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Asymmetric directional microphone fittings for individuals with an asymmetric hearing loss

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ASYMMETRIC DIRECTIONAL MICROPHONE FITTINGS FOR INDIVIDUALS WITH AN ASYMMETRIC HEARING LOSS

by

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ABSTRACT

The present study investigated the effects of asymmetric directional microphone fittings on participants' acceptance of background noise and speech understanding in noise abilities. Thirteen adult, bilateral hearing aid users or non-hearing aid users with bilateral asymmetrical sensorineural hearing loss were fit binaurally with four different microphone conditions (i.e., bilateral omnidirectional, asymmetric directional poorer ear, asymmetric directional better ear, and bilateral directional) and monaurally with two microphone conditions (i.e., unilateral directional better ear and unilateral omnidirectional better ear). The amplification used was a pair of Siemens Intuis directional behind-the-ear hearing aids and comply earmolds.

The results indicated speech understanding in noise abilities are enhanced when fit with an asymmetric directional better ear microphone fitting (i.e., directional microphone on the better ear and omnidirectional microphone on the poorer ear) or bilateral directional microphone fitting as compare to a bilateral omnidirectional microphone fitting. In the monaural conditions, speech understanding in noise ability improved when using a unilateral directional microphone as compared to a unilateral omnidirectional microphone (Note: For the monaural conditions, the directional microphone was coupled to the better ear and poorer ear was plugged). Next, speech understanding in noise ability is not affected when utilizing a unilateral directional

microphone fitting as compared to an asymmetric directional better ear microphone configuration.

The results further revealed that acceptance of background noise was similar for all microphone configurations (i.e., bilateral omnidirectional, asymmetric directional poorer ear, asymmetric directional better ear, or bilateral directional) for listeners with asymmetric hearing loss. These results indicate that willingness to accept background noise is unchanged in the binaural microphone conditions. When comparing the monaural fitting conditions, the unilateral directional fitting provided significantly greater acceptance of background noise compared to the unilateral omnidirectional microphone fitting, indicating a person is more willing to accept background noise (i.e., more willing to wear hearing aids) with a unilateral directional microphone versus a unilateral omnidirectional microphone. Therefore, when considering a monaural hearing aid fitting a directional microphone should be considered. When comparing the binaural asymmetric directional better ear condition to the monaural directional microphone condition, there was difference in a person's willingness to accept background noise. Therefore, a person's willingness to wear amplification would be unaffected when fit monaurally or binaurally, as long a directional microphone is on the better ear.

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DEDICATION

To my family, without each of you none of my life's achievements would be or will continue to be possible.

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CHAPTER I

INTRODUCTION

An agreed upon definition of asymmetric hearing loss is lacking within the literature. Asymmetric hearing loss has been defined as a difference between the (1) ear's pure tone averages, (2) audiogram shape, (3) speech intelligibility testing, (4) dynamic range, or (5) level of discomfort (Dillon, 2001). More specifically, definitions of asymmetry have included (1) a difference of 10 dB HL or more at one or more frequencies and (2) a pure tone air conduction difference between ears equal to or greater than 20 dB HL at three or more octave frequencies (Segal, Shkolnik, Kochba, Segal, & Kraus, 2007; Silverman, Silman, Emmer, Schoepflin & Lutolf, 2006; Mackenzie & Lutman, 2005). Furthermore, Hornsby and Ricketts (2007) defined a symmetrical hearing loss as a difference between ears of less than or equal to 20 dB HL at octave frequencies of 250 – 8000 Hz, thus indicating that a reasonable definition of asymmetrical hearing loss would be difference of 20 dB HL at these frequencies. Furthermore, all individuals with hearing impairments have difficulty understanding speech in the presence of background noise. This effect is worsened by the occurrence of an asymmetric hearing loss (Dillon, 2001). Furthermore, there is a debate among researchers over what type of hearing aid fitting will yield the best speech understanding for a person with an asymmetrical hearing loss. Commonly, these individuals are aided unilaterally, bilaterally, or use a BICROS hearing aid. If aided unilaterally the audiologist must decide which ear should receive the aid (Dillon, 2001). It should be noted that none of the above options have led to major success.

Moreover, directional microphones are one of the few technologies that can help minimize the difficulty experienced when trying to understand speech in the presence of background noise. Although speech understanding can improve by using directional microphones, the hearing impaired rarely report using the directional microphone program. Often patients have difficulty determining which listening situations to use the directional microphone program or are incapable of changing between the omnidirectional and directional microphone programs. This leads to patients who stop changing the hearing aid programs, ultimately not receiving the benefit of the directional microphone. Furthermore, research shows that the use of bilateral directional microphones provide the best speech understanding ability; however, this microphone set-up is most appropriate when speech is presented from the front and noise is presented from the back. Because this situation rarely occurs in the real world, patients have reported using directional microphones rarely or not at all (Cord, Surr, Walden & Olson, 2002). Therefore, the lack of using directional microphones has led to the development of adaptive hearing instruments.

In an adaptive directional microphone system, each hearing aid analyzes the incoming signal and changes microphone conditions independent of one another. Since the microphones change independently, there is an opportunity for an asymmetric directional microphone fitting to occur. An asymmetric directional microphone fitting consists of one ear being fit with a directional microphone and the opposite ear being fit with an omnidirectional microphone. Because the microphones of the two adaptive hearing aids change at different times, there may be adverse affects on speech understanding ability. The risk of adverse effects on performance when microphones are changing programs independent of one another in the real world has led to the possibility of an asymmetric directional microphone fitting (Mackenzie & Lutman, 2005).

To this end, Cord, Walden, Surr, and Dittberner (2007) investigated the effects of asymmetric directional microphone fittings on speech understanding in noise. Furthermore, Cord et al. (2007) sought to determine if the benefit seen by hearing aid users with asymmetric directional fittings in the laboratory would translate into a greater ease of listening compared to those fit with bilateral omnidirectional microphones. The results indicated that an asymmetric directional microphone fitting provides significantly better speech understanding in noise scores compared to an omnidirectional microphone fitting. In addition, speech understanding in noise scores obtained using asymmetrical directional microphones were not significantly worse than those obtained using bilateral directional microphones. Based on these findings, it was concluded that in situations where a hearing aid user may select a bilateral omnidirectional program, an asymmetric directional fitting may still provide some directional advantages. Furthermore, an asymmetric directional fitting does not cause damaging effects to the ease of listening (Cord et al., 2007).

In a similar study, Kim and Bryan (2011) investigated the effects asymmetric directional microphone fittings on speech understanding in noise and acceptance of background noise. Speech understanding in noise was assessed using the Hearing in

Noise Test (HINT) while acceptance of background noise was assessed using the acceptable noise level (ANL) procedure (see Nabelek, Freyaldenhoven, Tampas, Burchfield, & Muenchen, 2006). Fifteen adults with symmetrical sensorineural hearing loss served as the participants for this study. Four different microphone conditions were employed: (a) bilateral omnidirectional, (b) bilateral directional, (c) asymmetrical right (i.e., a directional microphone on the right ear and an omnidirectional microphone on the left ear), and (d) asymmetrical left (i.e., a directional microphone on the left ear and an omnidirectional microphone on the right ear). The results of this study revealed a significant improvement in speech understanding in noise scores when participants were fit with either an asymmetric directional microphone fitting or a binaural directional microphone fitting versus a binaural omnidirectional fitting. In addition, there was not a significant difference between speech understanding in noise scores when participants were fit with an asymmetric directional microphone fitting or binaurally with directional microphones, indicating that speech understanding ability was not decreased when fit with an asymmetric directional fitting compared to a bilateral directional fitting. Furthermore, when utilizing asymmetric directional microphones, listeners had lower acceptable noise levels (ANL) when compared to a binaural omnidirectional fitting. In addition, ANLs were lower in the binaural directional microphone condition as compared to either the asymmetric directional or binaural omnidirectional. The authors concluded that because ANL was directly related to hearing aid users' willingness to wear hearing aids, a hearing aid users success would increase when fit with an asymmetric directional fitting as opposed to a binaural omnidirectional fitting. The authors further determined that an asymmetric directional microphone fitting may be an option for hearing aid users who are unable or unwilling to change their hearing aid programs.

In conclusion, there are many amplification options for a person with an asymmetrical hearing loss, although the best amplification option has yet to be determined (Dillon, 2001). Research suggests asymmetric directional microphone fittings will increase speech understanding in noise and acceptance of background noise compared to an omnidirectional fitting (Kim & Bryan, 2011). In addition, an asymmetric directional microphone fitting may be an ideal option for those who cannot or will not manually change from the bilateral omnidirectional microphone configuration to the bilateral directional configuration (Cord et al., 2007). However, the above research on asymmetric directional microphone fittings has focused on those with symmetrical hearing loss. Therefore, the purpose of this study is to determine the effect of an asymmetric directional hearing aid fitting on acceptance of background noise and speech understanding in noise for on those with an asymmetric hearing loss.

CHAPTER II

REVIEW OF LITERATURE

Hearing Loss

In the United States, approximately 34.25 million Americans report hearing loss (Kochkin, 2010). Furthermore, there are three types of hearing loss: conductive, sensorineural and mixed. A conductive hearing loss occurs in the middle or outer ear and is easily improved through amplification. A sensorineural hearing loss, the most common type of hearing loss, occurs as a result of an incident inflicted upon the cochlea or auditory nerve and is a permanent hearing loss that cannot be surgically corrected (Martin & Clark, 2006). A typical symptom of a sensorineural hearing loss is decreased ability to understand speech (ASHA, 2005a). Lastly, a mixed hearing loss occurs when there is damage to the outer or middle ear and inner ear/auditory nerve structures; thus, it is a sensorineural and conductive hearing loss combined. Furthermore, a hearing loss can be either unilateral or bilateral. A unilateral hearing loss refers to a hearing loss that only occurs in one ear while the opposite ear has normal hearing. In contrast, a bilateral hearing loss refers to a hearing loss being present in both ears (ASHA, 2005a). Hearing losses can also be either symmetric or asymmetric. A symmetric hearing loss refers to both ears having similar hearing thresholds while an asymmetric hearing loss refers to both ears having different amounts of hearing loss (ASHA, 2005a).

Asymmetric Hearing Loss

There is a controversy over what constitutes an asymmetric hearing loss. According to Dillon (2001), an asymmetrical hearing loss can be defined as a difference between the ears in between the ears in one of the following areas: averaged thresholds, audiogram shape, speech intelligibility testing, dynamic range, or level of discomfort. Definitions of asymmetry have also included a difference of 10 dB HL or more at one or more frequencies; a pure tone air conduction difference between ears equal to or greater than 20 dB HL at three or more octave frequencies; and a difference of 20 dB HL between the averaged thresholds 500, 1000, 2000, and 4000 Hz (Segal et al., 2007; Silverman et al., 2006; Mackenzie & Lutman, 2005). Furthermore, Hornsby and Ricketts (2007) defined a symmetrical hearing loss as a difference between ears of less than or equal to 20 dB HL.

Causes of asymmetric hearing loss. First, asymmetrical hearing losses can be the result of repeated noise exposure. When a person is repeatedly exposed to hazardous levels of noise (i.e., 85 dB or above), the outer hair cells of the cochlea can be damaged and a sensorineural hearing loss could result (NIDCD, 2008). Some leisure activities have been known to result in a noise induced hearing loss (NIHL), such as shooting guns, working with power tools, playing in a band, or frequently attending concerts (NIDCD, 2008). Depending on the location of the sound source, a NIHL can result in either an asymmetric or symmetric hearing loss. For instance, a person who shoots rifles may suffer from an asymmetrical hearing loss. When shooting a rifle, a right-handed shooter will tuck the right ear, leaving the left ear exposed to more hazardous noise levels, so poorer hearing could result in the left ear (Katz, 2002). Audiometrically, a NIHL is characterized by a sensorineural hearing loss with a notch at 4000 Hz (Katz, 2002). In addition, acoustic tumors can result in asymmetric hearing thresholds (Schlauch, Levine, Li, & Haines, 1995).

Effects of an asymmetrical hearing loss. Segal et al. (2007) investigated the effect of asymmetric mild to moderate sensorineural hearing loss and its effects on handedness, age, noise exposure and gender. This study consisted of 429 participants (range = 16-75 years; 89 female and 340 male). The inclusion criteria were as follows: (a) an asymmetrical hearing loss (defined as a difference of 10 dB between ears at one or more frequencies); (b) no history of otologic disorders; (c) SRT $\leq$ 30 dB HL with a maximum SRTs difference between ears of 5 dB; (d) at least one hearing threshold with a sensorineural component greater than 30 dB HL; and (e) and no conductive component at any frequency. Furthermore, if a participant had a difference greater than 10 dB HL between ears, the participant was referred for retrocochlear testing. If retrocochlear pathology was discovered, the participant was removed from the study.

The study yielded the following results for each variable. First, the participants were placed into one of six groups based on age: younger than 30, 30 to 45, 46 to 55, 56 to 65, 66 to 75, and older than 75. In all age groups, the left thresholds were worse above 1500 Hz, except in the under 30 category where the right threshold was worse. The second variable was handedness. The population included 399 right-handed people and 30 left-handed people. The findings did not suggest a significant correlation between handedness and hearing thresholds. The third variable was noise exposure. Of the participants. 241 had been exposed to noise and 188 had not been exposed to noise. The results indicated the participants who had been exposed to noise had considerably worse hearing thresholds above 1500 Hz in the left ear. The participants who were not exposed to noise also had worse left ear thresholds, but the difference between right and left thresholds in this population was not considered a significant finding. The last variable was gender and noise exposure. For men who had not been exposed to noise (N = 116), the findings revealed no difference between hearing thresholds for the right and left ears. For the men exposed to noise (N = 224), the right hearing thresholds were better than the left at frequencies above 2000 Hz. In the women subgroup, there was not a difference between ears in those that were exposed to noise and those that were not. The authors believe the results of noise exposure for women should be viewed carefully because of the small sample of women (N = 89) included in the study. Seventeen had been and exposed to noise and 72 had not been exposed to noise. In summary, no relationship was found between asymmetric hearing loss and age above 30 years, gender, or handedness. The majority of participants who had been exposed to noise had asymmetric hearing thresholds; the right ear was usually the better ear (Segal et al., 2007).

Next, Arkebauer, Mencher and McCall (1971) investigated asymmetrical hearing loss by measuring the relationship between speech discrimination scores and different listening conditions. The listening conditions were as follows: (a) a monaural presentation with the poorer ear under headphones, (b) a monaural presentation with the better ear under headphones, (c) soundfield (both ears unoccluded), and (d) soundfield poorer ear occluded. The difference between the ears' hearing thresholds was believed to cause distortion to the signal when amplified binaurally. Ten subjects with mean thresholds of 55 to 65 dB HL in the poorer ear were divided into two groups. Participants in Group 2 had worse hearing in the better ear than those in Group 1. The experimental procedures were to obtain SRTs word recognition scores at 35 dB above SRT in each ear at each of the four conditions. The results showed a small difference when comparing better ear word recognition scores (under headphones) and soundfield (ears unoccluded), indicating improved WRS scores when a monaural presentation was given to the better ear. The results also showed that speech understanding abilities improved by 8% when the poorer ear was occluded versus when both ears received the signal via soundfield speakers. This indicated the best discrimination abilities occur when the poorer ear was occluded. This effect was heightened for Group 2. Next, the results showed that WRSs obtained in the soundfield with poorer ear occluded were better than or equal to the results in the better ear under a headphone, indicating a patient with an asymmetric hearing loss may perform better when the poorer ear is occluded than when the signal is only presented to the better ear (i.e. only amplifying one ear). In conclusion, a person with an asymmetric hearing loss may perform better on word recognition tasks if only the better ear is receiving the signal and best when the poorer ear is occluded (Arkebauer et al., 1971).

Current hearing aid fitting options for those with asymmetric hearing loss. According to Dillon (2001), those with asymmetric hearing losses have three amplification options: BICROS, a unilateral fitting or a bilateral fitting. BICROS stands for bilateral contralateral routing of signals and consists of a microphone mounted on each ear; however, the microphone on the poorer ear sends the signal to the amplifier and receiver located on the opposite ear. Therefore, with a BICROS hearing aid, the two signals are combined at the amplifier and routed to the better ear.

Another fitting option for an asymmetric hearing loss is a unilateral hearing aid fitting. With this fitting option, the better hearing ear is fit with a traditional hearing aid while the poorer ear remains unaided. Research has suggested that a monaural fitting has negative effects on the unaided ear (i.e., auditory deprivation). For example, Silverman et al. (2006) examined the effects of asymmetric sensorineural hearing loss by comparing a group of non-hearing aid users to a group of monaural hearing aid users. All participants had stable, asymmetric sensorineural hearing loss that was not the result of retrocochlear or conductive pathology and no neurological disorders. All participants' hearing loss had been acquired during their adult life as a result of noise exposure or acoustic trauma. The following experimental procedures were employed: (a) pure tone air conduction testing was administered at the octave frequencies from 250 to 8000 Hz, bilaterally, (b) SRTs were measured, and (c) WRS was conducted at 40 dB SL. Each participant in the monaural hearing aid group was then fit with a hearing aid on the poorer ear. Participants from each group were tested at the beginning of the study, one year from the start of the study, and two years from the start of the study.

At the conclusion of the study, the pure tone averages (PTA) had a slight improvement in the better ear in both groups. In addition, the results showed no change in word recognition testing for the better ear of either group (i.e., unaided versus monaurally aided). This led the authors to conclude that auditory deprivation effects are best measured through suprathreshold testing as opposed to pure tone testing or SRT. Suprathreshold measures revealed that a lack of amplification on the poorer ear may result in decreasing WRS in the poorer ear over time. The authors hypothesized that that auditory deprivation would be a progressive problem for those with an asymmetric sensorineural hearing loss. Finally, the results of the study suggested that a person with an asymmetric sensorineural hearing loss should wear amplification in both ears (Silverman et al., 2006).

Lastly, persons with an asymmetric hearing loss could also be fit with bilateral amplification (Dillon, 2001). There are many benefits a hearing impaired person can receive from bilateral amplification, such as binaural squelch, head diffraction effects, localization, binaural redundancy, and binaural summation. Binaural squelch is a phenomenon that enables a person to separate speech from noise, which occurs when the signal between the two ears are combined at the level of the brain. Another advantage of binaural hearing aid fitting is the reduction of head diffraction. Head diffraction is an acoustical phenomenon that occurs when a signal originates from one side of a person's head, which causes an attenuation of sounds at the opposite ear. This signal attenuation causes the signal at each ear to be perceived differently, which causes an increased signal-to-noise ratio (SNR) that can only occur when both ears receive a signal (Dillon, 2001). Next, a hearing loss will greatly affect a person's ability to localize sound. Localization is the ability to determine where sounds are originating based on interauarl timing and intensity cues. Interaural timing and intensity differences cues are two localization cues that are only maximized through binaural hearing. In addition, when a sound arrives on one side of the head, the head will diffract some of the sound (called head diffraction). Head diffraction will result in a decrease in the loudness perceived by the opposite ear (Dillon, 2001).

Furthermore, an advantage of binaural hearing aids is binaural redundancy which occurs when the brain combines the signals received at both ears. Binaural redundancy gives the brain two opportunities to hear the signal, resulting in a 1 to 2 dB increase in SNR. Binaural redundancy is completely lost if a person is aided unilaterally because it is only useful if the sound is audible in each ear. Last, binaural loudness summation occurs when both ears hear the signal; therefore the signal is perceived louder than if it was only heard monaurally. Binaural summation will result in an increase in the signals intensity because both ears perceived the signal (Dillon, 2001).

Directional Microphones

The hearing impaired population often complains of the inability to understand speech in the presence of background noise. Directional microphones are one of the few technologies that can improve speech understanding in noise. Directional microphones aim at suppressing the signals arriving from the back (i.e., noise) while maintaining good sensitivity to signals arriving from the front of the listener (i.e., speech). In addition, directional microphones provide an increased SNR when speech is presented from the front of the listener and noise originates from the back.

Select research on directional microphones. Cord et al. (2002) investigated the "real-world" use of directional microphones in 48 participants (mean age = 73.6, range = 45-91) who were fit with manually changing omnidirectional/directional hearing aids. All participants were mailed two questionnaires, which assessed a variety of listening situations. Participants were also interviewed and asked the following questions: (a) how much participants fit with manually changing omnidirectional/directional microphones use the directional mode, (b) if experienced hearing aid users knew the ideal characteristics of listening situations for the use of directional microphones, and (c) how often are ideal directional microphone conditions encountered. Each participant was also mailed an Abbreviated Profile of Hearing Aid Benefit (APHAB; Cox & Alexander, 1995) and a Microphone Performance Questionnaire (MPQ, Cord et al., 2002). Participants were asked to complete the APHAB for both aided and unaided performance as well as assessment of directional and omnidirectional performance. Furthermore, the MPQ listed 31 listening situations; participants were asked to select the best microphone condition (ranging from omnidirectional is much better to directional is much better) for each situation. The participant also indicated how often they were in each listening situation.

APHAB results showed less communication difficulties when using a directional microphone for all four subtests (i.e., Ease of Communication, Reverberation, Background Noise, and Aversiveness to Sound). The MPQ showed when the signal was in front and the noise was behind the listener; a directional microphone was preferred. Also, as reverberation increased the directional microphone was less effective but still preferred over an omnidirectional microphone. An omnidirectional microphone was preferred when the signal of interest came from any direction other than in front of the speaker, when the reverberation was low, or when the noise came from a direction other than behind the participant. Participants reported encountering more situations that required an omnidirectional microphone than situations that required a directional microphone.

The first interview question investigated whether participants who are fit with manually changing omnidirectional/directional hearing aids use the directional mode in daily living and how much they use each of them. Participants eventually stopped using the directional microphone condition. One-third of the telephoned participants who reported using hearing aids more than four hours a day were not changing the microphone condition. Reasons given for not changing the microphone condition included the inability to remember how to use the programs and a lack of benefit when using the directional microphone condition. The second question explored whether experienced hearing aid users know the characteristics of listening situations that are ideal for the use directional microphones. Participants who completed the APHAB indicated knowledge of knowing when to utilize the directional microphone. The MPQ also indicated that the participants understood when to use an omnidirectional microphone verses a directional microphone. The last question investigated how often the above listening situations were encountered. Participants reported they were in situations that required the use of the omnidirectional microphone more often than they were in situations that may require a directional microphone (Cord et al., 2002).

Asymmetric Directional Microphone Hearing Aid Fittings

Research on directional microphones has begun focusing on the effects on speech perception in noise when a person is fit with an asymmetric directional microphone fitting (i.e., fitting of a directional microphone on one ear and an omnidirectional microphone on the opposite ear). Many of these researchers have reported little difference in speech perception in noise scores when comparing asymmetric directional microphone fittings and bilateral directional microphone fittings (Cord et al., 2007). However, they report significantly better speech perception in noise scores when comparing asymmetric directional microphone fittings to omnidirectional microphone fittings. The following section summarizes the current research on asymmetrical directional microphone fittings.

First, Mackenzie and Lutman (2005) investigated the effects of speech recognition performance on those who were fit bilaterally with either omnidirectional microphones, fixed directional microphones, adaptive microphones, or a mixed microphones (i.e., omnidirectional microphone on one side and an adaptive directional microphone on the opposite side). The participants included 16 persons with symmetrical sensorineural hearing loss and 14 participants with normal hearing. All participants completed the Bamford-Knowal-Bench sentences (BKB; Bench, Knowal, & Bamford, 1979).

Five noise conditions: noise from the front, noise from the back, noise from the sides, asymmetric noise right, and asymmetric noise left. In all conditions, the speech was presented from 0° azimuth. When noise was presented at 0° azimuth (i.e., the front) there was not a significant difference in performance between the microphones conditions. However, the normal hearing group performed significantly better than the hearing impaired group in all microphone conditions. When the noise was presented from the back, there was a significant advantage for all fittings that contained directional components over the bilateral omnidirectional fittings. In addition, the bilateral adaptive microphone condition yielded significantly better results than the asymmetric fixed microphone conditions. Furthermore, normal hearing participants performed better than the hearing impaired group when omnidirectional microphones were utilized. Next, when the noise was presented from the sides the hearing impaired group performed the worst with bilateral omnidirectional microphones and best with the bilateral adaptive microphone fitting. Furthermore, the bilateral directional fitting was significantly worse than both asymmetric microphone conditions. Normal hearing participants only scored better than the hearing impaired group when the bilateral omnidirectional condition or bilateral directional condition was used. In the last condition, noise was presented at either 120° and 190° azimuth or 170° and 240° azimuth. Performance was the worst with the bilateral omnidirectional fitting, and the bilateral adaptive performance yielded the best performance. The normal hearing participants performed better than the hearing impaired group when the microphone condition was bilateral directional with the noise coming from the left loudspeaker and for each of the asymmetric adaptive microphone fittings in each of the loudspeaker conditions. Participants also completed a quality survey for each noise condition while in each microphone condition. Bilateral adaptive and the bilateral directional fittings were rated to provide the most comfort and clarity, as compared to the other microphones conditions.

In conclusion, generally the normal hearing group only performed significantly better than the hearing impaired group when a bilateral fixed microphone configuration (i.e., bilateral omnidirectional or bilateral directional) was used, suggesting that an asymmetric fixed microphone configuration is a viable option. Therefore, the authors believe the greatest benefit is received when using either bilateral adaptive or bilateral directional microphone fittings. Furthermore, bilateral fixed microphones do not provide benefit in all listening situations; bilateral adaptive microphones were considered to be the most beneficial (Mackenzie & Lutman, 2005).

Next, Hornsby and Ricketts (2007) compared a bilateral directional microphone fitting to an asymmetric microphone fitting with the speech and noise coming from different directions. Sixteen participants (mean age = 70.8) with mild to severe symmetrical (≤ 20 dB HL) sensorineural hearing loss were included in the study. The

Hearing in Noise Test (HINT; as cited in Hornsby & Ricketts, 2007) was used to assess speech understanding in 12 different conditions, which included three different noise configurations and four hearing aid fittings.

When speech was presented from the front and noise around (i.e., cafeteria noise was presented at 36°, 108°, 180°, 252°, and 324°), the results indicated poorer HINT scores for the bilateral omnidirectional mode than the bilateral directional and asymmetric directional modes. In the second noise condition (i.e., cafeteria noise presented on the left side at 50°, 70°, 90°, 110°, and 130°), speech and noise were presented on the sides of the listener; the HINT scores were significantly better in binaural omnidirectional mode than in either bilateral directional or asymmetric directional microphone modes. In noise conditions 1 and 2, the participants performance did not vary based on the ear that received the directional microphone. In the third noise condition (from 0.6m), speech was presented from one side and traffic noise was presented from the opposite side. Performance was optimal with a bilateral omnidirectional.

In conclusion, the results indicated that the ideal type of fitting is dependent upon where the noise and speech originate. The maximum directional benefit occurs with a bilateral directional microphone when the signal of interest is at 0° azimuth and the noise surrounds or comes from the side of the listener. However, a bilateral omnidirectional fitting gives the most benefit when the signal of interest and noise originate from the same side. Despite the similar scores of asymmetric directional microphone fitting and the directional microphone fitting, the authors recommend using a bilateral directional microphone fitting when the signal of interest is located 0° azimuth and the noise is surrounding (Hornsby & Ricketts, 2007).

Cord et al. (2007) investigated if the directional benefit in an asymmetric directional microphone fitting would provide benefit in the real world. Twelve experienced hearing aid users (mean age = 73), that reported rarely using their directional microphone program, served as the participants for this study. At each participant's first appointment the hearing aids were randomly set to either a bilateral omnidirectional fitting or to an asymmetrical directional fitting. At the second appointment, the opposite microphone configuration was implemented. At the final appointment, the participants reported his or her preferred microphone condition. Speech recognition in noise was also tested using three lists of sentences (the Institute of Electrical and Electronic Engineer (IEEE)/Harvard) in each of the four microphone conditions: (a) bilateral omnidirectional, (b) bilateral directional, (c) asymmetric directional right ear, and (d) asymmetric directional left ear. Participants also used the completed the Hearing Aid Use Log (HAUL; Surr, Cord, Walden, & Olson, 2002; Walden Surr, Cord, & Dyrlund, 2004) throughout the study. They HAUL is a daily log to document microphone preference, subjective measures of performance, descriptions of real world listening situations, and difficultly level of certain situations.

Results of the investigation revealed bilateral omnidirectional performance to be significantly worse than other conditions when noise originated from the back or sides and speech originates from the front. The HAUL indicated a significant preference for the asymmetric directional microphone fitting over the omnidirectional fitting. The results showed a statistically significant difference on performance when comparing omnidirectional and asymmetric directional microphone fittings. In addition, there was a statistical significance when comparing the listening situations directional versus omnidirectional/no preference. At the conclusion of the experiment, participants reported which fitting they preferred: four preferred the asymmetric directional fitting; three preferred the omnidirectional fitting; and five had no preference.

In conclusion, most participants reported a greater ease of listening with an asymmetrical fitting versus an omnidirectional fitting. However, when the HAULs were separated based on listening situation, the asymmetric fitting was only preferred in the situations where a directional microphone would be beneficial. In the situations where an omnidirectional fitting would be beneficial, there was no reported difference between ease of listening with an asymmetrical or omnidirectional fitting, indicating that an asymmetric configuration did not decrease ease of listening. In other words, ease of listening was not degraded with an asymmetrical directional configuration when an omnidirectional configuration is suggested. Lastly, the authors believe an asymmetric fitting is a good option for participants who cannot or will not alter the hearing aid programs in particular listening situations (Cord et al., 2007).

Kim and Bryan (2011) investigated the effects of speech understanding in noise and acceptance of background noise with an asymmetric directional microphone fitting for those with a symmetrical sensorineural hearing loss. Fifteen listeners with a symmetrical sensorineural hearing impairment (defined as no more than a 15 dB HL difference between pure tone thresholds at octave frequencies from 250 to 8000 Hz) participated in this study. The HINT was used to test the participants' ability to understand speech in the presence of background noise while the ANL procedure was used to assess acceptance of background noise. The HINT and ANL were conducted in the following microphone conditions (i.e., binaural omnidirectional, right asymmetric directional microphone, left asymmetric directional microphone, and binaural directional).

The study revealed a significant improvement in speech understanding in noise scores when participants were fit with either an asymmetric directional microphone fitting or a binaural directional microphone fitting as compared to a binaural omnidirectional fitting. In addition, there was no significant difference between the two asymmetric directional fittings. There was also not a significant difference between speech understanding in noise scores when participants were fit with an asymmetric directional microphone fitting or when fit binaurally with directional microphones, indicating that speech understanding ability is not decreased when fit with an asymmetric directional fitting compared to a bilateral directional fitting. Another finding of this study includes that asymmetric directional microphone fittings provide the listener with a lower ANL when compared to a binaural omnidirectional fitting. Furthermore, there was not a significant difference between the two asymmetric directional microphone conditions (i.e., right versus left). In addition, ANLs were lower in the binaural directional microphone condition as compared to either the asymmetric directional or binaural omnidirectional. The authors concluded that because ANL is directly related to hearing aid users' willingness to wear hearing aids, a hearing aid users success would increase when fit with an asymmetric directional fitting as opposed to a binaural omnidirectional fitting. The authors further determined that an asymmetric directional microphone fitting may be an option to hearing aid users who are unable or unwilling to change the programs of their hearing aids.

In summary, research on the effects of asymmetric directional microphones fittings on speech in noise has shown that an asymmetric directional fitting provides benefits over the more commonly selected bilateral omnidirectional microphone configuration. In addition, when comparing asymmetric directional microphone fittings and directional microphone fittings, an asymmetric directional microphone fitting does not degrade a person's ability to understand speech in background noise as compared to a directional microphone fitting.

Acceptable Noise Level

In 1991, Nabelek et al. investigated if hearing aid acceptance was a result of a patient's ability to accept background noise. The study contained five groups of participants: (a) young people with normal hearing (Group 1), (b) elderly with normal hearing (Group 2), (c) elderly full-time hearing aid users (Group 3), (d) elderly part-time hearing aid users (Group 4), and (e) elderly non-hearing aid users (Group 5). Participants in Groups 3, 4, and 5 completed a survey to categorize them into one of three hearing aid use groups: full-time, part-time, or non–users of hearing aids). A full-time hearing aid user (i.e., Group 3) was defined as those who use hearing aids when needed. A part-time hearing aid user (i.e., Group 4) was defined as someone who uses his or her hearing aids on occasion. Group 5 contained participants who rejected hearing aids because of the lack of perceived benefit and/or satisfaction. The primary stimulus was an Auditec recording of a women's voice. Five different background noises were used: (a) 12 talker speech babble (SPIN; Bilger, Neutzel, Rabinowltz, & Rzeczkowski, 1984), (b) speech spectrum noise, (c) traffic noise, (d) music that would be played in a waiting room, and (e) a recording of a pneumatic drill. All test signals were presented monaurally. To obtain the listener's acceptable noise level (ANL), first, the patients were asked to set the levels of the story to their most comfortable listening level (MCL). Next, the background noise was added, and the listeners were instructed to indicate when the maximum level of background noise they could "put up with" was reached (called background noise level or BNL). The BNL was then subtracted from MCL to achieve the most tolerated level (now called acceptable noise level or ANL).

The results indicated that the tolerated SNR varied between groups depending on the type of noise. Group 3, full-time hearing aid users, tolerated higher levels of music than all other groups, higher levels of speech spectrum noise than part-time hearing aid users and non-users, and higher levels of traffic noise than non-users. Groups 1, 2, 4, and 5 did not have different levels of tolerated noise even though the hearing thresholds were very different. When comparing ages of those who used hearing aids, younger subjects tolerated a higher SNR than elderly subjects. Full time hearing aid users had an average tolerated SNR of 7.5 dB whereas the average tolerated SNR for part-time and non-users of hearing aids was 13.99 and 14.49, respectively. Furthermore, there was no correlation between tolerated SNR, age, or hearing threshold levels. Participants of Groups 3 and 4 were also asked to complete the Hearing Handicap Inventory for the Elderly-Screener (HHIE-S, Ventry & Weinstein, 1983), answering each question as if they were wearing hearing aids and as if they were not wearing hearing aids. Group 3 had a significant perceived difference when they were wearing hearing aids and when they were not wearing hearing aids; Group 4 did not. The subjects in Group 4 did not view themselves as more handicapped when they were not wearing hearing aids. This perception is a direct reflection of the reason Group 4 only wore hearing aids occasionally. In contrast, subjects of Group 3 reported using hearing aids more because they felt less handicapped when wearing their hearing aids.

In conclusion, full-time hearing aid users' were able to tolerate lower SNRs than part-time and non-users of hearing aids. The authors suggested this may be a reflection of their innate tolerance and their previous adaptation to hearing aids. Furthermore, the researchers could not determine if differences in a tolerated SNR between the hearing impaired groups were innate in each subject or a result of their predetermined acceptance or non-acceptance of background noise. The authors recommended a longitudinal study of tolerance of background noise including pre- and post-hearing aid fitting data (Nabelek et al., 1991).

Nabelek et al. (2006) continued researching if the ANL procedure could predict hearing aid use. They tested 191 hearing aid users who had worn binaural hearing aids for at least three months and had no known cognitive issues served. Participants completed a survey that subsequently assigned them to a subgroup: full-time hearing aid user (n = 69), part-time user (n = 69), or non-user (n = 53). Unaided and aided ANLs were determined through using a male running voice and a 12-talker speech babble (see Nabelek et al., 1991 for review of ANL procedures). Unaided and aided SPIN tests were administered at a +8 SNR. The results indicated that both unaided and aided ANLs were not dependent on gender, age, or PTA. Furthermore, mean unaided ANL and aided ANLs were not different for any of the hearing aid groups. Both aided and unaided ANL scores were different among the full-time, part-time and non-hearing aid users and ANLs may be able to predict success with hearing aids. Furthermore, mean SPIN scores increased when amplification was utilized for all three hearing aid groups, indicating that speech perception scores may not be a predictor of success with hearing aids. These scores, however, may be a good measure of hearing aid benefit, use, or satisfaction.

As a result of the findings, the authors concluded that full-time hearing aid users (i.e., successful) were participants whose ANL score was below seven. Part-time hearing aid users and non-hearing aid users were considered to be unsuccessful hearing aid users. Participants whose ANL score is between 7 and 13 could be either successful or unsuccessful; and participants whose ANL score is above 13 are likely to be unsuccessful hearing aids users. The ANL procedure predicted hearing aid users' successfulness with 85% accuracy (Nabelek et al., 2006).

Acceptable noise level and binaural versus monaural amplification. Freyaldenhoven, Plyler, Thelin, and Burchfield (2006) investigated the effect of monaural and binaural amplification on speech understanding in noise and acceptance of background noise. Thirty-nine binaural hearing aid users (mean age = 69 years old) served as participants in the study. Each participant had a symmetrical sensorineural hearing loss and had used his or her hearing aids for at least three months. The testing was completed with participants' personal hearing aids in the omnidirectional microphone condition. Speech understanding in noise was established using a masked SRT procedure and was obtained as a control measure because its effects on monaural and binaural amplification are well established. Acceptance of background noise was measured using the ANL procedure. The signal of interest was male running speech (presented at 0° azimuth) and multi-talker speech babble served as the competing stimulus (presented at 180° azimuth). Both masked SRT and ANL were tested in three conditions: monaural right, monaural left, and binaural. When testing monaurally, the opposing ear was plugged with a preshaped foam earplug.

Results of masked SRT indicated an increased SNR when using binaural hearing aids versus a monaural hearing aid. However, there was no difference between the two monaural conditions. These results suggest that speech understanding in noise is better when binaural amplification is utilized. The results also suggest that speech understanding in noise is not changed based on the ear that was fit monaurally. Furthermore, the ANL results showed no significant difference between the monaural and binaural conditions, suggesting that a person's ability to accept background noise does not change if fit binaurally or monaurally. Secondary analyses revealed that some patients preformed significantly better with monaural amplification while others preformed significantly better with binaural amplification, suggesting that people with different monaural (i.e., right or left) and binaural ANLs may be more likely to accept hearing aids if fit in the condition where the lower ANL was scored. Also, when interaural ANL differences are present, monaural amplification success may be dependent on the ear amplified. Therefore, when conducting a hearing aid evaluation, the ANL procedure should be conducted monaurally (i.e., right and left ears) and binaurally to determine the fitting that will yield the most success (i.e., lowest ANL). In conclusion, masked SRT scores were significantly improved through binaural amplification. In contrast, ANLs were not significantly affected through binaural or monaural amplification (Freyaldenhoven et al., 2006).

Acceptable noise level and directional microphones. Lastly, Freyaldenhoven et al. (2005) investigated if ANL could be used to measure the directional benefit of hearing aids. To make this determination, the effects of directivity on masked SRTs, FBRs, and ANLs was evaluated (for a review on masked SRT and FBR, see Freyaldenhoven et al., 2005) utilizing both omnidirectional and directional microphone programs. Forty hearing aid users (N = 69, range = 30-89) served as the participants for this study. The results of the study indicated that directional benefit measured using ANL, masked SRT and FBR were comparable. Furthermore, masked SRT and FBR were weakly significantly correlated, while ANL and masked SRT were more significantly correlated. This indicated that that masked SRT, FBR, and ANL provide equally similar measures of directivity. Therefore, the authors concluded that ANL is a good alternative method for measuring the directional benefit of hearing aids (Freyaldenhoven et al., 2005).

CHAPTER III

METHODS

Participants

Thirteen adult bilateral hearing aid users or non-hearing aid users with bilateral asymmetrical sensorineural hearing loss served as participants for this study (mean age = 66.3 years; range = 40-94 years). This study included 3 females and 10 males (subject 8, a male, was excluded). In addition, the study included 3 non-hearing aid users and 9 binaural users of hearing aids. Each subject was recruited from either the Louisiana Tech University Speech and Hearing Center or via flyers distributed to local audiologists (see Appendix A for participant recruitment form). Upon arrival, each participant was given a verbal description of the study and required to read and sign an informed consent as required by the Institutional Review Board at Louisiana Tech University (see Appendix B). The inclusion criteria were as follows: (a) adult listeners (i.e., 21 years or older); (b) an asymmetric sensorineural hearing loss (average of ≥ 15 dB HL at 500, 1000, 2000, and 4000 Hz); (c) either bilateral hearing aid users or non-users of hearing aids; (d) no known cognitive deficits (as determined by case history); and (e) a native English speaker (as determined by case history). If all inclusion criteria were not met, participants were excluded from the study. Figure 1 shows the participants', excluding subject 8, mean thresholds at the octave frequencies 250 to 8000 Hz for both the better and poorer ear.

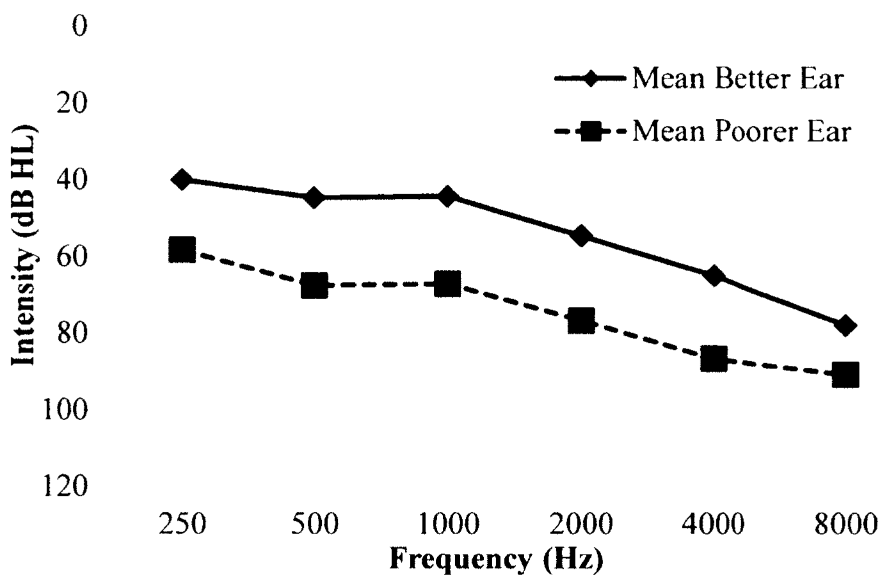

Figure 1. Mean pure tone thresholds of participants for octave frequencies 250 to 8000 Hz for both the better and poorer ear.

Materials and Procedures

Qualification procedures. All testing was conducted in Woodard Hall at Louisiana Tech University Speech and Hearing Center in a sound-treated booth (2.4m x 2.2m x 1.9m) with appropriate levels of ambient noise for testing unoccluded ears (ANSI S3.1-1991). The audiometer used during testing was a Grason Stadler (GSI 61) audiometer and was confirmed to be in good working order via current calibration and daily biologic checks. Each participant completed a written case history; follow-up questions were asked by the researcher as needed (see Appendix C). Otoscopy was used to confirm no outer ear pathology was present. Lastly, air and bone conduction testing was conducted prior to fitting participants with hearing aids (masking was used when necessary).

Hearing aids. Each participant was then fit separately for the purpose of testing with the same pair of Siemens Intuis Dir behind-the-ear (BTE) hearing aids with comply earmolds. The hearing aids had twin microphones with fixed hypercardioid polar plots. Each participant's audiometric data was entered into the NOAH software, and the hearing aids were programmed using the National Acoustic Laboratories (NAL-R) fitting strategy (Byrne & Dillon, 1986) and Siemens' first fit (Note: Linear processing was utilized to prevent differential effects caused by compression [Ricketts, 2000]). Each hearing aid had two programs, an omnidirectional microphone program and a directional microphone program; all other parameters were consistent between the two programs. The noise reduction and feedback suppression features were deactivated, along with the volume control.

Testbox measures. First, the hearing aids were placed in an Audioscan Verifit (serial # X112C36BA) testbox with the front microphone port facing the left loudspeaker and the rear microphone port facing the right loudspeaker. Both omnidirectional and directional microphone conditions were tested to confirm they were working appropriately. The response from the front loudspeaker was subtracted from the back loudspeaker to measure directivity of each microphone configuration. Pink noise was presented at 65 dB SPL from 250 to 8000 Hz. Four measurements were obtained with the omnidirectional microphone and four measurements with the directional microphone, resulting in eight total measurements. The testing conditions were as follows: omnidirectional front loudspeaker, omnidirectional back loudspeaker, directional front loudspeaker, and directional back loudspeaker. If directivity was not confirmed, experimental testing was rescheduled.

One subject was excluded from the study post-testing, due to hearing aid malfunction (i.e., Seiemen Intuis Dir behind-the-ear hearing aids). Hearing aids had been sent for repair due to inconsistencies with directional microphones, upon arrival from repair all ANSI measurements were met; however post-subject testing, testbox measures determined the directional microphones of the left hearing aid was not working appropriately. Therefore, subject 8's data was removed from the study and a new pair of Siemens Intius BTE with twin microphones and fixed hypercardioid polar plots were ordered and utilized for the remaining subjects.

Speech understanding in noise. Speech understanding in noise was evaluated using the Hearing In Noise Test (HINT; Nilsson, Soli, & Sullivan, 1994). The HINT consists of 250 sentences that are separated into groups of either 25 lists of 10 sentences or 12 lists of 20 sentences. In standard HINT procedures, the speech and noise are presented through soundfield speakers. A list of 20 sentences are administered; the first sentence is presented 4 dB below the level of the noise. The noise is presented at a constant level (65 dBA), and the level of the speech was varied. The intensity of a sentence is increased if the previous sentence is incorrect; however, if the previous sentence is answered correctly, the intensity of the next sentence is decreased. For a correct or incorrect response on sentences one through four the variation is ± 4 dB; for sentences 5 through 20, the level of the speech is varied in ± 2 dB. However, for this project, the traditional procedures were modified whereas the speech was kept constant and noise was varied to ensure that the speech levels were consistent between the HINT and ANL stimuli.

The HINT was performed for the following six microphone conditions:

(a) bilateral omnidirectional fitting;

(b) asymmetric directional – poorer ear fitting (i.e., a directional microphone on the poorer ear and an omnidirectional microphone on the better ear);

(c) asymmetric directional – better ear fitting (i.e., a directional microphone on the better ear and an omnidirectional microphone on the poorer ear);

(d) bilateral directional fitting;

(e) unilateral directional better ear (i.e., directional microphone on the better ear while the poorer ear is plugged with an insert ear plug [NRR = 35 dBA]); and

(f) unilateral omnidirectional better ear (i.e., omnidirectional microphone on the better ear while the poorer ear is plugged with an insert ear plug [NRR = 35dBA]).

A list of HINT sentences was chosen at random for each participant. The sentences originated from an ear-level loudspeaker at 0° azimuth, and noise originated from an ear-level loudspeaker at 180° azimuth. Two HINT scores were obtained for each microphone condition; the average of the two scores created the final HINT score.

Acceptance of background noise. Acceptance of background noise was measured using the ANL procedure. Initially, the participants were asked to adjust male running speech (Arizona Travelogue, Cosmos, Inc.) to his or her most comfortable listening level (MCL). Next, background noise (i.e., multitalker speech babble, Revised SPIN; Bilger et al., 1984) was added. Participants were instructed to determine the maximum amount of background noise they would be willing to "put up with" while still following the story (called background noise level or BNL). The initial level used to obtain the MCL and the maximum level of background noise was 30 dB HL. The BNL was then subtracted from the MCL to achieve the ANL.

ANL was obtained in each microphone condition: bilateral omnidirectional, asymmetric directional – better ear, asymmetric directional – poorer ear, bilateral directional, unilateral directional better ear, and unilateral omnidirectional better ear. Again, the speech and noise were presented through two ear-level loudspeakers located at 0° azimuth (i.e., speech) and 180° azimuth (i.e., noise). Two ANLs were obtained for each microphone condition, and the average of the two ANLs resulted in each participant's individual ANL score.

CHAPTER IV

RESULTS

Test Box Measures

In order to guarantee proper hearing aid function, test box measures were completed using each patient's hearing aid settings, which were programmed using their audiometric data. Using an Audioscan Verifit, directionality of the hearing devices was measured in each microphone condition (omnidirectional and directional). Pink noise delivered at 65 dB SPL was utilized when capturing the curve. Eight curves were recorded for each subject: omnidirectional response from the front speaker, omnidirectional response from the back speaker, directional response from the front speaker, and directional response from the back speaker for the right and left ears. Figure 2 shows the frequency response curves when the hearing aid was set to the omnidirectional and directional modes and the noise was arriving from the front and back speakers.

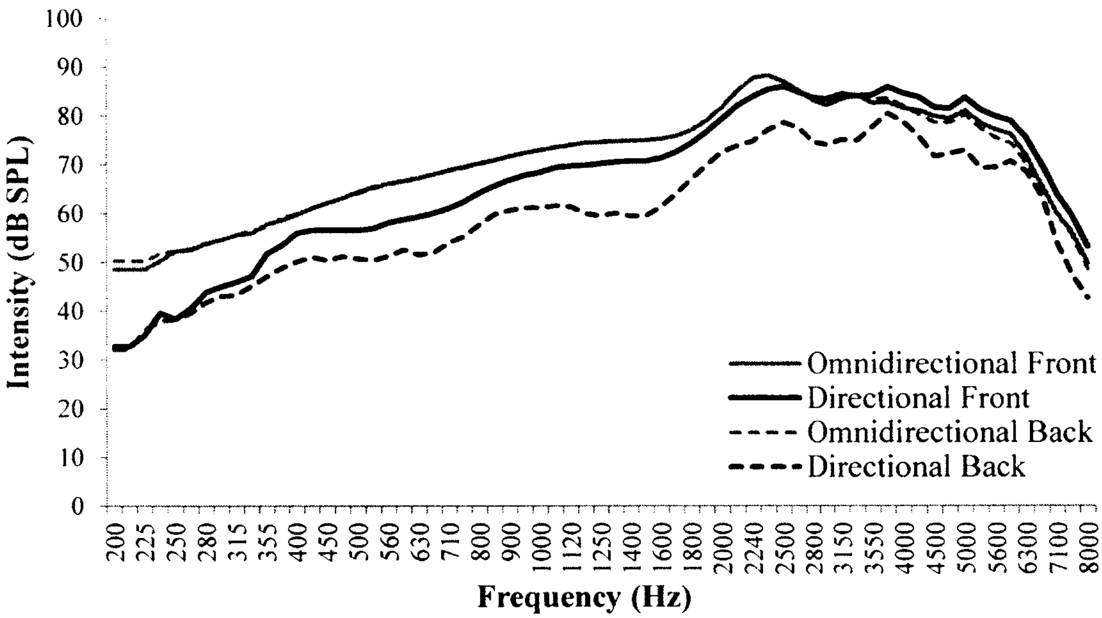

Figure 2. Average SPLs as a function of frequency for the omnidrectional and directional settings when measured from the front and back loudspeakers of the Verifit for 24 ears (12 particpants).

In the omnidirectional condition, the average response curves of the front and back speakers indicate a similar response; this verifies that the omnidirectional microphone was functioning appropriately. In contrast, the response curve from the directional microphone front condition was more sensitive than the response curve obtained from the directional microphone back condition, indicating that the directional microphone was suppressing noise arriving from the back while sustaining sensitivity to the front. In Figures 3 and 4, the response from the back microphone was subtracted from that of the front microphone for both the omnidirectional and directional microphone conditions. Figures 3 and 4 show data for the right left ears, respectively. These figures indicate the directional microphone settings generated a 5 to 10 dB intensity difference across the test frequencies for both ears compared to the omnidirectional microphone settings, indicating that the directional microphones were functioning properly.

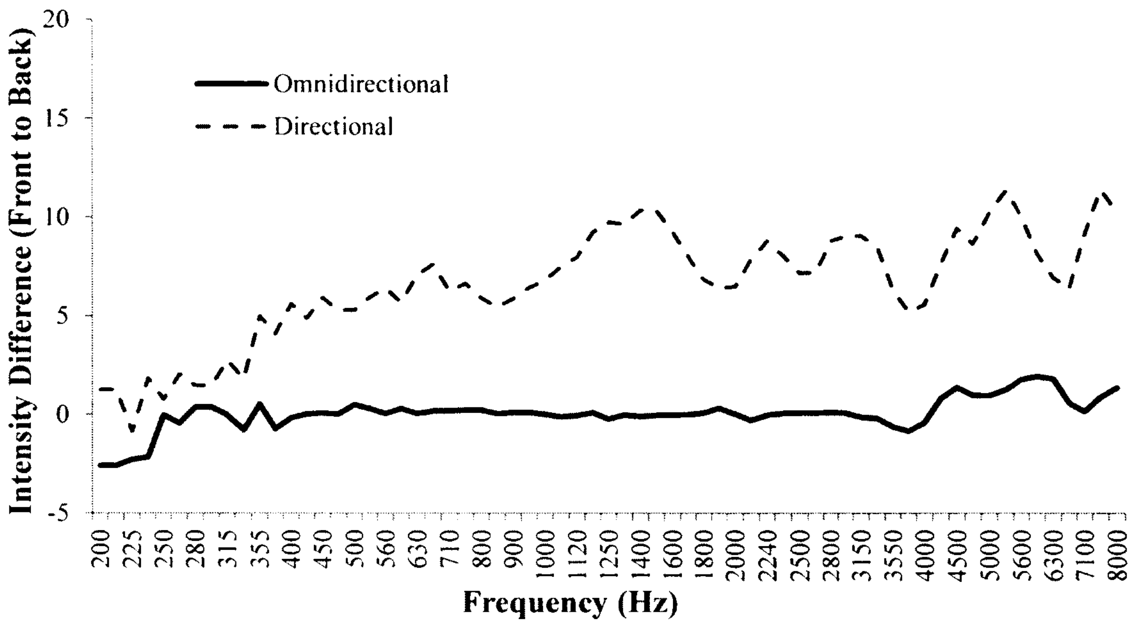

Figure 3. SPL difference between the front and back response for the omnidirectional and directional microphone conditions for all right ears. Note: Difference was calculated by subtracting front response from the back response.

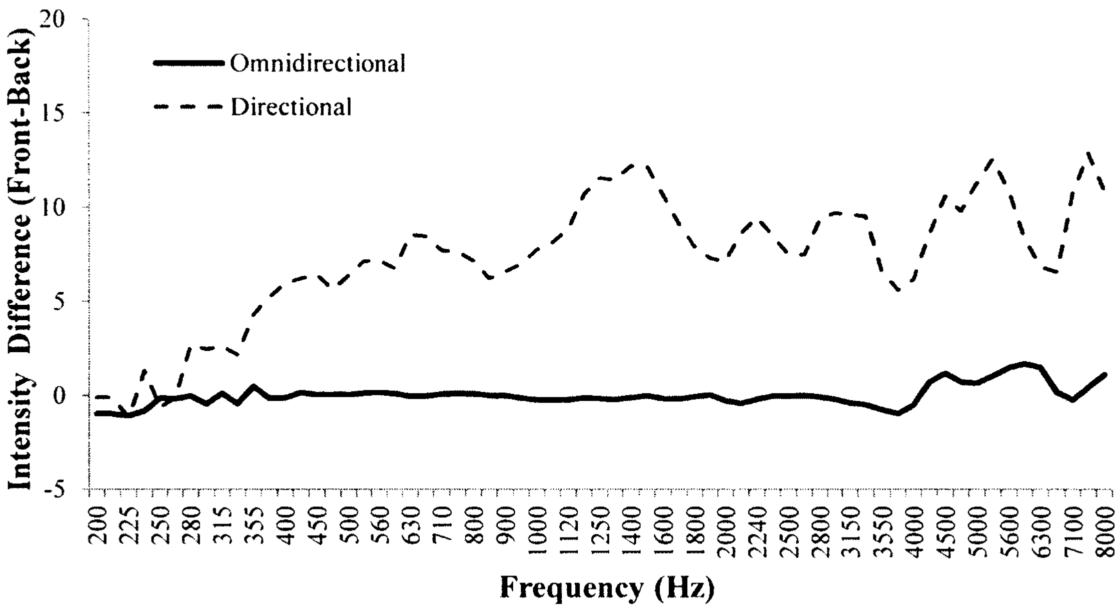

Figure 4. SPL difference between the front and back response for the omnidirectional and directional microphone conditions for all left ears. Note: Difference was calculated by subtracting front response from the back response.

Speech Understanding in Noise

One purpose of the present study was to investigate the effect of asymmetric directional microphone fittings on speech understanding in noise on persons with asymmetric hearing loss. HINT scores were measured in each microphone condition (i.e., bilateral omnidirectional, asymmetric directional poorer ear, asymmetric directional better ear, bilateral directional, unilateral directional better ear, and unilateral directional poorer ear) at the listener's MCL, which was obtained using the ANL procedure. The HINT was replicated for each condition, and mean HINT scores were determined for each participant. Mean HINT scores across participants and condition are shown in Figures 5 and 6. Figure 5 includes mean HINT scores for all binaural test conditions (i.e., bilateral omnidirectional, asymmetric directional better ear, asymmetric directional poorer ear, and bilateral directional), and Figure 6 includes mean HINT scores for all monaural test conditions (i.e., unilateral directional better ear and unilateral directional poorer ear).

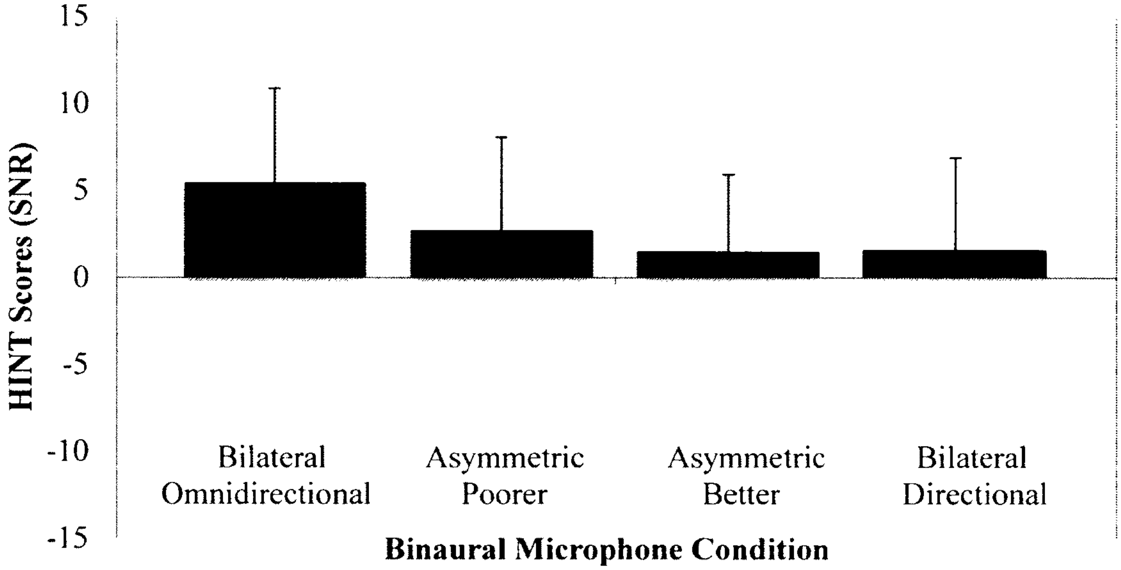

Figure 5. Mean HINT scores and standard deviations as a function of the four binaural microphone conditions.

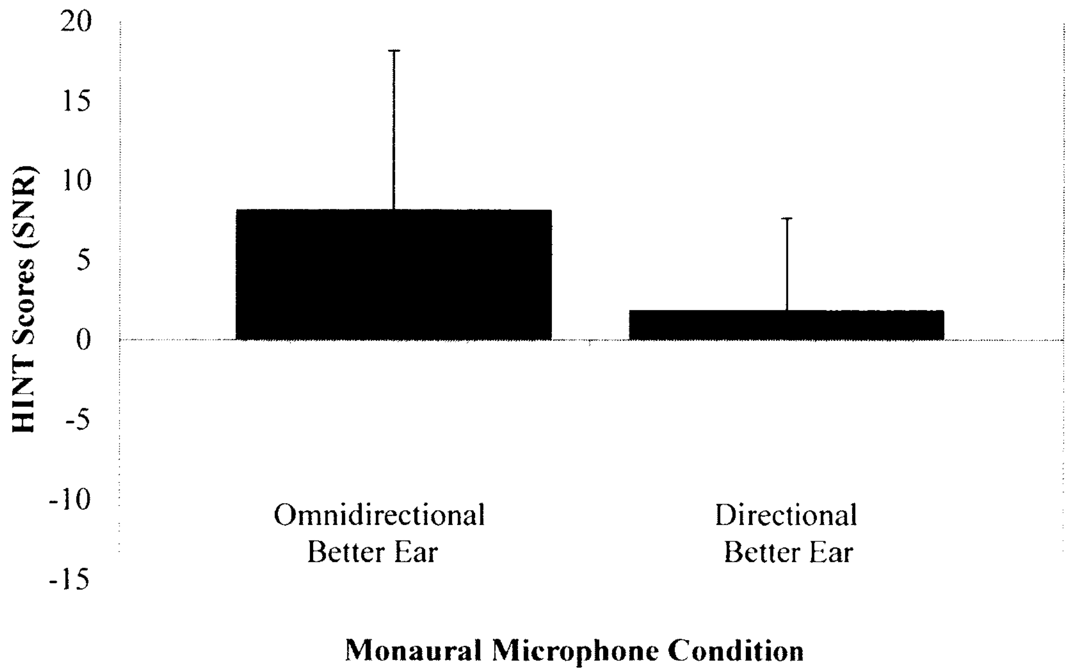

Figure 6. Mean HINT scores and standard deviations as a function of two monaural microphone conditions.

Two one-way repeated measured analysis of variance (ANOVAs) were conducted to evaluate the effects of the microphone condition on speech understanding in noise. The dependent variable was HINT score. In the first ANOVA, the within subjects factor was microphone condition with four levels (i.e., bilateral omnidirectional, asymmetric directional poorer ear, asymmetric directional better ear, and bilateral directional). The analysis revealed a significant main effect for microphone condition ($F[3, 33] = 10.821$, $p < 0.001$). Furthermore, post hoc analyses were conducted using pairwise comparisons; a Bonferroni adjustment was applied for multiple comparisons.

Pairwise comparison results revealed HINT scores were significantly better for the asymmetric directional better ear (i.e., directional microphone on the better ear and omnidirectional microphone on the poorer ear; M = 1.5) and bilateral directional (M = 1.6) conditions as compared to the bilateral omnidirectional (M = 5.4) condition. However, the asymmetric directional poorer ear (M = 2.7) condition was not significantly different than any of the other measures (i.e., bilateral omnidirectional (M = 5.4), asymmetric directional better ear (M = 1.5), or bilateral directional (M = 1.6)). Furthermore, the asymmetric directional better ear (M = 2.7) and the bilateral directional (M = 1.6) condition were not significantly different than one another.

Table 1. Post hoc analysis comparing mean HINT scores for each binaural microphone condition. Note: Any two means with the same subscript are significantly different.

Microphone Condition	HINT scores (SDs)
Bilateral Omnidirectional	$5.44\ (5.4)_{A,B}$
Asymmetric Directional Better Ear	$1.50\ (4.4)_{A}$
Asymmetric Directional Poorer Ear	2.72 (5.4)
Bilateral Directional	$1.62\ (5.3)_{B}$

These results indicated a significant improvement in speech in noise scores when listeners were fit with either an asymmetric directional microphone fitting with the directional microphone placed on the better ear or a bilateral directional microphone fitting as compared to a bilateral omnidirectional fitting. However, there were no differences in speech scores when subjects were fit with an asymmetric directional better ear fitting or a bilateral directional microphone fitting. Furthermore, participants' speech understanding did not change between the two asymmetric directional microphone conditions or between the asymmetric poorer ear condition as compared to the bilateral directional or bilateral omnidirectional condition. Collectively, these results indicate that speech in noise scores improve if patients are fit with bilateral directional microphones or asymmetric directional microphones when the better ear is fit with the directional microphone as compared to a bilateral omnidirectional fitting. Furthermore, speech understanding in noise scores are not hindered when using an asymmetric directional microphone fitting and placing the directional microphone on the better ear compared to a bilateral directional microphone fitting. Lastly, speech understanding in noise abilities seem to be in the middle if fit with the asymmetric directional microphone on the poorer ear as compared to bilateral omnidirectional microphones, bilateral directional microphones, or an asymmetric directional microphone fitting with the directional microphone on the better ear. Specifically, asymmetric directional poorer ear microphone fittings produce speech in noise scores slightly better than a bilateral omnidirectional microphone fitting and slightly worse than a bilateral directional or asymmetric directional better ear fitting. Based on this data, the author concluded that speech understanding in noise is maximized in both the asymmetric directional better ear and bilateral directional fittings for listeners with asymmetric hearing loss.

As a part of this ANOVA, partial eta squared values were calculated to determine effect sizes of clinical significance (Nolan & Heinzen, 2007). Nolan and Heinzen (2007) state that the ranges for effect sizes of clinical significance for partial eta squared are evaluated as follows: (1) a large effect size is greater than or equal to 0.138, (2) a medium effect size ranges from 0.059 to 0.137, and (3) a small effect size is less than 0.058 (Nolan & Heinzen, 2007). Statistical analysis showed that there was a clinically significant large effect size (partial $\eta^2 = 0.496$) for microphone condition. These results support the statistical significance found, indicating that these results are also clinically significant.

In the second ANOVA, the within subjects factor was microphone condition with two levels (i.e., unilateral omnidirectional better ear and unilateral directional better ear). The analysis revealed a significant main effect for microphone condition ($F[1, 11] = 14.82$, $p = 0.003$) with a clinically significant large effect size (partial $\eta^2 = 0.574$). These results indicate that listeners performed significantly better when a directional microphone is utilized over an omnidirectional microphone in the better ear and the poorer ear is unaided.

Table 2. Post hoc analysis comparing mean HINT scores for each monaural microphone condition.

Microphone Condition	HINT scores (SDs)
Unilateral Omnidirectional Better Ear	8.17 (10.0)
Unilateral Directional Better Ear	1.87 (5.8)

Secondary HINT analysis. A secondary HINT analysis was conducted to determine if an asymmetrical binaural microphone fitting with the directional microphone on the better ear (M = 1.5) yielded better speech understanding in noise scores than a monaural directional microphone fitting with the hearing aid on the better ear (M = 1.9). A paired t-test was completed to compare the asymmetric directional better ear microphone condition to the unilateral directional microphone condition (i.e., directional microphone on the better ear and poorer ear plugged). The results showed no significant difference ($t = -0.408$, $p = 0.691$) between speech understanding in noise scores, indicating that speech understanding in noise results are similar when selecting one directional hearing aid versus two hearing aids where a directional microphone is fitted to the better ear. Clinically, this may mean that audiologists sometimes fit a monaural directional microphone and other times fit an asymmetric directional microphone, depending on other factors associated with hearing (i.e., binaural effects of hearing, patient preference, acceptance of background noise, etc.). Please note for the current study, speech and noise were presented from 0° and 180° azimuths, respectively.

Acceptance of Background Noise

Another purpose of the present study was to determine if asymmetric directional microphone fittings affected acceptance of background noise for those with asymmetric hearing loss. ANLs were obtained twice for each microphone condition (i.e., bilateral omnidirectional, asymmetric directional poorer ear, asymmetric directional better ear, bilateral directional, unilateral directional better ear, and unilateral directional poorer ear), and a mean ANL was determined for each participant. The mean ANL scores across participants are shown in Figures 7 and 8.

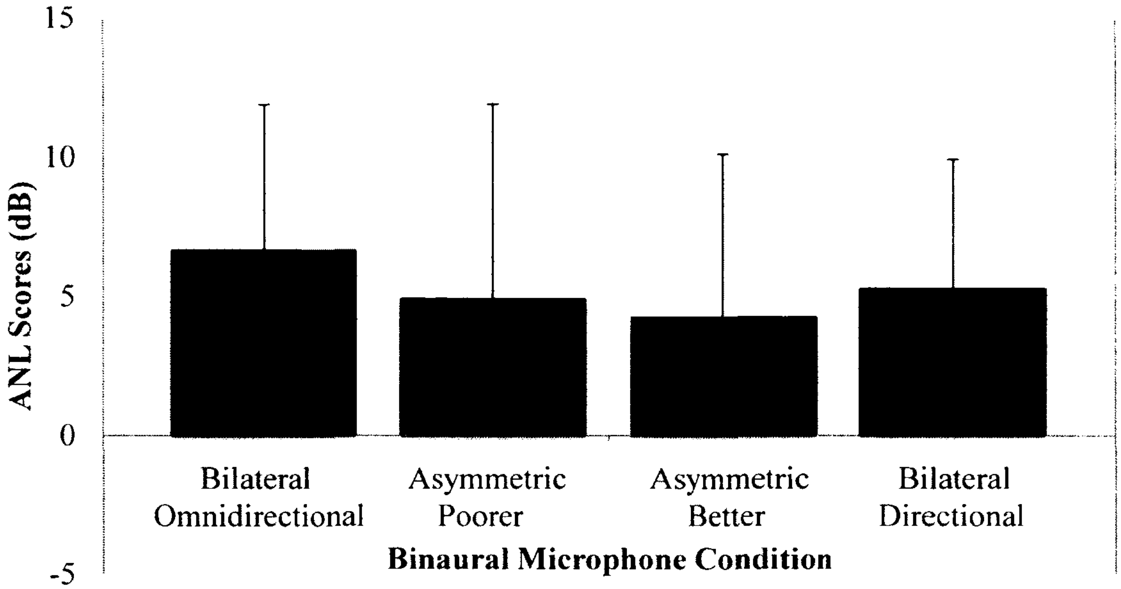

Figure 7. Mean ANLs and standard deviations for the four binaural microphone conditions.

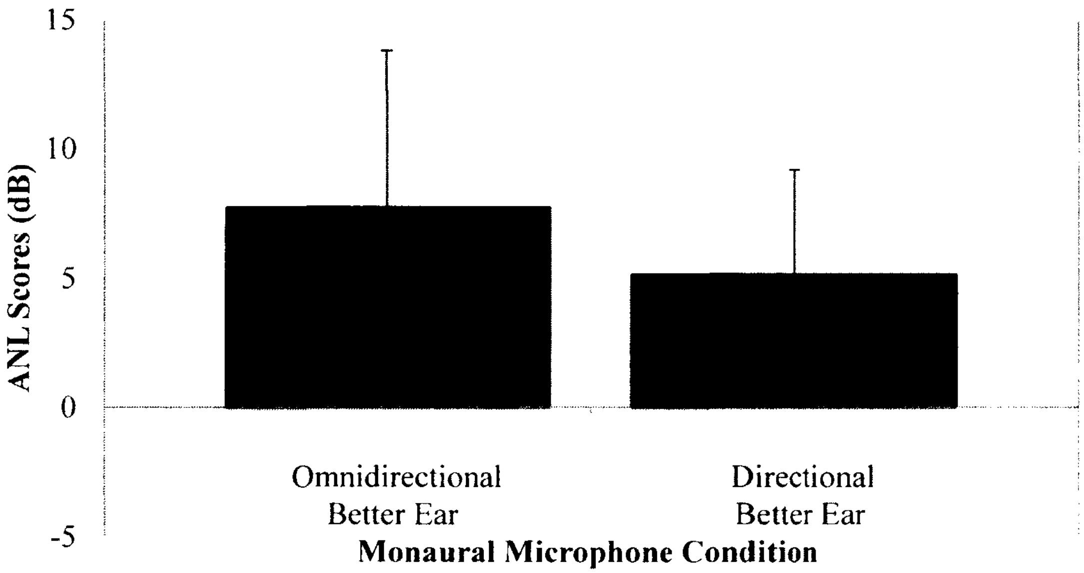

Figure 8. Mean ANLs and standard deviations for the two monaural microphone conditions.

Two one-way repeated measure ANOVAs were performed to evaluate the effects of microphone condition on acceptance of background noise for (1) the binaural fitting conditions and (2) monaural fitting conditions. For both ANOVAs, the dependent variable was the ANL. The within subjects factor was microphone condition with four levels in the binaural fitting condition (i.e., bilateral omnidirectional, asymmetric directional poorer ear, asymmetric directional better ear, and bilateral directional). The analysis revealed a no significant main effect for microphone condition ($F[3, 33] = 1.30$, $p = 0.29$). The results indicated that no one binaural microphone condition provided listeners with more acceptance of background noise over another when noise originated from directly behind the listener.

Table 3. Post hoc analysis comparing mean ANL scores for each binaural microphone condition. All comparisons were non-significant.

Microphone Condition	ANL scores (SDs)
Bilateral Omnidirectional	6.66 (5.2)
Asymmetric Directional Better Ear	4.25 (5.8)
Asymmetric Directional Poorer Ear	4.91 (6.9)
Bilateral Directional	5.29 (4.6)

A one-way repeated measure ANOVA was also performed on the monaural fitting conditions (i.e., unilateral omnidirectional better ear and unilateral directional better ear). The within subjects factor was microphone condition with two levels (i.e., unilateral omnidirectional better ear and unilateral directional better ear). The analysis revealed a significant main effect for microphone condition ($F[1, 11] = 1.46$, $p = 0.008$) and a clinically significant large effect size (partial $\eta^2 = 0.491$) . These results indicate that ANLs were lower (i.e., better) with the hearing aid in the directional microphone mode over the omnidirectional microphone mode with the poorer ear plugged and with noise originating from behind the listener.

Table 4. Post hoc analysis comparing mean ANL scores for each monaural microphone condition.

Microphone Condition	ANL scores (SDs)
Unilateral Omnidirectional Better Ear	7.75 (6.0)
Unilateral Directional Better Ear	5.16 (4.0)

Secondary ANL analysis. A secondary ANL analysis was also conducted to compare the asymmetric directional better ear condition (M = 4.3) to the unilateral directional better ear condition (i.e., directional microphone on the better ear and poorer ear plugged, M = 5.2) utilizing a paired t-test. The results showed no significant difference in the two microphone conditions ($t = -0.966$, $p = 0.355$), indicating there was no significant difference in a person's ability to accept background noise when using one directional microphone in the better ear versus using a directional microphone in the better ear and an omnidirectional microphone in the poorer ear. In other words, hearing aid acceptance may not increase or decrease when patients are fit with a directional microphone monaurally versus asymmetric directional microphone fitting, as long as the directional microphone is on the better ear. Therefore, a person with an asymmetric hearing loss will have similar hearing aid success when fit monaurally or binaurally as long as they are fit with a directional microphone on better hearing ear.

CHAPTER V

DISCUSSION

There are multiple amplification options for those with an asymmetrical hearing loss, although the best amplification option has yet to be determined (Dillon, 2001). One of these options is an asymmetric directional microphone fitting (i.e., an omnidirectional microphone placed on one ear and a directional microphone placed on the other). Previous research suggests that if chosen, this option will increase speech understanding in noise and acceptance of background noise compared to a bilateral omnidirectional fitting (Kim & Bryan, 2011). In addition, an asymmetric directional microphone fitting may be an ideal option for those who cannot or will not manually change from the bilateral omnidirectional microphone configuration to the bilateral directional configuration (Cord et al., 2007). However, the previous research on asymmetric directional microphone fittings has focused on those with symmetrical sensorineural hearing loss. Furthermore, the current study focuses on determining the effects of an asymmetric directional microphone fitting on speech understanding in noise and acceptance of background noise for on those with an asymmetric hearing loss.

Speech Understanding in Noise

One purpose was to determine the effects of an asymmetrical directional microphone fitting on speech understanding in noise for those with an asymmetric hearing loss. The results revealed speech in noise scores were significantly better for the asymmetric directional better ear and bilateral directional conditions as compared to the bilateral omnidirectional condition. The results further revealed that the asymmetric directional poorer ear condition was not significantly different than any of the other measures. Likewise, the asymmetric directional better ear and the bilateral directional condition were not significantly different than one another. These results indicated that speech understanding in noise abilities increase when fit with an asymmetric directional microphone fitting with the directional microphone on the better ear (M = 1.5) or with bilateral directional microphones (M = 1.6) as compare to a bilateral omnidirectional microphone fitting (M = 5.4). Furthermore, these results indicate that speech understanding is not degraded when fit with an asymmetric directional microphone fitting with the directional microphone on the better ear (M = 1.5) as compared to a bilateral directional fitting (M = 1.6). Lastly, while not significant speech understanding in noise scores for the asymmetric directional fitting with the directional microphone fit to the poorer ear (M = 2.7) were slightly better than scores for the bilateral omnidirectional fitting (M = 5.4) and slightly worse than the speech in noise scores for both the asymmetric directional microphone fitting with the directional microphone fit to the better ear (M = 1.5) and the bilateral directional microphone fitting (M = 1.6). These results might suggest that for speech in noise abilities an asymmetric directional fitting with the directional microphone on the poorer ear might be chosen over a bilateral omnidirectional fitting but not preferred over a bilateral directional or asymmetric directional better ear fitting.

These finding were somewhat expected based on data by Cord et al. (2007) and Kim and Bryan (2011). First, Cord et al. (2007) indicated speech understanding in noise scores were not significantly worse with an asymmetric directional fitting as compared to a bilateral directional fitting. Furthermore, bilateral omnidirectional fittings showed worse speech understanding in noise abilities than all other microphone conditions. Therefore, Cord et al. (2007) concluded that in situations where a hearing aid user may select a bilateral omnidirectional program, an asymmetric directional fitting may be an option because it provides some directional advantages (Cord et al., 2007). Secondly, Kim and Bryan (2011) indicated similar findings as Cord et al. (2007) on speech understanding in noise, whereas speech in noise scores for the asymmetric directional fittings were similar to those obtained with the bilateral directional fitting while both the asymmetric and bilateral directional fittings produced better speech in noise scores than the bilateral omnidirectional fitting. These results are comparable to the current study in that both the asymmetric directional better ear microphone fitting and the bilateral directional microphone fitting yielded better speech understanding in noise as compared to the bilateral omnidirectional microphone fitting. In addition, speech scores were not hindered when a participant was fit with an asymmetric directional microphone fitting with the directional microphone on the better ear compared to bilateral directional microphones (Cord et al., 2007; Kim & Bryan, 2011). Moreover, previous research results are different than the current research findings in that the asymmetric directional poorer ear microphone fitting was not significantly different than either the bilateral omnidirectional microphone fitting or the bilateral directional microphone fitting. Furthermore, speech in noise scores for the two asymmetric directional fittings were not different. In other words, fitting the directional microphone to the poorer ear with an omnidirectional microphone on the better ear slightly degrades speech in noise abilities compared to the bilateral directional and asymmetric directional better ear fittings and slightly improves it compared to a bilateral omnidirectional fitting. This degradation in speech in noise abilities is most likely due to the fact that a directional microphone was fit on the poorer ear while an omnidirectional microphone was fit on the better ear, thus only increasing the signal-to-noise ratio for the poorer ear. The difference in research findings between the current study, Cord et al. (2007), and Kim and Bryan (2010) could also be due to the fact that in the current study, participants' hearing loss was asymmetrical.

While writing the present study findings, Cord, Surr, Walden and Dittberner (2011) released a similar study aimed at determining if asymmetric speech understanding in noise scores were related to success with or preference for an asymmetric directional microphone fitting. Specifically, in one fitting an omnidirectional microphone was fit on one ear and a directional microphone was fit to the other ear, and in the second fitting the configuration was switched. Twenty-eight participants were place into either the symmetrical (N = 16) or asymmetrical (N = 12) group based on aided speech recognition in noise scores. Specifically, all participants had symmetrical pure tone thresholds and word recognition scores in quiet; however, when fit monaurally with an omnidirectional microphone and the opposite ear plugged, speech in noise scores were asymmetrical. Participants placed in the asymmetric group had a left ear signal to noise ratio that was better (i.e., lower) than the right ear by at least 2.5 dB. Furthermore, four different speech in noise configurations were utilized: speech in front, speech in back, speech at the right and speech at the left; the noise was always presented via all four speakers (i.e., front, back, right and left). The following results are only those from the asymmetric group.

First, when speech was presented from the front and noise from all four loudspeakers, the bilateral directional microphone and asymmetrical directional better ear fittings provide significantly better speech in noise performance than a bilateral omnidirectional fitting. Furthermore, speech in noise performance was similar when comparing the bilateral directional fitting with the asymmetric fitting when the directional microphone was on the better ear; however, speech in noise performance was significantly better in the bilateral directional fitting versus the asymmetric directional poorer ear fitting. Secondly, when speech originated from behind the listener and noise was presented from the four speakers, the listener preformed significantly better using an asymmetrical directional poorer ear fitting versus a bilateral directional fitting. Thirdly, when the speech originated from either side of the listener and noise surrounded, subjects performed better with asymmetric microphone configurations as compared to symmetrical microphone configurations, however only when the omnidirectional microphone was located on the side of the signal of interest. Lastly, the authors stated the most notable finding was that speech in noise was minimally affected between the two asymmetric microphone configurations, even though the listeners had asymmetric hearing in noise abilities.

In addition, 12 participants participated in a field trial where they were required to complete a Hearing Aid Use Log (HAUL), which was used to obtain descriptions of everyday listening situations that are known to affect the preference of omnidirectional versus directional microphone fittings. Upon receipt, the HAULs were separated into two categories: (1) listening situations were directional processing is typically preferred and (2) listening situations were either omnidirectional microphones are typically preferred or situations in which neither microphone processing is preferred. The HAULs indicated the majority of listening situations involve the signal originating from in front of the listener. Furthermore, a general inspection of the HAULs indicated no strong tendencies towards a preference for either the better or poorer ear asymmetric directional fitting. Furthermore, participants were asked if they preferred one of the asymmetric hearing aid fittings over another and no participant expressed a strong preference.

Based on these findings, the authors noted that asymmetric directional microphones should be fit based on a patient's frequently encountered listening situations and the situations' noise environment (i.e., if when in a restaurant they sit to the left of their spouse an omnidirectional microphone should be on the right ear and directional on left ear). The speech understanding in noise findings from the current study were in agreement with Cord et al. (2011). Specifically, the poorest speech understanding in noise was observed in the bilateral omnidirectional condition, while, the best performance was observed in the bilateral directional and asymmetric directional better ear conditions. Furthermore, speech in noise performance was similar between the asymmetrical testing conditions.

Another purpose of the study was to determine if listeners would perform better with a monaural microphone fitting with an omnidirectional microphone on the better ear or a directional microphone on the better ear. The results indicated that listeners' speech in noise improved in the unilateral directional microphone condition versus the unilateral omnidirectional microphone condition when the poorer ear was plugged and speech was presented from the front and noise from behind the listener. This finding makes sense because the directional microphone is placing emphasis on the signal arriving in the front (i.e., speech); whereas, the omnidirectional microphone is placing equal emphasis on the signal from front (i.e., the speech) as well as the signal arriving from behind the listener (i.e., the noise). Therefore, the noise is degrading the speech signal and making it more difficult for the listener to understand the signal of interest. Furthermore, this finding agrees with previous research, which shows directional microphones increase speech intelligibility in noise, especially when noise is behind the listener (Cord et al., 2002).

Furthermore, the secondary HINT analysis compared the asymmetric directional better ear microphone condition to the unilateral directional microphone condition. The results showed no significant difference between speech understanding in noise scores for these two conditions, indicating speech understanding in noise ability is similar whether a person is fit binaurally with an asymmetric directional microphone fitting or monaurally with a directional on the better ear, at least when speech originates from the front and noise from the back. This means for a listener with asymmetric hearing loss, speech understanding in noise ability will not change when aided monaurally with a directional microphone on the better ear as compared to an asymmetric directional microphone configuration where the directional microphone is on the better ear and the omnidirectional microphone is on the poorer ear.

Acceptance of Background Noise

The second purpose was to determine the effect of an asymmetric directional microphone fitting on acceptance of background noise for those with asymmetric hearing loss. The results showed acceptance of background noise was similar for all four microphone fittings (i.e., bilateral omnidirectional, asymmetric directional poorer ear, asymmetric directional better ear, and bilateral directional). Because acceptance of background noise (i.e., ANL) is directly related to hearing aid success, these results indicate that listeners' willingness to wear hearing aids is not dictated by the microphone configuration in listeners with asymmetric hearing loss. These findings were unexpected when compared to reports by Freyaldenhoven et al. (2005) and Kim and Bryan (2011). First, Freyaldenhoven et al. (2005) found that ANLs decrease (i.e., improve) when the hearing aid was changed from the bilateral omnidirectional condition to the bilateral directional condition when speech oriented from the front and noise from behind the listener. Furthermore, Kim and Bryan (2011) found increased acceptance of background noise when listeners used binaural directional microphones as compared to either asymmetric directional microphones or binaural omnidirectional microphones. In the current study, no differences were seen in acceptance of background noise for any of the microphone conditions. The difference in findings between previous directional ANL studies and the current study could be due to the fact that listeners in the current study had asymmetric hearing loss. Specifically, if poorer ear ANL was not equal to the better ear ANL, the poorer ear ANL may have affected the overall ANL when measured using both ears. These results should be further investigated. Nevertheless, because acceptance of noise is unaffected, which is directly related to hearing aid use/acceptance, microphone configuration should be fitted based on other factors such as speech intelligibility in noise measures, patient preference, etc.

In contrast, when comparing the monaural microphone conditions (i.e., unilateral omnidirectional better ear and unilateral directional better ear), ANLs were better with the hearing aid in the directional microphone mode versus the omnidirectional microphone mode with the poorer ear plugged. This finding suggests that greater acceptance of background noise occurs when a greater signal to noise ratio is achieved, which occurs when utilizing a directional microphone versus an omnidirectional microphone. Since acceptance of background noise is directly related to hearing aid use/acceptance, a person may be more likely to wear/accept hearing aids when fit with a directional microphone versus an omnidirectional microphone, at least when the signal of interest arrive from the front and noise arrives from the rear. Furthermore, these results were expected based on data from Freyaldenhoven et al. (2005), who found that acceptance of background noise increased when utilizing a directional microphone fitting.

Furthermore, the secondary ANL analysis comparing the asymmetric directional better ear condition and the unilateral directional better ear condition showed no difference in ANL for these two conditions. These results suggest that acceptance of background noise was unchanged whether the listener was fit with a directional microphone monaurally or binaurally with one omnidirectional microphone and one directional microphone. As stated previously, acceptance of noise is related to hearing aid use/acceptance. Therefore, being fit monaurally or binaurally, as long a directional microphone is on the better ear, should not change a person's willingness to wear amplification.

Future Research

Future research should include the development of a definition for asymmetric sensorineural hearing loss. Furthermore, a limitation of the present study is that speech was presented at 0° azimuth and noise was presented at 180° azimuth, which does not occur frequently in the real world. Therefore, future research should focus on the effects of an asymmetric directional microphone fitting when the originating location of the speech and noise are varied for those with asymmetric hearing loss.

Clinical Implications

For listeners with asymmetric hearing losses', speech understanding in noise abilities are maximized when fit with an asymmetric directional better ear microphone fitting (i.e., directional microphone on the better ear and omnidirectional microphone on the poorer ear) or with bilateral directional microphones. In addition, speech understanding in noise is not hindered when fit with an asymmetric directional better ear microphone fitting as compared to a bilateral directional microphone fitting. Furthermore, an asymmetric directional poorer ear fitting slightly degrades speech in noise abilities compared to bilateral directional and asymmetric directional better ear fitting and slightly improves it compared to a bilateral omnidirectional fitting.

In the monaural microphone conditions listeners' speech understanding in noise ability improved in the unilateral directional microphone condition as compared to the unilateral omnidirectional microphone condition. Again, these results indicate that speech understanding in noise is maximized when directional microphones are utilized. Furthermore, speech understanding in noise ability is not affected when utilizing a unilateral directional better ear microphone fitting as compared to an asymmetric directional better ear microphone configuration. Therefore, when selecting an appropriate hearing aid fitting for a person with asymmetric hearing loss either a monaural directional fitting or an asymmetric directional better ear microphone fitting will provide similar benefit when speech is arriving inform the front of the listener. It should be noted, however, in the real world the signal of interest does not always arrive in front of the listener. Furthermore, when fit with a unilateral directional microphone, one could assume the listener would not hear a signal of importance that arrives from behind or on the unaided side of the listener. Therefore, an asymmetric directional better ear microphone fitting may provide the most real world benefit due to having a hearing aid on each ear, thereby, increasing a listener's chance of hearing a message arriving from a direction other than in front of the listener. This type of fitting may also be chosen based on the positive findings on binaural hearing aid fittings (i.e., binaural summation, auditory deprivation, etc.).

Acceptance of background noise was also evaluated using the ANL procedure. The results showed that listeners with asymmetric hearing loss do not have a greater acceptance of background noise/increase in willingness to wear amplification in any of the binaural microphone conditions (i.e., bilateral omnidirectional, asymmetric directional poorer ear, asymmetric directional better ear, or bilateral directional). The results further revealed no difference between the two asymmetric directional microphone fittings, indicating that location of the directional microphone did not affect listeners' willingness to wear hearing aids. In contrast, a monaural directional fitting provided significantly greater acceptance of background noise compared to a monaural omnidirectional microphone fitting, indicating a person is more willing to accept background noise when fit monaurally with a directional microphone. In other words, hearing aid use may be maximized when using a directional microphone over an omnidirectional microphone in a monaural fitting, at least when speech is presented in front of the listener and noise is concentrated behind the listener. Additionally, no difference was noted between the asymmetric directional better ear and unilateral directional better ear conditions. In other words, acceptance of background noise/willingness to wear or accept hearing aids is not hindered by the selection of a monaural hearing aid fitting versus a binaural hearing aid fitting as long a directional microphone is placed on the better ear.

Conclusion

In conclusion, the purpose of this study was to determine if an asymmetric directional microphone fitting would benefit those with an asymmetric hearing loss by increasing their acceptance of background noise or by increasing their ability to understand speech in the presence of background noise. It was determined that an asymmetric directional better ear microphone fitting provides increased speech understanding in noise as compared to a bilateral omnidirectional microphone fitting. While the asymmetric directional better ear microphone fitting provided significant improvements in speech understanding in noise as compared to the bilateral omnidirectional microphone fitting, the asymmetric directional better ear fitting and asymmetric directional poorer fitting did not differ significantly. Therefore, an asymmetric directional microphone fitting with the directional microphone on the better ear improves speech understanding in noise while an asymmetric directional poorer ear microphone fitting does not hinder speech understanding in noise as compared to the bilateral omnidirectional fitting.

Next, acceptance of background noise was not hindered or enhanced by an asymmetric directional better ear microphone fitting or asymmetric directional poorer ear fitting, indicating the location of the directional microphone did not affect listeners' willingness to wear hearing aids when fit binaurally. However, a monaural directional fitting provided a significantly greater acceptance of background noise compared to a monaural omnidirectional microphone fitting, indicating a person is more willing to accept background noise when fit monaurally with a directional microphone. Furthermore, no difference was noted between the asymmetric directional better ear and unilateral directional better ear conditions, indicating that willingness to accept background noise is not affected by monaural or binaural hearing aid fitting as long as the directional microphone is located on the better hearing ear.

APPENDIX A

PARTICIPANT RECURITMENT FORM

Requirements to be in study:

1. 21 years or older;
2. Asymmetric sensorineural hearing loss
   (average of ≥ 15 dB HL at 500, 1000, 2000, and 4000 Hz);
3. Either bilateral hearing aid users or non-users of hearing aids;
4. No known cognitive deficits (as determined by case history); and
5. Native English speaker (as determined by case history).

If interested contact:

Melinda Bryan
melinda@latech.edu
318-257-2146

Jessica White
jlw089@latech.edu
870-723-0799

APPENDIX B

HUMAN SUBJECTS PERMISSION FORM

HUMAN SUBJECTS PERMISSION FORM
(Experimental Group)

The following is a brief summary of the project in which you have been asked to participate. Please read this information before signing below:

TITLE: Asymmetric Directional Microphone Fittings for Individuals with an Asymmetric Hearing Loss

PURPOSE OF STUDY/PROJECT: The purpose of this study is to determine if an asymmetric directional hearing aid fitting will benefit those with an asymmetric hearing loss by increasing their acceptance of background noise or by increasing their ability to understand speech in the presence of background noise.

PROCEDURES: If you volunteer to participate in this study, you must agree to have a hearing evaluation, which will be provided by the Louisiana Tech University Speech and Hearing Center free of charge. The hearing includes basic tests of ear canal health, middle ear functioning, and hearing sensitivity. The audiologic test will take about 30 minutes. If the test results do not satisfy the subject eligibility criteria of the study, you will be excluded from further study participation. However, if the results of the test meet the subject eligibility criteria, you will be asked to perform the following things.

You will be fitted with two hearing aids using standard (one-size fits all) earmolds. You will then be fit with a hearing aid with directional capabilities. Then, using various microphone configurations, you will be instructed to determine a level that is comfortable for listening to speech (called MCL). Then, background noise will be introduced, and you will be asked to determine a level of noise that you can "put up with" while listening to and following the words of the story (called BNL). Your acceptance of background noise will be calculated by subtracting the BNL from the MCL. Speech understanding in noise scores will also be assessed by using the Hearing in Noise Test. The goal of this test is to determine the point where you can understand 50% of the speech content. To obtain this level, background noise will be manipulated depending on if you produce a correct or incorrect response. All testing will be conducted in a sound-treated booth. You will be offered frequent breaks during the test. The entire project (i.e., hearing testing, fitting of hearing aids, and experimental procedures) will take approximately 1hour and 15 minutes.

INSTRUMENTS: The subject's identity will be confidential throughout the study and will not be utilized in any form in the analysis or representation of the data.

RISKS/ALTERNATIVE TREATMENTS: There are no known risks to the subject, however according to Louisiana Tech Office of Research the following statement must be made, the participant understands that Louisiana Tech is not able to offer financial compensation nor to absorb the costs of medical treatment should you be injured as a result of participating in this research. All testing procedures will be conducted at normal conversational speech levels and are similar to clinical audiometric measures. Participation is voluntary with informed consent. You are free to discontinue participation at any time. Participants are not expected to complete online surveys, however, the following disclosure applies to all participants using online survey tools: This server may collect information and your IP address indirectly and automatically via "cookies".

BENEFITS/COMPENSATION: Each participant will receive a free audiologic evaluation, a hearing aid check, and a free pack of hearing aid batteries in exchange for participation in this study. Furthermore, each participant will also be provided monetary compensation in the amount of $50 (funding by Siemens Hearing Instruments). Moreover, the clinical audiology community will receive a greater understanding of the effects of asymmetric directional microphone fittings on hearing aid use (i.e., willing to wear hearing aids).

I, ______________________________, attest with my signature that I have read and understood the above description of the study, "Asymmetric Directional Microphone Fittings for Individuals with an Asymmetric Hearing Loss," and its purposes and methods. I understand that my participation in this research is strictly voluntary and my participation or refusal to participate in this study will not affect my relationship with Louisiana Tech University, Louisiana Tech Speech and Hearing Center, or my current audiologist. Furthermore, I understand that I may withdraw at any time or refuse to answer questions without penalty. Upon completion of the study, I understand that the results will be freely available to me upon request. I understand that the results will be confidential, accessible only to the project director, principal experimenters, myself, or a legally appointed representative. I have not been requested to waive nor do I waive any of my rights related to participating in this study.

______________________________ ______________________

Signature of Participant Date

CONTACT INFORMATION: The principal experimenter listed below may be reached to answer questions about the research, subject's rights, or related matters:

Melinda F. Bryan, Ph.D., CCC-A; Jessica L. White, B.S.E. Department of Speech (318) 257-2146

Members of the Human Use Committee of Louisiana Tech University may also be contacted if a problem cannot be discussed with the experimenters: Dr. Les Guice (318)257-4647; Dr. Mary Livingston (318)257-2292; Nancy Fuller (318)257-5075.

APPENDIX C

CASE HISTORY

Case History

Participant Number: ____________________ Age: _________ Birth date: ______________

Hearing loss:

Age of onset: ____________

Progressive? Yes No

Sudden? Yes No

Have you taken any medications that affected your hearing? If so, list medication.

____

Tinnitus:

Ear: Right Left Both

Describe (i.e., low tone, high tone, constant, occasional): ______________________

____

Ear Infections: Yes No

Ear: Right Left Both

Treatment: ____

Ear Surgery: Yes No

Ear: Right Left Both

Date(s): ____

Type(s): ____

Dizziness: Yes No

Description: ____

Frequency? ____

Head Injuries:

Date(s): ____

Was hearing affected? ______________________________________

Comments: ____

____

Medical Examination:

Have you been examined by a licensed physician regarding your hearing loss?

Yes No

Did your physician determine the cause of your hearing loss?

Yes No

Comments: ____

Hearing Aids:

Do you currently wear hearing aids? Yes No

How long have you been a hearing aid user? ____________________________

Have you ever been fit with only one hearing aid? _________________________

If so, how long did you wear only one hearing aid? _______________________

Other Questions:

Are you a Native English Speaker? Yes No

Do you have any known cognitive or neurological deficits? If so, list: _____________

____

APPENDIX D

TEST BOX MEASURES

Test Box Measures

1. Turn on power supply
2. Click Test
3. Click Hearing Instrument Test Calibration
4. Open test box and line up reference microphone and coupler microphone
5. Close loud speaker lid and hit Calibration
    a. You should get a relatively flat line
6. Attach the hearing aid to the BTE coupler and turn the Volume Control full-on
7. Line up BTE hearing aid reference microphone
8. Click Directional under Hearing Instrument
9. Presentation: Single view
10. Format: Graph
11. Scale: dB SPL
12. Choose Dual Noise and Hit 65dB

APPENDIX E

HEARING AID FITTING PROCEDURES

HEARIG AID FITTING PROCEDURES (SIEMES INTUIS-DIR)

1. Click on NOAH program
2. Search subject or client and save it
3. Click on audiogram and insert threshold
4. Save the audiogram
5. Connect the hearing aids
6. Click on open module program: Siemens
7. Click on Detect
8. First Fit for both HA/use same fitting strategy for both /traditional
9. Click Next:
    a. Setting should be set to:

       Acclimation Level = 4

       NAL-NL1

       Volume Control = Default (0)

       2+A number of programs
10. Click Next
11. Venting settings will appear
    a. Should be set to:

       No Vent

       Earmold = Short

       Hook = Standard with damper
12. Click Apply 1st Fit
13. You will have 2 programs

a. Go to Program #1 (Universal)

   i. Click on Fine Tuning

      1. Compression (Compression Kneepoint & Ratio-Turn off on both hearing aids)

      2. Noise/Feedback/Microphone:

         Unclick Noise Reduction and Feedback

         Microphone System: Omnidirectional

      3. Extra:

         Unclick Volume Control

b. Go to Program # 2

   i. Click on Fine Tuning

      1. Compression (Compression Kneepoint & Ratio-Turn off on both hearing aids)

      2. Change to noisy environment (default to the last tap on the bottom)

      3. Noise/Feedback/Microphone:

         Unclick Noise Reduction and Feedback

         Microphone Mode: Directional

      4. Extra:

         Unclick Volume Control

14. Click program hearing aids

15. Save the program session with date

APPENDIX F

HEARING IN NOISE TEST INSTRUCTIONS

SPEECH UNDERSTADNING IN NOISE TESTING (HINT) INSTRUCTIONS

Prior to the measurement of HINT, each subject's hearing aids will be set to one of the six microphone configurations by pushing the program buttons: binaural omnidirectional, asymmetric directional better ear, asymmetric directional poorer ear, bilateral directional, unilateral directional better ear, and unilateral omnidirectional better ear.

Instructions for establishing HINT

You will listen to 12 lists of 10 sentences with background noise through the loudspeakers. I want you to repeat the sentences that you heard. After you have listened to two lists of 10 sentences, I will change your hearing aid program modes.

APPENDIX H

ACCEPTABLE NOISE LEVEL INSTRUCTIONS

ANL INSTRUCTIONS

Prior to the measurement of ANLs, each subject's hearing aids will be set to one of the six microphone configurations by pushing the program buttons: binaural omnidirectional, asymmetric directional better ear, asymmetric directional poorer ear, bilateral directional, unilateral directional better ear, and unilateral omnidirectional better ear.

Instructions for establishing MCL:

You will listen to a story through a loudspeaker. After a few moments, select the loudness of the story that is most comfortable for you, as if listening to a radio. Two hand-held buttons will allow you to make adjustments. First, turn the loudness of the story up until it is too loud and then down until it is too soft. Finally, select the loudness level of the story that is most comfortable for you.

Instructions for establishing BNL:

You will listen to the same story with background noise of several people talking at the same time. After you have listened to this for a few moments, select the level of background noise that is the most you would be willing to accept of "put-up-with" without becoming tense and tired while following the story. First, turn the noise up until it is too loud and then down until the story becomes very clear. Finally, adjust the noise (up and down) to the maximum noise level that you would be willing to "put-up-with" for a long period of time while following the words of the story.

APPENDIX I

BRIRB MEMO

LOUISIANA TECH
UNIVERSITY

ENVIRONMENTAL HEALTH & SAFETY

MEMORANDUM

TO: Dr. Sheryl Shoemaker

FROM: Don Braswell. BRIRC Chair

SUBJECT: BRIRC 5 – Annual Renewal Review

DATE: April 1, 2010

RE: "Speech and Hearing Services"

This proposal has been reviewed by the BRIRC and is recommended for approval.

The BRIRC recommended approval of this project is for one (1) calendar year from the date of approval. ***This approval was finalized on April 1, 2010 and this project will need to receive a continuation review by the BRIRB if the project, including data analysis, continues beyond April 1, 2011.*** The project is to be terminated at that time unless the BRIRC receives a request for continuance.

Modification of an approved project is STRICTLY PROHIBITED without prior BRIRC review and the approval of the Vice President of Research & Development of these modifications. **Request for continuance or protocol modification must be received by the VP Research's Office 30 days prior to the renewal date or before initiation of the modified protocol.**

If you have any questions, please contact Dr. Ed Griswold at 257-2120.

cc: Dr. Edward C. Jacobs
Human Use Committee

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