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AUDITORY LOCALIZATION OF STEADY STATE AND IMPULSE SOUNDS IN AN URBAN RELEVANT, REVERBERANT ENVIRONMENT

by

Sara K. Bernhard

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THESIS APPROVAL PAGE

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Jennifer L. Smart, Ph.D. Chair, Thesis Committee	4/28/2014 Date
Jeremy Gaston, Ph.D. Committee Member	4-28-14 Date
Paula Henry, Ph.D. Committee Member	4-28-14 Date
Stephen Pallett, Au.D. Committee Member	4-28-14 Date
Janet V DeLany Dean Graduate Studies	May 2, 2014

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ABSTRACT

Auditory Localization of Steady State and Impulse Sounds in an Urban Relevant, Reverberant Environment

Sara K. Bernhard

Auditory localization has been extensively studied in a free field environment but it is less understood in a complex, reverberant environment. Auditory localization abilities were assessed for 24 normal hearing participants aged 18 to 30 years. All participants took part in a source identification task that was conducted using a lap top computer and insert earphones. Participants were asked to identify which of the four sound source locations a stimulus was presented. This task was completed using two different noise stimuli (impulse, steady state) and five different manikin positions. Results revealed that the sound source location and manikin position significantly impacted localization performance in a reverberant environment. For example, manikin positions and sound source locations located next to two reverberant sources resulted in a decline in localization abilities. Although the type of stimulus did not affect performance overall, stimulus type did impact localization performance at different manikin position and sound source location combinations. This study provides additional information regarding auditory localization in a complex, reverberant environment.

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KEY TO ABBREVIATIONS

APG: Aberdeen Proving Grounds

ARL: Army Research Laboratory

ATF: Acoustic Test Fixture

BRIR: Binaural Room Impulse Response

BRTF: Binaural Room Transfer Function

dB: Decibel

dB HL: Decibel Hearing Level

dB SPL: Decibel Sound Pressure Level

dB P: Decibel Peak

FFT: Fast Fourier Theorem

GUI: Graphical User Interface

HALL: Hearing and Listening Lab

HRTF: Head Related Transfer Functions

Hz: Hertz

IID: Interaural Intensity Differences

ILD: Interaural Level Differences

IPD: Interaural Phase Differences

ITD: Interaural Timing Differences

KEMAR: Knowles Electronics Manikin for Acoustic Research

MD: Maryland

ms: Milliseconds

PINS: Pneumatic Impulse Noise Source

SSTF: Solider System Test Facility

Chapter 1: Introduction

Auditory localization is defined as the ability to identify the location of a sound (Moore 2012; Yost, 2000). Auditory localization is accomplished through the integration of information obtained by the auditory system as well as other sensory systems (Moore, 2012). When localizing a stimulus using the auditory system, there are several cues that assist in determining the direction of a sound. The cues vary according to the planes located around the subject's head. In the horizontal plane, binaural cues are dominant, which include interaural timing differences and interaural level differences (Rayleigh, 1907). Binaural cues vary depending on the frequency of the stimulus with timing differences being most useful for the lower frequencies (<1500 Hz) and level differences being most useful for the higher frequencies (>3000 Hz). In the vertical plane, monaural spectral cues, produced by the filtering capabilities of the pinna, are dominant (Yost, 2000). Although monaural spectral cues are dominant for vertical plane localization, they can also be beneficial for localizing sound in the horizontal plane.

In order to study the cues used to localize an auditory stimulus, auditory localization abilities may be examined through the presentation of sounds through loudspeakers within a sound-treated room or by presentation of spatialized sounds through earphones (Yost, 2000). The addition of head related transfer functions (HRTF), or binaural room transfer functions (BRTF) to auditory stimuli allows for the results of a headphone-based study to reflect the results of a room-based study (Faller & Merimaa, 2004; Wenzel et al., 1993).

In addition to binaural and spectral cues, there are characteristics of the auditory stimulus that also may assist a listener in identifying the location of a sound source.

These characteristics include the type of stimulus (impulsive versus continuous), onset and offset cues (short versus long), and the duration of the stimulus (short versus long). It has been reported in the literature that noise is easier to localize than pure tones (MacPherson & Middlebrooks, 2002; McFadden & Pasanen, 1976; Stevens & Newman, 1936), that brief stimulus onsets and offsets can assist in auditory localization (Boder & Goldman, 1941; Rakerd & Hartmann, 1986) and that longer duration stimuli may enhance localization accuracy if individual listeners are able to take advantage of head movements (Perrott et al., 1987; Rakerd & Hartmann, 1986).

Although there are several cues that can assist with localization, these cues may be negatively affected by the surrounding environment. In everyday environments there are surfaces that are reflective and cause reverberation. Reverberation can be defined as the reflection and absorption of a signal off surrounding obstacles (Ihlefeld & Shinn-Cunningham, 2011; Scharine & Letowski, 2005). In some cases, the presence of a small amount of reverberation can enhance localization performance by a phenomenon known as the precedence effect (e.g. Clifton, 1987; Gardner, 1973). However, in many cases the presence of reverberation smears the cues often used when localizing a sound. The smearing of these cues leads to mislocalization and can result in poor localization accuracy (Ihlefeld & Shinn-Cunningham, 2011; Rakerd & Hartmann, 1985; Scharine, Letowski, Mermagen, & Henry, 2010).

Several researchers have examined the effects of reverberation on localization abilities. The results of these studies do not provide a clear picture regarding localization in a difficult listening environment. Reverberation distorts the cues used for auditory localization and this may be seen as a problem when information from other sensory systems is not available. For example, soldiers in enemy territories may operate in urban environments where their visual systems are obstructed. In this scenario, the soldiers must rely on their auditory system to localize a sound. This may be difficult if the surrounding environment contains poor acoustics and multiple auditory signals. Researchers have investigated localization abilities in a reverberant environment for different types of stimuli and different listener locations. A further understanding of stimulus type and listener location is needed, so researchers can predict how soldiers may be affected in the urban environments that they operate.

Chapter 2: Review of the Literature

Definition of Auditory Localization

The ability to identify the location of a sound source is known as auditory localization. The identification of a sound source is a complex process performed primarily by the auditory system (Middlebrooks & Green, 1991; Moore, 2012). An auditory stimulus contains cues that assist the listener in determining the direction the stimulus originated. The cues embedded in the auditory stimulus assist the listener to localize in the different planes located around the head. The surrounding environment, however, may alter the cues that assist with auditory localization. The auditory system, along with other sensory systems, must integrate and process the available information in order to accurately localize the auditory stimulus (Middlebrooks & Green, 1991; Moore, 2012).

Significance of Binaural Cues in Auditory Localization

The theories behind the binaural cues used for auditory localization have evolved for at least one hundred years. Lord Rayleigh (1907) reported one of the first research studies on auditory localization. He proposed one of the dominant theories of auditory localization that is still discussed in a vast majority of the auditory localization publications today. The duplex theory states that localization is dominated by interaural timing differences (ITDs) for low frequency stimuli and interaural level differences (ILDs) for high frequency stimuli (Rayleigh, 1907). ITDs are defined as the timing differences between the ears and ILDs are defined as the intensity differences between the ears (Yost, 2000). The term ITD is often interchanged with the term interaural phase differences (IPDs), while ILD is often interchangeable with interaural intensity differences (IID) (Moore, 2012). For the purposes of this paper, ITDs and ILDs will be used to describe the interaural cues.

Rayleigh (1907) examined interaural differences in the horizontal plane. In the horizontal plane, the position of the sound source is referred to as azimuth (Middlebrooks & Green, 1991; Moore, 2012). For localization in the horizontal plane, the auditory system uses both binaural and monaural cues, however, binaural cues are dominant (Moore, 2012). In general, depending on the location of the sound source and the angle of the sound source, one ear will receive the sound earlier in time and higher in level and the opposite ear will receive it later in time and lower in level (Gelfand, 2010).

For his study, Rayleigh (1907) used pure tones produced by tuning forks in an open-air environment. He discovered that ITDs were the dominant cues utilized by most listeners for low frequencies, but these cues were only effective up to about 1500 Hz. For high frequencies, ILDs were the dominant cue used by listeners, but they were only effective above about 3000 Hz. With these discoveries, it appeared that there was a frequency range that did not utilize either of these cues. The inability to use interaural differences for the frequency range of 1500 to 3000 Hz resulted in poor localization accuracy for sound stimuli in this range. Rayleigh (1907) also found that there were a high degree of localization confusions when the source was located directly in front of or directly behind the listener; listeners often reversed the perceived location of the stimulus. For example, if a sound was coming from directly behind the listener, he or she perceived it as originating in front of them. These responses are known as front to back confusions or reversals (Rayleigh, 1907).

Following the proposal of the duplex theory, Stevens and Newman (1936) examined auditory localization abilities in a free-field environment. The subject was seated on the top of a building and a boom loudspeaker was rotated around the subject's head. The researchers used noise stimuli to measure the accuracy of localization judgments. Prior to data analysis, the researchers corrected for front to back reversals so that those large errors did not skew the results. The results supported those found by Rayleigh (1907) in that timing effects were dominant for low frequencies and intensity effects were dominant for high frequencies. Also, Stevens and Newman (1936) found that between about 2000 and 4000 Hz, localization abilities were poor due to a lack of valid interaural cues. Further, they found that localization accuracy changed as the sound source varied throughout the horizontal plane. Localization accuracy was best at 0 degrees (directly in front of the listener) and declined as the sound source moved towards 90 degrees (directly to the side of the listener). This finding held true for both low frequencies and high frequencies (Stevens & Newman, 1936).

There are several explanations that have been provided for the basic findings of these early localization studies. First, a basic finding is that ITDs are an important cue in the localization of low frequency stimuli. For locations other than 0 and 180 degrees, the sound will reach the ear closest to the sound source first followed by the opposite ear (Gelfand, 2010; Rayleigh, 1907). This creates a slight timing difference between the sounds arriving at the two ears. Although the timing difference is very small, the auditory system is capable of detecting this difference and using it as a localization cue. ITDs are useful for frequencies of up to about 1400 Hz. Above 1400 Hz, after the initial arrival of the sound to the two ears, subsequent differences in phase are not consistent, and thus do not lead to accurate localizations (Kuhn, 1977; MacPherson & Middlebrooks, 2002; Rayleigh, 1907; Sandel, Teas, Feddersen, & Jeffress, 1955; Trimble, 1928).

In contrast, ILDs are utilized when localizing high frequency stimuli. High frequencies (approximately > 1400 Hz) have short wavelengths, which are smaller than the diameter of the head, and thus are attenuated by a baffling or head shadowing effect of the head (Gelfand, 2010; Rayleigh, 1907). Low frequencies (approximately < 1400 Hz) have wavelengths that are greater than the diameter of the head, and thus are not appreciably attenuated by a head shadowing effect. Although the head shadowing effect begins to become apparent above 1400 Hz (Kuhn, 1977), in general, the head shadowing effect does not provide a strong cue until about 3000 Hz (Rayleigh, 1907; Sandel et al. 1955; Trimble, 1928).

Recently, MacPherson and Middlebrooks (2002) further investigated the above findings and examined the plausibility of the duplex theory using low-pass and high-pass noise bursts. These researchers were examining localization judgments over headphones. They were able to manipulate and control for individual stimulus properties; for example, time independent of intensity and vice versa. From these data, they were able to determine which cues tended to be weighted the most for different stimulus conditions (MacPherson & Middlebrooks, 2002).

MacPherson and Middlebrooks (2002) found that localization judgments in the low pass and high pass conditions were similar to the results of Rayleigh (1907) and the results of a number of other researchers (e.g. Sandel et al., 1955; Stevens & Newman, 1936). For the low pass condition, most listeners utilized ITDs to identify the direction of the sound and little weight was placed on ILDs. In contrast, for the high pass condition, listeners accurately located sounds using ILDs and placed little emphasis on ITDs. The results of MacPherson and Middlebrooks (2002) and other similar research studies provide further evidence that binaural cues are dominant in the horizontal plane (Kuhn, 1977; MacPherson & Middlebrooks, 2002; Rayleigh, 1907; Sandel et al., 1955; Stevens & Newman, 1936).

Significance of Monaural Cues in Auditory Localization

The theories behind the use of monaural cues apply mostly to differences in elevation. Elevation is defined as the place a sound is located in the vertical plane (Moore, 2012). Similar to the horizontal plane, both binaural cues and monaural cues are present to the listener in the vertical plane. Specifically, binaural cues are important for determining the “X” coordinates, while monaural cues are important for determining the “Y” coordinates of a sound source. One very important source of monaural cues is the spectral information produced by the pinna (Moore, 2012). The shape and folds of the pinna filter the incoming signal to provide directional cues to the listener. The filtering capabilities of the pinna are dependent on the frequency of the stimulus and are most pronounced in the higher frequencies (Moore, 2012).

A number of researchers have shown that the filtering capabilities of the pinna are an effective localization cue. These studies examined the effects of the pinna by altering or blocking the folds of the pinna. Gardner (1973) occluded the cavities of the pinna, while Fisher and Freedman (1968) covered the pinna with headphones, or a mold of someone else’s pinna. In these studies, listeners were asked to make localization judgments with their own pinna and again in the different, altered pinna conditions. In general, localization performance is better when listeners used their own pinna as opposed to the altered pinna (e.g. Fisher & Freedman, 1968; Gardner, 1973). Additionally, the role of the pinna has been examined in the frontal or median plane for monaural and binaural conditions. Gardner (1973) found that when one or both pinnae were occluded, auditory localization abilities declined. This is due to the filtering capabilities of the pinna being suppressed when the cavities of the pinna are occluded such that they do not provide additional localization cues.

Spectral cues are produced by a sound's interaction with the head, torso, and pinna, but there are several reasons why the pinna provides especially important localization cues. The pinna has a series of folds and convolutions that help filter the incoming signal to provide localization specific cues (Fisher & Freedman, 1968). The pinna acts as a shadow that alters the path of the sound reaching the ear. The pinna filters the different parts of complex stimuli differently and it delays and attenuates the different components depending on its interaction with the sound. The shadowing effect is dominant for the high frequencies because the wavelengths are similar to the size of the folds of the pinna (Moore, 2012).

The pinna alters the spectral content of the stimulus, which is seen as peaks and valleys in the spectrum of the stimulus. The peaks and valleys in the spectrum can be seen when recording a sound at the level of the eardrum and this process is known as head related transfer functions [HRTFs (Yost, 2000)]. The peaks and valleys in the signal represent changes in the spectral profile that vary based on the direction of the originating sound. It is these spectral changes that the auditory system uses as a localization cue

(Butler & Belenduik, 1977). These changes are ear specific and angle specific, which supports the ability to accurately localize sounds in monaural conditions (Yost, 2000).

In addition to localizing in monaural listening situations, the filtering capabilities of the pinna may help resolve front to back confusions. Recall that several researchers have shown that binaural cues are dominant cues in the horizontal plane. However, areas directly in front of or behind the listener as well as directly above or directly below the listener can produce large errors. This area is known as the cone of confusion (Moore, 2012; Yost, 2000). It is the cone around the ear where the interaural cues are the same for two locations (one in the front and one in the back) making binaural cues ineffective (Moore, 2012; Yost, 2000). Pinna cues can enhance binaural localization by helping to disambiguate front-back confusions (Moore, 2012) as was demonstrated by Gardner (1973). Recall that in that study, Gardner (1973) occluded the cavities of the pinnae to see its effect on localization abilities. Localization abilities declined when the pinnae were occluded in comparison to when the pinnae were not occluded. These results suggest that the filtering capabilities of the pinna provide an additional localization cue, which assists listeners when binaural cues are equivalent (Gardner, 1973).

In addition to pinna cues, head movements may also assist in resolving the front to back confusions. In an experiment by Perrott et al. (1987), brief pulsed tones and continuous tones were used to determine a subject's ability to accurately localize a sound source. Unlimited control of the head allowed the subject to move their head in any direction. The researchers found that the ability to move the head enhanced localization judgments (Perrott et al., 1987). The movement of the head changes the perceived location of the sound source. The perceived location of the sound source shifts because the head is no longer in the same position relative to the position of the sound source. Thus, the original area of confusion is no longer present. The movements of the head may help resolve front to back confusions (Moore, 2012; Yost, 2000).

Distance Perception

An area in the field of auditory research that receives less attention is auditory distance perception. Auditory distance perception can be defined as the ability to determine the distance a sound source is from the listener (Grantham, 1995; Moore, 2012). Similar to auditory localization, there are a number of cues a listener can use to determine the distance of a sound source. These cues include monaural cues, such as amplitude, frequency spectrum, and pinna effects, as well as binaural cues. Amplitude and frequency spectrum are two cues that receive a lot of attention in this field (Coleman, 1963). The amplitude of the signal is the amount of energy that reaches the listener. Amplitude of the signal decreases as the sound source location increases. This is due to the absorption and therefore attenuation of the signal through air and environmental materials (Coleman, 1963). For example, the greater the sound source is from the listener, the less intense the signal is perceived to be. The signal decreases by 6 dB as the distance doubles and this is known as the inverse square law (Coleman, 1963; Grantham, 1995; Moore, 2012).

Another important cue that can be used to judge the distance of a sound source is the spectral content of the signal (Coleman, 1963; Scharine & Letowski, 2005). There is some debate about the use of spectral information for distance perception. Changes in the frequency spectrum of a broadband signal can occur at distances exceeding 20-30 feet (Coleman, 1963). The changes in the spectral content are greatest for the high frequencies. Air and the environment absorb high frequencies with increases in distance resulting in sounds that are primarily low frequency in nature with greater distances (Coleman, 1963).

Researchers have indicated that distance perception may also be affected by the listeners' familiarity with the stimulus (Coleman, 1963; Grantham, 1995; Scharine & Letowski, 2005). If a stimulus is unfamiliar to a listener, the distance perception judgment is typically poor and highly variable. If a listener is familiar with a stimulus, the distance perception is more accurate and less variable (Coleman, 1963). In an everyday environment, the listener may have to incorporate the different localization and distance perception cues to accurately determine where the stimulus originated.

Localization versus Lateralization

The two main types of studies researchers use when examining auditory localization abilities are known as auditory localization and auditory lateralization (Middlebrooks & Green, 1991; Moore, 2012; Yost, 2000). These two types of studies use different methodologies and there is some debate as to whether the results from the two types of studies are comparable. In sound localization studies, the sound source is typically located in space around the listener and can be presented either over an array of loudspeakers or a rotating boom with a loudspeaker attached (e.g. Fisher & Freedman, 1968; Hartmann, 1983; Makous & Middlebrooks, 1990; Oldfield & Parker, 1984; Sandel et al., 1955; Stevens & Newman, 1936). The sound source varies in azimuth and elevation across studies, and loudspeakers are arranged in arcs or rows varying from 180 degrees (from directly in front to directly behind or from one side across the front to the other side) to 360 degrees (surrounding the listener). Additionally, the degree of separation between the sound sources varies across studies. Typically, the listener is seated at the center of the arc and instructed to identify the direction of the sound source (e.g. Fisher & Freedman, 1968; Hartmann, 1983; Oldfield & Parker, 1984; Stevens & Newman, 1936). To calculate the accuracy of the localization judgments, the difference in angle between the actual sound location and the perceived location is calculated to yield the angular localization error (e.g. Makous & Middlebrooks, 1990; Oldfield & Parker, 1984; Stevens & Newman, 1936).

In contrast, auditory lateralization studies are conducted through headphones where the perceived location of the sound source is within the subject's head (Grantham, 1995; Moore, 2012; Yost, 2000). The stimuli are perceived to fall somewhere along an imaginary line connecting both of the ears. The advantage of headphone-based studies is the ability to control aspects of the stimuli that the subject will hear. For example, researchers can manipulate the stimulus so that it is perceived to lateralize toward one ear by manipulating the binaural timing and intensity differences of the signal, such as was done by MacPherson and Middlebrooks (2002). In this way, the researcher can control where the signal lateralizes and thereby learn more about how different binaural difference cues contribute to auditory localization in general (Grantham, 1995).

There is some debate in the literature about the relationship between auditory localization and auditory lateralization studies. Researchers argue that these two types of studies differ and the results are not comparable (e.g. Grantham, 1995). Localization studies involve the identification of the direction of a sound source in that is located in space and in these cases, the sound source is likewise perceived as originating outside the head. In contrast, in lateralization studies, sounds are presented over headphones and the sound tends to be perceived as having occurred inside the head (Yost, 2000).

Although the perceived location of the auditory stimulus can vary between these two types of studies, headphone studies, which incorporate HRTFs, can cause the location of the auditory stimulus to be perceived outside the listener's head (Yost, 2000). Recall that HRTFs are based on the filtering characteristics of the ear. The original sound source is altered by these filtering characteristics, which changes the sound arriving to a listener. HRTFs are unique to each individual due to the listener's head, pinna, and torso shape (Faller & Merimaa, 2004; MacPherson & Middlebrooks, 2002; Wenzel et al., 1993; Wightman & Kistler, 1989). To record an HRTF, a microphone is placed in the ear canal and a sound is recorded at the level of the eardrum. The HRTF is then calculated as the spectral change in the sound between the sound source and the listener's ear (Wenzel et al., 1993).

Researchers have incorporated HRTFs into headphone-based studies to determine the relationship to localization studies. For example, Wenzel and colleagues (1993) had participants listen to noise stimuli in a free-field environment and then over headphones filtered by HRTFs to investigate the HRTFs effects on auditory localization abilities. Performance was measured with listeners using individualized HRTFs as well as using the HRTFs of other listeners. The researchers found that relatively accurate judgments could be made when listening to sounds filtered by other listeners' individualized HRTFs. However, the best performance occurred when the listener used his or her own HRTF. Additionally, performance in the free-field condition and the headphone condition was similar indicating that some lateralization studies (those that incorporate HRTFs) are comparable to localization studies (e.g. Wenzel et al., 1993; Yost, 2000). These findings indicate that the unique properties of the head, torso, and pinna enhance auditory localization judgments for that individual (Wenzel et al., 1993).

The addition of reverberation in headphone-based studies may also affect the perceived location of the sound source. Reflections and echoes are present in almost all real-world environments (Devore, Ihlefeld, Hancock, Shinn-Cunningham, & Delgutte, 2009; Guski, 1990; Ihlefeld & Shinn-Cunningham, 2011; Rakerd & Hartman, 1985). In headphone-based studies, however, the signal presented to the listener does not typically contain the same complexity as a signal in a real-world environment. In these scenarios, the researchers only have control over ITDs, ILDs, and some spectral characteristics (Yost, 2000). This means the effects of reverberation are often lost. The addition of reverberation increases the complexity of the stimulus and helps the listener to externalize the stimulus. Reflections and echoes may be included in headphone-based studies by recording HRTFs in a reverberant environment (Faller & Merimaa, 2004) sometimes referred to as binaural room transfer functions (BRTFs) or by imparting reverberation effects through a sound editing software package on a computer (Huang, Ohishu, & Sugie, 1997). Overall, the addition of HRTFs and reverberation in headphone-based studies allows these studies to mirror the results in localization studies and makes the stimuli most similar to what would be heard in real-world environments (Yost, 2000).

Stimulus Effects on Auditory Localization

The real-world environment contains many different types of sounds ranging from the very simple, like pure tones and chords, to the very complex, like speech. For this reason, a range of different stimuli has been investigated in auditory localization studies.

Each of these stimuli contains different acoustic characteristics that can be used by the listener when determining the direction that a sound originated. These characteristics, or cues, include the type of stimulus, onset and offset cues, and the length or duration of the stimulus. Each of these properties will be discussed further in the following sections.

Type of Stimuli. In auditory localization research, the effects of several types of stimuli on localization have been researched. As stated earlier, Rayleigh (1907) and Sandel and colleagues (1955) examined the accuracy of localization using pure tones, while MacPherson and Middlebrooks (2002) and McFadden and Pasanen (1976) examined the effects of noise bands. Pure tones have energy at a single frequency and narrow bands of noise have energy across a limited range of frequencies. Accuracy of auditory localization for these stimuli relies primarily on the availability of useful ITD and ILD cues (MacPherson & Middlebrooks, 2002; McFadden & Pasanen, 1976; Rayleigh, 1907; Sandel et al., 1955; Yost, 2000). In these cases, the duplex theory is plausible because the listener utilizes either the ITD or the ILD to determine the direction of the sound source. In a real-world environment, however, pure tones and narrow bands of noise are not frequent stimuli (McFadden & Pasanen, 1976). For this reason, a number of researchers have examined the effects of more ecologically valid complex wide band noise stimuli on auditory localization. An example of this work comes from MacPherson and Middlebrooks (2002) where they employed wide band noise stimuli with a frequency range between 500 and 16000 Hz. They found that both ITDs and ILDs were used relatively equally for the wideband noise. Overall, this work indicates that when both low and high frequencies are present in a stimulus, multiple binaural cues are integrated to make localization judgments (MacPherson & Middlebrooks, 2002).

The increase in the accuracy of localization using wideband noise stimuli suggests noise is easier to localize than pure tones (MacPherson & Middlebrooks, 2002; McFadden & Pasanen, 1976; Stevens & Newman, 1936). Researchers have offered several reasons for this finding. Noise contains information over a broad frequency range. Since there are multiple frequencies present, there are multiple and redundant localization cues available to the listener. These cues include ITDs below about 1400 Hz, ILDs above approximately 3000 Hz, and spectral cues above 4000 Hz. When available, the auditory system integrates these different cues to make relatively accurate localization judgments. In addition, the presence of multiple cues leads to fewer front to back confusions because there is more information present to resolve ambiguous cues (MacPherson & Middlebrooks, 2002; McFadden & Pasanen, 1976; Stevens & Newman, 1936). For complex stimuli, the integration of multiple cues makes these stimuli easier to localize.

Onset and Offset Cues. Another set of cues that may assist in auditory localization is onset and offset cues. An onset cue is the beginning or the start of the stimulus, while an offset cue is defined as the end of the stimulus (Rakerd & Hartmann, 1986). Several researchers have found that onset and offset cues are important for auditory localization accuracy (Boder & Goldman, 1941; Elfner & Tomsic, 1967; Perrott, 1968; Rakerd & Hartmann, 1986). For example, Boder and Goldman (1941) examined the efficacy of onset cues using a series of continuous tones and intermittent tones in indoor and outdoor environments. The researchers found that intermittent stimuli were localized more accurately in comparison to continuous stimuli, and this finding held true for both environments. The researchers offered two reasons for these findings. First, the intermittent tone provides abrupt and distinct onsets that cue the subject where the sound originates. Second, after the onset of the continuous tone, the stimulus provides no additional cues to where the sound is located and this makes it difficult to make an accurate localization judgment (Boder & Goldman, 1941).

Additional support for these findings comes from Rakerd and Hartmann (1986) who examined the effects of different onset cues in an indoor room. The rise time for their stimuli varied from 0 seconds, which is considered an impulse sound, to 5 seconds, which is considered a slow onset sound. The researchers found that sounds with a short, abrupt onset were localized with greater accuracy in comparison to longer onset sounds. In particular, onset rise times between 0 and 100 ms were localized with a high degree of accuracy. When the rise time of the stimulus increased above 100 ms, the stimulus provided a poor localization cue evidenced by the decline in accuracy of localization (Rakerd & Hartmann, 1986). In addition to onset cues, the researchers examined the effects of offset cues on localization as a function of the duration of the offset. For a continuous sound, they found that an abrupt offset may assist with auditory localization because the abrupt offset signals the subject to where the sound originated (Rakerd & Hartmann, 1986).

Duration of the Stimuli. Recall that the duration of a stimulus may help resolve the cone of confusion because it allows the subject to move their head and have multiple samples of the stimulus from different angles. Differences in stimulus duration can thereby affect the accuracy of the localization judgment (Boder & Goldman, 1941; Perrott et al., 1987; Rakerd & Hartmann, 1986). In a study of the effects of duration on localization ability, Perrott et al. (1987), found that localization accuracy for continuous pulsed tones was better in comparison to single pulsed stimuli because continuous tones allowed sufficient time for the listener to turn their head. In contrast, the shorter stimuli did not allow enough time for the listeners to move their heads and thus resulted in poorer localization abilities (Perrott et al., 1987).

In another study, Rakerd and Hartmann (1986) found somewhat different results from Perrott et al. (1987) and show that the benefit of head movements may largely depend on the individual. The researchers examined the effects of stimulus duration for pulsed tones ranging from 5 ms to 2 sec in length and found that there were a large number of individual differences in localization judgments as a function of duration. The researchers suggested that this largely had to do with the large individual differences in the use of head movements evidenced by listeners (Rakerd & Hartmann, 1986).

Reverberation

In most auditory localization research, a listener determines the direction of a sound in a sound-treated room. This type of environment allows the subject to utilize ITDs and ILDs, which are the dominant cues for sound localization in the horizontal plane (Grantham, 1995; Moore, 2012; Yost, 2000). Both of these cues provide reliable information for listeners in a sound-treated environment when the subject perceives only the direct sound. However, these circumstances are somewhat artificial. In real-world environments, there are echoes and reflections that interfere with the direct signal, which may in turn interfere with localization abilities (Rakerd & Hartmann, 1985; Scharine & Letowski, 2005).

Reverberation can be defined as the reflection and absorption of a signal off of surrounding obstacles (Ihlefeld & Shinn-Cunningham, 2011; Rakerd & Hartmann, 1985; Scharine, et al., 2010). This can cause a listener to hear multiple reflected signals in addition to the direct signal. Real-world environments are filled with surfaces that can cause reverberation. Reflections off walls, buildings, and different features in a room (e.g. windows) are often seen as a problem for accurate localization (Ihlefeld & Shinn-Cunningham, 2011; Rakerd & Hartmann, 1992; Scharine & Letowski, 2005).

A number of researchers have investigated the effects of reverberation on auditory localization abilities. In some cases, such as the precedence effect, reverberation can assist in sound localization (Clifton, 1987; Gardner, 1968; Lindemann, 1986; Litovsky, Colburn, Yost, & Guzman, 1999; Wallach, Newman, & Rosenweig, 1949), while in other cases, reverberation can negatively affect auditory localization abilities and increase errors (Devore et al., 2009; Giguere & Abel, 1993; Guski, 1990; Ihlefeld & Shinn-Cunningham, 2011; Rakerd & Hartmann, 1985; Zurek, Freyman, & Balakrishanan, 2004;).

The Precedence Effect. A phenomenon known as the precedence effect has been shown to assist with auditory localization in a reverberant environment (Clifton, 1987; Gardner, 1968). The precedence effect may be defined as a single auditory fused image consisting of the direct signal and the reflected signal (Gardner, 1968; Wallach et al., 1949). For this to occur, the reflections of the signal must arrive at the ear between 1 and 50 ms after the direct sound source (Gardner, 1968). If the sounds are fused, the localization judgment is determined primarily by the direct signal. This causes the accuracy of localization judgments to be high because the listener perceives one auditory image that is dominated by the direct signal (Litovsky et al., 1999; Wallach et al., 1949).

For the precedence effect to be at its greatest, the stimulus should be discontinuous and transient (Wallach et al., 1949). The use of discontinuous or interrupted tones allows for distinct transitions between sounds, which provide the listener with additional localization cues. The intensity and the type of signal can also enhance the precedence effect. If the intensities of the sounds are similar, the precedence effect will be significant. In addition, if the intensity of the reflected stimulus is lower than the lead stimulus, the listener will place a larger emphasis on the direct signal. Finally, in most research on the precedence effect, the stimuli presented to the listener are similar. Wallach and colleagues (1949) suggested that similar auditory stimuli enhance the precedence effect, and thus localization abilities, because the listeners perceive a single auditory image rather than two separate auditory images.

Localization Judgments in a Reverberant Environment. Interaural differences, spectral cues produced by the pinna, and head movements are all cues a listener can use to help determine the location of a sound (Fisher & Freedman, 1968; Gardner, 1973; Kuhn, 1977; MacPherson & Middlebrooks, 2002; Moore, 2012; Perrott et al, 1987; Rayleigh, 1907). These cues, however, may be affected when reflections (or echoes) are present in the environment. In a reverberant environment, the listener will perceive the direct signal as well as multiple reflections (Ihlefeld & Shinn-Cunningham, 2011; Rakerd & Hartmann, 1985; Scharine et al., 2010). Scharine and Letowski (2005) reported that the reflections have the potential to draw the listener’s attention away from the direct signal and thereby alter the localization cues. First, the reflections add more spectral information to the original stimulus, which lessens the effect of monaural cues. In regards to binaural cues, ILDs are often reduced in the presence of reverberation. Additionally, multiple ITDs may be present due to the reflections. The alteration of these cues results in poorer localization accuracy in reverberant environments than that observed in anechoic environments (Scharine & Letowski, 2005).

Recall that the precedence effect may help resolve localization difficulties in a reverberant environment. Although the precedence effect may be effective in an ideal environment, different characteristics of the stimulus and different room characteristics can affect the precedence effect (Wallach et al., 1949). For example, continuous tones are often difficult to localize, especially in a reverberant environment. The direct sound will arrive at the ear first but since the stimulus is continuous, the ongoing direct sound and subsequent reflections will overlap. The overlap between direct and reflected sound leads to poor localization cues, which may then lead to inaccurate localization judgments. In some cases, the reflected sound can be more intense than the direct sound. In these cases, auditory localization can suffer because the emphasis is placed on the reflection (Wallach et al., 1949). Finally, the precedence effect can break down in difficult listening situations. For example, Rakerd and Hartmann (1985) examined the precedence effect in a room with a single reflecting surface. The researchers found that the precedence effect was not completely resolved when the reflected surface was present and that room reflections interfered with the arrival of the direct sound source (Rakerd & Hartmann, 1985).

In addition to their work investigating the precedence effect, Rakerd and Hartmann (1985) were also interested in examining localization accuracy in azimuth for reverberant environments. The researchers measured the accuracy of auditory localization in a room with a single reflecting surface. The reflecting surface was positioned either on the ceiling, the sidewalls, or the floor, which lead to four different reflection conditions. The stimulus was a 500 Hz rapid onset tone and a 500 Hz slow onset tone. Results indicated that overall, localization was better for the rapid onset stimuli than slow-onset stimuli. In addition, the type of reflecting surface affected localization differently. Vertical reflecting surfaces (side walls) negatively impacted localization, while horizontal reflecting surfaces (ceiling and floor) did not change localization from baseline free field conditions (Rakerd & Hartmann, 1985).

Guski (1990) performed a similar study to that of Rakerd and Hartmann (1985), but instead looked at the effects of a single reflecting surface on localization accuracy in azimuth and elevation. In contrast to the results of Rakerd and Hartmann (1985), Guski (1990) did not find any systematic effect of the reflecting surface in azimuth. However, he did find that that floor reflections improved localization abilities, while ceiling reflections hurt localization abilities, and sidewalls did not change localization ability (Guski, 1990).

More recently, two studies examined the effects of typical room characteristics on localization (Ihlefeld & Shinn-Cunningham, 2011; Shinn-Cunningham, Kopco, & Martin, 2005). Shinn-Cunningham et al. (2005) examined the effects of sound source position on the available binaural cues for localization in a typical classroom. Using a Knowles Electronics Manikin for Acoustic Research (KEMAR), the researchers measured BRTFs for sound source positions around the manikin in the reverberant classroom. BRTFs are similar to HRTFs, but in this case, they also include all of the spectra-temporal changes due to room effects. In general, reverberation was found to significantly alter available ITD, and ILD cues. Further, the magnitude of changes varied as a function of manikin position with respect to the sound source. These types of changes in ILD and ITD information should significantly affect localization abilities of listeners (Shinn-Cunningham et al., 2005).

Ihlefeld and Shinn-Cunningham (2011) were interested in auditory localization abilities and the effects of the frequency content of the stimulus. The researchers used octave wide noise bands centered at 750 and 6000 Hz, presented from a series of thirteen loudspeakers. The sources varied from + and – 90 degrees in the horizontal plane. The researchers found that for frontal sources, localization accuracy did not differ for the low frequency and high frequency noises. However, for lateral sources, localization accuracy was poorer for low than high frequency stimuli. In addition, the results of simultaneous presentations of low and high frequency noise stimuli showed performance that was poorer than performance for high noise stimuli alone, but as good as or better than low noise stimuli alone. These findings indicated that, in reverberant environments, subjects often place a strong weight on low frequency information even when high frequency information is superior (Ihlefeld & Shinn-Cunningham, 2011).

Distance Perception in a Reverberant Environment. As previously mentioned, there are several cues that can be used to determine how far a sound source is away from the listener. Most research regarding distance perception has been performed in an anechoic environment (Grantham, 1995; Moore, 2012). Unlike auditory localization, however, researchers have reported that reverberation does not negatively impact distance perception judgments and it can actually be a useful cue when determining the distance of a sound source (Scharine & Letowski, 2005). As the distance between a sound source and listener increases, the more reflected energy is present. This energy decays slower than the direct sound source. Since this energy is present longer, the researchers hypothesize that it can be used as a cue for distance perception (Scharine & Letowski, 2005). It is reported that the greater the direct to reflected energy ratio, the closer the sound source is perceived to be (Grantham, 1995). This cue, however, can be affected by the listener's hearing and how close the sound source is to a reverberant source. For these reasons, reverberation has been shown only to be effective when a listener is familiar with the space in which they are located (Scharine & Letowski, 2005).

Statement of Purpose

The research regarding localization accuracy does not provide a clear picture regarding localization abilities in an everyday environment. Reflective surfaces in the environment can create multiple signals in addition to the initial auditory signal and the presence of these additional signals can distort the cues used to localize a sound (Ihlefeld & Shinn-Cunningham, 2011; Rakerd & Hartmann, 1985; Scharine et al., 2010). The distortion of these cues should significantly affect localization abilities and therefore, auditory localization in a reverberant space is less accurate than when in an anechoic environment (Ihlefeld & Shinn-Cunningham, 2011; Scharine & Letowski, 2005). In an urban environment, the presence of different structures obstructs the path of the initial auditory signal to the listener creating reflected signals (Ihlefeld & Shinn-Cunningham, 2011; Rakerd & Hartmann, 1985; Scharine et al., 2010).

Several researchers have examined localization accuracy for the different types of stimuli and different locations within a reverberant space. Rakerd and Hartmann (1985) examined localization abilities in a room with a single reflecting source for signals with rapid and slow onset stimuli. Although localization abilities were negatively affected for both signals, when the reflecting surface was present, the stimulus with the rapid onset yielded better localization accuracy in comparison to the slow onset signal (Rakerd & Hartmann, 1985).

The distance between a reflective surface and a listener impacts localization accuracy whereby as the separation between a listener and reflective surfaces decrease, localization accuracy decreases (Kopco & Shinn-Cunningham, 2002). The decrease in auditory localization performance is attributed to acoustic alterations in the binaural and monaural cues received by the listener particularly when a listener's ears are in close proximity to a reflective surface such as a wall (Shinn-Cunningham et al., 2005).

The current proposed study seeks to extend this previous work by investigating the accuracy of auditory localization in an everyday, urban environment. Localization accuracy will be evaluated through a headphone-based study in which BRTFs are incorporated. Three factors in particular will be examined: the type of noise stimuli (impulse, steady state), manikin position, and sound source location. By investigating localization abilities in a reverberant space, it is the hopes of the researchers to increase their knowledge on how accurately subjects can localize in these difficult environments. Based on the above studies, the following hypotheses have been made for the present study:

Hypotheses:

1. The impulse noise will yield greater localization accuracy when compared to the steady state noise. This has been previously shown by Rakerd and Hartmann (1985) and it is the basis for the current hypothesis.
2. The manikins, where neither of the ears is facing the walls, will yield the highest localization accuracy. This hypothesis was based off of the results of the Shinn-Cunningham et al. (2005) study.
3. Previous research has shown that the position of the sound source can affect the listener's perceived location of the sound source (e.g. distance perception). Since the present study will contain several sound source locations and several manikin positions, performance at the different sound source locations is expected to vary since the manikin positions vary in distance from the different sound source locations. A specific sound source location is not perceived to yield higher localization accuracy than another.

Chapter 3: Methodology

Participants

Twenty-four normal hearing adults, ages 18 to 30 (M = 23.6), completed the study. Twelve of the participants were male and twelve were female. All participants passed a pure tone hearing screening using a Grason-Sadler GSI-61 audiometer and ER-3A insert earphones with an intensity level of 20 dB HL, indicating normal hearing from 250 to 8000 Hz. Recruitment for this study took place mainly on Towson University's campus and participation in the study was voluntary. Approval for the study was obtained from the Institutional Review Board (IRB) at Towson University prior to data being collected.

Stimulus Recordings

The stimuli used in the present study were recordings previously made by the U.S. Army Research Lab (ARL) located at Aberdeen Proving Ground (APG), Maryland (MD). These recordings were of an impulsive noise source and of a steady state, white noise source made using a set of six identical acoustic test fixtures (ATFs) also known as manikins. Each of these manikins is a modified clothing mannequin that has a head, torso and pinnae into which electret microphones were placed at the entrance of both ear canals. All recordings were made in the Soldier-System Test Facility (SSTF) at APG. This test facility is a reverberant space that is roughly rectangular in shape. The space is open roofed and dirt floored, with walls that are made up of adjoining concrete barriers that are approximately 8' high. The two noise sources were independently moved to four different locations in the test space. Recordings were made simultaneously from 6 manikins for each of the sound presentations. Figure 1 shows a schematic drawing of the

SSTF and depicts the separate noise source positions and manikins (including manikin facing position).

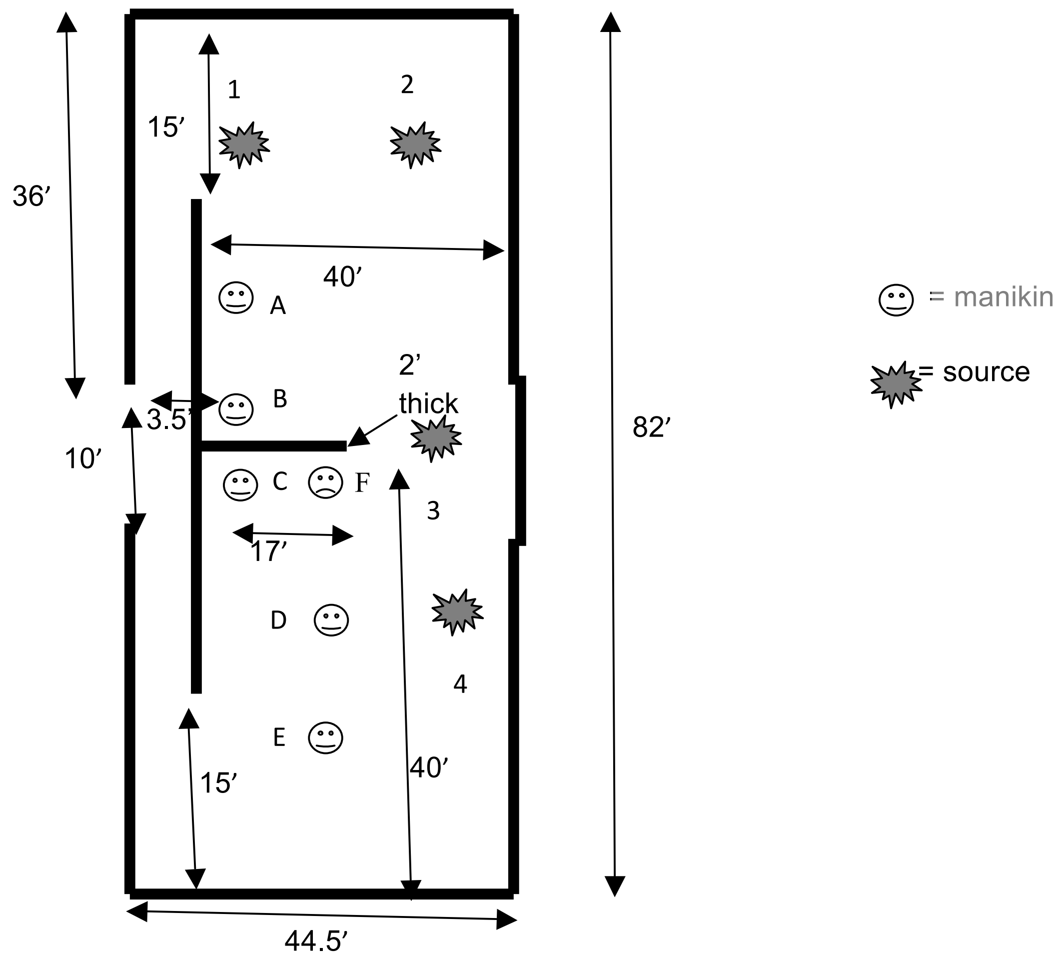

Figure 1: A schematic of the Solider System Test Facility (SSTF). Manikin positions are marked by smiley faces and the noise source locations are depicted by black burst symbols.

The impulse noise source was generated by the pneumatic impulse noise source (PINS), which is a shock-tube capable of generating repeatable impulse sounds of up to 170 dB (peak) at 1 m. Figure 2 shows a picture of the PINS system.

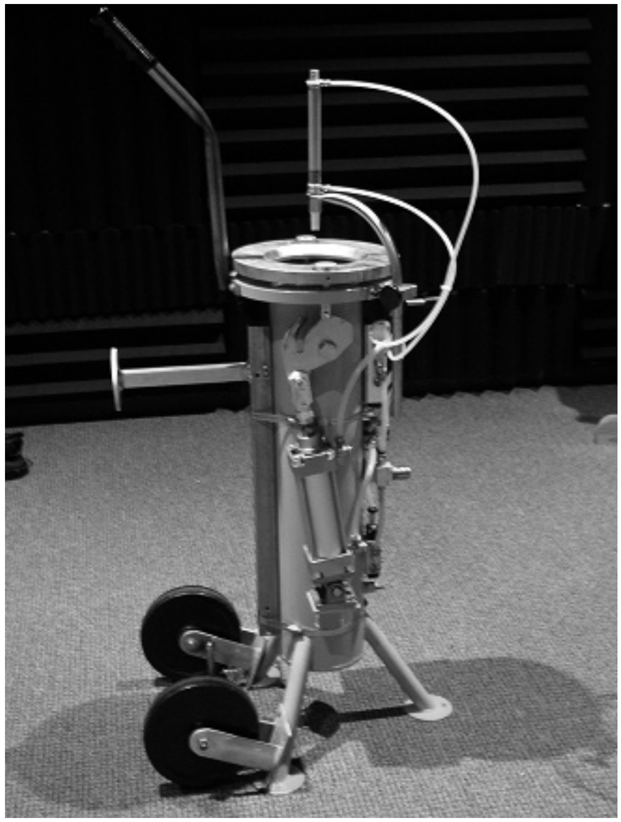

Figure 2: An image of the PINS, which was used to generate the impulse noise stimuli.

The PINS operates by sealing one end of a hollow cylinder with a sheet of coated paper and then filling the cavity with compressed air. Once the cavity is filled to the desired pressure, the paper is then punctured remotely to produce the impulse sound. All impulse noise stimuli were edited to begin 500 ms prior to the onset of the impulse peak, and end 1500 ms following the peak. Linear amplitude ramps applied over a 5 ms duration were applied to the beginning and end of each stimulus to minimize onset and offset acoustic transients. Figure 3 shows an image of the impulse noise waveform and spectral content.

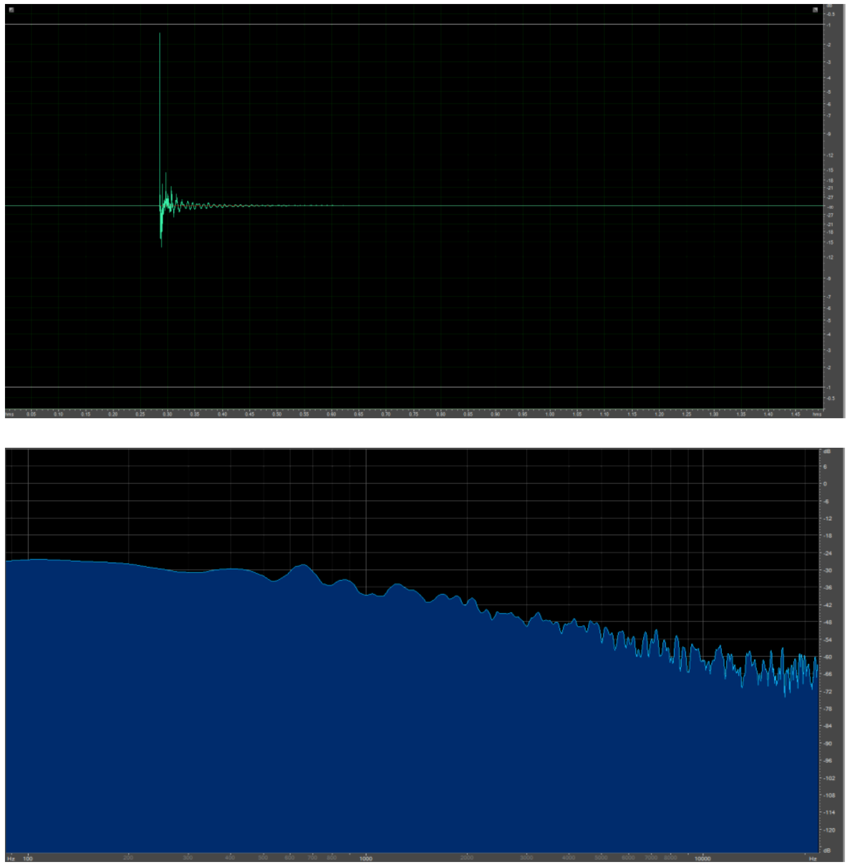

Figure 3. An image depicting the waveform and the spectral content for the impulse stimulus. The top frame shows the impulse time series and the bottom frame shows the Fast Fourier Theorem (FFT) results.

The steady-state noise source was a uniform white noise generated by a dodecahedron loudspeaker system (Cesva BP012) and a 10” subwoofer (Genelec 7060B). Figure 4 shows a picture of both the dodecahedron loudspeaker system and the subwoofer.

Figure 4: An image of the audio equipment used to generate the steady-state noise stimuli. The dodecahedron loudspeaker system is on the left and the subwoofer is on the right.

The dodecahedron loudspeaker is a set of 12 loudspeakers arranged in a dodecahedron housing that allows for the uniform distribution of sound power in all directions. This system is capable of generating a relatively flat spectrum at a sound pressure level of approximately 115 dB SPL at 1 m. All steady state, white noise stimuli were edited to 1000 ms in length. Linear amplitude ramps applied over a 5 ms duration were applied to the beginning and end of each stimulus to minimize onset and offset acoustic transients. Figure 5 shows the steady state noise waveform and spectral content.

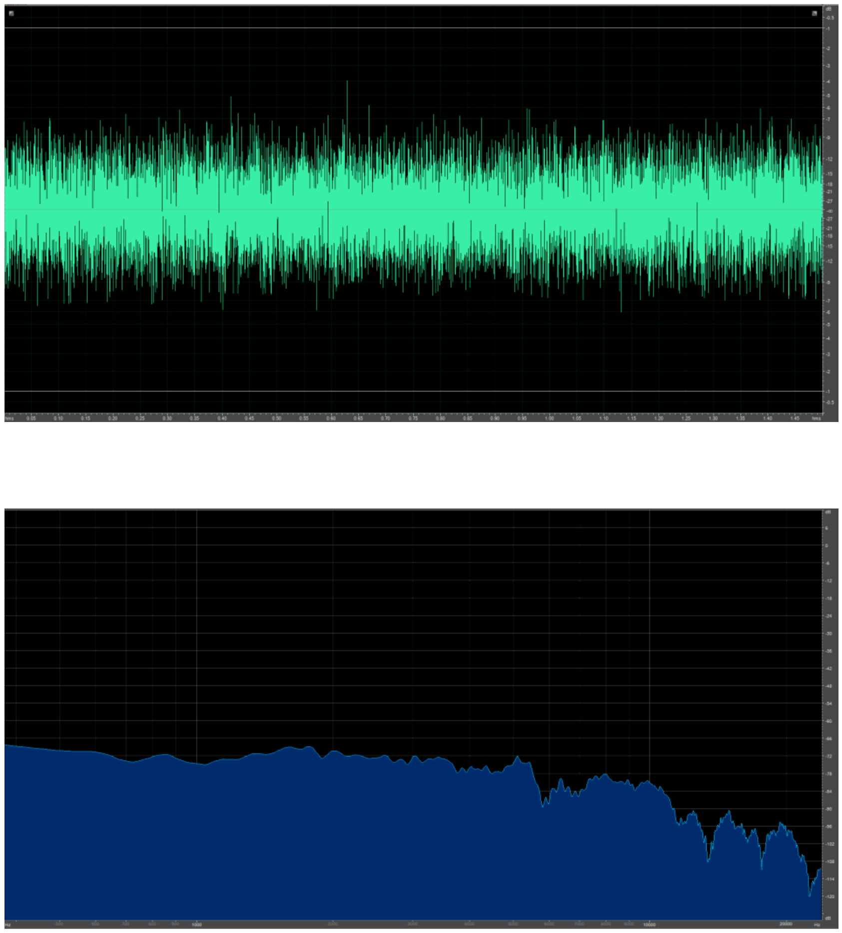

Figure 5. An image depicting the waveform and the spectral content for the steady state stimulus. The top frame shows the steady state time series and the bottom frame shows the FFT results.

A basic stimulus set for the steady-state and impulse noise sources is defined as five separate recordings of a sound presentation at each manikin position, for each noise source location. This resulted in a set of 120 unique stimuli for each stimulus type (5 sounds X 6 manikin locations X 4 sound source locations = 120).

Equipment

The study was conducted in a sound treated booth at the Hearing and Listening Lab (HALL) in Van Bokkelen Hall, on Towson University's campus. Following the hearing screening, each participant performed a series of localization tasks using a software program developed by ARL, with the stimuli described above. The software was presented through a Dell Latitude E6400 laptop computer using ER-3A insert earphones. Prior to testing, a simple control was implemented in an attempt to "equate" the levels of the two stimulus types. Although the perceived loudness of impulsive and steady state noise is somewhat different, a control for differences in loudness between the two stimulus sets was implemented by balancing the equivalent energy of each stimulus type using a 125 ms ("Fast" sound level meter) integration window. For stimulus presentation, the computer sound output was set to maximum and the output levels of the stimuli were measured to ensure that levels presented to participants did not exceed exposure limits recommended by the Occupational Noise and Safety Administration (OSHA) for an 8-hour period (90 dB A) or for unlimited exposure to impulse sounds [140 dB peak; (OSHA, 2012)]. The output levels of the stimuli were calibrated using a Quest 1200 Precision Integrating sound level meter (SLM) and a HA-2 coupler. The nub of the insert earphone was attached to the tube of the HA-2 coupler and the levels for the impulse and steady-state noise stimuli were measured for the most intense set of stimuli, for manikin position A, sound source location 1. The average noise level for the steady-state stimulus was 76 dB C using the fast mode setting on the SLM. For the impulse stimuli, the average noise level was 75 dB C using the fast mode setting on the SLM. The average peak of the impulse stimuli for manikin position A, sound source location 1 was 97 dBp.

Data Collection

Participants who met the criteria for hearing status completed a series of localization tasks on a laptop computer. For data collection, participants were seated at a table with a laptop computer in front of them. Participants used a USB mouse to the side of the laptop to interact with the computer program. The general procedure was as follows: the participant viewed a graphical user interface (GUI) on the computer screen similar to that shown in Figure 6.

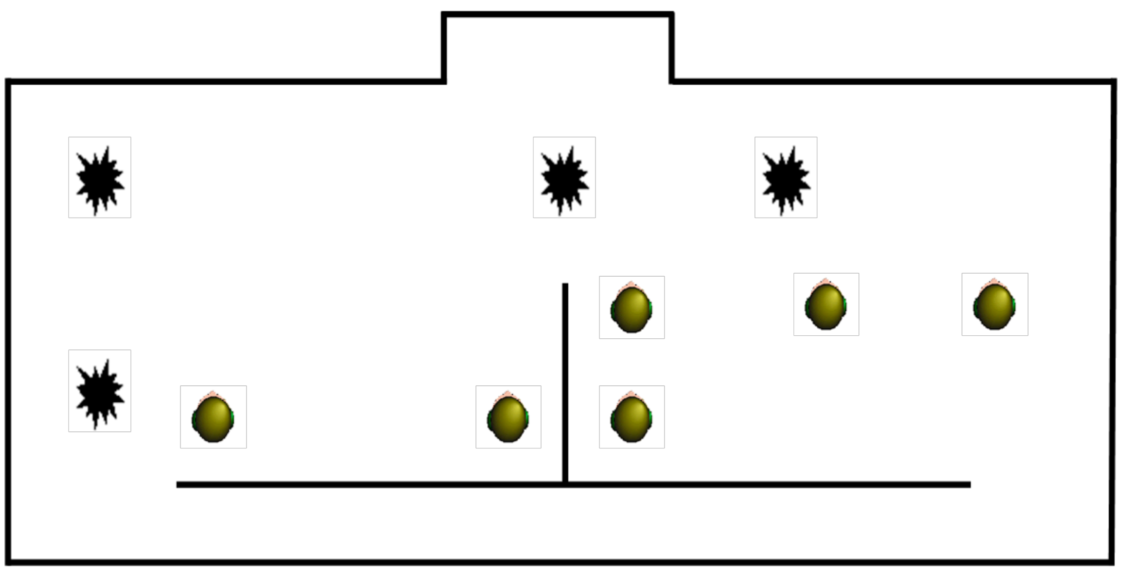

Figure 6: A screen shot of computer software similar to what participants saw during the different localization trials. For data collection trials, only one manikin was shown on the screen to indicate the position of the listener for the given condition.

The GUI represented a top-down view of the SSTF. The manikin position specific to a given block of trials was highlighted by a top-down view of a soldier's helmet. Burst icons indicated the possible sound source locations. The listener clicked on a button at the bottom of the GUI to present a stimulus and then clicked on one of the four possible sound source locations to register a response. Once the perceived location was selected, the participant clicked on the button marked "next" to move on to the next trial. When all trials within a block were presented, a button at the bottom of the screen was displayed to exit the program.

Prior to data collection, participants were given an opportunity to become familiar with the study procedures and the stimuli being used in a familiarization task. The participant was presented with a GUI display of the SSTF as described above, and they were able to select the different stimulus types (steady-state or impulse) and manikin positions to hear example stimuli. Once the desired condition was selected, the listener was able to click the different sound source locations to hear appropriate stimulus examples from a given manikin position.

Once the familiarization task was complete, the participant completed two blocks of trials for each of the 12 localization conditions (6 impulse and 6 steady-state). Each block contained 5 unique sound stimuli for each of the 4 sound source locations for a given manikin position for a total of 20 trials per block. The computer program randomized stimulus order and manikin position was randomized according to a Latin square. Each block of trials took approximately 5 minutes to complete, for a total completion time of 60 minutes per participant. The total test time including informed consent, audiometric screening and participant debriefing took approximately 1½ hours. Once testing was complete, percent correct for each block of trials per manikin position was calculated as an overall measure. This performance measure was entered into a spreadsheet in order to organize the data for analysis.

Data Analysis

The independent variables for the study were stimulus type (2 levels), manikin position (6 levels) and sound source location (4 levels). Prior to data analysis, it was discovered that a series of steady state stimuli were coded incorrectly. The steady state noise stimulus set labeled for manikin F, sound position 2 were actually stimuli for a different sound position. This resulted in missing data for that stimulus, manikin position, and sound source location. Due to these missing data, all data for manikin F were removed from data analysis, resulting in five total manikin positions. Auditory localization accuracy, as percent correct, was calculated for each manikin position, sound source location and stimulus type.

Chapter 4: Results

Percent correct accuracy was calculated for each participant within each localization condition. Figure 7 shows the average localization accuracy for each stimulus type as a function of sound source location, separately for each manikin position.

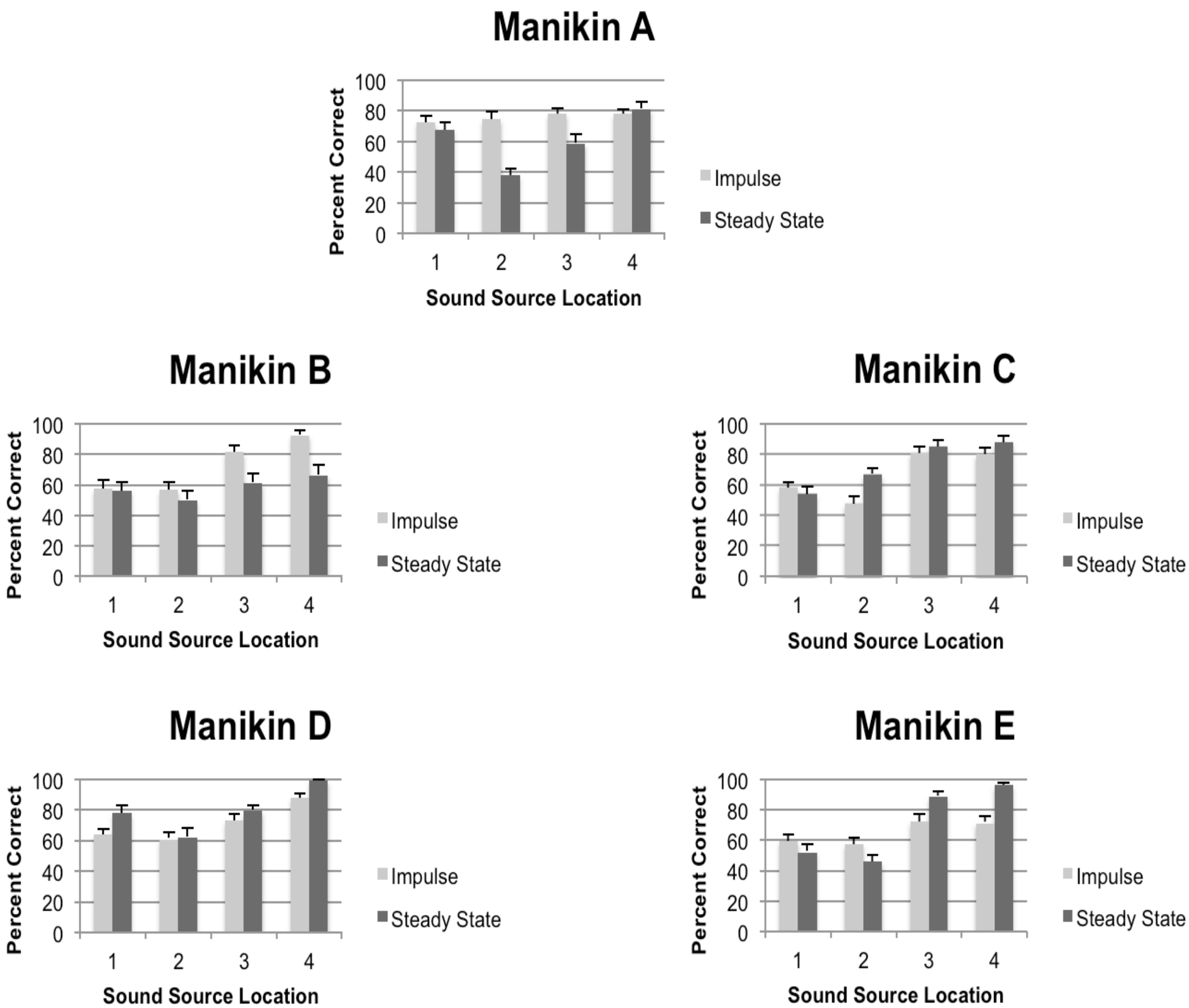

Figure 7. Average localization accuracy is shown across sound source location according to the five different manikin positions. The error bars represent +1 standard error.

A 3-Factor (5 x 4 x 2) repeated measures ANOVA was performed on the localization accuracy data to examine the within-subjects variables of manikin position, sound source location, and stimulus type. This analysis was performed using SPSS version 21. Mauchly's test indicated that the assumption of sphericity had been violated for the sound source location variable, $X^2(5) = .496$, $p < .05$, and for the interaction of manikin position and stimulus type, $X^2(9) = .343$, $p < .05$. Therefore degrees of freedom were adjusted using the Greenhouse-Geisser estimates of sphericity, $\varepsilon = .68$ for the sound source location variable and $\varepsilon = .62$ for the interaction of manikin position and stimulus type to reflect these corrections. Follow-up repeated measures ANOVAs and a t-test were conducted to further explore the data and the relevant statistics are reported where appropriate.

The statistical analysis revealed that there were significant main effects of manikin position, $F(4, 92) = 5.32$, $p < .05$, and sound source location, $F(2.04, 46.97) = 85.33$, $p < .001$. Contrary to expectations, the main effect of stimulus type was not significant, $F(1, 23) = .884$, $p > .05$, suggesting that the stimulus type did not impact localization abilities in the reverberant environment. Although stimulus type was not significant overall, there were significant two-way interactions between stimulus type and manikin position, $F(2.49, 57.27) = 10.71$, $p < .001$, and stimulus type and sound source location, $F(3, 69) = 3.25$, $p < .05$, as well as a significant three-way interaction between all of the independent variables, $F(12, 276) = 7.99$, $p < .001$. Finally, there was a significant two-way interaction between manikin position and sound source location, $F(12, 276) = 3.86$, $p < .001$. These findings will be explored further in the future section.

Follow-up analyses

The type of stimulus did not significantly affect localization accuracy overall, but all interactions between stimulus type and the other independent variables were significant. This suggests that although stimulus type did not impact overall performance, it was important for performance at specific sound source location and manikin position combinations

Figure 8 shows accuracy for each stimulus type (collapsed across sound source location) as a function of manikin position.

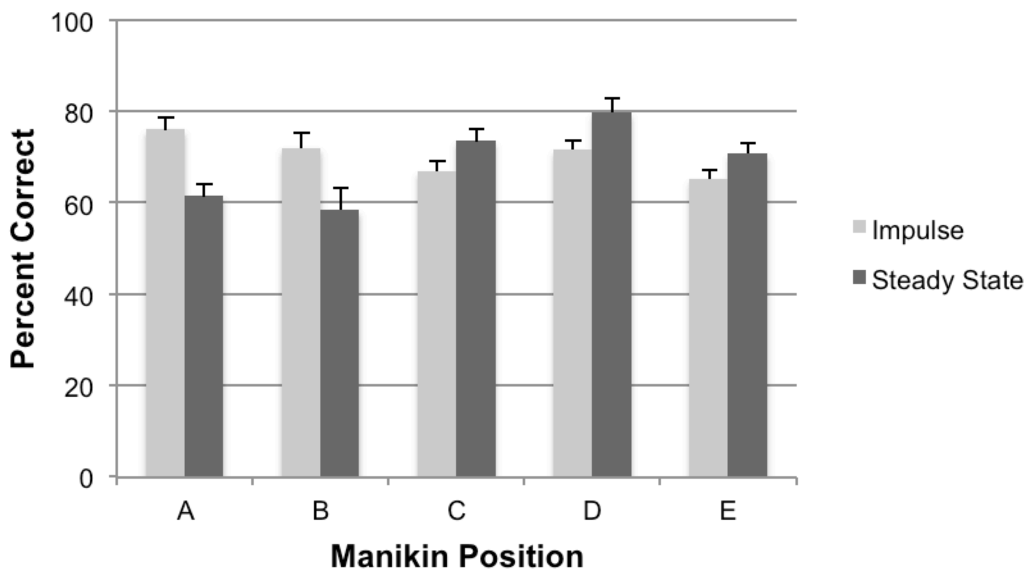

Figure 8. Average localization accuracy averaged across sound source location for each of the manikins. Error bars indicate +1 standard error.

Examination, of the accuracy patterns viewed in this way, suggests that performance is always better for the steady-state stimulus for manikin positions on the right side of the SSTF [positions C, D and E (see Figure 1)], and performance is always better for the impulse stimulus for manikin positions on the left side of the SSTF (positions A and B). To see if this pattern was statistically significant, accuracy was collapsed across manikin positions on each side of the space (manikin positions A&B = $SSTF_{L;}$ manikin positions C, D, & E = $SSTF_R$), and a follow-up repeated measures ANOVA with the within-subjects factors of stimulus type (impulse and steady-state) and SSTF listening side ($SSTF_L$ and $SSTF_R$) was performed. Results showed that there was a significant effect of stimulus type, $F(1,23) = 4.09$, $p < .05$, but the main effect of manikin side was not significant, $F(1,23) = 6.4$, $p > .05$. Nonetheless, of particular importance, the interaction between the stimulus type and manikin side was significant, $F(1,23) = 53.96$, $p < .001$. This significant interaction confirms the differential pattern of accuracy for alternate SSTF listening sides. The fact that the patterns are different across SSTF listening sides likely drove the non-significant main effect of stimulus type in the 3 factor ANOVA. These results suggest that the quality of information differed across room sides for each stimulus type.

Figure 9 shows auditory localization accuracy collapsed across all manikin positions, for the impulse and steady-state stimulus as a function of sound source location.

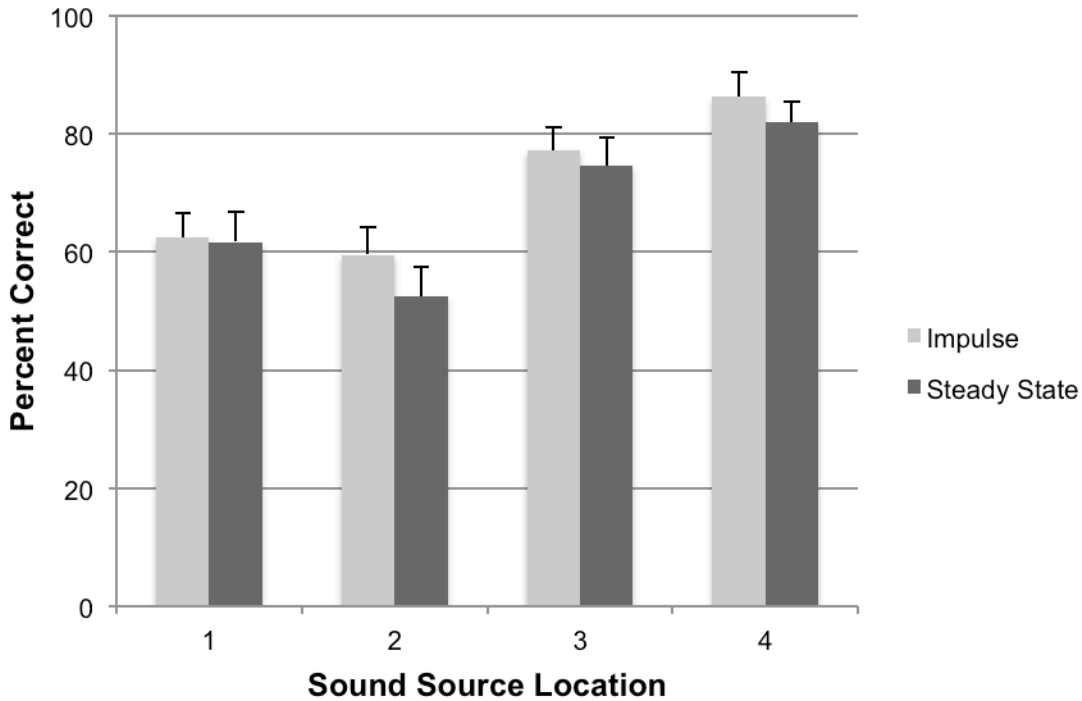

Figure 9. Auditory localization performance is shown according to the type of stimuli averaged across manikin position for each sound source location. Error bars indicate +1 standard error (SE).

When looking at the accuracy data as a function of stimulus type and sound source location only, there does not seem to be a systematic difference between stimulus types, and this is consistent with the findings of the overall ANOVA. However, what is apparent from Figure 9 is that the accuracy patterns for the leftward sound source locations 1 and 2 seem to be much lower than the accuracy patterns for the rightward sound source locations 3 and 4. To test this, accuracy was collapsed across sound source locations 1 and 2, and 3 and 4, respectively, and a follow-up Repeated Measures ANOVA was performed on the within-subjects variables of SSTF sound source side ($SSTF_L$ and $SSTF_R$) and stimulus type (impulse and steady-state). As expected from the overall ANOVA and the patterns in Figure 9, there was no significant difference across stimulus type, $F(1,23) = .84$, $p > .05$, but performance was significantly better for $SSTF_R$, than $SSTF_L$ sound source locations, $F(1,23) = 315.22$, $p < .001$. The interaction was not significant, $F(1,23) = 3.16$, $p > .05$. These results show that performance was significantly better for $SSTF_R$ than $SSTF_L$ sound source positions, and this seems to have been due to the way in which the sound sources were positioned in the SSTF. Specifically, sound source locations 1 and 2 were placed near corners, whereas sound source locations 3 and 4 were placed in more open space (see Figure 1). The placement near corners (positions 1 and 2) may have led to more complex reflections that led to the poorer performance for localizing these sound sources.

Figure 10 shows localization accuracy for each sound source location as a function of manikin position.

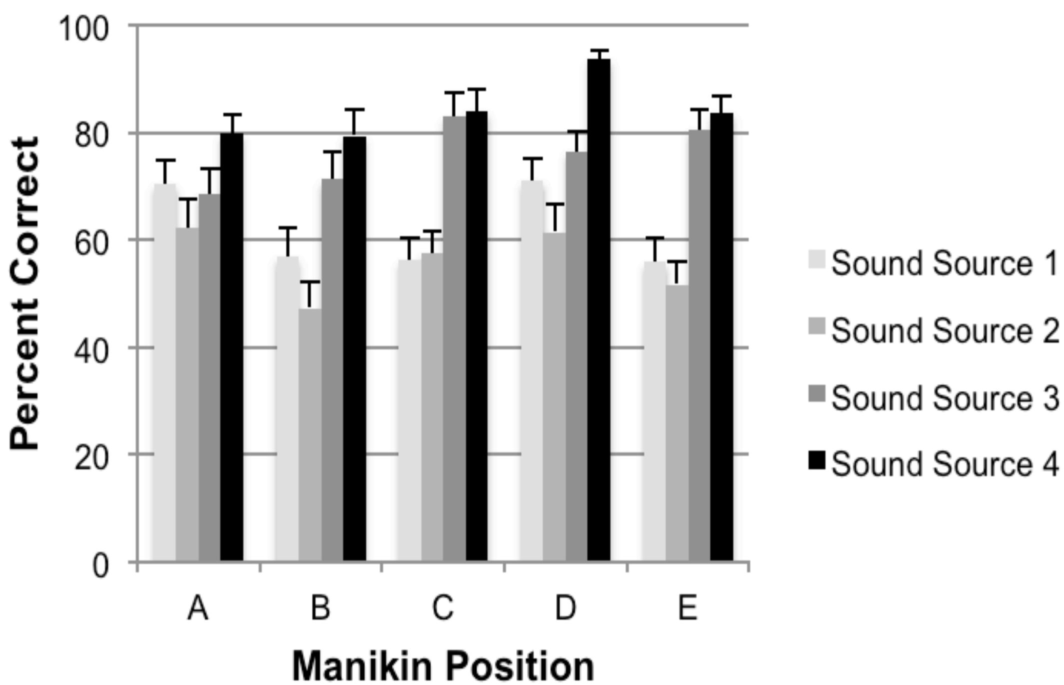

Figure 10. Average localization accuracy across stimulus type is shown for the five different manikin positions. The error bars represent +1 standard error.

To examine these relationships, a follow-up repeated measures ANOVA was performed with the within-subjects factors of sound source location and manikin position. Because the variable of sound source position violated the assumption of sphericity, a Greenhouse-Geisser correction was made to the degrees of freedom for this variable. Consistent with the previous analyses, there was a main effect of sound source position, $F(2.04,46.97) = 85.33$, $p < .001$, and a main effect of manikin location, $F(4,92) = 5.32$, $p < .01$, as well as a significant interaction, $F(12,276) = 3.86$, $p < .001$. One clear pattern from these data is that across manikins, accuracy for sound position 2, and for the most part sound position 1, is lower than accuracy for sound position 3 and 4. A follow up t-test confirmed that the average accuracy across sound positions 1 and 2 is significantly lower than the average accuracy across sound source locations 3 and 4, $t(23) = 16.4$, $p < .001$. Again, one obvious difference between these two groups of sound sources is that sound source locations 1 and 2 are placed close to corners (see Figure 1), whereas sound source locations 3 and 4 are placed in more open space. These differences in location may have affected the nature of the sound reflections arriving to the manikins, and thereby affected the patterns of accuracy by the listeners for those positions. Consistent with results from the 3 Factor ANOVA, the patterns in Figure 10 also shows systematic differences in accuracy across manikin position. The exact nature of the patterns is not entirely clear, but it is probably related to the specific relationships between those manikin positions and the locations selected for the sound sources.

Response Patterns

Following the examination of the inferential statistics, the participant's response patterns were examined for each sound source location to further explore the data. The total number of responses for each sound source location within each manikin position were tallied and displayed graphically, as shown through Figure 11 - 14.

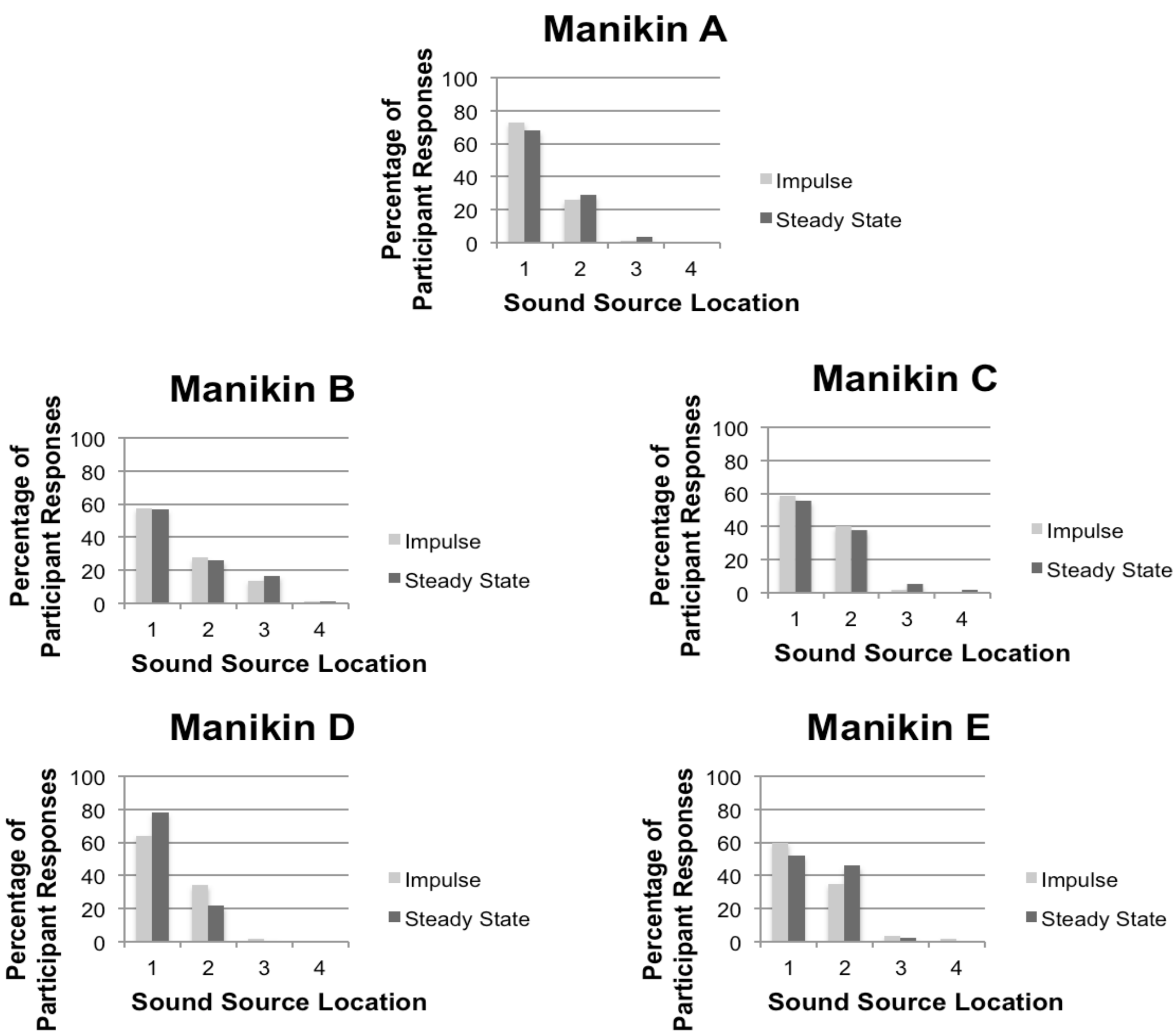

Figure 11. Total number of responses for each sound source location for manikins A through E when presented with sound source location 1.

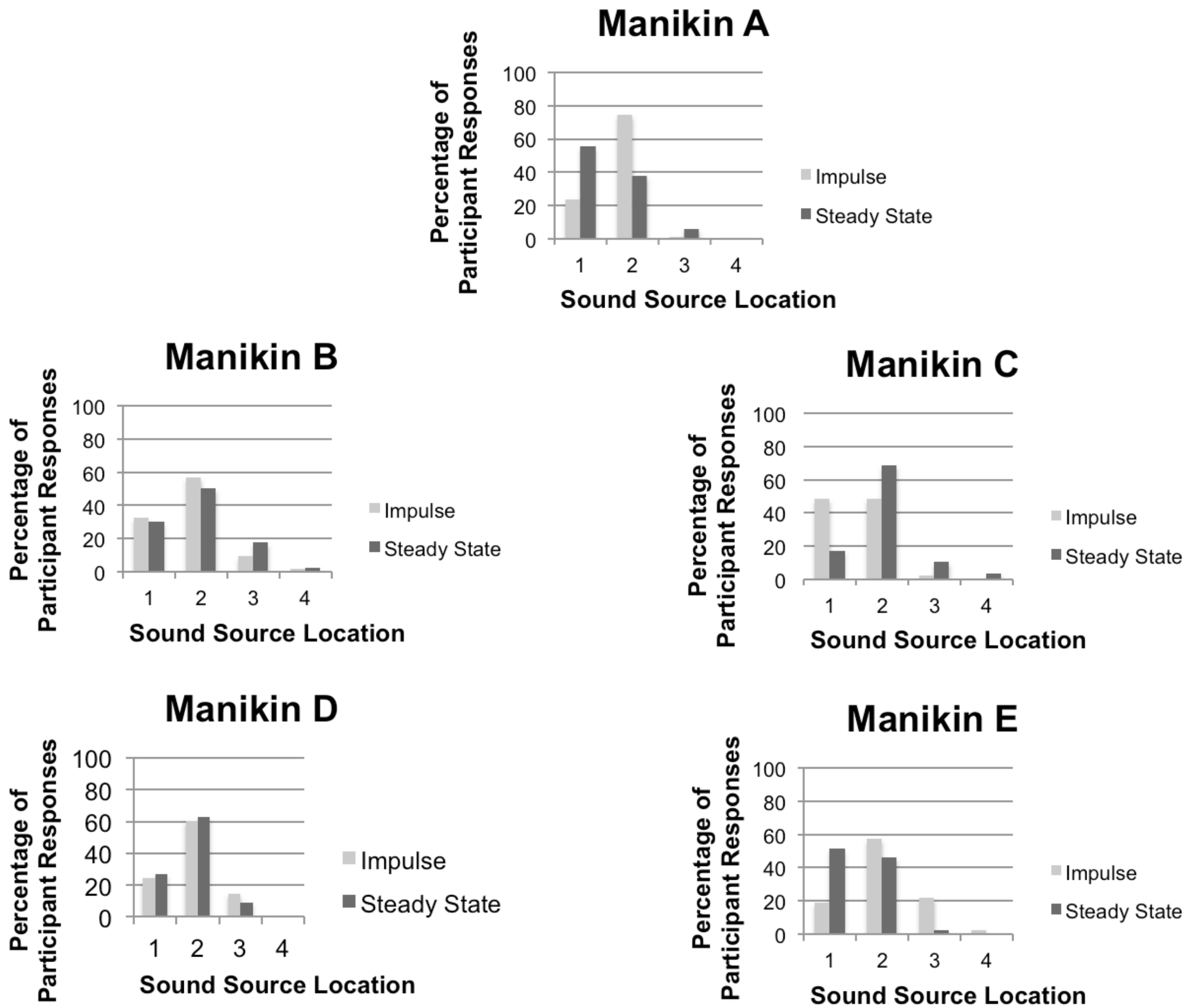

Figure 12. Total number of responses for each sound source location for manikins A through E when presented with sound source location 2.

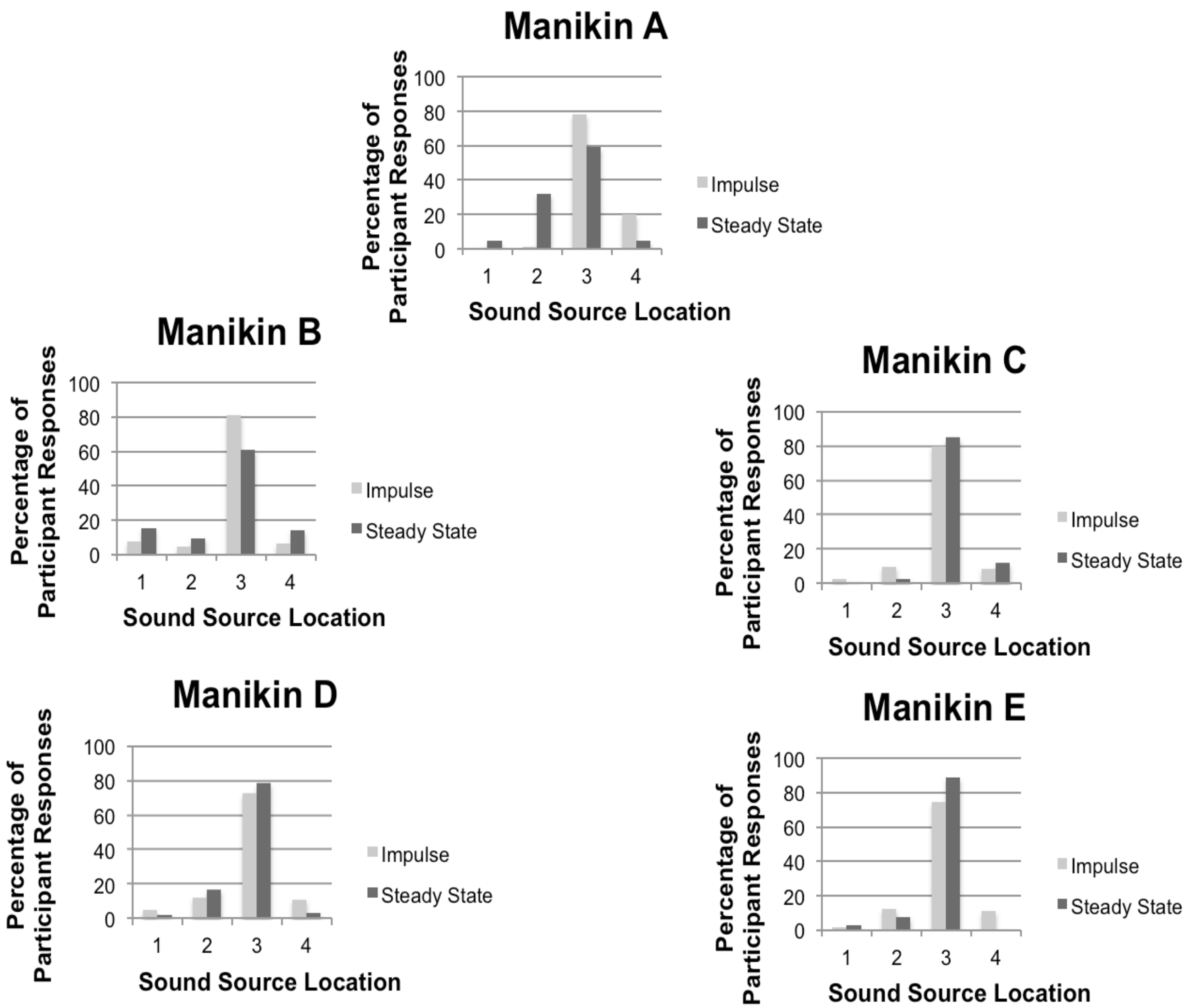

Figure 13. Total number of responses for each sound source location for manikins A through E when presented with sound source location 3.

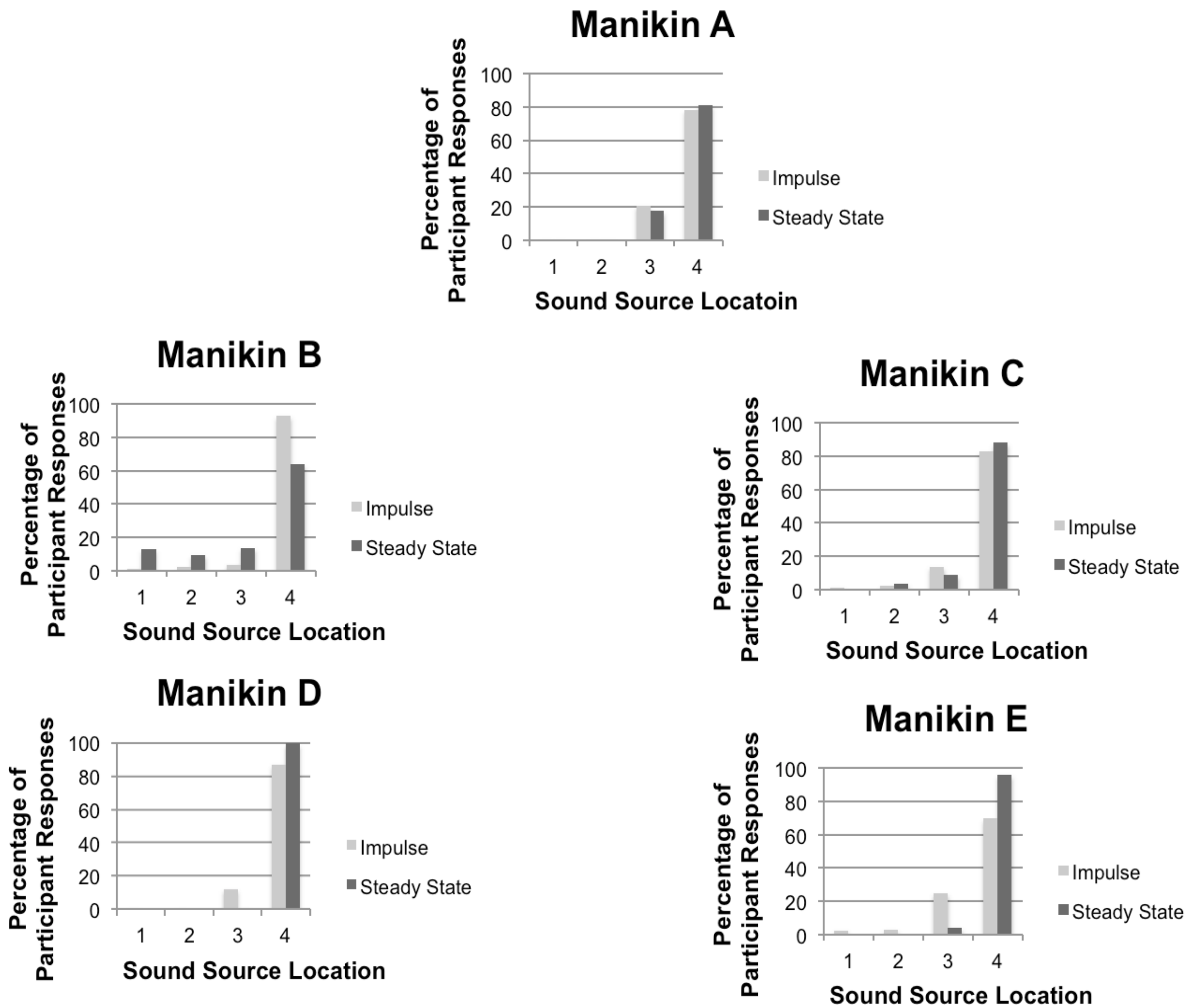

Figure 14. Total number of responses for each sound source location for manikins A through E when presented with sound source location 4.

Overall, the pattern of responses was consistent across manikin position and sound source location. The majority of responses were either correct or one sound source location to the left or right of the correct sound source location. When examining the response patterns, performance for sound source location 1 (Fig 11) was similar for all manikin positions. Participants either guessed the correct location (1) or they guessed one location to the right, which was sound source location 2. Both of these sound source locations are located on the left side of the SSTF facility. These results indicate that almost one hundred percent of the responses were either correct or on the correct side ($SSTF_L$) of the facility. The same pattern was observed for sound source location 2. Participants either guessed the correct location (2) or one sound source location to the left (1). Again, both of these sound source locations are located on the left side of the facility.

Sound source locations 3 and 4 are located on the opposite or the right side of the SSTF. A similar pattern is observed for the sound source locations on the right side as on the left side of the facility. Participants either guessed the correct sound source location or they guessed the other sound source location on the right side of the facility. Almost 100% of participant responses for sound source locations 3 and 4 were on the right side of the facility. These results indicate that the participants were conscious of at least the side where the sound source was being presented.

Chapter 5: Discussion

Auditory localization is fairly well understood for stationary listeners in free-field environments (Moore 2012; Yost, 2000), but less is known about localization in real-world, reverberant environments (Ihlefeld & Shinn-Cunningham, 2011). The present study addresses localization in this latter type of listening environment. The purpose of this study was to investigate localization abilities in a reverberant environment. Localization abilities were assessed using two different stimuli, five different manikin (listener) positions, and four different sound source locations. Results of statistical analyses revealed that localization performance changed as a function of manikin position and sound source location. The type of stimulus did not affect localization ability alone; however, the results indicate that localization performance varied at the different manikin positions and sound source locations across stimulus type. Furthermore, localization abilities varied according to different manikin position and sound source location combinations across the different stimulus types. Finally, results of the statistical analyses revealed that participant's localization performance was impacted by the different manikin positions and sound source locations when collapsed across the different stimuli. The significant factors that impacted localization abilities in the reverberant environment will be discussed in more detail.

Effects of Stimulus Type

The present study used two broadband stimuli (an impulse and a steady-state noise) and it has been reported several times in the literature that complex stimuli are localized better than pure tones and narrowband noise (MacPherson & Middlebrooks, 2002; McFadden & Pasanen, 1976; Stevens & Newman, 1936). Since the energy in a pure tone or narrow band noise is focused around a limited frequency range, the listener is exposed to limited localization cues (McFadden & Pasanen, 1976). Broadband noise is easier to localize because the listener is exposed to multiple localization cues, for example ITDs, ILDs, and monaural spectral cues, which reinforce to the listener where the sound is located (MacPherson & Middlebrooks, 2002; McFadden & Pasanen, 1976; Stevens & Newman, 1936). The high levels of accuracy (chance = 25%) in the present study across manikin positions and sound source locations are attributable to the use of complex impulsive and steady state noise as the sound sources rather than pure tones or other less complex stimuli.

Although accuracy was fairly good across the board, there was not a significant difference in auditory localization performance between the stimulus types. At the onset of the study, we anticipated seeing differences in localization ability based on the stimulus type. For example, two studies performed by Hartmann and colleagues (Hartmann, 1983; Rakerd & Hartmann, 1985) were part of a series of experiments examining the effects of reverberation on localization abilities. The stimuli used in these studies were a rapid onset, low frequency noise and a gradual onset, low frequency noise. The rapid onset stimulus had a clear onset cue, while the gradual onset noise had no onset cue, which has been shown in the literature to provide false localization cues (Hartmann, 1983; Rakerd & Hartmann, 1986; Rakerd & Hartmann, 1985). The researchers concluded that the rapid onset of the stimulus assisted listeners when a single reflecting source was present (Rakerd & Hartmann, 1985). Based on that work, we expected that the shorter, more abrupt impulse noise would be easier to localize than the steady-state noise.

Clearly, this was not the case for our stimuli, and this is probably due to some important differences between our stimuli and those used in the Rakerd and Hartmann studies (1985; 1983). One obvious difference between the present studies stimuli and Rakerd and Hartmann's is that they used pure tone stimuli, which contain limited localization cues compared to the present study's complex stimuli. The second important difference is that the effects of onset and offset cues. In the present study, onset and offset cues were reduced by applying the same amplitude onset ramps to the two stimuli, thus minimizing these localization cues. The stimuli in the Hartmann studies had distinct differences between the onset and offset cues, whereas the stimuli in the present study did not, which may have reduced the differences between our two stimuli and therefore produced differences between our results and those of the Hartmann studies.

A final difference that may contribute to the discrepancies between the present study and other findings in the literature is the presentation method of the stimuli. The two stimuli used in the present study were recorded through manikins in a reverberant environment and presented to listeners through earphones. Other researchers used different methodologies (Hartmann, 1983; Rakerd & Hartmann, 1985). For example in the Hartmann studies, the sounds were played through loudspeakers with a single reflecting source present. Furthermore, the participant heard the rapid onset stimulus once but the gradual onset stimulus continued to play until the participants made their localization judgment. The use of continuous stimuli played live to a listener can allow the participants to move their heads, which may assist or hinder localization judgments (Rakerd & Hartmann, 1986).

Effects of Manikin Position and Stimulus Type

Although there was no significant overall difference in auditory localization ability between the two stimuli, results of the present study revealed that there was a significant effect of manikin position, as well as a significant interaction between the manikin position and the stimulus type. Follow-up analyses showed that performance varied as a function of SSTF side and stimulus type. Specifically, performance for the steady-state stimulus was best for manikin positions on the right side of the SSTF, and performance for the impulse stimulus was best for manikin positions on the left side of the SSTF. These results seem to indicate that there were clear differences in the quality of information between listening sides. These differences between listening sides are not necessarily indicative of overall differences in acoustic characteristics between the right and left side of the SSTF, especially since the sides are constructed as essentially mirror images of each other. Instead, the differences reflect the unique manikin position and sound source location relationships investigated. Although the discussion of better performance for a given side is useful for organization purposes, differences in performance are really driven by the relative positioning of manikins and sound sources relative to one another and the reflective walls of the reverberant space.

In terms of the relative positioning of manikins to walls, we anticipated that performance would be worst for listening positions located closest to walls, and best for positions placed away from walls. This expectation was based on the results of Shinn-Cunningham et al. (2005) that showed localization performance improved when listeners were farther away from walls. The researchers reported that reflections from the walls did not significantly interfere with localization abilities when the listener was not near a reflective surface. In contrast, when listeners were close to walls, localization performance suffered (Shinn-Cunningham et al., 2005).

Another study by Shinn-Cunningham (2000) examined the effect of listener position using a series of HRTFs made in an anechoic environment and a reverberant environment. The results showed that when a listener was within 1 m of a reverberant source, reverberation distorted the auditory stimulus. The ear closest to the reverberant source was not as affected as the ear farthest from the reverberant source. The signal reaching the far ear had increased variability in the spectrum and some of the spectral information may have been distorted (Shinn-Cunningham, 2000). For example, the presence of reverberation reduced the ILDs and impacted the binaural information being received by the listener, which could have made the localization judgments more difficult (Shinn-Cunningham, 2000).

Hartmann (1983) also looked at the effects of reverberation in relation to where a listener was located. The study used rapid onset and slow onset noise stimuli and the researcher found similar results to Shinn-Cunningham (2000) in regards to the effects on binaural cues. The researchers also found that the presence of reverberation alters the spectral cues used to localize a stimulus. The reflections can result in a poorer ability to differentiate sources that are presented in front or behind the listener, leading to front to back confusions (Hartmann, 1983). The alteration in binaural cues may cause listeners to perceive that a stimulus is located more medial than the actual location. These changes in binaural cues seemed to have the greatest influence when a listener was located with their ears next to a wall or if the listener was positioned in a corner of the facility (Hartmann, 1983; Shinn-Cunningham, 2000).

For the present study, Figure 8 shows the performance of each stimulus type as a function of manikin position. Looking at these patterns, opposite to expectations, there does not seem to be any systematic relationship between the proximity of the manikin (listening) position to the walls (see Figure 1). For example, performance for the impulse stimulus was relatively uniform across manikin positions. For the steady-state noise stimulus, performance was worst for manikin positions A and B, which were located near two reflective surfaces. However, performance was as high for the corner placed manikin position C as it was for manikin position E, which was placed out in open space.

Effects of Sound Source Location and Stimulus Type

Overall results showed that there was a significant effect of sound source location, as well as a significant interaction between the sound source location and the stimulus type. Follow-up analyses showed that, similar to that found for manikin position, performance for sound source locations differed across sides of the SSTF space. Unlike that found for manikin positions, however, performance for stimulus type did not significantly differ across sound source locations.

In the present localization task, correct performance requires not only localizing in the azimuth, but more importantly as a function of distance. For distance localization, the literature has shown that intensity cues are an important distance perception cue (Coleman, 1963; Grantham, 1995; Moore, 2012). In the present study, the use of intensity cues may have assisted the listener in determining if the sound source was close to them or farther away. The farther the sound source is from a listener, the more low frequency dominant the stimulus becomes. Coleman (1963) indicated that changes in spectral content occur for sounds at distances exceeding 20 to 30 feet.

Since there are several sound sources in the present study located at distances greater than 20 feet from the listener, the sounds likely varied in their spectral content, which may have contributed to where the listener perceived the stimulus (Coleman, 1963; Grantham, 1995; Moore, 2012). The cues for distance perception have been extensively researched in an anechoic environment. How these cues are affected in a reverberant environment is less understood, but in general, the presence of reflections could be an asset in distance perception (e.g. Scharine & Letowski, 2005). Reflections can last longer than the direct sound source, which may provide the listener with some information regarding the location of the sound source (Scharine & Letowski, 2005). This last point is especially important for the positioning of the sound sources in the present study. Performance was worst for sound source locations 1 and 2, and these were the sources that were positioned nearest to walls and closest to corners (see Figure 1). This positioning likely resulted in stronger reflections relative to the direct sound from the sources, which could lead to poorer localization across distance.

Previous research has also shown that reverberation can affect localization in the azimuth by causing listeners to place greater weight on specific localization cues. For example, Ihlefeld and Shinn-Cunningham (2011) found that in reverberant environments, listeners place a strong weight on ITDs, even though ILDs may be more beneficial. In addition, the presence of multiple reflections may draw a listener's attention away from the actual sound source location (Scharine & Letowski, 2005). The placement of sound source locations 1 and 2 in the present study likely increased the complexity of the reverberation and thus the quality of ITD information. Listeners may have relied too strongly on the poorer ITD information to localize the sound source, which would negatively impact performance and may explain why localization performance is poorer at sound source locations 1 and 2 in comparison to sound source locations 3 and 4.

Effects of Manikin Position and Sound Source Location

As noted, localization in the present study depends on the unique relationships between the manikin positions and the sound source locations, as well as the positioning of both relative to the reverberant space's walls. These complex relationships have the potential to alter the information available to the listener. Listeners may have to integrate different localization cues to make the localization decision as a function of distance (e.g. Coleman, 1963) and azimuth (e.g. Shinn-Cunningham, 2000). Alterations in the nature of the reflections and thus the binaural (e.g. Ihlefeld & Shin-Cunningham, 2011) and spectral information available (e.g. Hartmann, 1983) to the listener may negatively impact localization judgments.

Response Patterns

In addition to looking at the effects of the independent variables and the relationships between the independent variables, the participant's patterns of responses were also examined. Overall, the results showed that the participants were fairly accurate in their localization judgments. If the participants did not guess the correct sound source location, they often selected the other sound source location on the same side of the facility. These results indicate that the listener was aware of what side of the facility the sound source was located.

Several researchers have reported that location abilities decline in a reverberant environment (Ihlefeld & Shinn-Cunningham, 2011; Rakerd & Hartmann, 1985; Scharine et al., 2010). Evidence of this was seen in the present study with localization performance being poorer at certain sound source locations and manikin positions, particularly those located near multiple reverberant sources or located in a corner of the facility. However, the response patterns of the listeners in the present study indicate that when the listener does not guess the correct sound source location, their perceived estimate of the sound source location is not far off. Furthermore, it shows that the listener is at least aware of what side of the facility the sound source originates. These results indicate that the listener is able to extract relevant localization cues even in the presence of reverberation.

Limitations of the Study

The present study aimed to investigate localization abilities in a reverberant environment. There were, however, several limitations to the present study. These limitations include the recording method of the stimuli, the location of the sound sources, and the exclusion of manikin position F. Each of these limitations will be examined further.

Recording of the Stimuli. The stimuli used in the present study were recorded in a reverberant facility at APG. This facility is located outside and several researchers from the ARL performed the recording of the stimuli. Recall that the stimuli were recorded simultaneously at all five manikin positions at once. During the recording of one set of the impulse stimuli, one of the researchers could be heard after the stimulus ended, which resulted in five stimuli being contaminated. This was discovered half way through data collection and the stimulus files were identified. Localization performance was examined for each of the stimulus files identified and it appeared that the voice in the sound files did not affect localization performance. This was evidenced through variable performance for these sound files across participants. Furthermore, a number of participants were not aware that there was a voice in some of the sound files. Those participants who informed the researchers that a voice was present did not vary in performance from the participants who did not hear the voice. For future studies, however, the researchers should make sure that the stimuli do not contain any additional noises, which may influence localization performance.

Sound Source Locations. For the present study, there were four sound source locations used in the reverberant facility. The reverberant facility is symmetrical in regards to the layout. The location of the sound sources, however, was not symmetrical on the left and the right sides of the facility. The locations of sound sources and manikin positions were selected so the researchers could obtain information about localization performance at different sound source locations and manikin positions as opposed to examining different sound source locations for a single manikin. The researchers believed that a symmetrical set up would have resulted in redundant information, so an asymmetrical layout was chosen to reduce data collection time and participant effort. For future studies, however, it may be beneficial to have sound source locations and manikin positions similar across the facility to see how performance is affected at the different manikin positions in relation to the reverberant sources and to confirm the lack of a difference in overall acoustics between the two sides of the facility.

Removal of Manikin F. At the beginning of the study, stimuli were recorded using six different manikin positions. Following the completion of data collection, it was discovered that the stimulus files labeled and used for manikin F (see Figure 1), sound source location 2 were coded incorrectly. Manikin F was located near the center divider on the right side of the facility. The researchers decided to exclude manikin F altogether, as it would have been difficult to make comparisons between manikin positions and sound source locations when no data was recorded for manikin F, sound source location 2. It may have been beneficial to have information from manikin F to further explore if performance varied according to the different manikin positions. If manikin F were included, the study would have had three manikin positions located near two reverberant sources and three manikins located near one reverberant source. This may have provided the researchers further information about the effects of reverberation on auditory localization performance.

Clinical Relevance

The present study showed that localization performance is affected by the presence of reverberation through reflective surfaces. These results may be beneficial for listeners in everyday environments, particularly soldiers working in urban, reverberant environments. If further information is obtained about how different stimuli are affected in a reverberant environment, potential strategies could be provided to the soldiers to help locate where sounds originate. If such strategies were developed, it may help soldiers defend themselves from the enemy when they are operating in some of these urban, reverberant environments.

Recall that it was the hope of the researchers to use auditory localization performance information to assist soldiers who are operating in these complex, reverberant environments. In addition to the application to the military, the results of this study also provide some evidence for preferential seating in classrooms. Acoustics in many classrooms are poor, which may negatively affect a child's ability to hear the teacher. This is especially true if a child has hearing loss. The results of the present study showed that localization abilities for listeners with normal hearing were poor when the sound source was located near two reverberant sources. Furthermore, localization abilities were the greatest when the listener was located in more of an open environment (e.g. Manikin D). Knowing where a sound is located within an environment and using that information advantageously are two separate issues, but it is reasonable to expect the difficulty in one aspect can lead to difficulty in another. In the educational setting, the teacher may use techniques to reduce distortion present in the signal. This may be done by placing children away from the walls in the classroom. Furthermore, the teacher may improve the students' ability to attend to his or her instruction by not standing near two reverberant sources when instructing students.

Future Directions

The present study provided valuable information regarding the effects of reverberation on auditory localization abilities. This information could be used to help soldiers in the environments in which they operate. Further examination of how reverberation affects localization abilities, in particular the effects of the different stimuli used, could be obtained from the recordings used in the present study. For example, the spectral content of the different stimuli at the different manikin positions and sound source locations could be examined. Performing an analysis on the different stimuli may provide researchers with specific information regarding how the reverberation impacted the spectral content of the stimulus. If the effects of reverberation on the stimulus are understood, the researchers may be able to hypothesize what is driving listeners' localization judgments.

Conclusions

Reverberation negatively impacts a listener's ability to accurately identify the location of a sound source. Results from this study suggest that sound sources located closer to reflective surfaces result in poorer localization accuracy than sound sources located away from reflective surfaces.

APPENDIX A

TOWSON UNIVERSITY

Date: Wednesday, August 21, 2013

APPROVED AUG 21 2013 TOWSON IRB

NOTICE OF APPROVAL

TO: Sara Bernhard **DEPT:** ASLD

PROJECT TITLE: *Auditory Localization of Steady State and Impulse Sounds in an Urban Relevant, Reverberant Environment*

SPONSORING AGENCY:

APPROVAL NUMBER: 14-A006

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: 21-Aug-2013

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

, MPA (Sor)

Elizabeth Katz, Member

Towson University Institutional Review Board

APPENDIX B

TOWSON UNIVERSITY

Department of Audiology, Speech-Language Pathology, and Deaf Studies

INFORMED CONSENT FORM

Project title: Auditory Localization of Steady State and Impulse Noise in an Urban Relevant, Reverberant Environment

Principal Investigator:

Sara K. Bernhard
sara.k.bernhard@gmail.com

Faculty Sponsor

Jennifer Smart, Ph.D.
Towson University
Dept. of ASLD

8000 York Road
Towson, MD 21252
(410) 704-3105
JSmart@towson.edu

Purpose of the Study:

This study is designed to evaluate listening abilities in a poor listening environment. Particularly, the ability to identify where a sound is coming from will be examined. Listening abilities, using impulse sounds (e.g. gunshot) and continuous sounds (e.g. white noise), will be assessed from different locations within a virtual environment.

Procedures:

If you take part in this study, a series of assessments will be performed. The study will consist of one session, which should take an hour and a half. During this session, you will receive a free hearing screening. If the hearing screening reveals non-normal hearing, you will be excluded from the remainder of the study and you will be referred to an audiologist for a complete audiologic evaluation. If you pass the hearing screening, you will be able to participate in a series of listening tasks. For the listening tasks, a mock test facility will be shown on a computer screen. The mock test facility will show your location in the facility and four different loudspeaker locations. A sound will be presented and it is your responsibility to pick the location the sound originated. You will participate in a block of trials for the impulse sound and a block of trials for the continuous sound. All testing will be performed at the Hearing and Listening Lab (HALL) in Van Bokkelen Hall on Towson University's campus.

Risks/Discomfort:

There are no known risks for participating in this study. The tests included in this study are a part of routine clinical and research test batteries. It should be noted that some of the sounds presented through the earphones may be perceived as "loud" but none of the sounds will be presented at a harmfully loud level. Additionally, a hearing loss may be uncovered during the hearing screening portion of this research project and the discovery of a hearing loss may be upsetting. The principal investigator will discuss the results of the hearing screening with you and you will be referred for a complete audiologic evaluation to further investigate a hearing loss. You may go to an audiologist of your choice for the evaluation or contact information for the Towson University Speech, Language, and Hearing Center will be provided. Contact information for the Towson University Counseling Center will also be provided.

Benefits:

The results from this research study will have no direct benefit to you. Results from previous research studies do not provide a clear picture regarding listening abilities in a poor listening environment. This study will help researchers to develop a further understanding about how human listening abilities are affected by sound type and listener position in a poor listening environment. These findings can then be used to make predictions about how soldier listening ability might be affected in the urban environments that they operate.

Alternatives to Participation:

Participation in this study is voluntary. You are free to withdraw or discontinue participation at any time.

Cost Compensation:

Participation in this study will involve no costs or payments to you.

Confidentiality:

All information collected during the study period will be kept strictly confidential and will be located in a locked cabinet in the Hearing and Listening Laboratory (HALL). You will be identified through identification numbers. No publications or reports from this project will include identifying information. If you agree to join this study, please sign your name below.

_____ I have read and understood the information on this form.

_____ I have had the opportunity to ask questions about the information on this form.

____

Participant's Name (printed)

____

Participant's Signature Date

____

Principal Investigator Date

If you have any questions regarding this study please contact the Principal Investigator, Sara K. Bernhard, email: sara.k.bernhard@gmail.com, the Faculty Sponsor, Dr. Jennifer L. Smart, phone: (410) 704-3105 or email: JSmart@towson.edu or the Institutional Review Board Chairperson, Dr. Patricia Alt, Office of University Research Services, 8000 York Road, Towson University, Towson, Maryland 21252; phone (410) 704-2236.

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

APPENDIX C

TOWSON UNIVERSITY

Do You Have Normal Hearing? Are You Between The Ages Of 18 And 40?

If you answered "yes" to these two questions, your participation in this hearing research study would be greatly appreciated!

Purpose of the Study:

This study is designed to evaluate listening abilities in a poor listening environment. This study is being performed in conjunction with the Army Research Lab (ARL) at the Aberdeen Proving Grounds (APG). The results from this study may be used to make predictions about how soldier listening ability might be affected in the urban environments that they operate.

Procedure for the Study:

All testing will be conducted in the Listening and Hearing Laboratory (HALL) in Van Bokkelen Hall, which is located on Towson University's campus. Each participant will receive a free hearing screening and participate in a series of computer games. The study is expected to take approximately an hour and a half. If you would like more information, please contact:

Sara K. Bernhard (Principal Investigator) at sara.k.bernhard@ gmail.com

Dr. Jennifer Smart (Faculty Sponsor) at JSmart@towson.edu

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

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CURRICULUM VITA

Sara K. Bernhard

[redacted]

Audiology

Doctor of Audiology (Au.D.), Expected May 2015

Education:

TOWSON UNIVERSITY – Towson, MD
Doctor of Audiology (Au.D.), August 2011 - Present
Anticipated graduation: May 2015

THE PENNSYLVANIA STATE UNIVERSITY – State College, PA
Bachelor of Science in Communication Sciences and Disorders, May 2011

Clinical Experience:

JOHNS HOPKINS HEARING CENTER – Baltimore, MD
Audiology Student Clinician, January 2014 – May 2014

ENTAA CARE– Columbia, MD & Glenn Burnie, MD
Audiology Student Clinician, August 2013 – December 2013

THE HEARING AND SPEECH AGENCY – Baltimore, MD
Audiology Student Clinician, June 2013 – August 2013

HARMONY HEARING AND AUDIOLOGY – Bel Air, MD
Audiology Student Clinician, January 2013 – May 2013

TOWSON UNIVERSITY SPEECH, LANGUAGE & HEARING CENTER – Towson, MD
Audiology Student Clinician, January 2012 – December 2012

Research Presentations

MARYLAND SPEECH LANGUAGE HEARING ASSOCIATION (MSHA) 2014 ANNUAL CONVENTION- Towson, MD
Poster Sessions, April 2014

AUDIOLOGYNOW 2014 – Orlando, FL
Student Research Poster Forum, March 2014