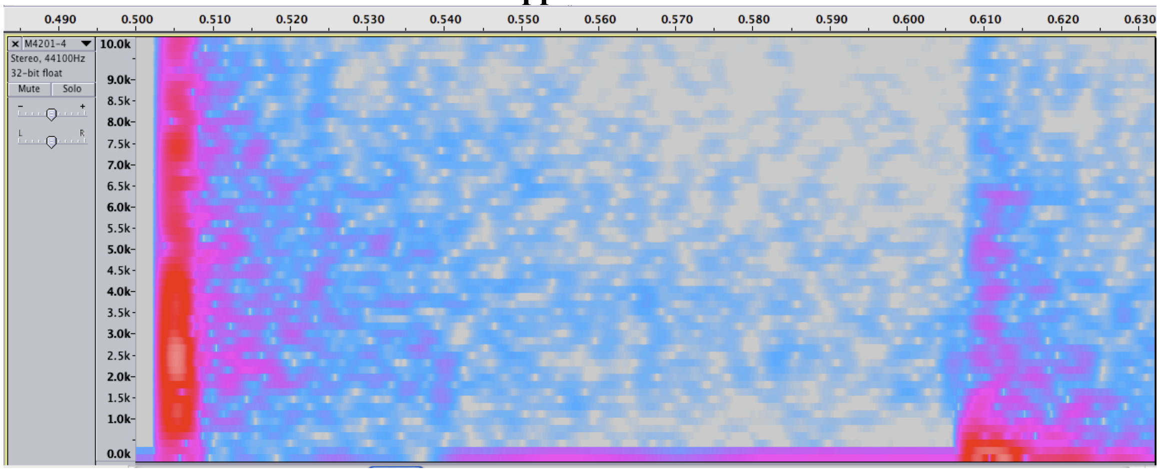
Please check the types of weapons that you typically use. List any that you have used.

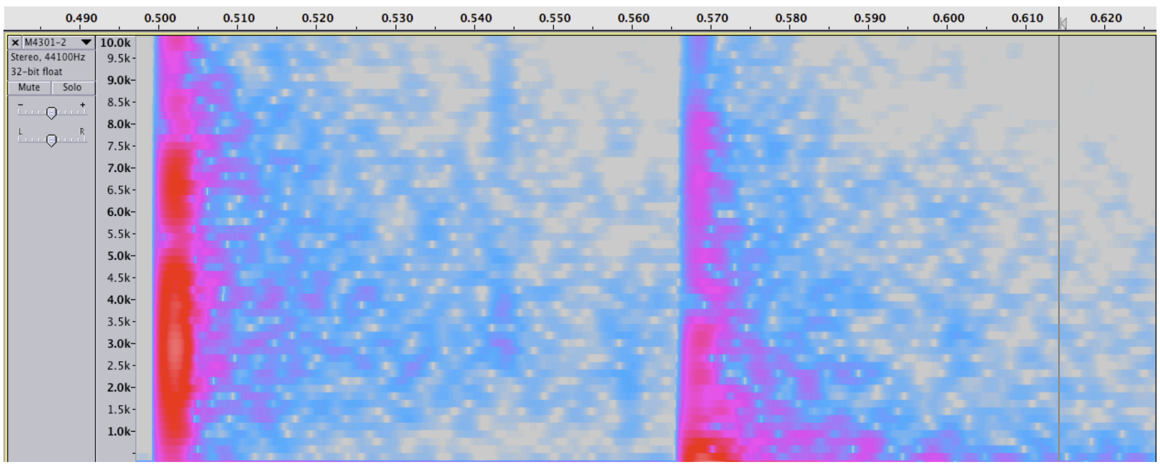
_____ Rifles	_____ Handguns	_____ Others

Musical Abilities

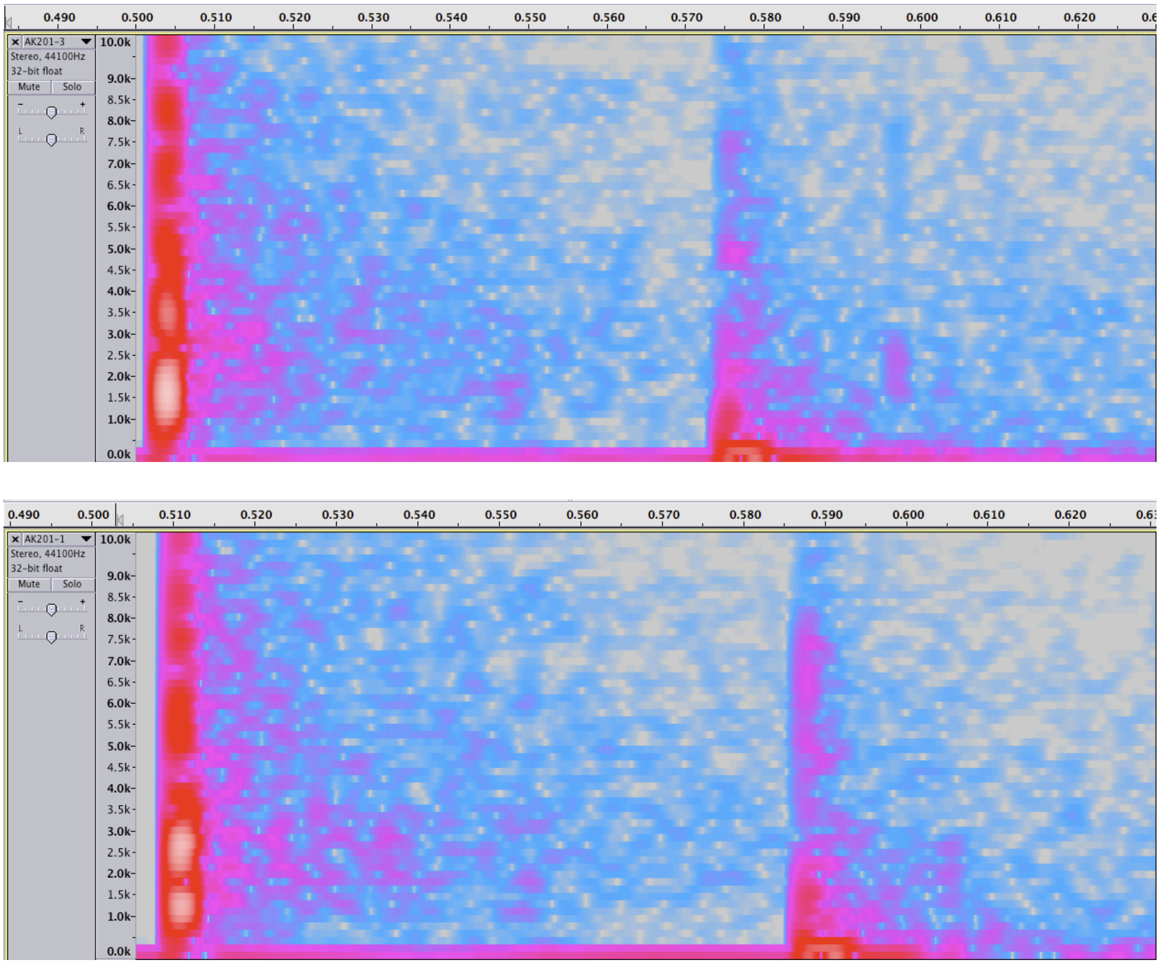
Do you have had musical training? _____Yes_____No
How long since your last lesson? ___________________
Do you play an instrument? _____Yes_____No
If Yes, what type(s)? ___________________
How long did you play an instrument? ___________________
Do you actively practice an instrument? _____Yes _____No
When was the last time you actively played an instrument? ___________________

Appendix B



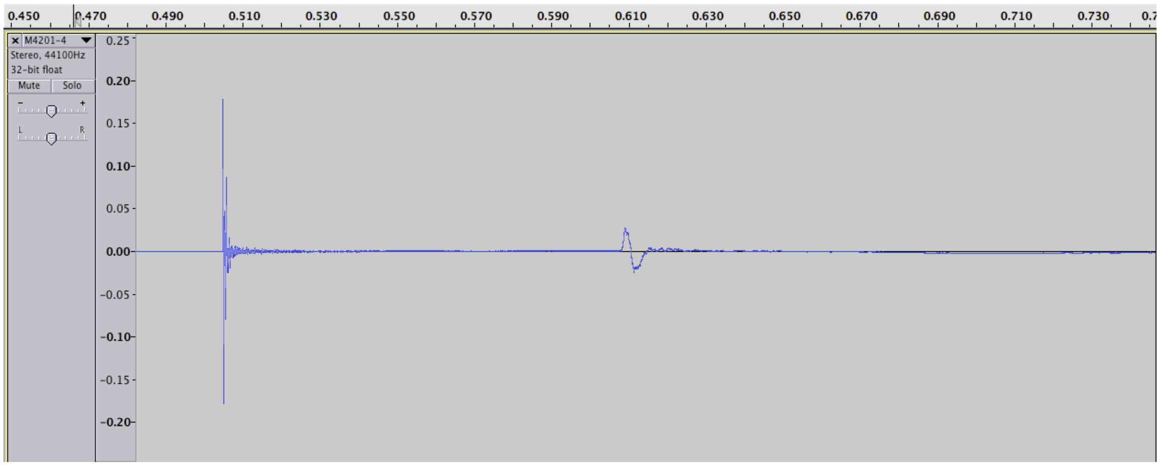


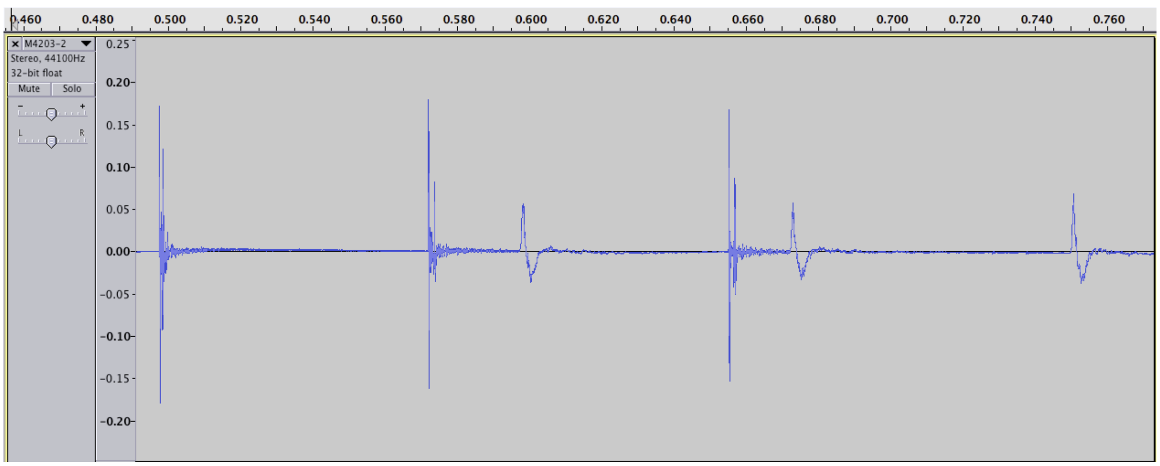
Examples of spectrogram of M4 1 shot recording.



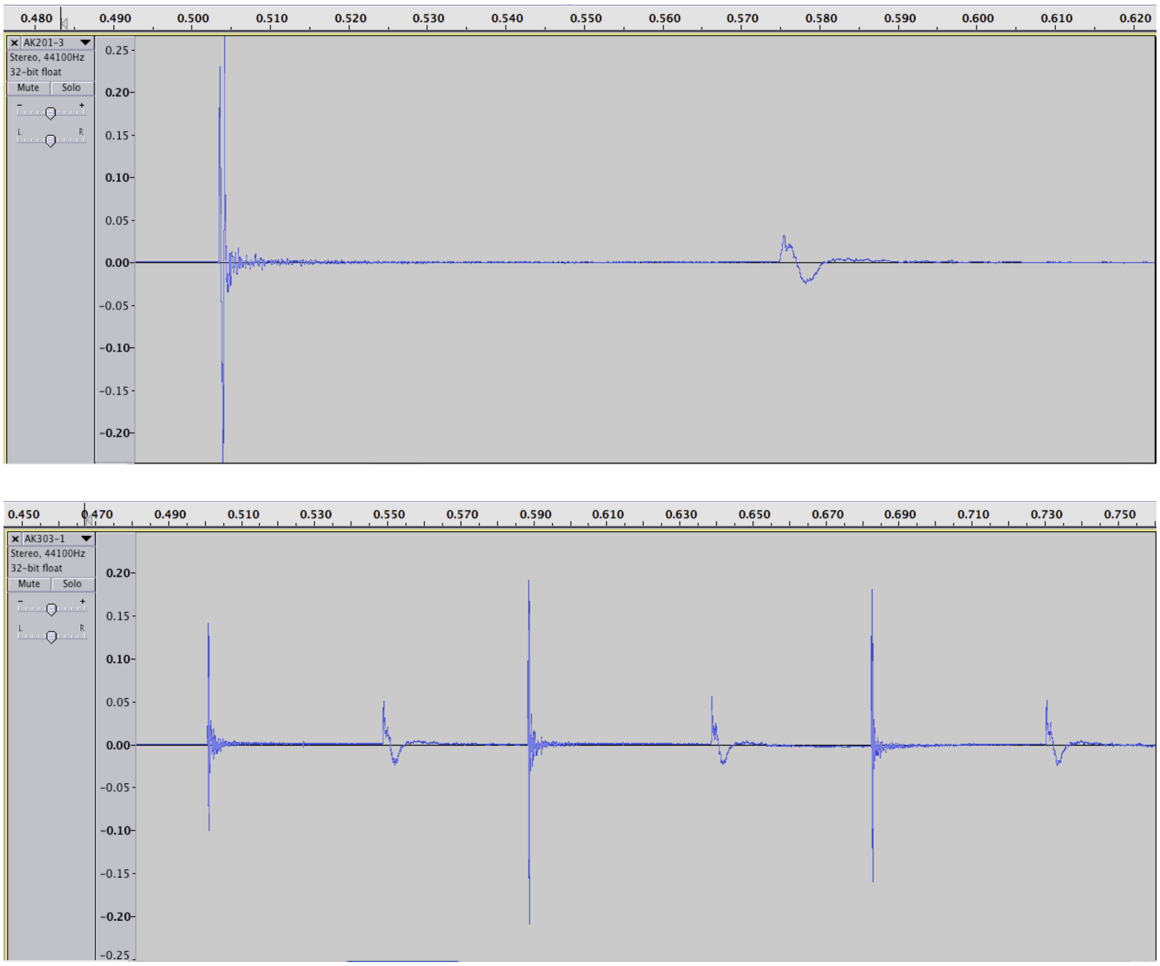
Examples of spectrogram of AK-47 1 shot recording.

Appendix C





Example of temporal waveform of 1 shot (top) and 3 shot (bottom) recordings from an M4 rifle.



Example of temporal waveform of 1 shot (top) and 3 shot (bottom) recordings from an AK-47 rifle.

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CURRICULUM VITA

NAME: Katherine Peitsch

PERMANENT ADDRESS: 2354 Kateland Court

Abingdon, MD 21009

PROGRAM OF STUDY: Audiology

DEGREE AND DATE TO BE CONFERRED: Doctor of Audiology, 2014

Secondary education: Loyola College Maryland, Baltimore, Maryland, 2010

Collegiate institutions attended	Dates	Degree	Date of Degree
Towson University	August 2010-May 2014	Au.D	May 2014
Loyola University Maryland	September 2006-May 2010	B.A.	May 2010

Major: Speech Language Pathology & Audiology

Minor(s), if applicable: Special Education

Professional publications: N/A

Professional positions held: N/A