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LOCALIZATION ABILITIES OF PERSONAL AUDIO DEVICE USERS

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ABSTRACT

Portable audio devices are frequently used in loud background noises (such as street noise). In such situations, listeners increase volume levels in order to maintain an adequate music-to-noise ratio. This study assessed the preferred listening levels and the ability to detect and spatially localize an environmental sound (a horn honk) while listening to an MP3 player in two background noise conditions (ambient room noise and 70 dBA traffic noise).

Participants were 20 normal hearing young adults who regularly used MP3 players to listen to music. Real-ear measures of preferred listening levels and a localization task were conducted in these listening situations with three different headphones as well as in an open ear condition.

On average, listeners increased the music levels by 28 dB in the traffic noise (with smaller increases with noise-reducing insert earphones) and had significantly more localization errors in traffic noise regardless of the type of headphones worn.

KEYWORDS: Personal Audio Devices, Localization, Preferred Listening Levels.

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CHAPTER 1: INTRODUCTION

Noise, whether environmental, occupational, or recreational in nature, can be hazardous to the hearing health of humans by causing noise-induced hearing loss (NIHL) (Bistrup, Babisch, Stansfeld, & Sulkowski, 2006; Gershon, Neitzel, Barrera, & Akram, 2006; Hwang et al., 2001; Maassen et al., 2001; May, 2000). NIHL, which generally affects the frequency region around 4000 Hz first, is sensorineural in nature and develops gradually over time as a result of extended exposure to high intensity sounds. Sounds that exceed an average of 80 dBA are generally considered potentially harmful with sufficient exposure. (Rabinowitz, 2000)

Permanent and irreversible damage to hearing is possible with prolonged exposure to loud sounds such as music, which is a popular source of recreational or leisure noise (Cheesman, Ciona, Mendoza, & Grew, 2001). Because of the associated potential for NIHL as a result of listening to loud music, portable audio devices (PADs) such as portable compact-disc players, or the more current MP3 players such as Apple iPods, have been the focus of recent research (Ahmed, King, Morrish, Zadzewska, & Pichora-Fuller, 2006; Fligor & Cox, 2004; Fligor & Ives, 2006; Hodgetts, Rieger, & Szarko, 2007; Mostafapour, Lahargoue, & Gates, 1998; Portnuff & Fligor, 2006; Serra et al., 2005; among others). In response to concerns about listening levels with PADs, particularly in noisy environments, noise attenuating and noise occluding headphones are available. The ability to detect and spatially localize important environmental sounds (such as a honking car horn and other warning signals) while using PADs coupled to headphones is unknown. This study sought to assess the sound localization abilities of

PAD users, taking into account their preferred user settings and common situations and environmental conditions to which users are exposed.

1.1 TECHNOLOGY AND TRENDS OF USE

Developments in technology have allowed PADs to become increasingly more portable due to their small size and more personalized to each individual user, by allowing them to upload hundreds to thousands of MP3 music files. With battery life generally exceeding eight hours, users may listen to these devices for extended periods of time. This has motivated current researchers to investigate the output of PADs and the headphones coupled to these devices (Fligor & Cox, 2004; Portnuff & Fligor, 2006), as well as the trends of use pertaining to volume levels, length of use, and the environments in which they are used (for example, in quiet vs. noisy environments) (Ahmed et al., 2006, Fligor & Ives 2006; Hodgetts et al., 2007; Williams, 2005).

1.1.1 Technology

1.1.1.1 *Output levels and recommended use*

The measurement of output levels of PADs and headphones used with these devices has helped researchers come up with recommended listening levels. Portnuff and Fligor (2006) measured the output levels of five MP3 devices (The iPod, iPod Mini, iPod Nano, Sandisk Sansa and Creative Zen Micro) and found that the devices all had similar output levels, especially at the highest volume control settings. Based on these measurements, a general guideline for recommended daily use was calculated: with the volume set at 70%, a listener can use the device for 4.6 hours without exceeding a specified daily noise exposure level that exceeds a time-weighted average of 85 dBA, in compliance with the National Institute for Occupational Safety and Health (NIOSH) guidelines (NIOSH, 1996). These NIOSH guidelines recommend an exposure limit of 85 dBA for an 8 hour time-weighted average. However, when increasing the volume to 100%, it is recommended that a listener use the device for no more than five minutes. Fligor and Cox (2004) found similar results when testing the output levels of various personal CD players. All devices in both of these studies were capable of producing dangerous outputs at the highest volume settings.

1.1.1.2 *Headphones*

Fligor and Cox (2004) also investigated how the type of headphone coupled to portable CD players affects the output presented to the listener's ear canal. They found a general trend that higher output levels were produced as the headphones were reduced in size. Ear-bud style earphones, which in today's society are seen frequently and are included with most PAD units, rest closer to the tympanic membrane than circumaural and other over-the-ear style headphones. This closer proximity creates a smaller volume of air in the ear canal, and less force is needed to create a high level of pressure on the tympanic membrane.

A recent study by Hodgetts et al. (2007) investigated preferred listening levels (PLLs) while listening to music on an MP3 player coupled to ear buds and over-the-ear headphones. Results concur with the findings by Fligor and Cox (2004) in that participants selected a significantly higher PLL when listening with the ear bud earphones.

Should a user couple an ear bud earphone to a PAD that is capable of dangerously loud outputs, it may seem that a greater risk of damage to hearing may be indicated; however, users may adjust the volume setting of the PAD to maintain a constant ear canal intensity (Fligor & Ives, 2006).

1.1.2 Trends of Use

1.1.2.1 *Length of Use*

In surveys of university and highschool students, Ahmed et al. (2006) and Zogby (2006) reported similar typical lengths of iPod listening sessions. The majority (approximately 60%) used their iPods for 1 hour or less in a typical listening session. Approximately 30% of both groups listened for 1 to 4 hours, and only 10% or less listened for 4 hours or more.

1.1.2.2 *Volume levels*

There is an undeniable risk of NIHL if a user were to listen to his/her PAD at 100% volume for 40 hours a week. However, PAD users are not listening for extended periods of time, and recent research has revealed that only a small percentage of young people listening to PADs are placing themselves at risk for NIHL when using these devices in quiet environments. The situation changes in noisy environments, where listeners increase the volume of their device to maintain an adequate music-to-noise ratio (Ahmed et al., 2006; Fligor and Ives, 2006; Hodgetts et al., 2007; Williams, 2005). Fligor and Ives (2006) investigated the listening habits of 100 doctoral students using iPods under varying conditions of background noise levels. The participants were seated in a sound attenuating test booth and recorded noise, of both simulated and real-world sounds, was presented over the loudspeakers. Under each noise condition, using four styles of headphones of varying degrees of sound isolation, the participants were instructed to adjust the volume on the PAD to the level they prefer. In the quiet condition only 6% of participants adjusted the volume to dangerous levels (defined here as a listening level of 85 dBA in the sound field or higher), whereas in the presence of 80 dBA background airplane noise, the number of at-risk listeners increased to 80%.

These results were obtained by using a probe-tube microphone set-up and conducting real-ear measurements that were then converted to sound field equivalent levels. Depending on the frequency content of a sound, the measured sound pressure in a person's ear canal may be 12 to 17 dB higher than the equivalent measurement in the sound field. This real-ear enhancement of sound levels is caused by the natural amplification provided by the human ear canal acoustics (Shaw, 1966). Because standards for noise exposure are referenced to the sound field, the conversion implemented by Fligor and Ives (2006) is necessary, should an assessment of risk for noise-induced hearing loss be required. Sound intensities are referenced to either a position adjacent to the ear canal opening or to the position where the listeners head would be, while the listener is not present (ISO 1999, 1990). Equivalent damage risk criteria for real-ear measures have not been established.

In an investigation of the listening habits of 24 undergraduate students, Ahmed et al. (2006) found similar results to those of Hodgetts et al. (2007). Listeners were instructed to adjust the volume setting on an iPod to their PLL under varying levels and types of background noise. Preferred levels were recorded and outputs were presented to a Brüel and Kjær Sound Quality Head and Torso Simulator (HATS type 4128-C-001) via headphones. Output levels were measured using binaural probe-tube microphones and

Zwislocki couplers to simulate the actual sound pressure level exerted on an individual's tympanic membrane. Background noise conditions included low-level and high-level multitalker babble, low-level and high-level traffic noise, and quiet (ambient room noise). Low-level and high-level conditions refer to an A-weighted sound pressure level of 50 dBA and 70 dBA, respectively, as measured in the sound field. An average output music level of 67.6 dBA was selected by listeners; however levels varied significantly depending on the background noise condition. PLLs were significantly higher in the high-level noise conditions than the low level conditions. Similar music output levels of 71.7 dBA in multitalker babble and 73.3 dBA in traffic noise were measured in the high-level conditions; however, within the low-level conditions, the music output measured in low-level traffic noise (67.2 dBA) was significantly higher than in the quiet (62.1 dBA) and low-level babble (63.4 dBA) conditions.

1.1.2.3 *Location of use*

The situation in which PAD users wear their devices may influence their PLLs and communication needs. Twenty percent of participants reported that the most common situation in which they use a portable audio device is when they are commuting and 35.1% reported that they frequently used a portable audio device while travelling (by bus or car) (Ahmed et al., 2006). Depending on the traffic flow, traffic noise levels may be measured above 100 dBA (Chakrabarty, Santra, Mukherjee, Roy, & Das, 1997; Onuu, 2000) and subway platforms and bus stops have been measured to have maximum levels of 106 and 89 dBA, respectively (Gershon et al., 2006). Therefore, wearers may be using their devices in the very situations which would cause them to significantly increase the volume on their PADs. Media reports suggest heightened risk to pedestrians who may try to cross the street while wearing their PADs since listeners are less aware of vehicles approaching and their direction. One New York City Senator has even proposed legislation to ban the use of portable electronic devices, including personal audio devices, for pedestrians while crossing the street (Zeller, 2007).

1.1.2.4 *Subjective Listening Problems*

Ahmed et al. (2006) asked 123 students who owned a PAD if they experience communication problems when wearing their device. The students were asked to report on five different communication situations: hearing the doorbell, talking on the phone, hearing someone who is whispering, talking in quiet, and talking in noise. Eighty percent of these students reported communication problems in all of these situations. The majority of students also reported a frequent need to adjust the volume on their device in response to environmental changes (i.e. an increase or decrease in background noise level) in order to maintain adequate listening levels for their music. This subjective report was supported by the objective data collected in varying background noise conditions.

Many users are aware of the need to increase PAD volume when listening in noise and use noise-cancelling or noise-occluding headphones. These transducers can attenuate noise by forming a tight seal in the ear canal (passive attenuation), or may reduce noise electronically through phase cancellation or other techniques (active attenuation). Phase cancellation headphones monitor the external noise, and electronically produce a signal opposite in phase, thus cancelling the original signal and eliminating background noise. Zogby (2006) reported that only 23% of students and 19% of adults had purchased specially designed earphones to reduce ambient or distracting noise. With the increased popularity of PADs and widespread media attention given to the hazards of high output levels from PADs, these headsets are expected to increase in popularity.

CHAPTER 2: MOTIVATION AND STATEMENT OF QUESTION

2.1 MOTIVATION FOR THE RESEARCH

As outlined above, PAD users are using their devices in situations of loud background noise, which results in the increase of volume levels to maintain an adequate music-to-noise ratio. Selection of noise-occluding headphones is one way to deal with the annoyance of background noise. Research has shown that using headsets of varying degrees of sound isolation can reduce the necessity to increase volume levels since the noise is not masking the music as it may with inexpensive, non-noise-occluding headsets such as the ear bud style earphones that come with the purchase of the majority of PADs sold. Fligor and Ives (2006) reported on four different types of headsets and found that each occluded the ear canal to a different degree, thus providing different amounts of sound isolation. The Etymotic Research ER-6i in-the-ear earphone provided the most amount of isolation (25 dB) and the Apple iPod ear-bud provided the least (1 dB). An over-the-ear headphone (Koss KSC11) provided 2 dB of sound isolation, which is only slightly more isolation than the iPod ear-bud and an in-the-ear Sony earphone (MDR-EX51LP) provided 9 dB of isolation.

Sound isolation may impact PAD users in ways of which they may not be aware. Listeners may be motivated to purchase noise-reducing headsets to block out the noise and people around them and may also be concerned about the need to increase the volume levels on their devices in noisy environments. They may feel that they are protecting their hearing by purchasing noise-reducing headsets in order to maintain an acceptable music-to-noise ratio in noisy environments without having to increase the volume to a dangerous level. However, this also results in the listener being isolated from environmental noises. As a result, listeners may be putting themselves at risk of not being able to detect and locate important environmental warning signals, such as a horn honking, the location of an oncoming vehicle, or a shout of warning, that may alert them to potentially dangerous situations.

2.2 STATEMENT OF QUESTION

This study compared localization abilities in ambient room noise and amidst 70 dBA of traffic noise in the sound field and sought to answer the following question: While listening to music on a PAD, what are the effects of headphone type and background noise level on sound localization abilities and PAD output levels?

2.3 BACKGROUND INFORMATION:

2.3.1 Sound localization

Sound localization is the ability of a listener to spatially locate the direction of a source. This is a complex perceptual construct that involves three different coordinates: the horizontal coordinate, elevation, and distance of the sound source (Middlebrooks & Green, 1991). The horizontal coordinate, or azimuth, is the measure of angle of deviance from which the sound source originates as referenced to the listener facing forward (zero degrees azimuth). The elevation of the source is used to identify whether a sound is coming from above or below ear level, and distance is the estimate of distance of the sound source from the listener's ears.

Different cues are available to the listener to perceive these three coordinates. The listener uses interaural difference cues to perceive the azimuth of the source stimulus in the horizontal plane. The head shadow effect (when the listener's head interferes with the path of the stimulus to the far ear) essentially shadows the ear furthest from the sound source, resulting in an interaural level difference (ILD), depending on the frequency of the source stimulus. High frequency stimuli have short wave lengths and are affected more by ILDs than low frequency stimuli, which may have wavelengths that are greater than the dimensions of the head and can overcome the interruption created by the location of the head (Middlebrooks & Green, 1991). Because of the longer wavelengths of the low frequency sound waves, the localization of these stimuli in the horizontal plane relies more on interaural timing or phase differences (IPDs). One ear will receive the stimulus first and then the low frequency signal travels around the head to reach the far ear (Middlebrooks & Green, 1991).

The cues used to perceive distance of a sound source are complex and not well understood. Human listeners do not localize distance well and little research has been done on the use of potential localization cues (which may include such cues as sound frequency, intensity, and reflection of sound energy) (Middlebrooks & Green, 1991).

As sound energy reaches the pinna and ear canal, it is reflected in different ways depending on the location and spectral information of the source, and the shape of the ear structures. Frequency and resonance cues of the external ear canal and pinna are used to perceive the elevation of the source. With ILDs and IPDs being constant, spectral shape cues result because the shape of the pinna and ear canal will reflect a source stimulus along various paths towards the listener's tympanic membrane (Middlebrooks & Green, 1991).

2.3.2 Degradation of Localization Abilities

Interference of the incoming sound by the addition of background noise or the attenuation of the sound source via hearing protection, can interfere with the ability to process these complex cues and localization abilities may be degraded (Getzmann, 2003; Noble, Murray & Waugh, 1990). Wearing hearing protection devices (HPDs) not only attenuates the sound source, but also occludes portions of the ear and can interfere with the natural shape of the pinna and ear canal, which can affect localization abilities (Roffler & Butler, 1968). Because headphones also obstruct the ear canal and provide sound isolation (although, often to a lesser degree than HPDs), it is expected that wearing headphones may also result in the interference of localization cues, thus leading to degradation of sound localization abilities. As noted, the role of the pinna is primarily focused on the elevation of the source, however malformations or obstructions of the pinna may also impact localization on the horizontal plane, especially front-back confusions (where the signal is misidentified as being from the front) in which localization relies heavily on high frequency spectral cues produced by the pinna and ear canal (Vause & Grantham, 1999). This type of confusion is of particular relevance for PAD users as they may misidentify the location of an approaching hazard. The degradation of localization abilities as well as other implications for personal safety when isolated from environmental sounds has been well documented (e.g. Laroche, Ross, Lefebvre, & Larocque, 1995).

Research investigating the concept of detecting and localizing important environmental signals while under varying degrees of occlusion has mainly been investigated from the perspective of HPD use in the context of occupational noise environments. Noise has been proven to cause damage to hearing, which has led to noise exposure regulations mandating the use of HPDs under certain noise conditions in many occupational settings, such as construction sites and factories (ISO 1999, 1990). These regulations are put in place to protect the employee from the potential irreversible damage to hearing; however studies have shown degradation of localization abilities is associated with the use of HPDs, which occlude the external ear canal and often cover the outer ear (Berger, 2003; Boila & McKinley, 2000; Laroche et al., 1995; Robinson & Casali, 1995; Simpson, Bolisa, McKinley, & Brungart, 2005). In fact, higher workplace accidents have been recorded in cases of HPD use, due to the degradation of localization abilities, both in azimuth and elevation (Laroche et al., 1995). Additionally, higher front-back localization errors have been shown to occur when HPDs are used (Vause & Grantham, 1999). In general, HPDs are designed to provide various levels of protection, with noise reduction ratings ranging from 15 to 30 dB; however, when HPDs are used in real-world situations, employees were only able to achieve attenuation results ranging from 2 to 15 dB (Berger, 2003). Therefore, noise-reducing headphones may be comparable to HPDs as used in the real-world, which would indicate a potential degradation of localization abilities, and a risk to PAD users.

2.4 HYPOTHESES

In summary, the following hypotheses are made regarding the listening levels and localization abilities of PAD users:

1. Listeners will increase the volume setting of their device to maintain an adequate music-to-noise ratio in the Traffic Noise condition.
2. Noise-Reduction insert phones will be adjusted by listeners to produce lower sound pressure levels in the ear canal because they are blocking out the surrounding traffic noise and therefore can have lower sound pressure level in the ear canal and yet a good music-to-noise ratio.
3. Due to the presence of music in the ear canal and the potential for some attenuation of background noise, listeners will have increased localization errors.
4. Headphones that provide greater attenuation of environmental sounds will yield a higher percentage of localization errors.
5. Front-back confusions will increase with the presence of music in the ear canal, as well as with the addition of traffic noise.

CHAPTER 3: METHODS

The following methodology was approved by the Research Ethics Board of the University of Western Ontario (Appendix A). Participants were recruited by responding to posters that were affixed in various locations at the University of Western Ontario (Appendix B). Upon stating their interest, an electronic letter of information was sent to all interested parties (Appendix C). This letter was again presented to each participant upon arrival for the test session at which time a consent form was signed (Appendix D).

3.1 PARTICIPANTS AND SELECTION CRITERIA

Participants (N=20) were normal hearing young adults, aged 21 to 30. Sample size was selected based on a sample size estimation, calculated using the Horatio software (Lee, 2004). This program identified that 20 subjects should reveal a medium within-subjects effect size ($r^2 = .12$), with an alpha level of .05 and a power of .90, across two independent variable levels. A medium effect size was chosen for the purposes of this study because the effects of PAD use on localization abilities are not yet established in the literature.

As mentioned above, all participants had thresholds within the limits of normal hearing, as determined by the successful completion of an acoustic immittance screening and a hearing screening at .5, 1, 2, and 4 kHz at a level of 25 dB HL. Participants also each owned and used a PAD for the purpose of listening to music.

Each participant completed a hearing history survey, with information regarding their personal listening habits, hearing health and noise exposure history (Appendix E). For the purposes of this study, this information was collected to verify that each participant owned and used a PAD on a subjectively regular basis, but no analysis was conducted on the participants' responses, which can be found in Appendix F.

3.1.1 Unsuccessful candidates

Two additional participants were not included in the data set. One did not successfully pass the hearing screening and the other had inadvertently been informed of procedural information to which participants were meant to be blinded.

3.2 OVERVIEW OF TASKS AND MEASUREMENTS

Upon successfully meeting all of the inclusion criteria, participants then took part in two stages of data collection: real-ear measurements of their PLLs and a sound localization task.

For all tasks and measurements, participants were seated in the centre of a 64-speaker array in the Beltone Anechoic Laboratory, which is a hemianechoic chamber. The centre of the speaker array places the participant at a distance of 1.5 metres from all speakers. Stimuli and environmental noises were presented via a 360° subset of 8 speakers (Appendix G), separated by 45° and located on the horizontal plane at the height of the listener's ear. Participants were notified of the height of the target speakers, but were not informed that only 8 speakers were active during testing. All tasks were completed by each participant in one session of less than 1.5 hours.

3.2.1 Stimuli and Conditions

This study was designed with two independent variables: background noise and headphone type. Background noise conditions consisted of the Quiet condition (ambient room noise of 30 dBA or less) and the Traffic Noise condition of 70 dBA recorded traffic noise as measured in the sound field. The anechoic chamber was calibrated for this signal (with a tolerance of ±3 dB due to the variability in amplitude of the traffic signal) by a microphone suspended at the approximate location of the participant's head and pink noise as the stimulus. All tasks were completed under these two environmental conditions and across four headphone conditions (Table 1).

The level of traffic noise (70 dBA) was selected based on results from Ahmed et al., (2006) which indicated that it is around this level where background noise affects user PAD volume control preferences, in that listeners increase the volume on their PADs in order to maintain an adequate signal-to-noise ratio.

For the sound localization task, the target stimulus was a recorded horn honk presented amidst the 70 dBA background noise, at a signal-to-noise ratio of 10 dB on average, roving over a ±3 dB range.

3.3 EQUIPMENT AND SONG SELECTION

During the tasks and recordings, except while under the open-ear condition, participants listened to music (at their PLLs) via the various types of headphones. A sufficient number of popular music files (purchased from the online music store, iTunes) and were post-processed to ensure that each file was relatively continuous in amplitude across time and that all files were matched in volume. A 60-second portion of each of the

Table 1. Headphone and Background Noise Conditions

Headphone Type	Open Ear Canal	No headphone
	Ear-Bud	Samsung EP370 earbuds
	Over-The-Ear	Sony Stereo headphones (MDR210LP)
	Noise-Reduction inserts	Skullcandy Smokin Buds (SCUDP)
Background Noise*	Quiet	< 30 dBA ambient room noise
	Traffic Noise	70 dBA traffic noise recording

*As measured in the sound field.

processed songs was stored in the PAD and participants chose one song to listen to throughout the test session (See Section 3.3.2, below).

3.3.1 Audio Equipment

The sole criterion for the choice of PAD used for this project was that the volume setting on the PAD must be displayed in numerical format, so the setting could be recorded in the initial measurements of PLLs and real-ear measures and then reproduced for the localization portion of the study. For this reason, the Samsung YP-T9JBQP was selected for use in this project. This PAD was also considered reasonably priced (approximately $125.00) and manufactured by a well-known company, lending to the practicality of selecting this particular device for the project.

Three transducers were selected for this project: Samsung EP370 ear-buds, Sony MDR 210-LP over-the-ear headphones, and the Skullcandy Smokin' Buds noise-reducing SCBUDP insert earphones. After an internet search, of widely available inexpensive transducers, these transducers were selected for the following reasons.

The EP370 ear-bud style earphones were supplied with the purchase of the Samsung MP3 player and were selected for this project since it can be assumed that many people who purchase PADs may choose to simply use the earphones provided with their device. The Sony MDR 210-LP over-the-ear headphones were selected based on several media reports suggesting that using over-the-ear headphones is a good alternative to the ear-bud style phones which are closer to the ear drum and can increase pressure in the ear canal (Canadian Broadcasting Corporation, 2006; Oswald, 2006) and their increasing popularity among MP3 users.

Based on reports that PAD users may choose to purchase noise-reducing or noise-cancelling varieties of headphones (Zogby, 2006), the Skullcandy Smokin' Buds were selected. These earphones are marketed as noise-occluding earphones and form a seal in the ear canal of the user with a single soft rubber flange. Three different size rubber seals were provided with the purchase of these earphones, and the most appropriate size for each participant was used.

3.3.2 Music Selection

Participants were required to select a song to listen to throughout the real-ear measurements and localization tasks. They were provided with a list of eleven songs of various genres from which to choose (Appendix H).

Songs were selected based on published lists ranking the popularity of songs as reported on the websites for three local radio stations on Wednesday, August 7th, 2007 (Appendix I). The top five songs from each radio station at that time were selected and using Audacity software, the amplitude over time was normalized. These fifteen songs were then inspected for breaks or quiet periods in the file. Songs with quiet periods were eliminated in order to avoid altered performance on the localization task should the target stimulus be presented at the precise moment a quiet period begins, resulting in the eleven songs used in this study.

3.3.3 Sanitization Procedures

To sanitize the equipment used by each participant, disinfectant wipes were used on all hard surfaces that contacted the participants' ears after each session. Single-use probe tubes were used for the real-ear measures. All foam earphone and immittance tips used for screening purposes were sterilized using an autoclave.

3.4 DATA COLLECTION

3.4.1 Stage 1: Real-ear measurements

Otoscopy was performed to ensure the ear canal was free of any cerumen or debris. An ER-7C probe tube microphone system was placed in the left ear canal of each participant, medial to the output of the earphone. Probe tubes were marked at a length of 28mm for females and 30mm for males. The probe tube was inserted so the marker rested in the intra-tragal notch. Otoscopy was performed a second time to verify that the tip of the probe tube was within 5mm from the participant's tympanic membrane (Audioscan, 2007). A piece of surgical tape was used to secure the position of the probe tube to ensure the placement was maintained with each change of headphone. SpectraPlus software was used to store the microphone data and post-process the sampled data.

In total, eleven measurements were made for each participant (Appendix J). Measurements in the open ear canal were recorded in both background noise conditions (Quiet and Traffic Noise) in order to serve as a baseline for comparison with the three headphone types. PLLs for music as well as a measure of the noise reduction provided by each earphone type were measured using the probe tube system. Measurements were recorded using an A-weighting filter in the SpectraPlus software.

3.4.1.1 *Attenuation*

Attenuation measurements were done with the participant in the centre of the speaker array with 70 dBA of traffic noise presented over the two lateral speakers. A measurement of the sound pressure in the ear canal in the open ear condition was made. With no music playing on the PAD, this measurement was then repeated with each of the headphones under the same noise condition. The difference between these two measures yielded a measure of the traffic noise attenuation provided by each earphone.

3.4.1.2 *Preferred Listening Levels*

Output levels of the PAD (as adjusted by each participant) in the ear canal were measured across all conditions. Beginning with their chosen song at a volume level of 0 ("mute"), the participants were instructed to adjust the volume to "where it sounds best to you." Participants were not able to see the numerical volume display on the PAD during this time. Under each headphone condition, the ear canal sound levels were measured and the numeric volume setting of the device was documented (Appendix K) and used to set the volume control for the sound localization task.

Every effort was made to ensure the participant understood to select a volume setting (without seeing the display screen on the PAD) where the music 'sounded best.' One participant did select the maximum volume setting in one condition (Noise-Reduction inserts in Traffic Noise). When the maximum value was noted, the participant was asked if this was where it sounded best, or would she prefer it louder if possible. T' participant confirmed that this was the chosen level and she would not increase the volume even if it were possible.

3.4.2 Stage 2: Sound Localization Task

In the centre of the speaker array and while listening to the PAD with the volume adjusted to their PLL, participants began by facing forward (zero azimuth) in a chair that swivels 360°. They were fit with a head-worn LED and sensor tracking device and provided with a hand-held response button. Participants were instructed to turn their head to face the speaker (shining the LED on the speaker) from which the horn was heard. They then pushed the response button to record their response (in degrees, as referenced to zero azimuth). To activate the next target stimulus, the participant then returned to face the zero azimuth position. Once returned to this starting position, there was a 600 ms delay before the next target stimulus was presented. This procedure has been used successfully in a previous localization study with both adults and children (Crukley, 2007).

3.4.2.1 *Task Training*

A block of training familiarized the participant with the method of spatially locating a target stimulus and indicating their desired response location. With open ear canals (no headphones) and in the quiet condition, three blocks of 10 target stimuli were presented via the subset of eight speakers. The stimulus used was a 65 dBA pink noise burst. See Appendix J for training procedure outline.

3.4.2.2 *Sound Localization Task*

To ensure participants were able to detect the horn honk target stimulus under each condition, a trial of five targets was presented via the speaker located at zero azimuth. Participants were instructed to press the response button to indicate they heard the target. Had the participant not been able to detect these sounds, they would not have been required to complete the localization portion of the study. However, all participants were able to detect all stimuli and so continued to complete the localization task.

Participants were randomly presented with the horn honk stimulus three times via each of the 8 speakers under each of the background noise and headphone conditions. Using the method outlined above (Section 3.4.2.1), they indicated where they believed the target stimulus originated. In total, under each condition, 24 targets were randomly presented (three from each speaker). Appendix J provides a summary of the localization procedure.

CHAPTER 4: ANALYSES AND RESULTS

4.1 ANALYSES

Real-ear measurements results for the PLLs and a computation of the overall attenuation of traffic noise are reported in A-weighted sound pressure levels (dBA). Sound localization responses were quantized such that any response that was 22.5° or more from the source speaker was scored as an error (i.e. within ± 22.5° of the next nearest sound source). Sound localization task results were computed for the overall number of errors and Front-Back and Left-Right (lateralization) error patterns. Front-Back confusion counts were based on the presentation of stimuli from the speakers in front of and behind the two lateral speakers (Figure 1). Left-right confusion counts were based on the presentation of stimuli from the six speakers to the left and right of the participant (Figure 1).

Repeated measures analysis of variances (ANOVA) were performed to investigate real-ear measurements and sound localization abilities across the two independent variable conditions (headphone type and background noise). Bonferroni corrections were used for post-hoc tests, as needed.

4.2 RESULTS

4.2.1 Stage 1: Real-ear Measurements

All reported sound pressure levels were measured in the ear canal. Open ear measures and all PLL results were recorded from all 20 participants. Attenuation results were recorded from 19 participants due to a change in protocol after the first session of data collection. The change resulted in attenuation data being collected in the Traffic

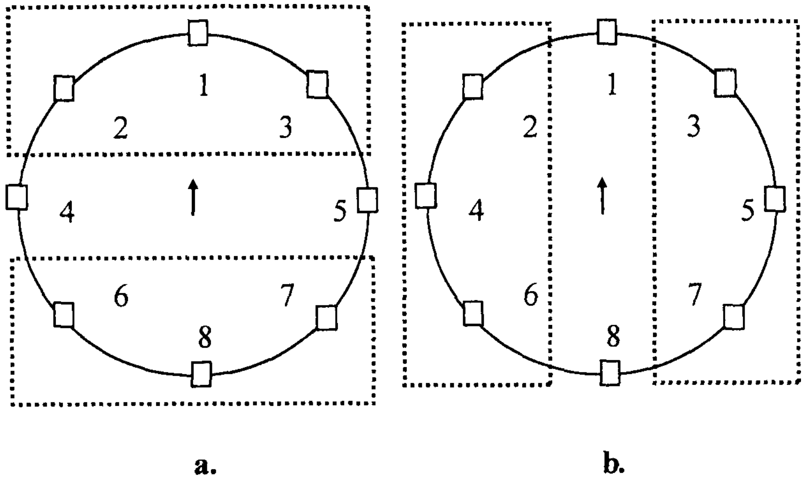

Figure 1. Speakers used to identify Front-Back (a) and Left-Right (b) confusions with participant in centre of speaker array, facing speaker 1 (arrow denotes participant location and direction).

Noise condition as opposed to in Quiet, because measures in Quiet approached the noise measurement floor.

4.2.1.1 *Measured Levels in the Open Ear Canal*

Open ear canal measurements were made in the quiet and traffic noise conditions. Mean ambient room noise measured in the open ear canal was 46.8 dBA (SD = 0 .8, N = 20).

4.2.1.2 *Attenuation by Headphone Type*

To determine a measure of attenuation, the sound pressure levels in the ear canal for each headphone type (with no music playing) was compared to the mean measure of traffic noise in the open ear canal (M = 84.74 dBA, SD = 1.46, N = 20). The Ear-Bud (M = 84.87 dBA, SD = 1.51, N = 19) and the Over-The-Ear headphones (M = 84.76 dBA, SD = 9.36, N = 19) were not significantly different from the open ear canal measurement (see Figure 2). These two headphone types, therefore, did not provide attenuation of the traffic noise (Figure 3). The Noise-Reduction insert phones, however, yielded a significantly lower mean sound pressure (M = 71.79 dBA, SD = 11.12, N = 19, $p<.001$) in the ear canal as compared to all headphone types, with approximately 13 dB of attenuation of the traffic noise (M = 12.95, SD = 2.58, N = 19) (Figure 3).

4.2.1.3 *Preferred Listening Levels*

The overall average PLL for all three headphone types in both background noise conditions was found to be 70.6 dBA (SD = 3.2, N = 20). Overall PLLs in the Quiet condition were 57.93 dBA (SD = 1.2, N = 20) and were 83.3 dBA (SD = 5.3, N = 20) in the Traffic Noise condition. Figure 4 shows these levels as compared to the measured

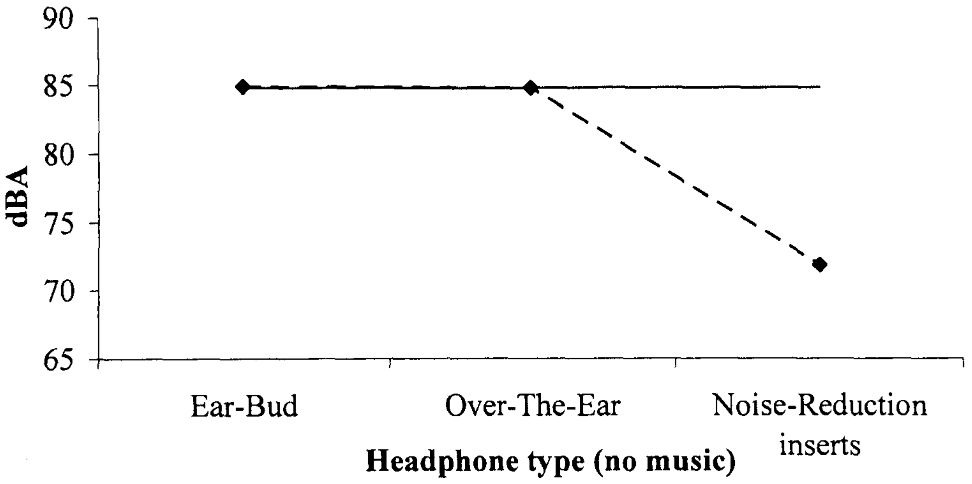

Figure 2. Average levels of traffic noise in the ear canal with each headphone type (dashed line). Solid line represents baseline traffic noise measure in open ear canal (84.74 dBA).

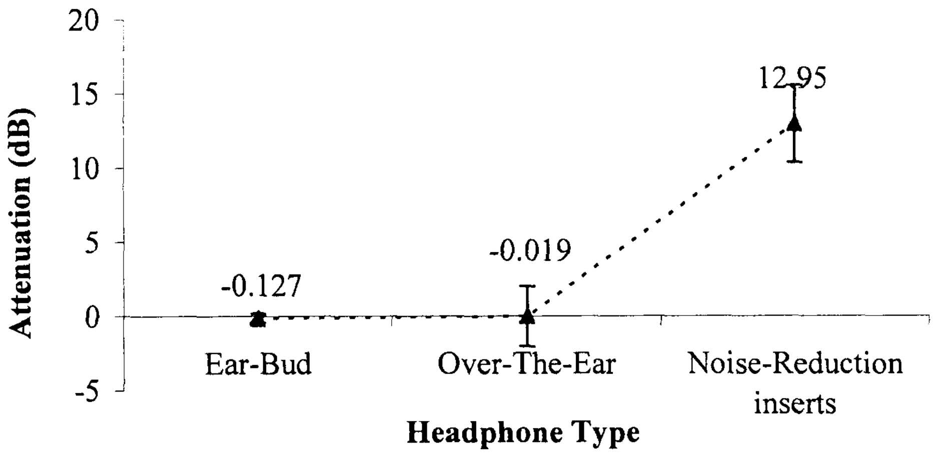

Figure 3. Overall attenuation of traffic noise in the ear canal provided by each headphone type.

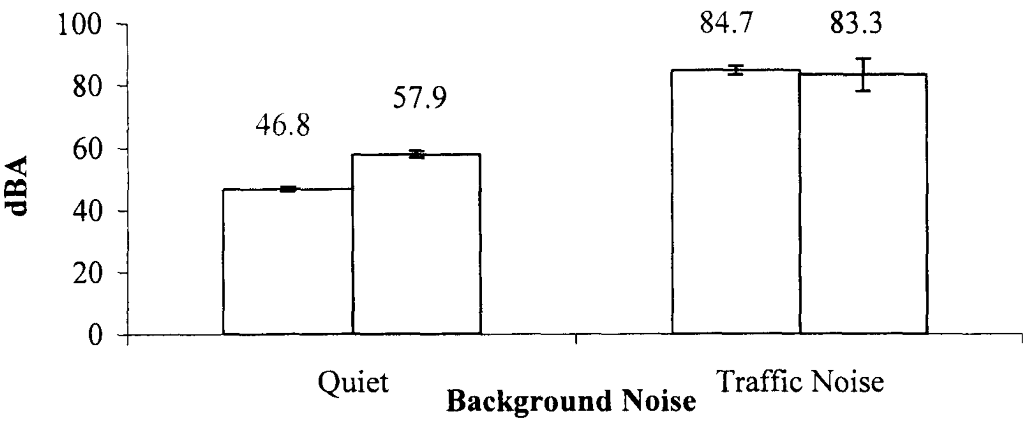

Figure 4. Overall average PLLs for all headphone types (black) versus the measured levels in the Open Ear condition (grey) in both background noise conditions combined.

levels in the open ear canal in both background noise conditions. PLLs for all headphones in both the Quiet and Traffic Noise conditions are displayed in Table 2.

Figure 5 illustrates the overall PLLs for the individual headphone types for both the quiet and traffic noise conditions combined (black line) as referenced to the average A-weighted sound pressure level in the open ear canal (grey line) which is 65.7 dBA (SD = 0.22, N = 20). A repeated measures two-by-four analysis of variance (background noise x headphone type) revealed significant main effects of Headphone Type ($F[3,57]= 20.18$, $N = 20$, $p<.001$) and Background Noise ($F[1,19]=542.13$, $N = 20$, $p<.001$). PLLs were lower for the Noise-Reduction insert phones (Figure 5) and PLLs were higher overall in the Traffic Noise condition (Figure 6).

A significant interaction between Background Noise and Headphone Type was also identified ($F[3,57]=36.68$, $N = 20$, $p<.001$). The increase in PLLs with the addition of Traffic Noise varied with Headphone Type, in that the Noise-Reduction insert phones resulted in a smaller increase (M = 20.8 dB, SD = 8.7, N = 20) in sound pressure in the ear canal than the Ear-Buds (M = 26.3 dB, SD = 7.6, N = 20) and Over-The-Ear headphones (M = 29.0 dB, SD = 8.1, N = 20). The Open Ear baseline measure in Traffic, did not differ from the Ear-Buds PLLs, but the measured sound pressure levels with the Over-The-Ear headphones were found to be significantly higher than the Open Ear measure (one-tailed t-test, $t = 6.67$, $df = 19$, $p<.001$). In traffic, the Noise-Reduction inserts were found to have significantly lower mean PLLs than both Ear-Buds (one-tailed t-test, $t = 5.7$, $df = 19$, $p<.001$) and Over-The-Ear headphones (one-tailed t-test, $t = 7.6$, $df = 19$, $p<.001$). The mean PLL in Traffic for the Noise-Reduction inserts were also significantly lower than the measure of traffic noise in the Open Ear condition

Table 2. Preferred Listening Levels for all headphone types in Quiet and Traffic Noise conditions.

	Quiet		Traffic	
Headphone Type	**M**	**SD**	**M**	**SD**
Ear-Bud	58.72	7.9	85.04	1.8
Over-The-Ear	58.51	9.1	87.51	1.9
Noise-Reduction inserts	56.56	10.3	77.56	6.0

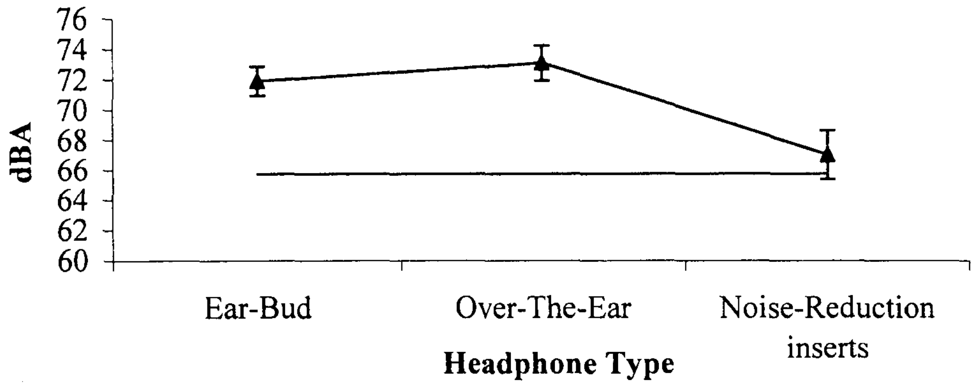

Figure 5. Average overall PLL for each headphone with background noise conditions combined (black) versus baseline measurement of overall background noise levels in the Open Ear condition (65.7 dBA) (grey).

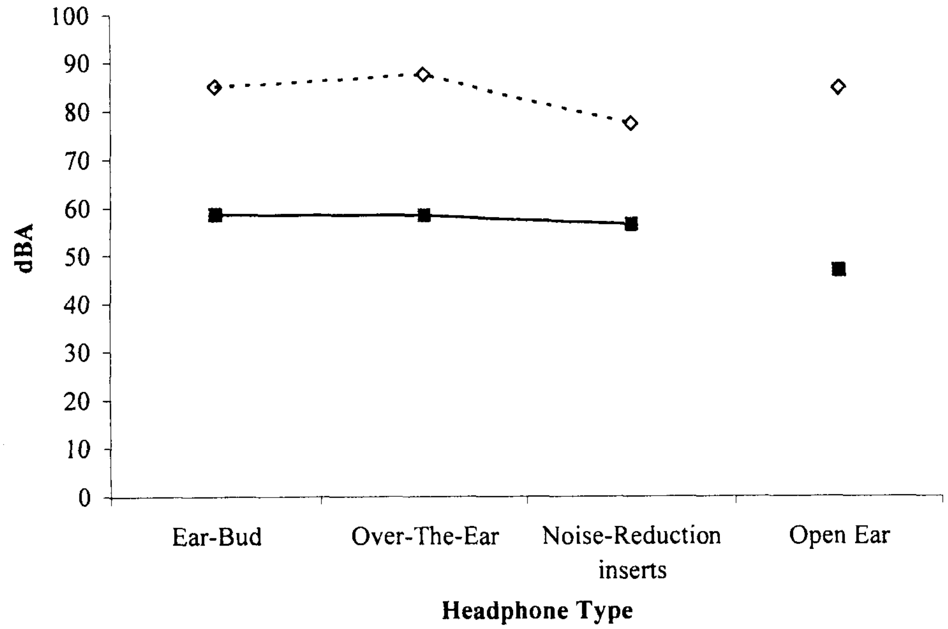

Figure 6. PLLs in Quiet (solid line) and Traffic Noise (dashed line). Data points for baseline noise levels in Quiet (square) and Traffic (diamond) as measured in the Open Ear (no music playing) are provided to the right.

(one-tailed t-test, $t = 5.17$, $df = 19$, $p<.001$). Additionally, mean PLLs in Traffic Noise with the Ear-Buds were found to be significantly lower than the Over-The-Ear headphones (two-tailed t-test, $t = 8.3$, $df = 19$, $p<.001$).

4.2.1.4 *Headphone Effect*

The overall PLLs for the Ear-Bud ($M = 71.88$ dBA $SD = 0.96$, $N = 20$) and the Over-The-Ear headphones ($M = 73.01$ dBA $SD = 1.16$, $N = 20$) did not differ. The Noise-Reduction insert phones, in comparison, resulted in a significantly lower overall PLL ($M = 66.98$ dBA $SD = 1.609$, $N = 20$, $p<.01$).

4.2.1.5 *Background Noise Effect*

With the addition of traffic noise, the measured sound pressure level in the ear canal increased in all conditions (Figure 6). The overall increase in PLL in Traffic Noise was 28.5 dB ($SD = 1.23$, $N = 20$, $p<.001$).

4.2.2 Stage 2: Sound Localization Task

4.2.2.1 *Localization Errors*

Table 3 provides a summary of overall localization errors by listening conditions. In Appendix L, total errors made in each condition, collapsed across all 20 subjects, are available in table format. A repeated measures two-by-four ANOVA revealed significant main effects of Background Noise ($F[1,19]=35.97$, $N = 20$, $p<.001$) and Headphone Type ($F[3,57]=10.99$, $N = 20$, $p<.001$). Localization errors increased in the Traffic Noise condition (Figure 7) and with the use of the Noise-Reduction insert phones in the Quiet condition (Figure 8). There was no significant interaction between Background Noise and Headphone Type.

Table 3. Localization errors by headphone type in Quiet and Traffic Noise conditions. N=20, total trials per condition = 24.

	Quiet			Traffic			Increase
Headphone Type	**M**	**SD**	**%**	**M**	**SD**	**%**	**M (%)**
Open Ear (no music)	6.4	3.2	26.7	8.9	3.8	37.1	2.5 (10.4%)
Ear-Bud	8.5	3.3	35.4	10.4	2.8	43.3	1.9 (7.9%)
Over-The-Ear	8.1	2.5	33.8	11.3	2.4	47.1	3.2 (13.3%)
Noise-Reduction inserts	10.3	2.2	42.9	11.2	2.2	46.7	0.9 (3.8%)

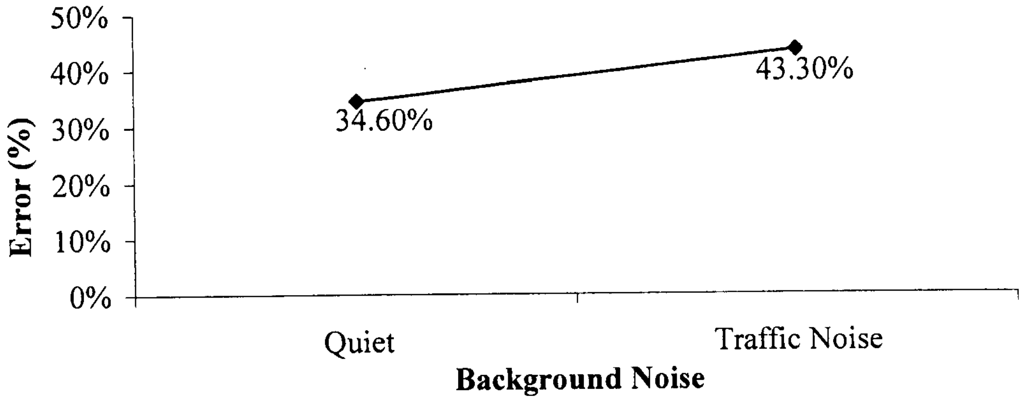

Figure 7. Percent localization errors under all headphone conditions combined in Quiet and Traffic Noise.

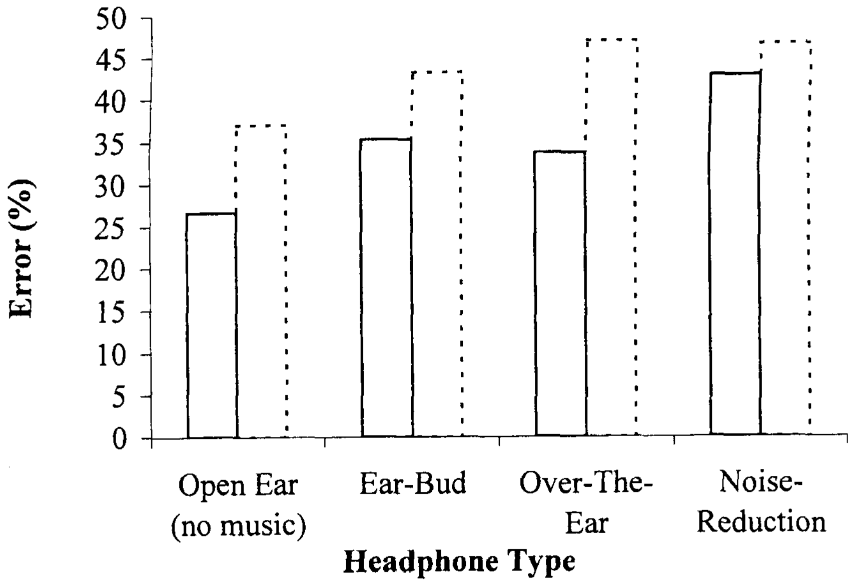

Figure 8. Percent localization errors in Quiet (solid) and Traffic Noise (dashed) by headphone type.

4.2.2.2 *Error Patterns*

For the purposes of this study, two specific error patterns were investigated: Front-Back confusions and Left-Right (lateralization) confusions by reanalyzing the data for these two specific types of errors.

4.2.2.2.1 Front-Back Confusions

A repeated measures two-by-two-by-four ANOVA, using the variables of Background Noise and Error Type (Front-Back vs. Back-Front), and Headphone Type revealed a significant main effect of Error Type ($F[1,19]=47.7$, $p<.0001$) and Background Noise ($F[1,19]=5.8$, $p<.05$). Front-Back confusions are more common than Back-Front confusions under all Headphone Type and Background Noise conditions and overall, more confusions (of both types) occurred in the Traffic Noise condition (Figure 9). A significant interaction was also found between Background Noise and Error Type ($F[1,19]=5.74$, $p<.05$). Front-Back errors were more common in both Quiet and Traffic Noise and Back-Front errors were negligible in both background noise conditions. Table 4 provides a summary of Front-Back confusions by listening conditions.

4.2.2.2.2 Left-Right Confusions

Due to the concerns about sound localization while wearing PADs in traffic, Left-Right confusions were also investigated. Results revealed that the occurrence of these confusions was infrequent. Only three participants made this type of error at all (Table 5). Each participant had 144 chances to make this error (3 stimuli from each of the 6 lateral speakers for each of the 8 blocks) and only one participant produced this type of error under each headphone condition (Table 5).

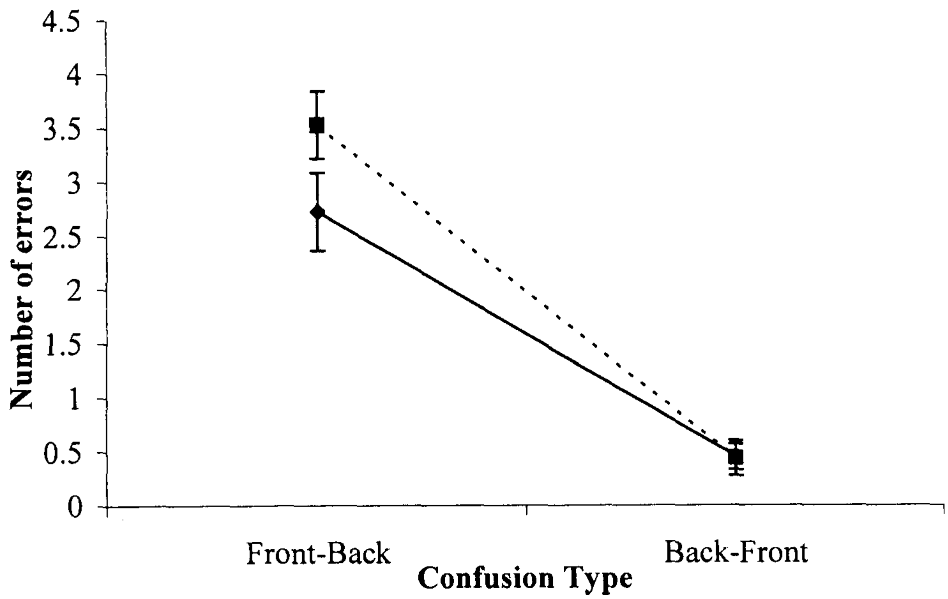

Figure 9. Average overall Front-Back and Back-Front confusions in Quiet (solid line) and Traffic Noise (dotted line) conditions.

Table 4. Front-Back confusions by headphone type in Quiet and Traffic Noise conditions. N=20, total trials per condition = 180

	Quiet			Traffic			Increase
Headphone Type	**M**	**SD**	**%**	**M**	**SD**	**%**	**M (%)**
Open Ear (no music)	48	2.3	26.7	70	2.0	38.9	22 (12.2%)
Ear-Bud	57	2.2	31.7	65	1.9	36.1	8 (4.4%)
Over-The-Ear	56	1.9	31.1	81	2.1	45.0	25 (13.9%)
Noise-Reduction inserts	57	1.3	31.7	66	1.5	36.7	9 (4%)

Table 5. Left-Right Confusions by headphone type.
(N=3, total trials=144)

Participant	Open Ear (no music)	Ear-Bud	Over-The-Ear	Noise-Reduction inserts
002	6 (12.5%)	6 (12.5%)	6 (12.5%)	6 (12.5%)
014	4 (8%)	-	1 (2%)	-
015	2 (4%)	-	-	-
Grand Total (N=20, total trials=960)	**12 (1.25%)**	**6 (0.63%)**	**7 (0.73%)**	**6 (0.63%)**

CHAPTER 5: DISCUSSION

This study confirmed that listeners increase the volume of their PADs when the background noise level around them is raised. The use of a PAD and the addition of traffic noise in the sound environment degraded the listener's ability to localize a horn honk.

5.1 REAL-EAR MEASUREMENTS

5.1.1 Preferred Listening Levels

5.1.1.1 *Overall PLLs*

The method of real-ear measurement used in the present study was similar to that conducted by Hodgetts et al. (2007). PLLs were recorded for three headphone types in both Quiet and 70 dBA of Traffic Noise. Results from the individual headphones in Quiet for Hodgetts et al. (2007) yielded PLLs that were slightly higher than those reported in the present study; however, PLLs in the Traffic Noise condition were very similar to the overall PLLs in the present study (Table 6). This indicates the participants in the study by Hodgetts et al. (2007) demonstrated a smaller increase in PLL with the addition of traffic noise.

When compared to PLLs reported by Ahmed et al. (2006), the mean PLLs measured in the present study were slightly higher. Of note are the PLLs in the Traffic condition. Both studies used a recorded traffic signal at a level of 70 dBA in the sound field, however the PLLs reported in this study are 10 dB higher than those reported by Ahmed et al. (2006). Differences could be attributed to the measurement of the sound pressures in a 2-cc coupler (Ahmed et al., 2006) versus that in the real-ear (present study). Perhaps the natural resonances of the ear canal are affected by the headphones in

Table 6. Comparison of PLLs in recent research.
ITE = in-the-ear; OTE = over-the-ear;
OTEw/NR = over-the-ear with noise reduction activated.

	Present Study (N = 20)	**Ahmed et al. 2006 (N = 24)**	**Hodgetts et al. 2007 (N = 38)**
Overall PLL	70.6 dBA	67.6 dBA	---
Overall PLL in Quiet	62.1 dBA	57.9 dBA	ITE: 77.8 dBA OTE: 75.2 dBA OTE w/NR: 75.2 dBA
Overall PLL in Traffic	83.3 dBA	73.3 dBA	ITE: 88.8 dBA OTE: 84.5 dBA OTE w/NR: 83.0 dBA

ways not replicable when a probe measurement system is coupled to a 2-cc coupler. Ear canal acoustics naturally emphasize mid-frequency spectral information. This enhancement may not be represented in the data based on a 2-cc coupler; however, this is merely a speculation, as the traffic noise recordings differ between the studies and the spectral characteristics of both signals are not available for comparison.

Caution should be taken when comparing results from the present study to the recent studies conducted by Ahmed et al. (2006) and Hodgetts et al. (2007), because each study used different headphones and traffic noise recordings. Additionally, the present study is unique in its use of an anechoic chamber as the listening environment. However, given the real-world scenarios in which PADs are used and the fact that no two street corners will have identical spectral, temporal, or amplitude information, a general comparison between studies is justified.

5.1.1.2 *PLLs by Headphone Type*

An increase in PLL in the Traffic Noise condition was noted for each headphone type; however the increase in the PLL was not uniform across all types, in that smaller increases were found with the Noise-Reduction insert phones. Because this type of headphone does attenuate the traffic noise, masking of the music is not as great. A lower sound pressure in the ear canal can yield a sufficient music-to-noise ratio since the noise does not contaminate the desired signal (music) to the same degree it does for the non-attenuating headphones.

5.1.1.3 *Music-to-noise Ratio*

When listening in Quiet, participants were listening at a higher music-to-noise ratio than when in the Traffic Noise condition. Figure 4 shows that in the Traffic Noise the overall PLL was virtually the same as the level of the traffic noise measured in the open ear canal, yielding a music-to-noise ratio of approximately 0 dB. In the Quiet condition the music-to-noise ratio is approximately 10 dB. So, while the hypothesis that listeners would increase the volume on their devices in the presence of background noise was supported, listeners were not maintaining the same music-to-noise ratio as they achieved in the quiet condition.

This trend is also seen when considering each headphone type individually (Figure 6). When using the Noise-Reduction insert earphones, listeners selected levels that yielded a music-to-noise ratio greater than 0 dB in the Traffic Noise condition. In this listening condition, the measured PLL was 77.56 dBA. Recall that traffic noise levels were 71.79 dBA, on average, when listeners were wearing the Noise-Reduction inserts (with no music playing). This is a music-to-noise ratio of approximately 6 dB, indicating that listeners decreased the music-to-noise ratio to a lesser degree with the Noise-Reduction insert earphones.

5.1.1.4 *Limitations of Real-Ear Measurements*

Participants of the present study were, for the most part, students in a health and/or rehabilitation science program and may not accurately represent the general population; however, a similar limitation is common among other published studies (Ahmed et al., 2006; Fligor & Ives, 2006) which were based solely on undergraduate and graduate students. It is possible that with a larger and more diverse sample size, a small percentage of participants may have been found to be listening to their PADs at higher levels.

Additionally, participants were free to choose a song that they might listen to in a real-world situation (albeit from a specified list of 11 songs that were equated for overall level) and this study did not attempt to control for frequency or temporal information, or other factors such as vocal tone or quality and genre of music. Output levels have been shown to vary with different genres of music (Fligor & Cox, 2004) and it is possible that PLLs could vary with genre as well.

5.1.2 Damage-risk Assessment

Although the present study did not directly address the risk of damage to hearing, listening levels reported in this study are consistent with claims by Fligor and Ives (2006) that the vast majority of listeners are not listening to their PADs at 'dangerous' levels. Fligor and Ives (2006) reported that only 6% (N = 100) of listeners exceeded the level of 85 dBA in sound field equivalent listening levels. While no conversions to sound field equivalent levels have been made to the present study's real-ear measurement data, only two participants had measured levels in their ear canal of greater than 90 dBA (with the highest being 92.3 dBA). Given that on average, depending on the frequency content of the signal, real-ear measurements are approximately 12 to 17 dB higher than the sound field equivalent, a conservative estimate would place the highest PLL recorded in this study at 80 dBA or below in the sound field. A future direction with this data set would be to convert frequency specific real-ear measures to sound field equivalent levels and evaluate them in relation to published damage-risk criteria.

5.2 SOUND LOCALIZATION TASK

5.2.1 Degradation of Localization Abilities

This study demonstrated how the addition of traffic noise in combination with music as heard via a PAD can degrade localization abilities in young adult listeners. The progression of increase in errors is summarized in Figure 8, in which the following trends are seen:

1. Localization errors increase when traffic noise alone is present (Open Ear Quiet vs. Open Ear Traffic Noise)
2. Localization errors increase when music alone is present (All headphones Quiet vs. Open Ear Quiet).
3. The greatest percentage of localization errors occur when both traffic noise and music are present. (All headphones in Traffic Noise vs. all other conditions).

For two of the headphone types (Ear Buds and Over-The-Ear headphones), the measured levels in the ear canal with traffic noise alone were similar to those with traffic noise and music combined (recall a roughly 0 dB music-to-noise ratio); however, localization abilities decreased further in the latter situation, demonstrating that music (or headphones) has a compounding affect on the degradation of localization abilities. This may indicate that differences in the temporal characteristics of traffic noise and music may effect localization abilities; however, this added degradation of abilities may simply be due to the fact that the listener was covering a portion of his or her pinna and ear canal with headphones, altering the spectral cues provided by these ear structures.

Additionally, in a real-world situation, unless the listener is wearing HPDs, there is no choice but to hear the surrounding environmental sounds. The listener has much more control over their choice to listen to music. With current PADs, listeners may select and upload the audio files they choose to listen to. Music is often a personal experience and may be capturing more of the listener's attention, resulting in this added degradation of localization abilities. The attenuation provided by the headphones must also be considered. The Noise-Reduction insert phones had the lowest mean PLLs but the highest number of localization errors in the Quiet condition. It is logical that the environmental noise is blocked out due to the attenuation provided by these headphones (approximately 13 dB); however, the target stimulus (horn honk) would most likely be attenuated to a similar degree. The attenuation of the environmental sound and the stimulus, combined with the presence of music in the ear canal, resulted in the listeners being at a disadvantage when performing the localization task under this condition.

5.2.1.1 *Limitations in Localization Task*

Participants were informed that they would be participating in two tasks and measurements and were given details in the letter of information; however, during the real-ear measurements the participants were not reminded that the selected levels would then be used during the localization task. Though some participants may not have recalled this logical connection between the two stages of the study, this was not controlled for and the discerning participant may have selected conservative PLLs in an attempt to increase their success on the localization task.

5.2.2 Error Types

Front-back confusions increased in the Open Ear condition in Traffic Noise and showed the same trend of additional errors made when the participant was also listening to music in this background noise condition. The increase in errors with the addition of traffic noise varied between headphone types, with the largest increase occurring with the Over-The-Ear headphones (13.9%).

Front-back errors increase with the use of HPDs (Noble, Murray & Waugh, 1990; Vause & Grantham, 1999), which not only isolate the listener from environmental sounds, but may also alter the spectral information available to the listener. Since the Over-The-Ear headphones cover a greater portion of the external ear, spectral shape cues may be affected more by these headphones than the Ear-Bud or Noise-Reduction inserts, accounting for the larger number of this type of error.

5.2.3 Localization Summary

In general, regardless of the type of headphone, participants demonstrated decreased localization abilities in both background noise conditions.
Factors that contributed to this degradation of localization abilities include, but are presumably not limited to: shape and style of headphone; attenuation provided by the headphones; sound environment; and PLLs. The contribution to the degradation of localization abilities from each factor in isolation is not known and further research is needed.

Should a PAD user attempt to consider all these factors, selection of headphones may prove to be quite difficult. In the Quiet condition, when wearing the Noise-

Reduction headphones, listeners were isolated from the environment and were at a greater disadvantage with respect to overall localization. Returning to the measured PLLs with the Noise Reduction insert phones, the low levels in the ear canal may be appealing to the listener who is concerned about risk of hearing loss; however, this would indicate a risk of improperly locating potentially important environmental sounds (horn honks, sirens, shouts etc.). If the source of the warning signal originated behind the listener, the use of Over-The-Ear headphones would indicate an increased risk of incorrectly identifying the source as originating in the front. The PAD user who does not want to feel isolated from environmental sounds may find this type of headphone (which provides little to no attenuation) appealing; however, spectral shape cues may be limiting their localization abilities.

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APPENDIX A: UWO Ethics Aproval Form

Western

Office of Research Ethics

The University of Western Ontario
Room 00045 Dental Sciences Building, London, ON, Canada N6A 5C1
Telephone:
Website:

Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. M.F. Cheesman
Review Number: 13429E **Review Level:** Expedited
Review Date: July 11, 2007
Protocol Title: Sound localization abilities of personal audio device users
Department and Institution: Communication Sciences & Disorders, University of Western Ontario
Sponsor:
Ethics Approval Date: July 20, 2007 **Expiry Date:** September 30, 2008
Documents Reviewed and Approved: UWO Protocol, Letter of Information and Consent, Advertisement (poster)
Documents Received for Information:

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines: and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced study on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the HSREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of monitor, telephone number). Expedited review of minor change(s) in ongoing studies will be considered. Subjects must receive a copy of the signed information/consent documentation.

Investigators must promptly also report to the HSREB:

a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to this office for approval.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

Chair of HSREB: Dr. John W. McDonald
Deputy Chair: Susan Hoddinott

Ethics Officer to Contact for Further Information		
☐ Jennifer McEwen (jmcewen4@uwo.ca)	☑ Denise Grafton (dgrafton@uwo.ca)	☐ Ethics Officer (ethics@uwo.ca)

cc: ORE File

This is an official document. Please retain the original in your files.

APPENDIX B: Participant Recruitment Poster

National Centre for Audiology UWO

Do you use an iPod or other MP3 player?

We are looking for people aged 18 to 30, who have normal hearing and who use MP3 players, to participate in a study of sound localization at The University of Western Ontario's National Centre for Audiology.

Participants will complete a routine hearing test and an experimental test of hearing the location of sounds while listening to music on an MP3 player. This will take place in the Anechoic Chamber at the National Centre for Audiology at U.W.O.

If you are interested in participating in this study or would like more information, please take the contact information from below and contact Rebecca:

Rebecca	Rebecca	Rebecca	Rebecca	Rebecca	Rebecca	Rebecca	Rebecca	Rebecca

APPENDIX C: Letter of Information

Letter of Information

Title: Sound localization abilities of personal audio device users.
Investigators: Margaret Cheesman, Rebecca Malcolmson, Mary Beth Jennings
Location: National Centre for Audiology, University of Western Ontario

The purpose of this research project is to investigate the impact personal audio devices may have on being able to accurately hear the correct location of a sound. We will be testing 20 young adults (aged 18 to 30) who have normal hearing and who regularly use personal audio devices. We will compare participants' localizing abilities while wearing and using a personal audio device to that of their abilities with no device in use.

This letter contains information to help you decide whether or not to participate in this research study. If you agree to participate, we will ask you to see us for one session, lasting no more than 90 minutes. This can be scheduled at a convenient time for you. Testing will take place in the Anechoic Laboratory of the National Centre for Audiology at The University of Western Ontario.

During the test sessions, you will be tested to confirm your hearing sensitivity and we will have you complete a hearing history form. After the hearing tests, you will be seated within a circle of speakers and asked to adjust the level of a personal audio device to your preferred listening level while wearing different headphones and while listening to background traffic noise. A small tube will be placed in your ear canal that will measure the sound levels in your ear canal.

Next you will be asked to wear a light-weight cap that will measure the position of your head. The cap will be outfitted with a measurement system that is connected to a computer. We will play sounds (horn honks) from these speakers. While listening to music from the personal audio device at your preferred listening level, you will tell us which speaker the sounds are coming from by turning your head towards the speaker and pushing a button to register your response.

The sound levels used in this study are within the range of normal sounds. If some sounds are louder than you would prefer to hear, we will stop the testing. At no point will the test sounds pose a risk to your hearing. Rest breaks will be provided at regular intervals to prevent you from becoming tired or thirsty. Free parking will be provided for the study. Participation in this study is voluntary.

You may refuse to participate. You may refuse to answer any questions or withdraw from the study at any time. This will not affect your future audiological care at any clinic. You will not benefit directly from your participation in this study. You do not waive any legal rights by signing the attached consent form.

The information obtained in this study will be used for scientific purposes, and may be included in scientific reports. Your name will not appear in any publication. Your confidentiality will be protected. We will assign you an ID number. All research data will be stored in a locked file. You will receive a copy of the results when the project is complete. If you have additional questions regarding this project, please contact Dr. Margaret Cheesman at

If you have any questions about the conduct of this study or your rights as a research subject, you may contact The Director, Office of Research Ethics, The University of Western Ontario . This letter is for you to keep.

Rebecca Malcolmson, Hon.B.A.	Margaret Cheesman, Ph.D.
Graduate Student	Principal Investigator

APPENDIX D: Participant Consent Form

Western

Consent Form

Sound localization abilities of personal audio device users.

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

Name (participant)	Signature	Date
Name (person obtaining informed consent)	Signature	Date

APPENDIX E: Hearing History Form

Hearing History

Demographics:

1. Subject ID #: _____
2. Year of Birth: _______Age: _____
3. Name: ___________________
4. Phone Number: ___________

Aural Health:

1. Is there any history of frequent ear infections? ☐Yes ☐No
   - If yes, describe: ____________________________
   - If yes, when was the last infection? ___________
2. Have you ever had any ear surgery? ☐ Yes ☐ No
   - If yes, describe: ____________________________
3. Have you ever experienced any trauma to the head/ear? ☐ Yes ☐ No
   - If yes, describe: ____________________________

Current Hearing Health:

1. Does your hearing seem to change from day to day? ☐ Yes ☐ No
2. Do you experience any ringing or buzzing sounds in your ears? ☐ Yes ☐ No
   - If yes: ☐ Right ☐ Left ☐ Both ears
3. Do you experience any dizziness? ☐ Yes ☐ No
   - If yes, describe: ____________________________
4. Is there a family history of hearing loss? ☐ Yes ☐ No
   - If yes, explain relationship: ____________________

Use of MP3 Players

1. How often do you listen to music/podcasts on your MP3 player?
   - _________ days per week.

2. About how long does a typical listening session last?
   ☐ 1-60 minutes ☐ 1-4 hours ☐ Over 4 hours

3. Where do you listen to your MP3 player most often?
   ☐ At home ☐ At work ☐ Working out ☐ Studying
   ☐ Commuting by car/bus ☐ Walking ☐ Other: ______________

4. Do you ever experience difficulties with the following situations while listening to your MP3 player? (check all that apply)
   ☐ hearing the doorbell
   ☐ talking on the phone
   ☐ hearing someone who is whispering
   ☐ talking in quiet
   ☐ talking in noise

5. On a scale of 0-100, where 0 is mute and 100 is maximum volume, at what volume do you typically listen to your audio device while using headphones? _________

Additional Comments:

____

____

____

APPENDIX F: Hearing History Form Responses (pg. 1 of 3)

DEMOGRAPHICS				AURAL HEALTH					
ID	Year of Birth	Age	Sex	History of Ear Infections	Describe	Last infection?	Ear surgery?	Describe	Trauma?
[redacted]									
003	1983	26	M	No			No		No
[redacted]									
005	1984	23	F	No			No		No
[redacted]									
007	1984	23	F	No			No		No
[redacted]									
010	1981	27	F	No			No		No
[redacted]									
012	1986	21	F	No			No		No
[redacted]									
014	1983	24	M	No			No		No
[redacted]									
016	1981	27	F	No			No		No
[redacted]									
018	1977	30	F	No			No		No
[redacted]									
020	1982	25	F	No			No		No
[redacted]									
022	1982	25	F	No			No		No

APPENDIX F: Hearing History Form Responses (pg. 2 of 3)

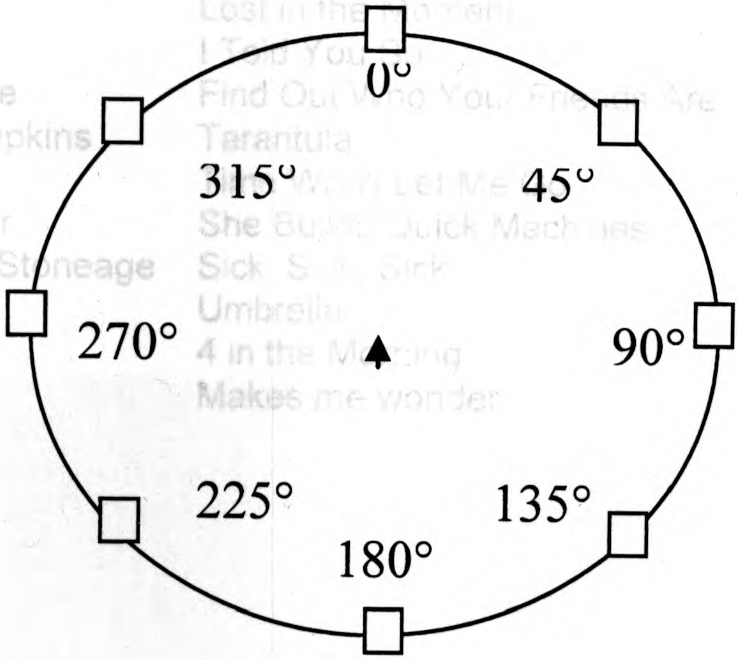
CURRENT HEARING HEALTH							
ID	Hearing change day to day?	Tinnitus?	R/L or both?	Dizziness?	Describe	Family History?	Relationship
[redacted]							
003	No	Yes	Both	No		No	
[redacted]							
005	No	No		No		No	
[redacted]							
007	No	No		No		No	
[redacted]							
010	No	No		No		No	
[redacted]							
012	No	No		No		No	
[redacted]							
014	No	No		No		No	
[redacted]							
016	No	No		No		No	
[redacted]							
018	No	No		No		No	
[redacted]							
020	No	No		No		Yes	grandmother
[redacted]							
022	No	No		No		Yes	grandfather, brother?

APPENDIX F: Hearing History Form Responses (pg. 3 of 3)

USE OF MP3 PLAYERS										
				Difficulties experienced						
ID	Days per wk	Listening Session	Where most often?	Explain other	Door-bell	Talking on phone	Hear whisper	Talk in quiet	Talk in noise	Vol. scale 1-100
[redacted]										
003	4	1-60 mins	At work				X		X	35
[redacted]										
005	5	1-60 mins	Commting by car/bus			X	X			50
[redacted]										
007	7	1-60 mins	Workingout /Walking Commuting by car/bus				X		X	50
[redacted]										
010	6	1-60 mins	Commuting /walking				X			40
[redacted]										
012	5	1-60 mins	Commuting				X		X	30
[redacted]										
014	3	1-60 mins	Working out				X	X	X	50
[redacted]										
016	2	1-4 hrs	Commuting by car/bus			X	X			40
[redacted]										
018	5	1-60 mins	Home /Commuting		X		X		X	85
[redacted]										
020	3	1-60 mins	Workingout /walking			X	X		X	40
[redacted]										
022	2	1-60 mins	Other	Subway			X	X	X	40

Appendix G: Speaker Diagram

Schematic of 8 speakers used for sound localization task



Appendix H: Song Selection List

MP3 LOCALIZATION STUDY – SONG SELECTION LIST

George Strait	Wrapped	92.7
Big & Rich	Lost in the Moment	92.7
Keith Urban	I Told You So	92.7
Tracy Lawrence	Find Out Who Your Friends Are	92.7
Smashing Pumpkins	Tarantula	95.9
The Bravery	Time Won't Let Me Go	95.9
Velvet Revolver	She Builds Quick Machines	95.9
Queens of the Stoneage	Sick, Sick, Sick	95.9
Rihanna	Umbrella	103.1
Gwen Stefani	4 in the Morning	103.1
Maroon 5	Makes me wonder	103.1

Appendix I: Radio Station Lists

BX 93 FM - American Country Countdown (Foxworthy Countdown)
Downloaded: Tuesday, August 7, 2007

#	Artist	Song
1.	George Strait	Wrapped
2.	MontgomeryGentry	Lucky Man
3.	Big & Rich	Lost In The Moment
4.	Keith Urban	I Told You So
5.	Tracy Lawrence	Find Out Who Your Friends Are

FM 96 CFPLFM Top 30 Countdown
Downloaded Tuesday, August 7, 2007

This Week	Last Week	Title	Artist
1	1	TARANTULA	SMASHING PUMPKINS
2	3	TIME WON'T LET ME GO	THE BRAVERY
3	2	SHE BUILDS QUICK MACHINES	VELVET REVOLVER
4	9	CAPITAL G	NINE INCH NAILS
5	5	SICK, SICK, SICK	QUEENS OF THE STONE AGE

103.1 FM – Fresh FM Top 30 Countdown
Downloaded: Tuesday, August 7, 2007

#	Artist	Title
01	Fergie	Big Girls Don't Cry
02	Rihanna	Umbrella
03	Gwen Stefani	4 in the Morning
04	Timbaland	Give It To Me
05	Maroon 5	Makes Me Wonder

Appendix J: Procedure Outline (pg. 1 of 2)

Subject No. _____ DOB ________ Test Date:__________

☐ Calibration of speakers, probe mic, SpectraPlus completed
☐ Provided letter of information
☐ Signed consent form
☐ Selected song: ______________________________

Audiometric screening/assessment:

☐ Hearing history form completed and attached
☐ Unremarkable otoscopy
☐ Normal tympanograms
☐ Pure tone response @ 25 dB HL at 500, 1000, 2000, 4000 Hz (L/R)

Real-ear measurements

☐ Quiet/open ear	Avg ____		☐ Data file: ____________
☐ Traffic/open ear	Avg ____		☐ Data file: ____________
☐ Traffic/earbuds/off	Avg ____		☐ Data file: ____________
☐ Quiet/earbuds	Avg ____	Vol. Level ___	☐ Data file: ____________
☐ Traffic/earbuds	Avg ____	Vol. Level ___	☐ Data file: ____________
☐ Traffic/OTE/off	Avg ____		☐ Data file: ____________
☐ Quiet/OTE	Avg ____	Vol. Level ___	☐ Data file: ____________
☐ Traffic/OTE	Avg ____	Vol. Level ___	☐ Data file: ____________
☐ Traffic/NR/off	Avg ____		☐ Data file: ____________
☐ Quiet/NR	Avg ____	Vol. Level ___	☐ Data file: ____________
☐ Traffic/NR	Avg ____	Vol. Level ___	☐ Data file: ____________

Localization Practice Tests: 8 speakers – open ear condition

☐ 500 ms x 3 – 10 trials. Data file:____________________

☐ 300 ms x 5 – 10 trials. Data file:____________________

☐ 300 ms x 3 – 10 trials. Data file:____________________

Localization Test Trials: 5 detection trials and 24 tests trials per block

BLOCK 1 ***Environment: Quiet*** ***Headphone: None***

☐ Detection test: Horn in quiet – 5 trials at speaker C18
Data file:____________________

☐ Horn in quiet – 24 trials
Data file:____________________

BLOCK 2 ***Environment: Traffic*** ***Headphone: None***

☐ Detection test: Horn in traffic – 5 trials at speaker C18
Data file:____________________

☐ Horn in traffic – 24 trials
Data file:____________________

Appendix J: Procedure Outline (pg. 2 of 2)

Subject No. ______ DOB ______ Test Date: __________

BLOCK 3 ***Environment: Quiet*** ***Headphone: Earbud***

- ☐ Detection test: Horn in quiet – 5 trials at speaker C18
  Data file: ______________________
- ☐ Horn in quiet – 24 trials
  Data file: ______________________

BLOCK 4 ***Environment: Traffic*** ***Headphone: Earbud***

- ☐ Detection test: Horn in traffic – 5 trials at speaker C18
  Data file: ______________________
- ☐ Horn in traffic – 24 trials
  Data file: ______________________

BLOCK 5 ***Environment: Quiet*** ***Headphone: Over-the-ear***

- ☐ Detection test: Horn in quiet – 5 trials at speaker C18
  Data file: ______________________
- ☐ Horn in quiet – 24 trials
  Data file: ______________________

BLOCK 6 ***Environment: Traffic*** ***Headphone: Over-the-ear***

- ☐ Detection test: Horn in traffic – 5 trials at speaker C18
  Data file: ______________________
- ☐ Horn in traffic – 24 trials
  Data file: ______________________

BLOCK 7 ***Environment: Quiet*** ***Headphone: Noise-reducing***

- ☐ Detection test: Horn in quiet – 5 trials at speaker C18
  Data file: ______________________
- ☐ Horn in quiet – 24 trials
  Data file: ______________________

BLOCK 8 ***Environment: Traffic*** ***Headphone: Noise-reducing***

- ☐ Detection test: Horn in traffic – 5 trials at speaker C18
  Data file: ______________________
- ☐ Horn in traffic – 24 trials
  Data file: ______________________

******Please staple all printouts to this sheet******

Audiologist: ____________ **Experimenter:** ________________

APPENDIX K: Volume Levels as Displayed on PAD

Recorded numeric volume settings for all conditions

	Quiet	Traffic	Quiet	Traffic	Quiet	Traffic
ID	Ear Bud	Ear Bud	Over-The-Ear	Over-The-Ear	Noise Reduction inserts	Noise Reduction inserts
002	6	17	8	26	14	34
003	11	21	18	30	37	40
004	17	29	23	37	12	21
005	12	20	10	28	6	13
006	14	29	27	37	13	21
007	12	27	13	31	7	12
009	9	18	16	31	7	11
010	15	28	18	35	11	15
011	3	25	5	30	1	9
012	5	27	6	32	2	13
013	14	30	25	37	14	19
014	26	37	31	40	29	32
015	17	32	16	31	9	15
016	9	27	8	26	5	11
017	9	24	10	29	7	14
018	16	23	30	36	25	29
019	9	34	13	37	6	17
020	8	20	9	23	4	8
021	6	14	7	24	4	9
022	8	20	14	29	8	12

APPENDIX L: Confusion Matrices (Total Errors) (pg. 1 of 2)

Block 1: Background = Quiet; Headphone = None (Open Ear)

		Source of Horn Honk							
		0	45	90	135	180	225	270	315
Response	0	56	2	3	3	18	1	1	2
	45	0	51	1	9	3	0	0	0
	90	0	1	50	10	2	2	0	0
	135	0	0	2	36	2	1	2	0
	180	0	0	2	1	33	0	1	0
	225	0	0	2	1	1	25	1	0
	270	1	3	0	0	0	18	38	8
	315	3	3	0	0	1	13	17	50

Block 2: Background = Traffic; Headphone = None (Open Ear)

		Source of Horn Honk							
		0	45	90	135	180	225	270	315
Response	0	53	1	4	4	27	5	3	4
	45	1	47	4	10	9	3	0	0
	90	0	9	51	22	3	0	0	0
	135	1	0	1	23	1	0	0	0
	180	2	0	0	1	18	1	0	0
	225	0	0	0	0	1	19	1	3
	270	0	0	0	0	0	21	34	4
	315	3	3	0	0	1	11	22	49

Block 3: Background = Quiet; Headphone = Ear Bud

		Source of Horn Honk							
		0	45	90	135	180	225	270	315
Response	0	50	0	5	0	23	2	3	2
	45	0	33	1	12	8	0	0	0
	90	0	21	46	14	5	0	0	0
	135	1	1	8	34	1	3	0	0
	180	4	2	0	0	19	0	0	0
	225	1	0	0	0	1	19	0	5
	270	3	0	0	0	0	27	42	6
	315	1	3	0	0	3	9	15	47

Block 4: Background = Traffic; Headphone = Ear Bud

		Source of Horn Honk							
		0	45	90	135	180	225	270	315
Response	0	54	0	3	0	29	1	5	4
	45	1	33	1	13	5	0	0	0
	90	0	24	50	29	4	3	0	0
	135	0	0	6	18	0	0	0	0
	180	1	0	0	0	16	1	0	0
	225	0	0	0	0	1	13	0	2
	270	0	0	0	0	1	29	37	9
	315	4	3	0	0	4	13	18	45

Appendix L: Confusion Matrices (Total Errors) (pg. 2 of 2)

Block 5: Background = Quiet; Headphone = Over-The-Ear

		Source of Horn Honk							
		0	45	90	135	180	225	270	315
Response	0	54	1	4	1	23	0	1	1
	45	0	44	2	14	4	0	1	0
	90	0	11	46	18	3	2	0	0
	135	1	1	8	26	0	1	0	0
	180	2	0	0	1	22	0	1	0
	225	0	0	0	0	3	21	0	4
	270	2	0	0	0	0	27	45	10
	315	1	3	0	0	5	9	12	45

Block 6: Background = Traffic; Headphone = Over-The-Ear

		Source of Horn Honk							
		0	45	90	135	180	225	270	315
Response	0	49	3	3	0	35	4	2	4
	45	3	31	5	22	3	0	1	0
	90	0	20	49	25	3	3	0	0
	135	0	2	3	13	0	0	0	0
	180	3	0	0	0	18	0	0	1
	225	0	1	0	0	1	9	1	3
	270	0	0	0	0	0	27	32	10
	315	5	3	0	0	0	17	24	42

Block 7: Background = Quiet; Headphone = Noise Reduction inserts

		Source of Horn Honk							
		0	45	90	135	180	225	270	315
Response	0	50	1	3	3	29	4	2	1
	45	2	32	3	4	9	0	1	0
	90	0	18	44	32	6	3	0	0
	135	1	6	10	21	1	0	0	0
	180	3	0	0	0	13	0	0	0
	225	0	0	0	0	0	14	0	4
	270	3	0	0	0	1	32	49	14
	315	1	3	0	0	1	7	8	41

Block 8: Background = Traffic; Headphone = Noise Reduction inserts

		Source of Horn Honk							
		0	45	90	135	180	225	270	315
Response	0	47	2	3	0	20	1	3	2
	45	3	31	6	10	14	0	0	0
	90	0	23	45	29	7	3	0	0
	135	3	1	6	21	1	0	0	0
	180	2	0	0	0	14	0	0	1
	225	1	0	0	0	0	10	1	8
	270	0	0	0	0	0	29	44	18
	315	1	3	0	0	4	17	12	31