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LISTENER ACCURACY IN THE LOCALIZATION OF SMALL ARMS FIRE:

THE EFFECT OF CHANGES IN AMPLITUDE AND TIMING DIFFERENCES

by

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AUDIOLOGY DOCTORAL THESIS APPROVAL PAGE

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Abstract

Listener Accuracy in the Localization of Small Arms Fire: The Effect of Changes in Amplitude and Timing Differences

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Sound localization is an essential skill for auditory situational awareness. It is the ability of the auditory system to analyze acoustic cues and hone in on the direction of a sound source. One class of impulse noises, specifically small arms fire, has unique auditory characteristics which impact sound localization abilities. The present study attempted to identify the driving force of gunfire localization by manipulating acoustic properties and assessing listener performance in localization tasks. The acoustic properties included the isolation of muzzle blast (MB) and ballistic crack (BC) sounds, differences between the onset times and intensity differences of the two components, azimuth changes, and amplitude and timing differences as a function of shooter/observer relationships. Results of this study showed significant differences between participants' ability to localize isolated MB and BC sounds. Similarly, significant effects of azimuth, amplitude differences, and distance were found. Overall, timing differences did not impact localization performance. The current research aims to build upon the knowledge base of how the human auditory system localizes small arms fire. Ultimately, this information may improve communication systems and tools that can increase situational awareness for those who are exposed to hostile/friendly fire.

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Chapter 1

Introduction

Individuals whose lives depend on a quick understanding of the objects present within an environment, such as military personnel and law enforcement officers, rely on sound localization (Fluitt, Gaston, Karna, & Letowski, 2010). Sound localization refers to the ability of the auditory system to analyze acoustic cues, and as a result, hone in on the direction of a sound. This skill is often essential for determining the location of enemy fire, in identifying the physical characteristics of a space, and navigating through an environment (Fluitt et al., 2010; Scharine, Letowski, & Sampson, 2009).

Certain sounds, such as impulse noises, have unique auditory characteristics which increase the difficulty of localization. One classification of impulse noises, small arms fire, consists of an acoustic wave created by the muzzle blast and a shockwave that results from the supersonic bullet. As the bullet moves through space faster than the speed of sound, information about the shockwave reaches the listener first (George & Kaplan, 2011). The variances created by these two characteristics may hinder localization abilities. Understanding how the human hearing mechanism works to localize gunfire may improve situational awareness for populations who are exposed to danger. In settings where impulse sounds are present, such as combat situations, auditory input can help an individual better identify the direction of objects and dangers within her/his environment. Sensory information accessed by the auditory system helps to create an awareness of the surrounding area and the threats or obstacles that may be present (Scharine et al., 2009).

Sound localization is not a new topic in research. In fact, one of the most important concepts of localization, the duplex theory, dates back to 1907 (Rayleigh, 1907). Past studies focused on the identification, recognition, and perception of environmental sounds (Ballas, 1993; Dunai, Peris-Fajarnes, Lengua, & Montana, 2012; Grassi, 2005; Li, Logan, & Pastore, 1991; Repp, 1987). Experiments specifically related to small arms fire researched the detection, localization, and classification of small arms fire abilities in listeners (Fluitt et al., 2010; Gaston & Letowski, 2012; Lo & Ferguson, 2012). The purpose of the present study is to look at a specific auditory event, i.e. gunfire, and determine how the manipulation of particular acoustic properties affects a listener's performance in localization tasks.

Chapter 2

Review of Literature

To determine the spatial location of a sound source, humans utilize an intrinsic, automatic ability known as sound localization. The auditory system relies on timing, intensity, and spectral aspects of sound information to localize sound sources. This information may be altered by the anatomy of the listener and the acoustic setting. For individuals such as police officers or active-duty military personnel, well-honed sound localization skills may aid in determining the location of hostile fire. The sound wave of gunfire is subject to several physical factors which can cause alterations of the signal. These factors include atmospheric conditions (wind, temperature gradient, and atmospheric absorption), objects within the space, and reflections off of various surfaces. An understanding of the anatomical structures responsible for sound localization, a review of the basics of sound localization, and the specifics of the localization of gunfire will be discussed in this section.

Anatomy and Physiology Involved in Localization

As sound travels, it interacts with the anatomical structures of the body (specifically: the ears, head, and chest). Diffractions and reflections around the pinnae, head, and torso filter how sounds enter the ear canal. These spectral changes aid in vertical localization (Gelfand, 2004; Musicant & Butler, 1984). The pinnae, head, and torso all contribute to localization cues in the frequency range of about 500-16000 Hz (Moore, 2012). The effects created by the pinnae, head, and torso help to clarify vague timing and intensity information and thus reduce front-back reversals (Middlebrooks & Green, 1991).

Peripheral anatomy. The peripheral portion of the auditory system is divided into the outer ear, middle ear, and inner ear spaces, as well as the auditory nerve. The outer ear extends from the pinnae to the tympanic membrane. As sound travels away from its source, the pinnae are the first anatomical structures to affect the sound signal. Due to the folds of each pinna, there are diffractions and reflections of the sound stimulus (Musicant & Butler, 1984). As will be discussed later, these cause spectral changes in the sound signal that are important for sound localization in the vertical plane and also disambiguating front from back localization errors (Middlebrooks & Green, 1991). The sound wave is then funneled through the ear canal toward the TM. The inherent resonant characteristics of the ear canal add about 15 dB to the levels of sounds in the frequency range of about 2000-5000 Hz (Gelfand, 2010; Hellstrom, 1995).

Similar to the structures of the outer ear, certain features of the middle ear space (e.g. the ossicles and impedance matching mechanisms) are also responsible for amplifying the signal (Denes & Pinson, 1993). This added amplification is necessary as there is an impedance mismatch between the air-filled space of the middle ear and the fluid-filled inner ear cavity. The TM separates the outer and middle ear spaces, and transfers the sound signal to a chain of three small bones known as the ossicles. The acoustic energy hitting the TM forces the movement of the ossicles and effectively transforms the acoustic wave into mechanical energy. The ossicles then amplify and transfer this energy to the inner ear through a membrane known as the oval window. Three mechanisms of the middle ear are responsible for this amplification. First, the differences in the surface area of the TM and the surface area of the oval window create a concentration of force that translates to about 38 dB of gain. Second, the variations in length between the first and second middle ear bones cause a lever action. The lever action delivers a force to the oval window which is increased by a factor of about 1.15. Lastly, due to the shape and flexibility of the TM, sound vibrations cause a buckling effect which translates to an increase of force by about a factor of two (Denes & Pinson, 1993). Without the TM and ossicles, sound energy would mostly reflect off the oval window.

Within the inner ear space, displacement of the oval window leads to a traveling wave in the fluid of the cochlea. The traveling wave affects the movement of the basilar membrane in a way that is related to the frequency of the stimulus. The basilar membrane is narrowest, and also stiffest, at the basal end (Denes & Pinson, 1993); consequently, high frequency sounds produce a traveling wave that peaks near the basal portion of the cochlea. Low frequency sounds, in contrast, peak at the wider, more flexible apical end of the basilar membrane. The intensity of the vibration that moves the basilar membrane is reflected in how many sensory cells are activated within the organ of corti.

The organ of corti, located on the basilar membrane, contains sensory receptors that indirectly relay the sound signal from the inner ear to the auditory brainstem via the auditory nerve. Sound information travels through the peripheral portion of the auditory system (i.e. the inner ear and auditory nerve) to the central auditory nervous system (CANS). The CANS consists of a number of nerve tracts and numerous nuclei responsible for higher-level auditory abilities, as well as more basic auditory skills (i.e. localization). The CANS pathway will be described in greater depth in the next section. The sensory cells within the organ of corti, called inner hair cells, transform the basilar membrane vibrations from mechanical energy to electrical information. Fine filaments known as stereocilia protrude from the surface of the inner hair cells (Denes & Pinson, 1993). Movement of the stereocilia cause conduction channels to open and close. When the stereocilia are stimulated, electro-chemical reactions occur that are then transmitted to the auditory nerve. Responses of the neurons that fire create patterns that correspond with stimulus frequencies (Evans, 1978; Licklider, 1951). This is known as frequency or rate coding. The intensity of the stimulus is directly related to the number of fibers firing in response to excitation (Kandel, Schwartz, & Jessell, 2000). Nerve fibers with characteristic frequencies which correspond to the frequencies present within the signal begin to respond at low levels. The rate of firing increases as stimulus intensity increases. A neuron may still fire if its characteristic frequency is similar to the frequency of the stimulus, albeit not as strongly. In order to code for high frequency signals, timing information from groups of neurons must be combined along the auditory nerve. The neurons respond to sound by firing action potentials which are slightly out of phase with one another. The summation of the firing potential helps to encode information about the frequency within a stimulus. This concept is known as the volley theory. Place coding is also used to analyze frequency information. The tonotopic organization of auditory neurons determines how the vibrations along the BM, and consequently the frequency information present within a stimulus are coded (Kandel et al., 2000). As described earlier, the traveling wave in the fluid of the cochlea causes displacement of the BM. The location of the displacement depends on the frequency of the stimulus. Maximum displacement of high-frequency sounds occurs at the basal end, while low-frequency sounds stimulate the apical portion of the BM. The frequency specific ordering of the BM corresponds with the tonotopic organization of the inner hair cells within the organ of corti. Therefore, frequency is coded as a function of the location of the maximum displacement along the BM (Zemlin, 1998).

Also present within the organ of corti are sensory elements known as outer hair cells (OHCs). As the motion of the BM triggers the movement of the OHCs, low level sounds are generated. The movement of the OHCs causes electromechanical feedback which increases the amplitude and frequency selectivity of sound vibrations by altering the pulses of the BM (Kemp, 2002). Otoacoustic emissions, which are the measured low level sounds generated by the OHCs, are essentially a by-product of a positive feedback mechanism known as the cochlear amplifier. Essentially, the OHCs are put into the motion by the movements of the BM. The motions of the OHCs then cause mechanical amplification of sound vibrations, which amplifies the motion of the BM. These active movements of the OHCs are in some part responsible for enhancing the sensitivity and frequency selectivity of the cochlea (Denes & Pinson, 1993; Kandel et al., 2000).

Central anatomy. From the auditory nerve, information travels to the auditory brainstem. Processing of auditory information occurs in parallel pathways. Specific characteristics of each signal are analyzed by dedicated tracts. The initial separation of information pathways begins in a bundle of neurons, known as the cochlear nuclei (CN). Structures on both sides of the brainstem work together. While some neurons are sensitive to stimulation from one ear, other neurons respond best to patterns of stimulation caused by information from both ears. Nerve fibers from the cochlear nuclei connect to the ipsilateral and contralateral portions of the superior olivary complex

(SOC). The SOC plays a vital role in the interpretation of timing cues and spatial processing as it is the minimum level for binaural crossover.

The primary nuclei of the SOC, the medial superior olive (MSO) and the lateral superior olive (LSO), contribute to localization abilities. Neurons which respond better to timing and intensity information project to the MSO and LSO, respectively. The MSO cells are sensitive to low-frequency sounds at or below 5 kHz. The neurons within the MSO are phase locked to the temporal characteristics of sounds. This feature of the neurons interprets the differences in the timing of inputs from the two ears (Spitzer & Semple, 1998). An important role of the MSO is to distinguish interaural timing delays. An acoustic signal reaching the fibers of the VIII cranial nerve will cause the excitation of axons that proceed from the CN to the MSO. This same sequence occurs in the ear which is initially stimulated as in the far ear. As the signal travels across the MSO, the action potentials of successive cells are activated. Neuronal firing can occur with excitatory input from either ear alone. Neurons can also be brought to threshold through simultaneous stimulation of both ears. A difference in the activation of the ipsilateral ear is balanced by the lag in the firing of action potentials of the contralateral ear. By analyzing the differences in action potentials, the MSO maps out the location of sound sources along the azimuth (Kandel et al., 2000).

In conjunction with timing differences, intensity cues, analyzed by the LSO, are used to perceive sound source location. Direct, ipsilateral projections from the CN, as well as contralateral projections which are relayed through the trapezoid body, provide information to the LSO. The neurons of the LSO are binaural and generally antagonistic; optimal excitement within a certain neuron will occur if the intensity level of the ipsilateral ear is sufficiently greater than the input from the contralateral side. The LSO is tonotopically organized, meaning various frequencies are processed according to the spatial arrangement of neurons. Within the LSO, the neurons are best tuned to high-frequency stimuli (Kandel et al., 2000). The MSO and LSO work together to provide information about sound sources in the horizontal plane (Kulesza, 2007).

From the SOC, projections travel upward toward the trapezoid body, the lateral lemniscus, and the inferior colliculus. The integration of the separated pathways happens within the inferior colliculus. Here, many neurons are sensitive to variations in interaural timing or intensity. Similarly, the next stage in processing, the medial geniculate body, also contains neurons which retain the same sensitivity to interaural differences that is displayed in the inferior colliculus (Kandel et al., 2000). Lastly, the ascending auditory pathway terminates in an area within the temporal lobe known as the primary auditory cortex.

Basics of Sound Localization

The locations of sound sources within a 360° spatial environment are often classified using Cartesian (x,y,z) or spherical (azimuth, elevation, distance) coordinates (Ahveninen, Kopčo, & Jääskeläinen, 2014). The distance between the ears, as well as the locations of sound sources relative to the head, allow for the processing of interaural difference cues. This complex information is collected and quickly processed by the auditory system to provide insight into the surrounding environment. The orientation of the listener to a sound on the horizontal plane is directly related to how the ears will receive the sound. Within the horizontal plane, binaural cues contribute to better localization performance. Conversely, monaural cues provide insight into vertical localization. Several factors may disrupt and distort the processing of sensory information that leads to correct localization. These obstacles include: the listener's head/torso, reverberation, competing signals, distance, and/or errors in the auditory pathway.

Localization in the horizontal plane. One focus of sound localization is the horizontal positions of sound sources. A sound in the environment can arrive from anywhere around the listener (360°) in the horizontal plane. The angle created by the leftward or rightward location of a sound source and the center of a listener's head on the horizontal axis describes azimuth (Middlebrooks & Green, 1991). As seen in Figure 1, a sound source with a 0° azimuth in relation to a listener will be located directly in front of the listener. For localization in the horizontal plane, interaural level differences (ILDs) and interaural timing differences (ITDs) are two primary binaural cues that provide information about the direction/angle of a sound source (Wightman & Kistler, 1992).

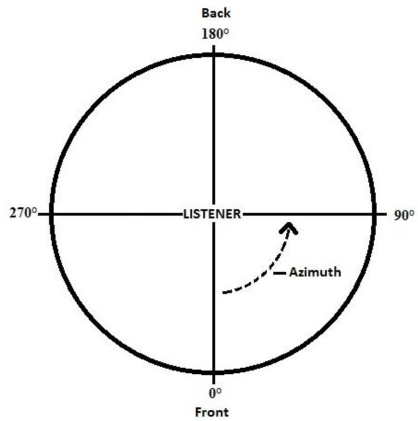

Figure 1. Visual representation of azimuth angle from a top-down view.

Duplex theory. The duplex theory explains how timing and intensity binaural differences (ILDs and ITDs) are utilized by the auditory system to perform high-and low-frequency localization within the horizontal plane (Rayleigh, 1907). ITDs are important for the localization of low frequency signals, while ILDs provide more information about high frequency sound inputs (Yost & Dye, 1988). However, the frequency region between 1500 Hz and 3000 Hz may result in ambiguous or negligible cues (Middlebrooks & Green, 1991). The exact frequency regions which result in unclear localization clues depend on the diameter of an individual's head (Kuhn, 1977). Due to these reasons, accurate localization may only occur when a combination of cues are present. This is especially true for complex sounds which may include both low and high frequency information.

Interaural level differences. Interaural level differences (ILDs) are important cues in duplex theory. A sound produced off-axis from the listener's midline causes intensity level differences between the ears. For example, a sound source positioned 90° to the right of an individual will cause a greater intensity in the right ear than in the ear of the opposite side. This decrease in amplitude on one side relative to the other creates an ILD between the ears (Middlebrooks & Green, 1991). Wavelength plays an important role in these interaural differences. Relative to the diameter of the head, low frequency sounds have a longer wavelength that is able to bend, or diffract, around the head. This means there is little interruption in the signal as it travels and arrives at the far ear. Conversely, the shorter wavelengths of high-frequency sounds are blocked by the head. This effectively creates an ILD. These interruptions of the sound pathway are referred to as the "head shadow effect" (Gelfand, 2010). Specifically; sound will be attenuated as it crosses from the near ear to the far ear. This effect occurs at stimulus frequencies (>1000 Hz) as their shorter wavelengths can be blocked by the head (Goldstein, 2010; Middlebrooks & Green, 1991). Therefore, the ILDs are the dominant binaural cue for higher frequency wavelengths (Lorenzi, Gatehouse, & Lever 1999).

Interaural timing differences. Interaural timing differences (ITDs) are the other type of important cues for duplex theory. When a sound is produced off the midline, disparities result in the arrival times of a signal at each ear. The signal travels a longer distance to the far ear than to the near ear, resulting in a time delay in the arrival of the sound at the more distant ear (Phillips, Quinlan, & Dingle, 2012). The ITD is in part explained by how sound propagates through a medium. The density and composition of a human head is very different from that of air. Sound that would normally travel through air will instead bend around the head. A sound produced to one side of a listener's head will result in a timing delay at the opposite ear of about 600-800 μs (Gelfand, 2010). The actual time delay for each person will vary based on the individual's head size. A greater head diameter correlates with a larger circumference and a bigger distance that sound has to travel from the near ear to the far ear.

For a signal that is both continuous and periodic, the timing difference between the arrival of the signal at each ear can be expressed as a variation in the phase of the signal, or interaural phase difference [IPD (Scharine & Letowski, 2005)]. While similar, this phrase is not interchangeable with ITD. IPDs refer to the shift in the phase of the waveform arriving at the listener's ears and are dependent on the frequency of the signal (Phillips et al., 2012). For abrupt stimuli, such as the set used for this project, the ITD is calculated by analyzing the difference between the onset of the signal received by each ear. Because of the complex nature of small arms fire, ITDs provide a more relevant cue than IPDs which may be more useful in stimuli such as pure tones. In regards to the present study, the focus will remain on ITDs and not IPDs.

The human threshold for ITDs is estimated at about 10-15 μs (Gelfand, 2010; Phillips et al., 2012). A sound source located at 90° azimuth to the side of a listener will result in the largest possible ITD as the signal will have to travel the maximum distance from the near ear to the far ear. Correspondingly, a sound source positioned at either 0° or 180° azimuth will result in essentially no time difference between the ears; this is explained by the sources being equidistant from both ears (Feddersen, Sandel, Teas, & Jeffress, 1957).

Cone of confusion. While the duplex theory addresses the binaural differences that aid in high- and low- frequency localization, the theory fails to account for accurate localization when interaural disparities are ambiguous. Information provided by interaural difference cues can be ambiguous across some azimuth positions. A range of sound source positions along the horizontal plane can produce identical interaural differences relative to the listener, despite changes in the angle of the sound source. For example, Figure 2 shows how an acoustic stimulus produced at 135° azimuth may have the same measured timing and intensity variances as a signal generated at 45°. The complementary, same side front-back positions of both sound sources result in identical cues and thus ambiguous localization. This concept holds true for any source positioned within the “cone of confusion”, and can result in identical binaural information (Middlebrooks & Green, 1991). This can lead to localization errors, specifically front-back confusions. Front-back confusions occur when an individual incorrectly judges the position of a sound source as being in the rear hemi-field when the actual location comes from the front direction or vice versa (Wightman & Kistler, 1992). If the only localization indications available were ITDs or ILDs, front-back reversals would occur quite frequently (Wightman & Kistler, 1999).

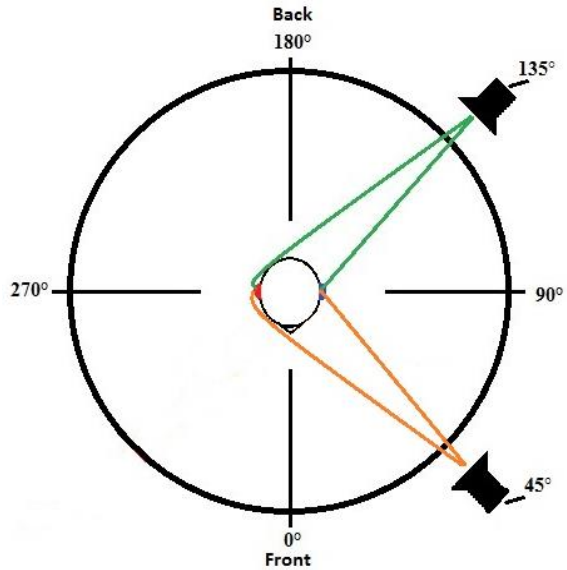

Figure 2. ITDs and ILDs from two sound sources. This figure illustrates sound sources at complementary azimuth angles which generate equivalent ITDs and ILDs.

While some controversy exists about the importance of head movements in localization tasks, the general consensus is that positional changes are beneficial (Wightman, & Kistler, 1999). If the head remains immobile, then the ITD or ILD that is produced will not be sufficient for disambiguating front from back. By changing the position of the head, the location of the cone of confusion shifts (Gelfand, 2004). By moving the head, new ITDs and ILDs are created which supply the listener with disambiguating binaural information.

Localization in the vertical plane. Another important aspect of sound localization is the origin of sound waves from a vertical position. The elevation of a sound source refers to the up-down angle created by the source and the horizontal plane (Middlebrooks & Green, 1991). The binaural timing and intensity differences that may be present in the horizontal plane do not cue changes in the vertical plane. A signal that originates from the x and y coordinates 0°, 0°, will be directly in front of an individual while a signal from 0°, 90°, is positioned directly overhead. This concept is demonstrated in Figure 3. The ears are located at the same height which, depending on the origin of the signal, will result in equivalent ITDs/ILDs as a function of changes in elevation. Instead, vertical cues tend to be based on monaural spectral cues.

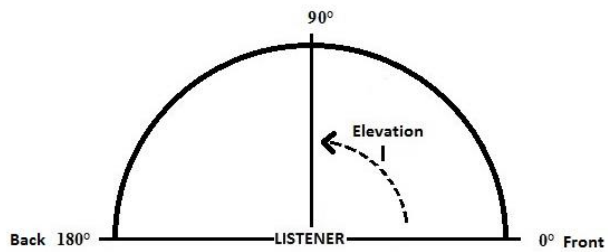

Figure 3. Visual explanation of elevation angles vertically around a listener. The bottom line denotes the horizontal plane. The perpendicular line that passes through the center of the listener's head is the median plane.

Spectral cues. Changes in high frequency spectral information, due to changes in the pinna folds, provide cues to localize the elevation of a sound, help in judgments of front-back discriminations, and aid in monaural localization (Gelfand, 2010; Middlebrooks & Green, 1991). These cues may also contribute to lateral localization (Macpherson, & Middlebrooks, 2002). The pinnae act as directionally dependent filters and interact with incoming sounds by amplifying some frequencies and attenuating others. The directionally dependent filtering action of the pinnae alters with head adjustments. Sound waves enter the ear via a direct pathway as well as reflected pathways. The phase of the reflected sound may interact with the direct signal and cause either amplification or cancellation of certain frequencies. Due to size of the pinna folds, the filtering aspect of the pinnae on monaural spectral cues for elevation tend to be useful only for high-frequency sounds >5-6 kHz (Wightman & Kistler, 1992; Moore, 2012). Changes in the spectra of the sound only occur if the wavelength is sufficiently smaller than the width of the pinnae folds. As a sound source travels from up around the head, a spectral notch, considered by Musicant and Butler (1985) to be a major elevation cue, changes in frequency from about 5 to 11 kHz (Gelfand, 2004).

Monaural spectral cues created by a change in the head's position, by a slant or head tilt, can shift the perception of the sound's location (Moore, 2012). Spectral changes will result from alterations in the positions of the head, ears, and torso, and their corresponding sound pathways. Head turns or tilts help to disambiguate vague cues and the front/back positions of sources (Wightman & Kistler, 1999).

Localization of distance. A third dimension of sound localization concentrates on the distance between the listener and the sound source. Intensity levels and the ratio of direct to reflected sound are two important cues in the localization of distance (Moore, 2012). These cues vary with different types of sound sources, as well as changes in azimuth. Psychoacoustic experiments conducted by Kim, Suzuki, Takane, & Sone (2001) suggest individuals are better able to judge distance when sound sources are located to the sides rather than at front or back positions. An individual is capable of noticing even small changes in distance (Strybel & Perrot, 1984). Direct/indirect pathways of signals, intensity levels, and spectral ranges are all factors which influence distance perception (Kim et al., 2001).

Various objects and surfaces within an acoustic environment affect the pathways of a sound signal. For a close sound source, there is a higher ratio of direct-to-reverberant energy than for a source that is located further away. This is explained by the fact that the direct path of a sound travels a shorter distance to the listener than the indirect paths of the sound signal’s reflections. As you increase the distance from the source, the amount of direct energy will decrease. Consequently, the ratio of reflected-to-direct energy in the stimulus increases (Brungart, 1998). When a sound is presented in a reverberant environment, listeners will perceive the source as further away than if the sound was produced in an anechoic environment (Brungart, 1998). Judgments of distance are typically better in reverberant settings rather than in an environment where reflections are absorbed (Brungart, 1998; Gelfand, 2004).

For familiar sounds, intensity levels may indicate the relative distance of a sound source to a listener. Intensity levels change as distance increases or decreases. For every twofold increase in distance, the intensity of a sound decreases by 6 dB in a free-field environment (Middlebrooks & Green, 1991). However, as a 6 dB difference often leads to perceptual underestimations of absolute distances, higher levels are necessary to indicate a doubling of distance (Gelfand, 2004).

The spectral ranges of sound may be influenced by distance. As a sound wave propagates, molecular absorption causes the sound energy to be transformed into heat energy; this results in attenuation of the signal (Beck, Nakasone, & Marr, 2011). The amount of absorption that occurs is associated with the frequency of the signal and the climate of the space [e.g. humidity, temperature, and atmospheric pressure (Larsson, 1997)]. As frequency increases, attenuation increases monotonically. The largest amount of attenuation occurs for any relative humidity ranging between 10 and 30 percent (Maher, 2007). More distant sound sources may be perceived as more muffled than closer sound sources as the high frequencies within the signal are attenuated by interactions with the environment. At stimulus frequencies below 4 kHz, the greatest possible attenuation caused by humidity is about 0.1 dB/m (Maher, 2007). While atmospheric absorption is an important consideration for large distances where a substantial low-pass filtering effect may occur, in most normal listening environments the amount of attenuation is negligible (Brungart, 1998).

Precedence effect. Another consideration in the judgment of distance is the phenomenon known as the precedence effect (Gelfand, 2004). If a listener is presented with two competing sound signals, the initial sound will be perceived as the most important. If the time delay between two brief sounds (originating from different sources) is small enough (<1 ms), the signals may be perceived as a single auditory event. The signal arriving first at the ears effectively suppresses any echoes or reverberations for up to about 40 ms (Wallach, Newman, & Rosenzweig, 1949). If the time lag exceeds 40 ms, the second sound is identified as an echo. When this occurs, the initial sound largely dominates the perception of the sound source's origin. The concept of the precedence effect is important for studies in which an auditory event consists of target sounds with an azimuth offset, such as the present study.

Head-related transfer function. Research involving localization tasks often makes use of the head-related transfer function (HRTF). The HRTF is a mathematical representation of the acoustic cues received by the ear. Specifically, the HRTF is a ratio of the spectrum of a sound source and the measured sound spectra arriving at the ear. The HRTF demonstrates how objects in the auditory space disrupt the pathway of a sound from the free-field to the eardrum (Wightman & Kistler, 1992). Diffractions and reflections of sound caused by the body, as well as the direction of the sound source relative to the head, impact the HRTF. A sound presented on one side of a listener's head will decrease in level and modify the HRTF as the sound source moves to the opposite side of the head. Similarly, changes in elevation can also affect the HRTF; the high-frequency facets are altered by the filtering effects of the pinna (Gelfand, 2010). HRTFs vary slightly from person to person. An HRTF can be measured specifically for one person, or generalized to an entire population (non-individualized). HRTFs are often collected for multiple sound source locations and used in localization experiments to present a novel set of sounds so that they appear to come from locations in space corresponding to HRTF measurement locations.

Listener performance in localization tasks. Several studies have looked at how precisely humans can perceive the direction of a sound source. In a study of 45 listeners between the ages of 21 and 49 years, Yost, Loiselle, Dorman, Burns, & Brown (2013), found that participants were able to accurately identify a loudspeaker presenting an acoustic signal in three conditions: low pass (81%), high pass (78%), and broadband (83%). This measurement was calculated by dividing the number of times a participant chose the correct loudspeaker divided by the number of trials. In another study, the sound localization abilities, in the presence of noise, of both normal-hearing listeners and cochlear implant users were explored (Kerber & Seeber, 2012). The set up for this study included 36 loudspeakers placed in the horizontal plane, 10 degrees apart. The participant sat facing the front, or the speaker at zero degrees azimuth. Loudspeakers, chosen at random, situated at 0, ±10, ±20, ±40, ±60, or ±80 degrees presented the auditory stimuli in either quiet or in diffuse background noise conditions. The signal-to-noise ratios (SNRs) of the noisy conditions ranged between +10 to -7dB. Following the stimulus presentation, a light appeared before the subject. The participant indicated his/her perception of the horizontal direction of the noise pulse by moving the lightspot with a trackball. For the normal-hearing subjects, the absolute localization error was between 2.3 and 6.6 degrees in the quiet condition. As SNR decreased, the localization acuity of all participants declined.

Nambu et al. (2013) examined the out-of-head sound localization abilities of seven young adults. The out-of-head sound localization technique involved stimulating the eardrum, with earphones, in a way that mimics the waveforms of an actual sound field. To ensure the abilities of the subjects to perform out-of-head sound localization tasks, the researchers first performed a localization test. Each participant was seated with six sound sources situated in different directions (30°, 90°, 150°, −150°, −90°, and −30°.) around his or her body. A subject indicated which speaker produced an acoustic stimulus based on his/her perception of the stimulus' direction. The average score, in percentage, was 92.4%.

Studies investigating the spatial acoustic perception in children help to explain the maturation of localization skills (Kuhnle et al., 2012). 13-18 year old subjects were able to pinpoint the loudspeaker location within 3.2-5.9 degrees for 90° left to 90° right speaker reference locations. Results from this study also indicated that localization abilities reach maturity by the age of six years, and that frontal presentations are more accurately perceived than lateral stimuli.

As demonstrated by the studies that were described above, humans with normally functioning auditory systems are able to localize sounds with fairly good accuracy. Frequency also plays a role in sound localization performance. Localization acuity of pure tones is improved when frequencies greater than 5000 Hz are presented. Above 5000 Hz, the difference levels between the two ears are great enough that the listener receives a cue. At lower frequencies, the ILDs are smaller because of the interference of the head; due to this relationship, a listener will underestimate the azimuth angle of the sound source. As frequency, as well as the azimuth angle, increases, localization becomes more accurate (Feddersen et al., 1957). This finding contrasts with later studies which indicated improved localization ability with frontal presentations (Kuhnle et al., 2012; Wightman & Kistler, 1992).

Listeners have better accuracy in determining the location of a noise burst when it is produced from a single source; however, individuals are capable of localizing the sources of "independently and simultaneously generated noise bursts" (Yost & Brown, 2013). Typically, environmental noises occur concurrently and result in complex listening situations. Localization accuracy tends to decline as more concurrent noise sources are added to the acoustic space (Brungart, Simpson, & Kordik, 2005). Sound is rarely transmitted in a straight shot from the source to the listener (Toshima, & Aoki, 2009); movement of the sound source or obstacles in the pathway of the sound can alter the signal. The unpredictable nature of environmental sounds makes them harder to identify, and ultimately localize, than more structured auditory events, such as speech.

Localization of Small Arms Fire

Unlike most environmental noises, the auditory signature of small arms fire is unique. The discharge of a small arms weapon consists of multiple acoustic events, with two major stimulus components: the muzzle blast and the ballistic crack (Beck et al., 2011). The perception of gunfire depends on the distance and angle between the observer and sound source. The disparities in the temporal, amplitude, and directional domains of these physical properties, caused by the spatial relationship of the listener and shooter, affect the perception of the gunfire (Gaston & Letowski, 2012). Despite the amount of information available regarding localization, the area of research focusing on localization within combat situations or the localization of impulse sounds is underserved.

Acoustics of small arms fire. Before one can explore the process of localizing gunfire, it is prudent to review the important characteristics of the acoustic event. In a traditional firearm, a sound emission, known as the muzzle blast, accompanies the propulsion of the bullet out of the gun barrel. The sound wave of the explosion lasts approximately 3-5 ms (Gaston & Letowski, 2012). The acoustic blast expels in all directions at the speed of sound; however, the greatest amount of energy is released in the same direction as where the gun barrel is aimed in a radial manner (Maher, 2006; Lo, &

Ferguson, 2012). Beck et al. (2011) conducted an experiment to determine the effects of different azimuth angles on muzzle blast recordings of a revolver. Four microphones were placed first at 3°, 30°, 60°, and 90° and then at 90°, 120°, 150°, and 180°. The overall results showed that as azimuth angle increases, the muzzle blast takes longer to arrive at the microphone. As the observer moves away from the line-of-fire, the energy of the muzzle blast is present but not as intense as the energy produced directly in front of the gun (Beck et al., 2011).

Whereas the acoustic wave of the muzzle blast generates from the hot, rapidly expanding gases emanating from the gun barrel, the ballistic crack of the gunshot is the result of a bullet traveling at a supersonic speed (Maher, 2007). At this supersonic level, an acoustic shockwave, with a distinctive N-shape waveform, emanates outward from the bullet's path in a conical shape. The angle of the shockwave changes as a function of bullet velocity (i.e. the faster the speed of the bullet, the narrower the angle of the shockwave). In comparison to the muzzle blast, the duration of the ballistic crack is much shorter and is typically 200-300 microseconds (Gaston & Letowski, 2012).

Shooter/observer position is an important consideration in the determination of sound origin. Letowski, Scharine, Gaston, Amrein, & Ericson (2012) provide an in-depth explanation of this concept:

> The sound of the supersonic bullet propagates outward from the target line and arrives to the observer at an angle that is a function of the bullet's speed. The arrival time to the observer then is the addition of the time it takes the supersonic bullet to reach the point of outward propagation from the target line, plus the time it takes the ballistic crack to propagate (at the speed of sound) from the target to

> the observer. In contrast, the sound of the muzzle blast travels at the speed of sound along a direct path from the weapon barrel to the observer. As a consequence, the perceived relative timing of the ballistic crack and muzzle blast sounds depends greatly on the distance of the observer from both the weapon barrel and the bullet target line. (p. 8)

In gunfire experiments, the gun being fired represents the shooter and the observer is the microphone. If a gun is fired in a forward facing position toward the observer, the observer will perceive a ballistic crack followed by a muzzle blast. However, as the angle between the shooter and observer increases, the listener's perception of the shockwave will decrease. The ballistic crack is typically only detected at angles less than -60° to +60° of the target line (Sherwin and Gaston, 2013). As displayed in Figure 4, an observer located behind a shooter will not perceive the ballistic crack and will hear a muzzle blast with decreased intensity.

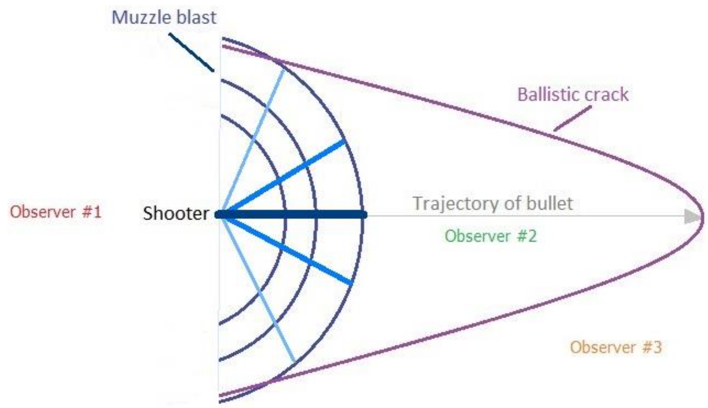

Figure 4. Visual explanation of gunshot acoustics perception based on observer/shooter position. Observer #1 will only hear a muzzle blast with decreased intensity and not the ballistic crack. Observer #2 will hear both auditory events, with the ballistic crack arriving first. Observer #3 may miss both sounds completely.

Timing differences between the muzzle blast and the ballistic crack may change as a result of the shooter/observer relationship. For example, at a 0° azimuth, the average time between the onset of the ballistic crack and the onset of the muzzle blast can be 20.3 ± 0.3 ms (Sherwin and Gaston, 2013). Despite the relatively short durations of the muzzle blast and ballistic crack, both have the capability to injure the hearing mechanism of any individual who is within close proximity. The shooter/observer relationship also factors into the possibility of hearing loss.

Auditory hazards of small arms fire. Certain professions, such as military personnel and police forces, are often exposed to gunfire, a common cause of noise-induced hearing loss (Moon, 2007). The amount of noise produced by a sniper's weapon may range from 147 dB to 171 dB following gunshot fire (Barkokebas Junior, Lago, Vasconcelos, & Oliveira, 2012). Noise exposure of this magnitude generates instant hearing loss. Acoustic trauma, a sudden hearing loss occurring after a noise of high intensity and short duration, may lead to severe structural damage to the middle and inner ear. Combat readiness and effectiveness may be negatively affected by hearing loss. In environments where noise levels exceed 85 dBA for steady state noise and 140 dB peak SPL for impulse noise, the use of hearing protection devices (HPDs) is recommended to minimize damage to the auditory system and prevent this auditory deficit (Department of the Army, 1998; Occupational Safety and Health Administration, 1981). Unfortunately, while HPDs may decrease the risk of noise-induced hearing loss, localization acuity may also degrade with the use of these devices (Bolia, D'Angelo, Mishler, & Morris, 2001; Talcott, Casali, Keady, & Killion, 2012). With the use of HPDs, azimuth and elevation errors, along with problems in the identification of the front/back dimension and/or the right/left component of the sound source's location, may occur. These errors are the result of a disruption (the HPD) in how the sound wave interacts with the pinnae (Bolia et al., 2001). These studies indicate that the hearing protection that is recommended due to the risk of noise exposure, may negatively impact a soldier's situational awareness. By gaining a better understanding of how gunfire is localized, devices may be created that both prevent hearing damage and allow for localization cues to make it to the ear.

Factors affecting localization of small arms fire. In addition to the use of hearing protection, other factors may also disturb and distort the processing of sensory information that leads to correct localization of gunfire. Within the environment, several factors (e.g. ground surface, temperature/wind levels, obstacles, etc.) interact with the muzzle blast and can cause distortion (Maher, 2007). Listener perception of the muzzle blast may also be affected by an acoustic suppressor. This piece of equipment is designed to reduce the intensity of the muzzle blast; thus providing concealment and possibly preventing acoustic trauma. Along with disruptions in the sound signal, the relative position of the observer to the shooter greatly affects an individual's sound localization of gunfire; this is due to the differences in the temporal and intensity domains of the acoustic gunshot information.

Simulated versus live gunfire. Similarly, localization ability may be affected when a gunshot stimulus is produced in an open, natural environment versus a simulated control experiment over headphones. When presented through earphones, sounds are typically judged as occurring within the head; this is known as internalized localization. External localization refers to the perception of sound outside of the head from a source that can be identified in the spatial environment (Gelfand, 2010). If not performed in a realistic setting, audio recordings of a discharging firearm may include propagation effects, multi-path reflections, and reverberations that are not present in a free field environment (Maher, 2007). The location of a recording microphone, in relation to the sound pathway, alters the driving effect of the acoustic signal. Information about the supersonic shockwave is only useful for localization purposes if the bullet passes sufficiently close to the listener (Gaston & Letowski, 2012). If a recording microphone is placed near to the weapon, the composition of the signal will primarily stem from the energy of the muzzle blast with lesser contributions from late-arriving sounds, such as those caused by reflections and scattering. The characteristics of this sound change with the distance and angle of the microphone relative to the source, as well as the size of the muzzle blast (Beck et al., 2011). These factors combine to produce specific acoustic cues, which when analyzed by a listener's brain, result in disparities in the performance of localizing the source of the stimuli.

Statement of Purpose.

Previous studies have researched the detection, localization, and classification of small arms fire abilities in listeners (Fluitt et al., 2010; Gaston & Letowski, 2012; Lo & Ferguson, 2012). In order to develop a better understanding of how listeners use this information to localize small arms fire noises, the aim of the present study was to determine the what effect, if any, acoustic characteristics (i.e. time and intensity) had on gunfire localization. This study focused on assessing listener performance in localizing sound sources by isolating specific amplitude and timing cues. The amplitude differences between the muzzle blast and ballistic crack of small arms fire as a function of shooter/observer relationships, as well as the timing differences between these two stimulus components, were manipulated to evaluate which cue was more significant. This knowledge may lead to more efficient hearing protection devices, enhanced communication systems during combat, and improve the determination of hostile/friendly fire.

Chapter 3

Research Methodology

Subjects

Thirty adults (13 males and 17 females), whose ages ranged from 20 to 63 years old, participated in each experiment of this study. Subjects were recruited through the use of word of mouth, e-mail, and flyers. A hearing screening was performed on all possible subjects before testing began. Pure tone stimuli were presented with a GSI 61 audiometer via TDH 49 headphones. The octave steps between 250 and 8000 Hz were tested using the modified Hughson Westlake method (Carhart & Jerger, 1959). All listeners demonstrated normal hearing, defined as 1) pure-tone air conduction thresholds $\leq$ 25 dB HL and 2) pure-tone bone conduction thresholds $\leq$ 25 dB HL for the octave steps between 500 and 4000 Hz. A subject was considered ineligible if she or he failed to meet these requirements due to the effects of hearing loss on localization acuity (Noble, Byrne, & Lepage, 1994). Participants displayed the physical ability to manipulate a computer mouse and/or keyboard. The procedures for this study were approved by Towson University's Institutional Review Board (IRB) for the Protection of Human Participants.

Equipment, Materials, and Test Environment

Stimuli were presented via AKG K701 circumaural headphones which were connected to a Lenovo ThinkPad laptop computer. Custom written software, developed for localization experiments in Visual Basic+, were created at the Auditory Research Laboratory (ARL) in Aberdeen, Maryland by engineer Tim Mermagen. Listeners interacted with the program through a graphic user interface. The analog circular screen represented a 180° frontal arc of the horizontal plane. Users indicated the perceived direction of the sound source by selecting a location on the circular graphic. After the presentation of each stimulus, the participant had seven seconds to respond before the onset of the next stimulus. Responses were recorded by the laptop computer. All testing was performed in a sound-treated acoustic lab on Towson University's campus.

Stimuli

Target sounds were created by taking the recording of an M4 carbine firing, and extracting muzzle blast (MB) and ballistic crack (BC) sounds separately. Recordings were made at a small arms firing range in Aberdeen, Maryland, at Aberdeen Proving Ground. The M4 was measured 16 m in front of the muzzle with a zero degree incidence. For the MB component, a 1000 ms segment of the reverberation tail was removed from the recording 200 ms following the peak. In each experimental condition, the MB and BC stimulus components were combined with appropriate time offsets and differences in peak amplitudes. To create a more realistic set of stimuli, a reverberation tail was added for context. All edits were made with Adobe Audition 3.0.

Each original recording of the MB and BC segments was normalized to the same -3 dB(P) peak amplitude. Virtual spatial sound sets were generated by combining each sound with a non-individualized Head-Related Transfer Function (HRTF). HRTFs were collected at fourteen source positions (-60°,-50°,-40°, -30°, -20°, -10°, 0°, 10°, 20°, 30°, 40°, 50°, 60°) and used a Knowles Electronic Manikin for Acoustic Research (KEMAR) dummy with B&K microphones placed in the conchas of KEMAR. Therefore, a set of fourteen MB stimuli and fourteen BC stimuli were used to construct the experimental stimuli for each condition.

Modeled observer/shooter positions, as a function of absolute distance and observer incidence angle of the shooter's target line, corresponded to the stimulus relationships. These relative stimulus differences were maintained throughout the stimuli. Therefore the stimuli were not played at the absolute modeled levels. For our purposes, the -3 dB level of the base stimuli prior to convolution is referenced to the 156 dB level for modeled relationships since this is the highest modeled peak level for any of the stimulus components. For all stimuli, following editing, the onset time to BC peak was set at 200 ms and the offset time following the final peak to stimulus end was set at 1200 ms. The total duration of BC + MB stimuli thus was 1400 ms plus the time delay between BC and MB peaks. The MB portion of the combined stimuli was 200 ms long and the final 1000 ms was a generic reverberation tail taken from the original gunshot stimulus inserted to make the stimuli sound more realistic.

For experiments 1-4, the stimuli consisted of seven spatial angles which ranged in increments of 20 degrees (-60°,-40°, -20°, 0°, 20°, 40°, 60°). However, in experiment 5, the stimuli were thirteen modeled angles which changed 10 degree increments (±60°, ±50°, ±40°, ±30°, ±20°, ±10°, 0°). In experiments 3-5, the BC sound acted as the reference and always occurred before the MB. The reference changed based on the positive or negative value of the target's stimuli location (i.e. all leftward, or negative, azimuths used a -60° reference and all rightward, or positive, azimuths used a +60° reference). Due to this, each experiment included both a +0° location and a -0° location. All appropriate timing differences and spatial mappings were maintained. None of the stimuli that were presented exceeded safe noise exposure levels for impulse sounds [i.e. 140 dB peak SPL - (Department of the Army, 1998)].

Experiment 1: Muzzle blast (MB) only. The MB stimuli were modeled to reference a peak level of 156 dB (P). The stimuli ranged from +60 to -60 degrees in increments of 20 degrees; this resulted in 7 stimuli. The 7 stimuli were randomly played for five repetitions for a total of 35 trials.

Experiment 2: Ballistic crack (BC) only. The BC stimuli were modeled to reference a peak level of 156 dB (P). The stimuli ranged from +60 to -60 degrees in increments of 20 degrees; this resulted in 7 stimuli. The 7 stimuli were randomly played for five repetitions for a total of 35 trials.

Experiment 3: Muzzle blast and ballistic crack amplitude. Muzzle blast and ballistic crack sounds were extracted separately from the recordings of an M4 firing. The MB portions of the stimuli range from +60 to -60 degrees in steps of 20 degrees. The BC angle was either +60° (for rightward stimuli) or –60° (for leftward stimuli). These were the only 2 values used for all BC +MB stimuli because across all of the modeled relationships, as the arrival angle of the MB changed so did the BC angle such that the two added to approximately 60 degrees. For example, at a MB angle of 0 degrees, the difference in angle was 60 degrees, at 20 degrees the difference in angle was 40 degrees, and at 60 degrees the difference was 0 degrees. For these stimuli, the MB was always referenced to 138 dB (P) and the time delay between BC and MB peaks was always 160 ms. What varied was the referenced BC peak levels, and these varied from 126 dB (P) to 156 dB (P) in 6 dB steps. This range covered the relative amplitude differences between BC and MB peaks across the range of modeled shooter-observer relationships. This experiment tested for how the difference in amplitude across BC and MB peaks affected localization. Timing was not a factor because the timing offset was fixed (160 ms) for all stimuli.

Experiment 4: Muzzle blast and ballistic crack timing. For these stimuli, the MB was referenced to 138 dB(P) and the BC amplitude was also fixed at 138 dB(P), thus there was a 0 dB difference. The timing offsets between BC and MB varied between 10, 20, 40, 80, 160, and 320 ms. This experiment tested for how the difference in timing between BC and MB peaks affected localization. Amplitude was not a factor because for all stimuli the amplitude offset was fixed (0 dB).

Experiment 5: Muzzle blast and ballistic crack amplitude and timing. In this Experiment, the timing and amplitude relationships were modeled for each specific observer/shooter position. As shown in Figure 5, there were 42 unique stimuli corresponding to the 14 modeled angles (+60 to -60 degrees in 10 degree increments, including both a +0° and -0 position°) at the 3 distances (64, 128, 256 m). The exact range of parameters for the stimuli is referenced in the file names of the stimuli.

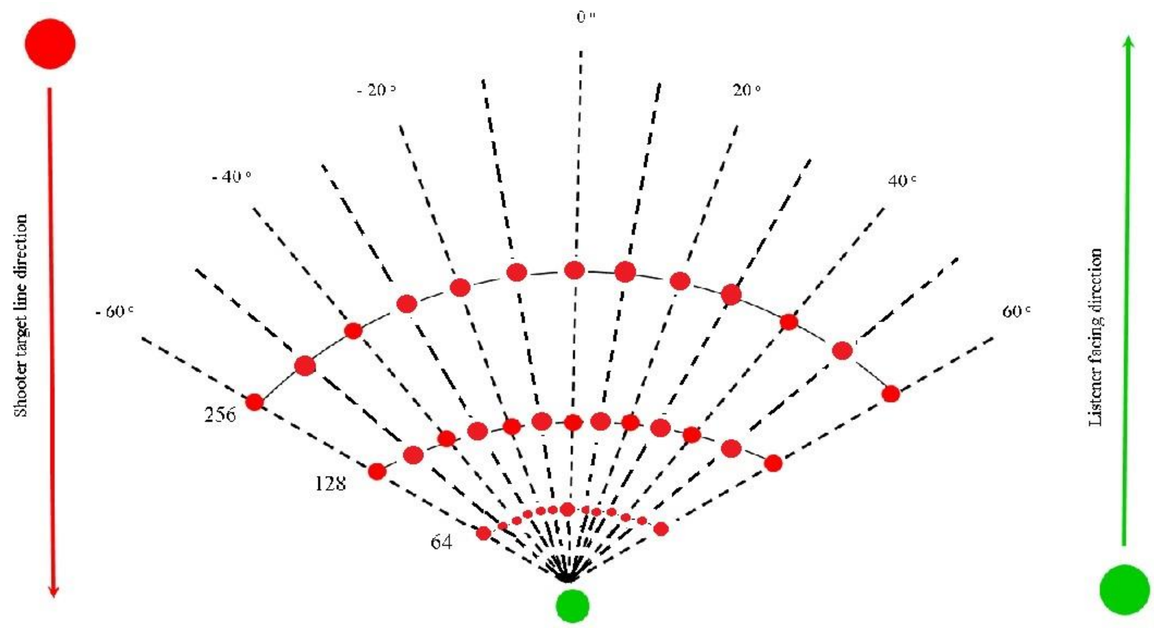

Figure 5. The modeled observer/shooter positions for experiment 5. A red circle represents the modeled distance and azimuth for each stimulus. The green circle indicates the location of the recording microphone.

Procedure

Each subject participated in one test session (60-90 minutes) that included five experimental conditions. The order of conditions was randomized for every individual. During the sessions, audiometric thresholds were measured before localization errors. When testing for the localization tasks began, subjects were seated in front of the laptop computer and given instructions. The participant had the option to perform five practice trials prior to the start of each experiment with additional practice trials as needed. The user initiated the program by clicking a button. After the target signal was presented, 7 seconds were allotted for the listener to respond on the graphic interface. The subject's task was to report, by clicking on the circular graphic, the location of the sound source relative to the his/her own position. Breaks were given periodically as needed.

Experiment 1: Muzzle blast (MB) only. Subjects listened to a gunshot recording from a set of seven randomized stimuli with 5 repetitions (total of 35 trials). Following the presentation of a stimulus, the listener used the computer mouse to point and click on the area of the response arc that most closely indicated where he/she believed the sound originated.

Experiment 2: Ballistic crack (BC) only. The instructions and procedure did not differ from experiment 1.

Experiment 3: Muzzle blast and ballistic crack amplitude. For experiment 3, the procedure was comparable to those of experiments 1 and 2 with some notable differences. Listeners were given additional instructions on how to complete the task. First, the listener was told that s/he would listen to multiple gunshot sounds. Then the listener was told to focus on the second sound and indicated on the screen the location of where s/he thought the second gunshot sound originated. In total, 210 trials were performed as the 42 stimuli were presented for five repetitions.

Experiment 4: Muzzle blast and ballistic crack timing. The instructions and procedure did not differ from experiment 3.

Experiment 5: Muzzle blast and ballistic crack amplitude and timing. Similarly to experiments 3 and 4, the instructions for experiment 5 advised the listener to listen to the gunshot sounds and indicate on the screen graphic where s/he perceived the second sound. Subjects were required to randomly play the set of 39 stimuli for 5 repetitions, for a total of 195 trials.

Chapter 4

Results

In total, 17 females and 13 males, ages ranging from 20 to 63 years (*M*=28.8; *SD*=11.31), completed this study. Each participant demonstrated normal hearing as defined in the methods section of this paper and did not report any physical or mental deficit which would inhibit the use of a computer mouse. Data were converted from raw scores to absolute values for analysis. For each experiment, a two-way repeated-measures Analysis of Variance (ANOVA) was conducted to observe the effects and interactions between the variable levels. Except for stimulus type, the sphericity assumption was violated for all variables, and Huynh-Feldt adjustments to the degrees of freedom were used as a result. Table 1 lists the independent variables analyzed for each experiment. Paired samples t-tests were performed to compare if there were significant differences between experiment levels.

Table 1

Factors and levels across experiments.

Experiment	Factors	Factor Levels
1	stimulus type	muzzle blast
	azimuth	-60°, -40°, -20°, 0°, +20°, +40°, +60°
2	stimulus type	ballistic crack
	azimuth	-60°, -40°, -20°, 0°, +20°, +40°, +60°
3	amplitude	-12, -6, 0, 6, 12, 18 dB
	azimuth	-60°, -40°, -20°, -0°, +0°, +20°, +40°, +60°
4	timing	10, 20, 40, 80, 160, 320 ms
	azimuth	-60°, -40°, -20°, -0°, +0°, +20°, +40°, +60°
5	distance	64, 128, 256 meters
	azimuth	-60°, -50°, -40°, -30°, -20°, -10°, -0°, +0°, +10°, +20°, +30°, +40°, +50°, +60°

Note. The positive and negative values assigned to 0° refer to the associated ballistic crack reference; i.e. data from the 0° position was measured twice, once with a +60° reference & again with a -60° reference.

Statistics

In an attempt to understand the driving effect within small arms fire localization, measurements of listener errors were obtained for this study. These measurements were the difference between the participant's perception of the angle of the sound source and the actual location of the gunshot's origin. Localization errors were calculated as the absolute value, in degrees, of the difference measurement. Statistical analysis of the data was performed using IBM SPSS Statistics 21 software and is described in Table 2. Descriptive statistics were completed to observe trends in the information about listener localization performance. The statistical significance for each experiment was determined by the chosen alpha level of $p<.05$. A Bonferroni correction was applied as needed for post-hoc testing to control for the family wise error rate. Results of statistical analysis are grouped based on the experiment variables.

Table 2

Statistical Tests by Experiment

Experiment	Statistical Test	Effect Measured
1 and 2	Two-Way Repeated Measures (ANOVA)	stimulus type, azimuth
3	Two-Way Repeated Measures (ANOVA)	amplitude, azimuth
4	Two-Way Repeated Measures (ANOVA)	timing, azimuth
5	Two-Way Repeated Measures (ANOVA)	distance, azimuth

Note. Data between experiments 1 and 2 were collapsed to determine the effect of stimulus type on listener performance.

Azimuth

There were significant main effects of azimuth on listener performance across all experiments (Experiments 1 and 2: $F(3.54, 517.28) = 30.7$, $p < .001$; Experiment 3: $F(4.39, 601.03) = 222.77$, $p < .001$; Experiment 4: $F(3.72, 516.76) = 198.2$, $p < .001$; Experiment 5: $F(8.23, 1193) = 115.5$, $p < .001$.) Overall, no significant differences existed between symmetric angles for experiments 1, 2, 3, and 5 mostly at $p = 1.0$. This also holds true for the majority of experiment 4 with the exception of azimuths ±0 and ±40; please refer to Appendix Table 6 for specific p-values. Similarly, almost universally, there were significant differences for all other (non-symmetric) angles for experiments 1, 2, 3, 4, and 5, mostly $p<.001$; see Appendix Tables 4, 5, 6, and 7 for detailed p-values. Within experiment 5, certain areas of non-significance occurred at the central azimuths (i.e., +0°, -0°, +10°, -10°) and the extreme azimuths (i.e., +50°, -50°, +60°, -60°). All angles within these zones were not significantly different from each other but were significantly different than all other angles, typically at $p<.001$. As shown by the mean scores in Table 3, localization errors generally decreased as the stimulus moved away from midline or the 0° position. Similarly, Figure 6 demonstrates a universal trend of reduced localization errors at the extreme angles versus midline.

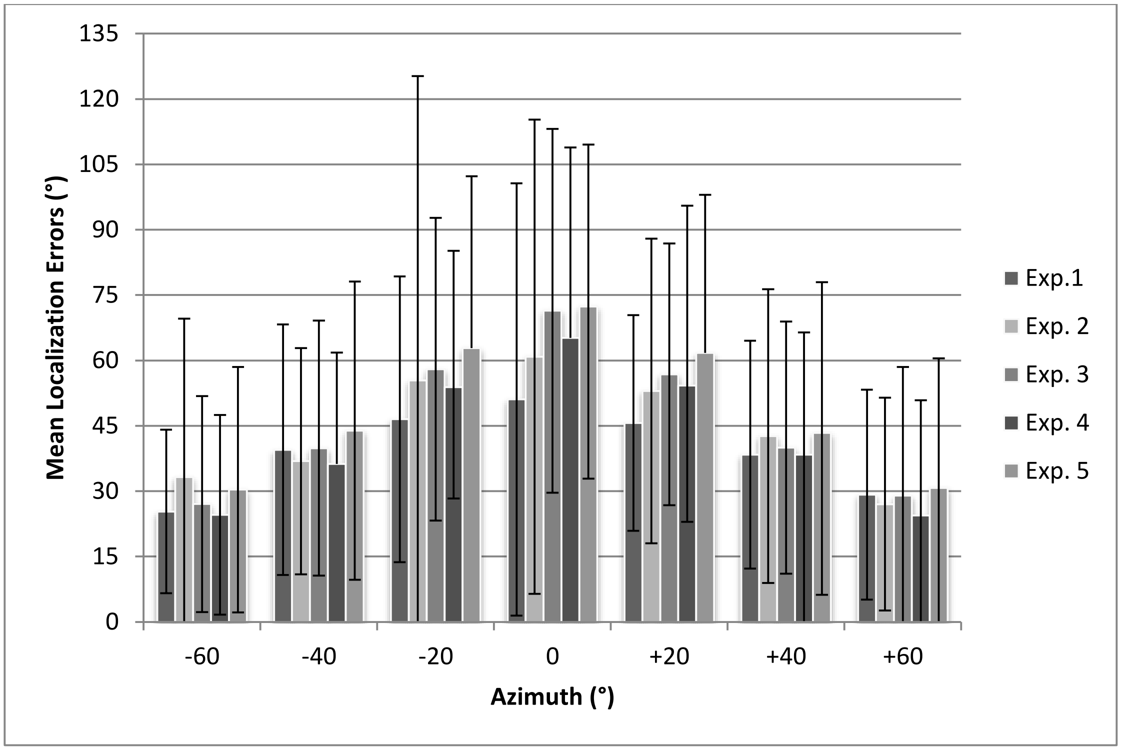

Figure 6. Graph showing mean localization errors across all experiments separated out by location of gunshot origin. Error bars mark one standard deviation.

Table 3

Mean Error Scores Based on Azimuth

	-60		-40		-20		-0		+0		+20		+40		+60	
Experiment	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
1	25.33	(18.77)	39.5	(28.76)	46.51	(32.78)	--	--	51.08	(49.61)	45.67	(24.75)	38.38	(26.16)	29.21	(24.11)
2	33.23	(36.33)	36.88	(25.99)	55.41	(69.86)	--	--	60.84	(54.42)	52.97	(34.95)	42.65	(33.70)	27.03	(24.43)
3	27.05	(24.79)	39.88	(29.26)	57.99	(34.75)	68.11	(41.18)	71.4	(41.75)	56.82	(30.07)	39.99	(28.93)	29.01	(29.51)
4	24.57	(22.89)	36.24	(25.57)	53.91	(31.29)	61.24	(43.69)	65.18	(41.25)	54.28	(28.03)	38.37	(26.49)	24.41	(21.08)
5	30.35	(28.19)	43.9	(34.20)	62.82	(39.47)	70.07	(37.25)	72.36	(37.19)	61.77	(36.27)	43.4	(34.58)	30.76	(29.73)

Note. The positive and negative values assigned to 0° refer to the associated ballistic crack reference; i.e. data from 0° was measured with both a +60° and a -60° reference. Since no reference sound existed for experiments 1 and 2, data from the 0° position was only measured once.

Stimulus Type

The results of a two-way repeated measures ANOVA on the collapsed data from experiments 1 and 2 revealed a significant effect of stimulus type on listener performance (F (1, 146) = 6.34, p = .013). As seen in figure 7, with the exception of azimuths -40 and +60, the mean absolute errors for the muzzle blast sounds were better than when compared to the ballistic crack sounds.

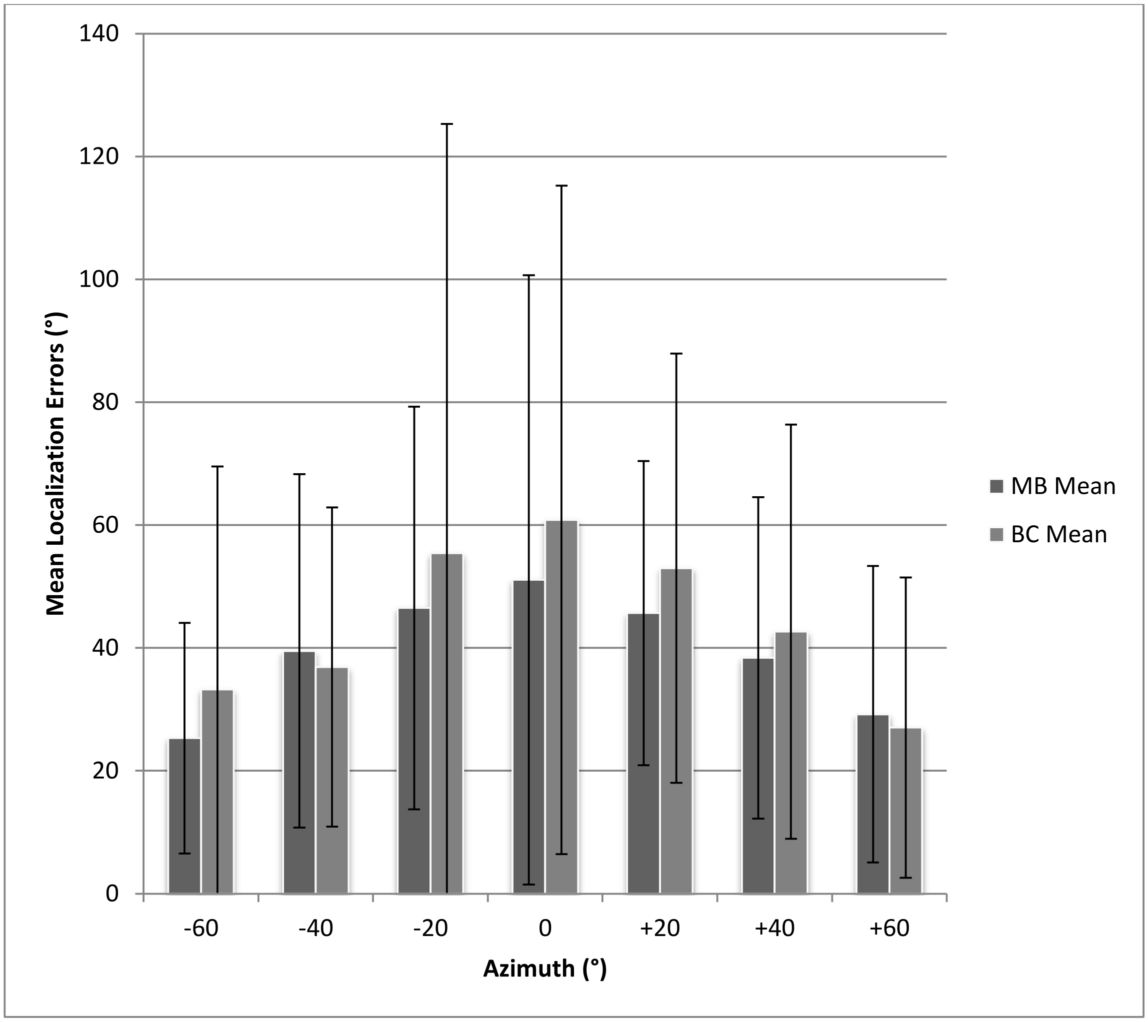

Figure 7. Graph showing the average of listener localization errors when presented with either a muzzle blast or ballistic crack sound at various azimuths. One standard deviation is represented by each of the error bars.

Amplitude

Results of statistical analysis showed a significant effect of amplitude on localization errors, $F(4.44, 973.77) = 4.98$, $p < .001$. Post-hoc testing indicated that the amplitude difference of -6 dB was significantly different than the amplitude differences of 6 dB ($p = .022$), 12 dB ($p = .046$), and 18 dB ($p = .022$). These differences are highlighted in Figure 8.

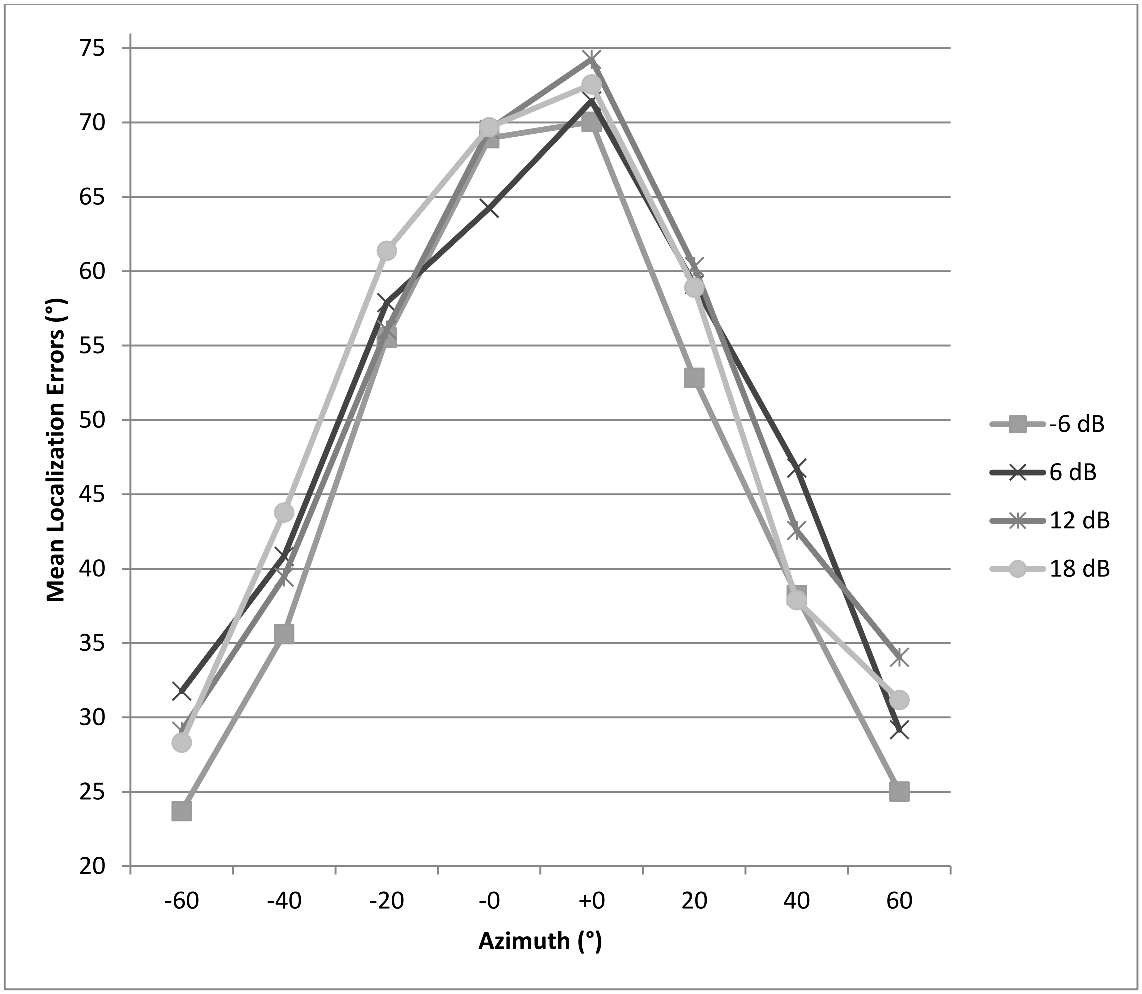

Figure 8. Graphical representation of the averages of listener localization errors at various azimuths based on the amplitude differences between the muzzle blast and ballistic crack stimuli. Only the amplitudes which are significantly different from one another are shown.

Timing

No significant effect was found for timing differences on listener localization errors, F (4.53, 630.25) = 2.18, p = .061. However, results from statistical analysis showed a significant interaction between timing and azimuth, F (25.21, 3504.52) = 1.68, p = .018. Figure 9 highlights this interaction, as there is no observable pattern between the error scores and timing differences; the main effect was not the same across the timing difference levels at angles -20°, +20°, -0°, and +0°.

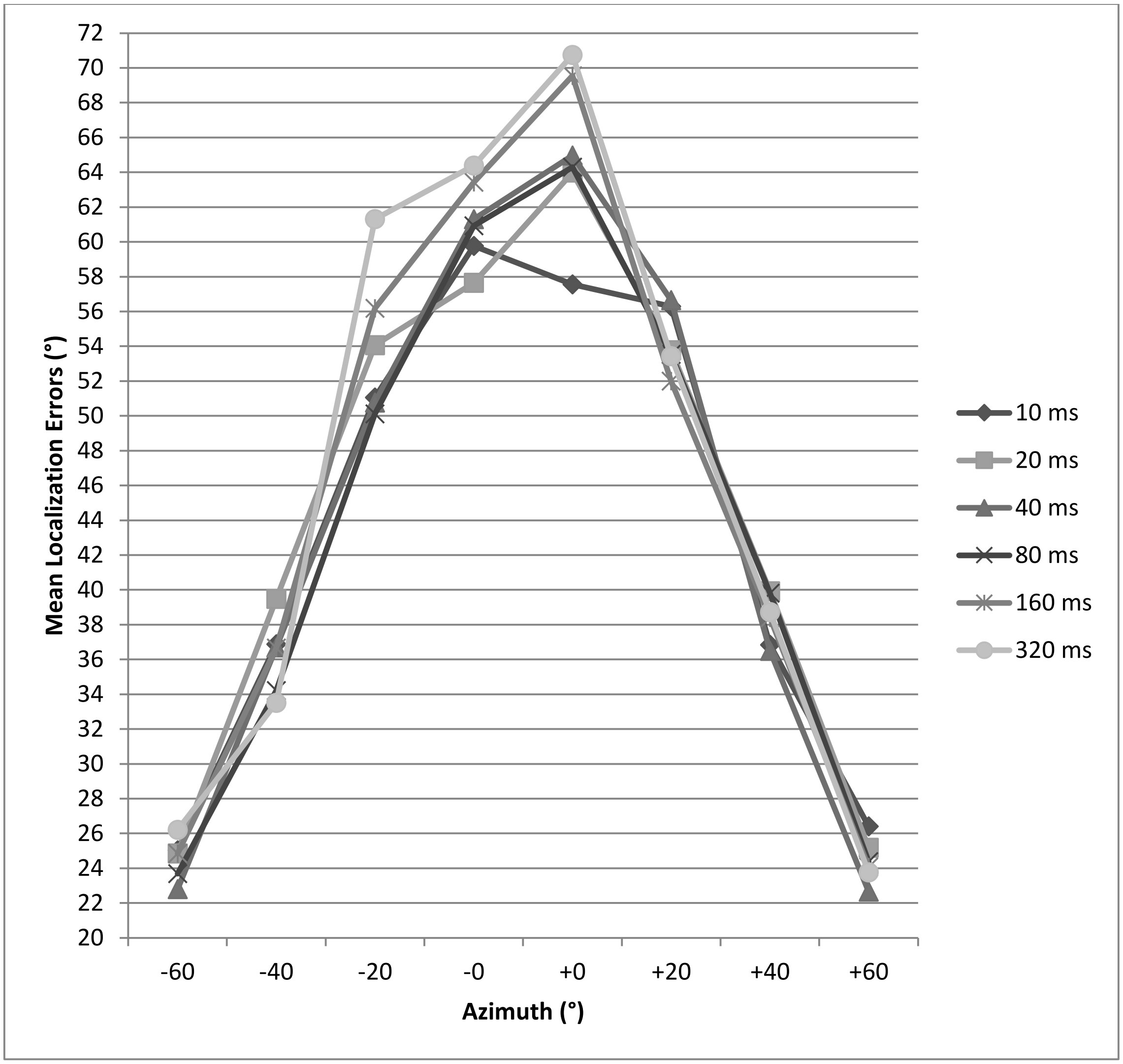

Figure 9. Graphical depiction of localization errors at 8 azimuths as a function of 6 timing differences between MB & BC stimuli.

Distance

A significant main effect was found for the effect of distance on localization errors, $F(1.65, 238.87) = 48.75$, $p < .001$. Each difference was shown to be significantly different than all other distances ($p < .001$). While Figure 10 shows a general trend of reduced localization errors at shorter distances, as well as at angles farther from midline, results from a two-way repeated measures ANOVA revealed the occurrence of a significant interaction between distance and azimuth, $F(23.38, 3390.52) = 1.58$, $p = .037$. As shown in Figure 10, the main effect was not the same across all levels of distance; at +50° and +60°, the pattern of optimal localization at the closest distance (i.e. 64 m) did not hold true.

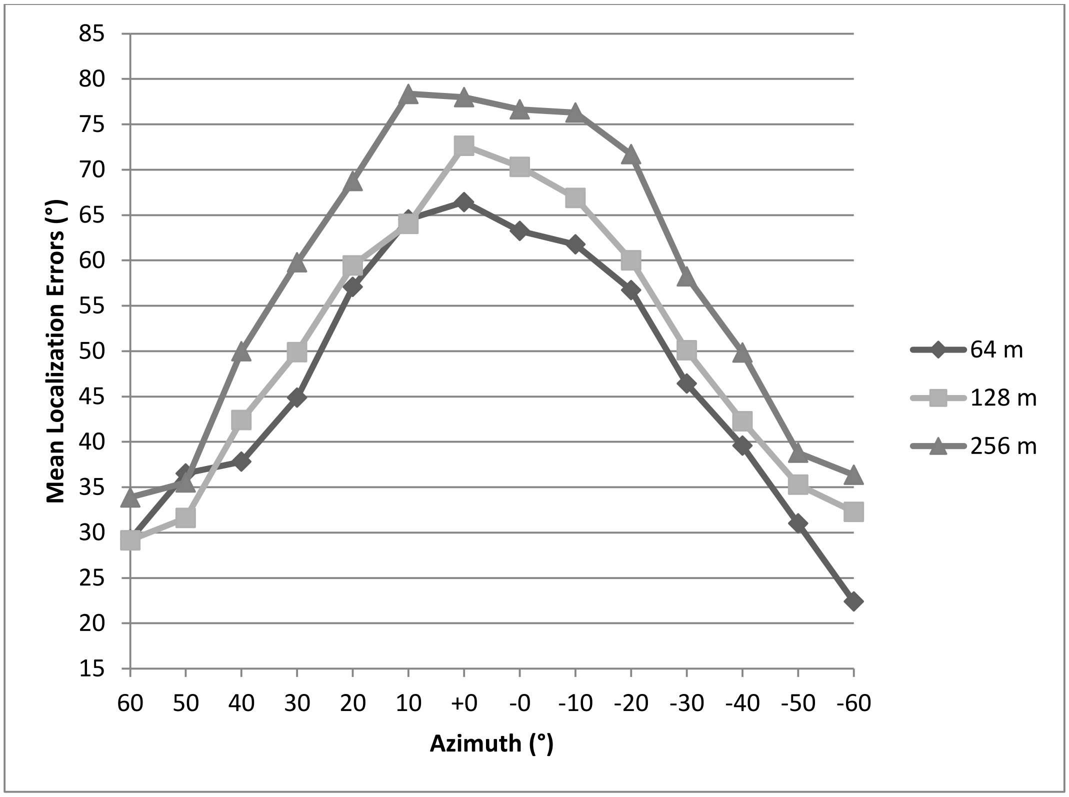

Figure 10. Graphical representation of localization errors at various azimuths as a function of three distances.

Chapter 5

Discussion

Sound localization is the complex ability to perceive the location of sound sources within an environment using multiple cues (Wightman & Kistler, 1992). This skill is particularly crucial for individuals whose lives depend on a rapid understanding of the placement of objects and people around them, such as police officers or active-duty military personnel. Effective sound localization skills can aid a person in situational awareness, and may assist in identifying the location of hostile activity, determining the physical aspects of an environment, and/or navigating through space (Fluitt et al., 2010; Scharine et al., 2009).

By manipulating certain acoustic properties, the present study attempted to specify which aspect of a gunfire event provided the most salient cue for sound localization. These acoustic properties included the separation of muzzle blast (MB) and ballistic crack (BC) components, as well as variations between the onset times and amplitude differences of the two sounds. Across all experiments, the effect of azimuth changes on the localization errors scores of listeners was tested. Lastly, the amplitude and timing differences between the MB and BC of small arms fire as a function of shooter/observer relationships were explored.

Azimuth

This study found that azimuth was an important factor in the overall errors of localization tasks. The participants of this study generally performed better when the stimulus sound was presented at extreme angles rather than at the midline. These results are consistent with the findings of Feddersen et al. (1957) but were not expected based on other previous literature.

Typically, research has shown improved localization performance with stimuli presentations towards the listener's midline rather than more lateral and/or rear presentations (Kuhnle et al., 2012; Makous & Middlebrooks, 1990; Smith, Lombard, & Shaba, 2012; Wightman & Kistler, 1992). It is possible the previous studies produced differing results from the present one due to variations in stimuli and procedure. For instance, none of the previously mentioned studies used gunfire sound recordings as their stimulus; either Gaussian noise bursts or broadband noises were utilized. In several of the studies, practice sessions were executed to familiarize a subject with the procedure and encourage stable performance (Kuhnle et al., 2012; Makous & Middlebrooks, 1990; Wightman & Kistler, 1992). Although participants of this study were given the option to complete practice trials, each participant declined and chose instead to skip straight to the experimental conditions. Kuhnle et al. (2012), Makous & Middlebrooks (1990), and Smith et al. (2012), presented stimuli via loudspeakers as opposed to the headphones used in this study. They employed the use of either laser pointers (Kuhnle et al., 2012; Makous and Middlebrooks, 1990; Smith et al., 2012) and/or head movements (Makous and Middlebrooks, 1990; Smith et al., 2012) to indicate the perceived location of a sound source. The participants of this study were not given the option to use head turns or upper body rotations in an effort to change the auditory spatial cues. Lastly, Wightman and Kistler (1992) estimated individualized Head-Related Transfer Functions for each participant, while this study used a generic HRTF measured on a KEMAR acoustic test fixture.

Stimulus Type

The findings of this study show the type of stimulus, i.e. the MB sound or the BC sound, impacted overall localization errors. Localization responses for the MB sounds were more precise than estimates of the location of BC sounds. This may be due to the energy present in the signal, as well as the duration of the stimuli.

As the MB propagates outward in all directions and the BC progresses in a conical shape, the location of the listener in relation to the sound source influences the perception of the gunfire (Gaston & Letowski, 2012; Maher, 2006). An observer will detect more energy in a MB sound compared to a BC sound because the MB travels in essentially a straight line toward the observer (Maher, 2006). The MB will be easier to detect from a variety of positions around the shooter whereas the BC is only perceived if the listener is within the path of the conical shockwave.

As impulse noises, both the MB and BC have sharp initial rise times but the duration of each signal is different. Both the duration of the MB (3-5 ms) and the BC (200-300 microseconds) can be considered brief sounds; however, the MB has a longer duration and therefore more total acoustic energy. The greater energy present in a MB signal, as well as the longer duration, suggests that the MB sound would be easier to localize than the BC component. For these reasons, the present findings (i.e. fewer localization errors to MB stimuli compared to BC stimuli) are expected, and reasonable.

Amplitude

Amplitude differences between the BC and the MB across a range of modeled shooter-observer relationships appeared to impact performance on localization tasks. This effect can be explained by temporal masking, specifically forward masking. When two stimuli are presented consecutively with no overlap in time, the first component can mask the second for intervals as long as about 200 ms (Gelfand, 2004). For this study, the difference between the onset of the BC and the onset of the MB was 160 ms. It is plausible that the MB sound was masked by the presentation of the BC. When the MB component was more intense relative to the BC signal, the BC was not as effective in masking the MB; therefore, localization errors were reduced.

Timing

Based on the results of this study, the manipulation of timing differences between the onset of the BC and the onset of the MB components neither increased nor decreased localization errors. One possible explanation may be that the participants relied more heavily on other variables, such as amplitude or distance.

Distance

Participants of this study performed better when stimuli were presented at shorter distances rather than longer ones. This suggests that stimuli presented at closer ranges may be easier to perceive than stimuli presented at further distances. These results are in line with the understanding that the location of the observer relative to the shooter affects the perception of gunfire (Gaston & Letowski, 2012). However, as the distance between the listener and the sound source increases, the amount of direct energy from the signal decreases. Kim et al. (2001) found that distance can be accurately perceived for a measurement of about 1.5 m. They concluded that a distance larger than 1.5 m leads to saturation in the ability to perceive distance. The stimuli for this study were modeled for shooter/listener positions at 64 m, 128 m, and 256 m—all of which exceed 1.5 m. Therefore, it is unexpected that distance should affect localization performance.

Limitations and Future Research

Several limitations of the current study should be considered. First, the gunfire to which military personnel and police officers are exposed is rarely produced in isolation. The target stimuli which were created for these experiments only incorporated one type of weapon, and did not include elevation estimates; it would not naturally occur in a real acoustic environment. All of the stimuli were digitally manipulated and approximated real-world situations. Future research focusing on small arms fire localization of various weapons in conjunction with competing sound signals, background noise, and reverberant environments would build upon the knowledge base of how gunfire is localized. Similarly, future testing should observe the effect of elevation on localization errors.

Another consideration is that the subject pool for this study was not very diverse in terms of age and hearing acuity. The range of ages provided a limited scope of how a population would perform in localization tasks; all but 5 of the subjects tested were under the age of 30 years and no participant was younger than 20 years old. In order to gain a better understanding of how gunfire is perceived by the auditory system, a subject population that encompasses a larger range of ages should be considered. Though Kuhnle et al. (2012) demonstrated localization abilities reach maturity by the age of six years, research can be conducted to explore if age affects how gunfire is localized.

Additionally, all subjects demonstrated normal hearing. A hearing loss may impact the brain’s ability to perceive auditory spatial cues and therefore increase localization errors. Future testing should explore the effect of hearing loss on sound localization of small arms fire as gunfire is a common cause of noise-induced hearing loss (Moon, 2007). Effects of race, ethnicity, gender, and/or gunfire experience on localization performance were not evaluated for this study. However, these variables should be explored to see if localization skills are affected.

Lastly, though practice trials were offered, all of the participants opted to forgo training prior to testing. Training (familiarization), experience, and contextual information can affect the perception of a signal (Fluitt, Gaston, Karna, & Letowski, 2010). Though each participant seemed capable and aware of how to perform the experiments, it is possible that with the completion of practice sessions, the localization errors may have decreased or become less variable. Future research should investigate the effects of practice on localization tasks.

Conclusion

Sound localization is a complex ability which can have a profound impact on the safety and situational awareness of soldiers and individuals exposed to gunfire. The current evidence suggests that small arms fire localization errors improve as azimuths increase away from the line-of-fire. Individuals within this study localized more accurately to muzzle blast sounds than to ballistic crack signals. While shorter distances and larger amplitude differences also affected localization errors, timing differences did not influence overall localization performance. Further research is necessary to include all of the complex variables associated with small arms fire localization. A better understanding of how the human auditory system localizes small arms fire may lead to advanced communication systems and/or training programs that could improve situational awareness for individuals who are exposed to gunfire.

Appendix A

Table 4

Pairwise Comparisons of Azimuth for Experiments 1 and 2

	0+	20	-20	40	-40	60	-60
0+		p=1.0	p=1.0	**p=.001**	**p<.001**	**p<.001**	**p<.001**
20	p=.81		p=1.0	**p=.001**	**p<.001**	**p<.001**	**p<.001**
-20	p=1.0	p=1.0		**p=.029**	**p=.001**	**p<.001**	**p<.001**
40	**p<.001**	**p=.001**	**p=.029**		p=1.0	**p<.001**	**p<.001**
-40	**p<.001**	**p<.001**	**p=.001**	p=1.0		**p<.001**	**p<.001**
60	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**		p=1.0
-60	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	p=1.0	

Note. All significant findings are in bold print.

Table 5

Pairwise Comparisons of Azimuth for Experiment 3

	0+	0-	20	-20	40	-40	60	-60
0+		p =.618	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**
0-	p =.618		**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**
20	**p<.001**	**p<.001**		p =1.0	**p<.001**	**p<.001**	**p<.001**	**p<.001**
-20	**p<.001**	**p<.001**	p =1.0		**p<.001**	**p<.001**	**p<.001**	**p<.001**
40	**p<.001**	**p<.001**	**p<.001**	**p<.001**		p =1.0	**p<.001**	**p<.001**
-40	**p<.001**	**p<.001**	**p<.001**	**p<.001**	p =1.0		**p<.001**	**p<.001**
60	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**		p =1.0
-60	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	p =1.0	

Note. All significant findings are in bold print.

Table 6

Pairwise Comparisons of Azimuth for Experiment 4

	0+	0-	20	-20	40	-40	60	-60
0+		**p=.021**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**
0-	**p=.021**		**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**
20	**p<.001**	**p<.001**		p=.77	**p<.001**	**p<.002**	**p<.003**	**p<.004**
-20	**p<.001**	**p<.001**	p=.77		**p<.001**	**p<.001**	**p<.001**	**p<.001**
40	**p<.001**	**p<.001**	**p<.001**	**p<.001**		**p=.032**	**p<.001**	**p<.001**
-40	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p=.032**		**p<.001**	**p<.001**
60	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**		p=.882
-60	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	p=.882	

Note. All significant findings are in bold print.

Table 7

Pairwise Comparisons of Azimuths in Experiment 5

	0+	0-	10	-10	20	-20	30	-30	40	-40	50	-50	60	-60
0+		p=1.0	p=1.0	p=1.0	**p<.001**	**p=.006**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**
0-	p=1.0		p=1.0	p=1.0	**p=.019**	p=.103	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**
10	p=1.0	p=1.0		p=1.0	**p=.011**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**
-10	**p<.001**	p=1.0	p=1.0		p=.068	p=0.465	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**
20	**p<.001**	**p=.019**	**p=.011**	p=.068		p=1.0	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**
-20	**p=.006**	p=.103	p=.332	p=.465	p=1.0		**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**
30	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**		p=1.0	**p<.001**	**p=.003**	**p<.001**	**p<.001**	**p<.001**	**p<.001**
-30	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	p=1.0		**p=.005**	**p=.007**	**p<.001**	**p<.001**	**p<.001**	**p<.001**
40	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p=.005**		p=1.0	**p<.001**	**p=.001**	**p<.001**	**p<.001**
-40	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p=.003**	**p=.007**	p=1.0		**p<.001**	**p<.001**	**p<.001**	**p<.001**
50	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**		p=1.0	p=1.0	p=1.0
-50	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p=.001**	**p<.001**	p=1.0		p=1.0	p=.238
60	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	p=1.0	p=1.0		p=1.0
-60	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	**p<.001**	p=1.0	p=.238	p=1.0	

Note. All significant findings are in bold print

Appendix B

TOWSON UNIVERSITY

APPROVAL NUMBER: 14-A042

To: Tyler Raup
8000 York Road
Towson MD 21252

From: Institutional Review Board for the Proctection of Human Subjects Stacy Spaulding, Member

Date: Wednesday, November 13, 2013

RE: Application for Approval of Research Involving the Use of Human Participants

Office of Sponsored Programs
& Research

Towson University
8000 York Road
Towson, MD 21252-0001

t. 410 704-2236
f. 410 704-4494

Thank you for submitting an Application for Approval of Research Involving the Use of Human Participants to the Institutional Review Board for the Protection of Human Participants (IRB) at Towson University. The IRB hereby approves your proposal titled:

Listener Accuracy in the Localization of Small Arms Fire: The Effect of Changes in Amplitude and Timing Differences

If you should encounter any new risks, reactions, or injuries while conducting your research, please notify the IRB. Should your research extend beyond one year in duration, or should there be substantive changes in your research protocol, you will need to submit another application for approval at that time.
We wish you every success in your research project. If you have any questions, please call me at (410) 704-2236.

CC: S. Nagle
File

TOWSON UNIVERSITY

Date: Wednesday, November 13, 2013

NOTICE OF APPROVAL

TO: Tyler Raup **DEPT:** ASLD

PROJECT TITLE: *Listener Accuracy in the Localization of Small Arms Fire: The Effect of Changes in Amplitude and Timing Differences*

SPONSORING AGENCY:

APPROVAL NUMBER: 14-A042

The Institutional Review Board for the Protection of Human Participants has approved the project described above. Approval was based on the descriptive material and procedures you submitted for review. Should any changes be made in your procedures, or if you should encounter any new risks, reactions, injuries, or deaths of persons as participants, you must notify the Board.

A consent form: [✓] is [ ] is not required of each participant

Assent: [ ] is [✓] is not required of each participant

This protocol was first approved on: 2013-11-13

This research will be reviewed every year from the date of first approval.

[signature], MPA (for)

Stacy Spaulding, Member

TOWSON UNIVERSITY

RENEWED APPROVAL NUMBER: 14-A042R1

To: Jillian Schmidt

From: Institutional Review Board for the Protection of Human Subjects, Stacy Spaulding, Member

Date: Saturday, November 08, 2014

RE: Application for Approval of Research Involving the Use of Human Participants

Office of Sponsored Programs
& Research

Towson University
8000 York Road
Towson, MD 21252-0001

t. 410 704-2236
f. 410 704-4494

Thank you for completing the Annual Review Notice for Projects Involving Human Participants for the project titled:

Listener Accuracy in the Localization of Small Arms Fire: The Effect of Changes in Amplitude and Timing Differences

Since you have indicated that your research project is still active, we are granting you a renewal of your approval. If you should encounter any new risks, reactions, or injuries while conducting your research, please notify the IRB. Should there be substantive changes in your research protocol, you will need to submit another application for approval at that time. This protocol will be reviewed again one year from this date of approval.

We wish you every success in your research project. If you have any questions, please call me at (410) 704-2236.

CC: S. Nagle
File

Appendix C

TOWSON UNIVERSITY

Consent Form for Participation in a Research Project

Principal Investigator: Jillian Schmidt

Study Title: Listener Accuracy in the Localization of Small Arms Fire: The Effect of Changes in Amplitude and Timing Differences

1. Invitation to Participate
   You are invited to participate in a study on localization abilities by Jillian Schmidt, graduate student at Towson University. Please take the time to read the following information before agreeing to be in the research study. Feel free to ask any questions before making an agreement.

2. Purpose
   The purpose of this study is to determine the extent to which localization of small arms gun fire is affected by changes in amplitude and timing differences of the gunshot acoustics.

3. Description of Procedures
   Participation in this study requires listening to small arms gunfire. You will be asked to listen to the sound sample, and then locate the approximate location of the gunshot on a computer screen. The study will include adult individuals with normal hearing. A hearing test must first be conducted to determine if your hearing is within normal limits. You may be excluded from the study if you have a hearing loss above normal limits or if any medical contraindications are present (i.e. ear infections). If we discover a hearing loss, we will let you know, and provide information about how to get your hearing more fully tested. During the duration of testing, you will only need to sit quietly while wearing headphones and listen to the simulated gunfire. Testing will last approximately 1-2 hours, and breaks will be provided if you need them. All testing will be conducted at Towson University.

4. Risks and Inconveniences
   It is our belief that there is minimal risk to you as a result of participation in this study. Other than fatigue or boredom, no pain or discomfort is associated with the task. All headphones are cleaned between users.

5. Benefits

Participation in this study will give you information regarding your own localization abilities. It will also aid in providing information to researchers in the armed services regarding soldier safety in the battlefield.

6. Economic Considerations
   You will not be charged or compensated for participation in this study.

7. Confidentiality
   All records from this study will be kept private from individuals unassociated with the study, and will be kept in a locked room for three years. No personal information will ever be revealed if/when the study is presented or published.

8. Voluntary Participation
   You are participating in this study by choice, and are in no way forced into participation. You are able to drop out of the study at any time, should you so choose, without any penalties or consequences. Your decision to participate or not participate will have no effect on your patient or student status at Towson University.

9. Questions?
   Please take as long as you need to make a decision regarding participation. I am happy to answer any questions you may have. If you have further questions or concerns about this study, you may contact the principal investigator at the following information: Jillian Schmidt, jschmi21@students.towson.edu. The faculty advisor, Dr. Stephanie Nagle, may be reached at (410)704-3920. If you have any questions concerning your rights as a participant in this research study, please contact Dr. Debi Gartland, Chairperson of the Towson University Institutional Review Board (IRB) at (410)704-2236 or by email at irb@towson.edu.

Authorization

I have read this form and decided that I, ________________________________ will participate in the project described above. Its general purposes, the particulars of involvement and possible hazards and inconveniences have been explained to my satisfaction.

Signature:_______________________________________

Date: ____

Signature of Student Investigator:_____________________________

Signature of Faculty Sponsor_________________________________

Phone:______________

THIS PROJECT HAS BEEN REVIEWED BY THE INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN PARTICIPANTS AT TOWSON UNIVERSITY.

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