Spring 2015

Ear specific ANL measurements in individuals with unilateral and asymmetrical sensorineural hearing loss

Rebecca Howard
Louisiana Tech University

EAR SPECIFIC ANL MEASUREMENTS IN INDIVIDUALS WITH UNILATERAL AND ASYMMETRICAL SENSORINEURAL HEARING LOSS

by

Rebecca Howard, B.S.

Dissertation Presented in Partial Fulfillment
Of the Requirements for the Degree
Doctor of Audiology

COLLEGE OF LIBERAL ARTS
LOUISIANA TECH UNIVERSITY

May 2015

LOUISIANA TECH UNIVERSITY

THE GRADUATE SCHOOL

March 20, 2015

Date

We hereby recommend that the dissertation prepared under our supervision by Rebecca Howard

entitled

Ear Specific ANL Measurements in Individuals with Unilateral and

Asymmetrical Senorineural Hearing Loss

be accepted in partial fulfillment of the requirements for the Degree of

Doctor of Audiology

Melinda F. Bryan

Supervisor of Dissertation Research

Head of Department

Communication Disorders

Department

Recommendation concurred in:

Sheryl S. Shoemaker

Advisory Committee

Approved:

Director of Graduate Studies

Dean of the College

Approved:

Sheryl S. Shoemaker

Dean of the Graduate School

GS Form 13a
(6/07)

Abstract

The present study sought to determine if ANLs differ between ears within subjects with unilateral or asymmetrical SNHL. ANL was measured in four conditions (i.e., binaural, better ear, poorer ear unmasked, and poorer ear masked) in fifteen adults, nine with unilateral SNHL and six with bilateral asymmetrical SNHL. A significant difference between ANL in the four conditions (i.e., binaural, better ear, poorer ear unmasked, and poorer ear masked) was identified; however, the subjects with unilateral and asymmetrical SNHL behaved similarly throughout the testing. When comparing the four conditions, the results showed a significant difference between both the binaural ANL and better ear ANL conditions and the poorer ear unmasked ANL condition. There was no significant difference between the binaural and better ear ANL conditions or the poorer ear unmasked and the poorer ear masked conditions. Furthermore, both the binaural ANL and better ear ANL conditions versus the poorer ear masked ANL condition approached significance. Collectively these results showed that when the better of the two ears was being used, subjects had lower ANLs compared to when the poorer ear was being used. This suggested that the peripheral auditory system could be at least in part contributing to the mediated point of ANL. Alternately, ANL may be due to auditory deprivation, thus a central auditory phenomenon is the result of ANL mediation. Clinical implications/applications will be discussed.

APPROVAL FOR SCHOLARLY DISSEMINATION

The author grants to the Prescott Memorial Library of Louisiana Tech University the right to reproduce, by appropriate methods, upon request, any or all portions of this Dissertation. It is understood that "proper request" consists of the agreement, on the part of the requesting party, that said reproduction is for his personal use and that subsequent reproduction will not occur without written approval of the author of this Dissertation. Further, any portions of the Dissertation used in books, papers, and other works must be appropriately referenced to this Dissertation.

Finally, the author of this Dissertation reserves the right to publish freely, in the literature, at any time, any or all portions of this Dissertation.

Author Rebecca Howard

Date 4-27-2015

GS Form 14
(5/03)

Dedication

I am dedicating my dissertation to my beautiful, smart, and selfless mother. Her endless love, support, and encouragement have made me the person I am today. She is the backbone to my past, present, and future.

Table of Contents

List of Figures

Acknowledgements

I would like to thank my dissertation committee members, Dr. Melinda F. Bryan, Dr. Matthew D. Bryan, and Dr. Sheryl S. Shoemaker, for all their expertise and guidance throughout this dissertation. It would not have been possible without all their support and endless time committed to this project. I would also like to thank all of my professors and clinical supervisors throughout my graduate school career for your time, support, encouragement, and knowledge. Furthermore, I would like to thank Mrs. Sarah Webb and Mrs. Tracy Shrell for always being there to listen, help, and support me during my time at Louisiana Tech. I would also like to thank all of my family, friends, and peers. All of your endless support and love helped me get through each and every day. Special thanks to Mom, Jeff, Emelia, and Mark, for all of their support and encouragement during this process and over the years. Each of you has been through all the ups and downs with me. I would not have it any other way. I would not be the person I am today without all of their love and help. I would also like to specially thank Lindsay, Brandee, and Jessica for all of the long hours of studying, endless phone calls, many laughs, and incredible memories. I could not ask for a better group of peers that have turned into lifelong friends. "To all of my family, friends, and peers, thank you for listening when I was mad, lifting me up when I was sad, and laughing with me." I am beyond blessed to have each and every one of you in my life. Thank you for helping me reach my goals. Finally, I would like to thank God for paving my way in life, listening to my prayers, and carrying me through each day. Thank you for making all things possible.

Chapter I

Introduction

Acceptable noise level (ANL) is defined by how much background noise an individual can accept while listening to speech (Nabelek, Tucker, & Letowski, 1991; Nabelek, Tampas, & Burchfield, 2004; Nabelek, Freyaldenhoven, Tampas, Burchfield, & Muenchen, 2006). ANLs are not affected by type of background noise, gender, age, hearing level, speech presentation level, efferent activity of the medial olivocochlear pathway, attitude, or motivation (Brannstrom, Zunic, Borovac, & Ibertsson, 2012; Freyaldenhoven et al., 2006; Gordon-Hickey & Moore, 2007; Harkrider & Smith, 2005; Nabelek et al., 1991, 2004, & 2006; Tampas & Harkrider, 2006). Furthermore, in 2006, Nabelek et al. sought to determine if ANL was directly related to hearing aid use. The authors found that hearing aid users who had low ANLs (i.e., no greater than 7 dB) accept more background noise and were willing to use their hearing aids more often. On the other hand, hearing aid users that had high ANLs (i.e., greater than 13 dB) accepted low amounts of background noise and were less likely to wear their hearing aids (Nabelek et al., 2006). Furthermore, they found that hearing aid success could be predicted using an individual's ANL score with 85% accuracy.

Furthermore, ANL is thought to be mediated in the central region of the auditory system. The following studies describe this phenomenon. First, in 2005, Harkrider and Smith evaluated the role of the efferent system on monotic (i.e., speech and noise presented to one ear) and dichotic ANLs (i.e., speech delivered to one ear and noise presented to the other ear; a contralateral ANL measurement) in normal hearing individuals. The results showed that monotic and dichotic listening conditions were directly related to how much background noise the subjects were able to accept. These results suggested that nonperipheral factors beyond the superior olivary complex (i.e., first level of binary processing) was the mediation point for ANL (Harkrider & Smith, 2005).

In 2006, Harkrider and Tampas continued this work as they measured otoacoustic emissions (OAE), auditory brainstem responses (ABRs), and middle late latency responses (MLRs) in individuals with low and high ANLs. The results showed a lack of difference in OAE amplitude and waves I and III of the ABR, indicating intersubject variability in ANLs was not related to cochlear differences. The results further showed differences in amplitude of wave V of the ABR and Na-Pa of the MLR. In addition, the high ANL group had more robust responses than the low ANL group. This indicated ANL may be mediated in the central auditory system. Specifically, the results indicate central efferent mechanisms may be stronger in the low ANL group, and/or the central afferent mechanisms maybe stronger in the high ANL group (Harkrider & Tampas, 2006).

Likewise, Tampas and Harkrider (2006) investigated auditory evoked potentials (AEPs) in females with normal hearing and low or high ANLs. Specifically, they looked at auditory brainstem response (ABR), middle latency responses (MLR), and late latency responses (LLR) tests. The results showed that there were no differences in AEPs until wave III of the ABR which suggest that ANL may be mediated in the central auditory system. Wave III is thought to originate at the level of the superior olivary complex (SOC), which is also the first place for binaural processing. Furthermore, results from the low ANL group showed increased waves III and V and smaller amplitudes compared to results from the high ANL group. These results indicated that the physiological variations in ANL were most likely mediated from central auditory system (Tampas & Harkrider, 2006).

To further evaluate the mediation of ANL, the presenest study aims to evaluate ANLs in listeners with asymmetrical and unilateral hearing loss. Listeners with asymmetrical and unilateral hearing loss encounter communication difficulties such as discriminating speech signals, separating two speech signals, communicating in groups, and communicating in background noise that listeners with symmetrical hearing and hearing loss do not. Specifically, research has shown that listeners with bilateral asymmetrical hearing loss have decreased ability to separate or integrate two speech signals (Arkebauer, Mencher, & McCall, 1971). Furthermore, Noble and Gatehouse (2004) showed that subjects with asymmetrical hearing loss reported having poorer ability when processing spatial and speech cues compared to the subjects with symmetrical hearing. The results further revealed that the subjects with asymmetrical hearing loss made physical adjustments for the differences between ears and worked to improve the signal-to-noise ratio (SNR) to have better communication. Additionally, Welsh, Welsh, Rosen, and Dragonette (2004) showed that subjects with unilateral hearing loss (UHL) and asymmetrical hearing loss had significantly impaired speech recognition abilities in background noise when compared to subjects with normal hearing. Likewise, Wie, Pripp, and Tvete (2010) found that unilateral deafness causes a significant disability in communication, speech perception, social interaction, especially when attempting to communicate in background noise. The authors further revealed that subjects with unilateral deafness reported having feelings of exclusion, reduced well-being, and wanting to avoid social situations, especially when background noise was present. Lastly, research seems to suggest that unilateral/asymmetrical hearing loss appears to be mediated in the central auditory system. Specifically, Ponton et al. (2001) investigated if a late-onset profound UHL changed the activation of the central auditory system. The results showed that there are changes in the plasticity of the central auditory system in the adult brains following the onset of a profound UHL. Furthermore, in 2003, Khosla et al. continued this work through examination of the activation of the central auditory system in relationship to the profound unilateral deafness (right versus left ear). The results from this study indicated evidence of reorganization occurring in the central auditory system because of left profound unilateral deafness.

In conclusion, the purpose of this study was to determine if ANLs differ between ears within subjects with unilateral or asymmetrical SNHL. The mediation of ANL has been hypothesized to be beyond the level of the SOC in the central auditory system. By testing ANLs in subjects with unilateral/asymmetrical hearing loss, we can examine both peripheral and central regions of the auditory system in the same individual. It is hypothesized that if ANLs stay the same between the better and poorer ears, then the mediation of ANL is in the central auditory system whereas if ANL differ between the two ears, ANL may be, in part, mediated by the peripheral auditory system. The following research question will be addressed:

1) Are ANLs the same or different between the two ears in those with UHL?

2) Are ANLs the same or different between the two ears in those with asymmetrical hearing loss?

Chapter II

Review of Literature

Acceptable Noise Level

A subject's ability to accept background noise while listening to speech is known as acceptable noise level (ANL). Conventionally, ANL is obtained by having subjects listen to a story in soundfield and adjust it to their most comfortable level (MCL). Once the MCL is ascertained, background noise is added, and subjects are asked to adjust background noise to their maximum acceptable background noise level while following the words of a story (called background noise level or BNL). ANL is calculated by subtracting the BNL from MCL (ANL = MCL – BNL).

ANL was first introduced by Nabelek, Tucker, and Letowski in 1991. The premise behind ANL is that some patients are not able to accept background noise in their everyday listening environments. Due to this inability, the patients are not willing to wear their hearing aids (Freyaldenhoven et al., 2007). The following section describes how ANL can be used as a predictor for hearing aid use and looks at the effect of various variables on ANL (e.g., age, gender, & hearing sensitivity).

In 1991, Nabelek et al. sought to determine how subjects accept background noise. Specifically, they evaluated (a) maximum tolerated signal-to-noise ratio (SNRs; now called ANL) while listening to speech; (b) ANLs in full-time, part-time, and nonusers of hearing aids; (c) ANL differences in listeners with both normal and impaired hearing; (d) and the dependence of ANLs on type of background noise. The second purpose was to determine if there was an association between ANL, age, hearing loss, and MCL. The third goal was to determine the subject's perceptions of hearing loss with and without hearing aids.

Three groups of 15 subjects served as the participants. Group 1 consisted of young (18-32 years old) listeners with normal hearing (less than 20 dB HL at .25 – 8 kHz). Group 2 was elderly (at least 65 years old) listeners with relatively good hearing. Group 3 consisted of elderly full-time hearing aid users. Group 4 was elderly part-time hearing aid users, and Group 5 was elderly listeners with hearing loss who were nonusers of hearing aids. Groups 3, 4, and 5 were categorized based on answers to a self-developed questionnaire on pattern of hearing aid use.

Acceptance of background noise was tested monaurally through headphones using an Auditec recording of female speech and five background noises: (1) 12 talker babble; (2) speech spectrum noise; (3) traffic noise; (4) light music; and (5) pneumatic drill noise. First, subjects listened to a story and were asked to set the story to their MCL. Then background noise was added in, and subjects were asked to adjust the level of the noise to the maximum BNL they could accept and still follow the story. The BNL was subtracted from the MCL to achieve tolerated SNR (currently called ANL). Furthermore, Groups 3, 4, and 5 were also asked to complete the Hearing Handicap Inventory for the Elderly (HHIE, Ventry & Weinstein, 1983) based on hearing aid use. The results showed ANLs for Group 3 (i.e., full-time hearing aid users) were different from all other groups when music was the stimulus. Furthermore, ANLs for Group 3 were different from

Groups 1 (young listeners), 4 (part-time hearing aid users), and 5 (non-users of hearing aids) when speech spectrum noise was the stimulus. ANLs for Group 3 (full-time hearing aid users) were different from Groups 1 (young listeners) and 5 (non-users of hearing aids) when traffic noise was the stimulus, and ANLs for Group 3 (full-time users) were different from Group 1 (young listeners) when babble and drill noise were the stimuli. All other differences were non-significant. Furthermore, ANL was not related to age, hearing threshold level, or MCL in any group. Lastly, the full-time hearing aid users (M = 7.47) had lower ANLs than the part-time (M = 13.99) and non-hearing aid users of hearing aids (M = 14.49). Additionally, scores on the HHIE for full-time hearing aid users were significantly different pre- and post-hearing aid use, indicating hearing aids were useful for full-time users. Collectively, these results indicated full-time hearing aid users (Group 3) accepted more background noise for music, speech spectrum noise, traffic noise, babble, and drill noise compared to part-time and non-users of hearing aids. Based on these finding, Nabelek et al. (1991) speculated that ANL might predict hearing aid use.

In 2006, Nabelek, Freyaldenhoven, Tampas, Burchfield, and Muenchen further investigated if ANL could be used to predict hearing aid use. Specifically, the investigators sought to determine (1) the relationship between ANL, age, gender, pure-tone average (PTA), speech perception in noise (SPIN), and hours of daily hearing aid use; (2) the consistency of the responses from the pattern of hearing aid use questionnaire; and (3) if hearing aids have an effect on ANL and SPIN scores. Subjects included 191 adults with hearing impairment, which were split into three groups based on their responses to the pattern of hearing aid use questionnaire. The three groups included full-time (N =69), part-time (N =69), and non-users of hearing aids (N =53). All subjects completed unaided ANLs and SPIN testing while only 164 subjects completed aided ANLs and SPIN testing. The results revealed that age, gender, and PTA were not related to unaided or aided ANL scores, indicating that ANL might be innate to each patient. Furthermore, a significant correlation was found between unaided and aided ANLs and hours of hearing aids use. Furthermore, unaided and aided ANLs were not different, indicating that ANLs were not affected by hearing aid use. However, when comparing unaided and aided SPIN scores, there was a significant difference, indicating that SPIN scores improved when subjects were wearing hearing aids compared to when they were not. From these results, the authors speculated that SPIN scores could be used as a measure of benefit of speech perception whereas ANLs might be used to determine if subjects would wear their hearing aids. The results further revealed that unaided ANLs were related to pattern of hearing aid use. Specifically, full-time users had lower ANLs then part-time and nonusers. Lastly, the prediction of hearing aid use from unaided ANL scores showed an accuracy of 85%.

Reliability of acceptable noise level. The following studies investigated the reliability of ANL and its relationship to personal preference of background sounds. First, Nabelek, Tampas, and Burchfield (2004) compared the reliability of ANL to the reliability of the SPIN scores in 50 hearing aid subjects (i.e., 41 full-time users & 9 part-time users). ANL and the SPIN tests were completed in the conventional manner in three sessions with and without hearing aids; the sessions included: (1) at the initial hearing aid fitting, (2) one month post-fitting, and (3) three months post-fitting.

Results from this study revealed that ANL and SPIN were highly reliable with and without hearing aids. Furthermore, over a three month time period, the mean ANL and SPIN scores revealed a lack of change, indicating consistency of both the ANL and SPIN scores. ANL and SPIN scores were, however, not related to each other. To conclude, the results indicated ANL and SPIN scores were highly reliable and consistent both with and without hearing aids, at least over a three month time period (Nabelek et al., 2004).

Next, Freyaldenhoven, Smiley, Muenchen, and Konrad (2006) sought to determine ANL reliability in normal hearing adults. The second purpose of this study was to examine the relationship between personal preference for background sound and ANL. Thirty subjects (15 females & 15 males) ages 10-25 years with normal hearing sensitivity (i.e., thresholds < 20 dB HL at 500, 1000, 2000, & 4000 Hz in each ear) participated in this study. ANL was obtained using two competing stimuli (i.e., speech-spectrum and speech-babble noises) over three different sessions within a week apart. During each session three ANLs were obtained and averaged to provide the mean ANL. The subjects also completed a preference for background sound questionnaire during each test session. This questionnaire was used to determine how often the subjects had voluntary background noise in their everyday listening environment. The questionnaire contained seven questions that asked the participant to rate how much background noise they preferred while completing the following tasks: reading, sleeping, driving, studying, preparing for a test, and doing chores.

The results showed high ANL test-retest reliability over all three test sessions when both speech-spectrum and speech-babble noises were the competing stimuli, indicating ANLs remained constant over multiple sessions. Furthermore, results of the questionnaire showed responses for each question were reliable, and each subject was consistent over each session; however, there was no relationship between ANL and the preference for background noise. This indicates that ANL cannot be predicted based on self-report of acceptance of background noise (Freyaldenhoven et al., 2006).

Lastly, Gordon-Hickey et al. (2012) sought to determine the inter-tester reliability of the measurements of ANL, MCL, and BNL. Three examiners (A, B, C) tested completed these measures on 25 young adults (ages 21–36 years) with normal hearing sensitivity (i.e., thresholds at < 25dB HL at .5, 1, 2, and 4k Hz). All testers were new to the ANL procedure and given detailed instructions on how to perform the test, and the 25 young adult subjects had never completed ANL testing. Traditional ANL testing was completed; however, each tester conducted MCL one time and BNL three times.

The results showed that all three measurements (i.e., ANL, MCL, & BNL) were reliable and comparable for all testers, indicating when ANL, MCL, and BNL are performed by different testers, these measurements do not change. Based on these results, the authors concluded that due to strong inter-tester reliability of ANL testing, researchers could have more than one tester collecting data during a study as long as the instructions are followed accurately. Furthermore, tester reliability can be ruled out as a contributing factor to discrepancy in mean ANLs (Gordon-Hickey et al., 2012).

Mediation of acceptable noise level. The following research studies investigated ANL in hopes to determine whether ANL is mediated in the peripheral or central auditory nervous system. First, Harkrider and Smith (2005) compared monotic ANL (ANLm) and dichotic ANL (ANLd) and traditional phonemic recognitionin noise (PRN). The second purpose of this study was to examine if the level of the efferent activity in the lower brainstem had an influence on the ANL and PRN scores. More specifically, they looked at the medial olivocochlear bundle (MOCB) and the acoustic reflex (AR) pathways in the efferent systems.

In this study there were 31 subjects, ages 19-40 years. All subjects had normal hearing thresholds (i.e., 25 dB HL or less from .25 to 8 kHz). Measures tested included: (a) ANLm (i.e., speech and noise in one ear); (b) ANLd (i.e., speech in one ear and noise in other ear); (c) PRN; (d) ipsilateral and contralateral acoustic reflex thresholds (ARTs); and (e) transient evoked otoacoustic emissions (TEOAEs). ANLm, ANLd, and PNR were measured in the right ear only. ARTs were obtained bilaterally using a 226 Hz probe tone and a broadband noise stimuli. Six TEOAEs were obtained in the right ear using a 60 dB SPL click stimuli with and without broadband noise.

The results showed a positive correlation between ANLm and ANLd and a negative relationship between ipsilateral ARTs and PRN. Furthermore, ANLs were unrelated to PRN, ARTs, or TEOAEs, indicating that ANLs are mediated at or beyond the level of the superior olivary complex (SOC). Additionally, the inter-subject variability of ANL does not correlate to the efferent activity of medial olivary cochlear bundle (MOCB) or the AR pathways, and the individual differences in the efferent MOCB do not influence PRN. Collectively, these results indicate that (1) the overall auditory efferent activity is below the olivocochlear bundle and may be pointing towards the AR or contralateral suppression of TEOAEs, and (2) ANLs are mediated beyond the level of the SOC where binaural processing takes place (Harkrider & Smith, 2005).

Next, Harkrider and Tampas (2006) sought to determine physiological activity differences from the cochlea to the peripheral and central auditory nervous systems in females with low versus high ANLs. Thirteen young females (ages 20 - 37 years) with normal hearing (i.e., thresholds of 15 dB HL or less at .5, 1, 2, 3, 4, 6, and 8 kHz in each ear) were included in this study. The subjects were split into two groups; one group consisted of seven subjects with low ANLs (i.e., 6 dB or less), and the second group had 6 subjects with high ANLs (i.e., 16 dB or greater). ANLs were measured diotically (both ears at the same time) in a soundfield booth. Click-evoked otoacoustic emissions (CEOAEs) were obtained using 10 clicks per second at levels of 75-80 dB SPL and greater. Waves I, III, and V of the ABR, and Na-Pa of the MLR were measured. All auditory evoked potentials (AEP) were recorded using a four-channel electrode and a tone burst at a 35 and 70 dB HL at 3000 Hz with negative polarity and a rate of 8.1 seconds.

Results of this study showed no significant differences between the two groups at the level of the cochlea (i.e., CEOAEs), 8th nerve, and the lower brainstem (i.e., waves I & III of the ABR). However, differences were found between the two groups in later AEPs. More specifically, the amplitudes of wave V of the ABR and Na-Pa of the MLR were more robust in females with high ANLs versus low ANLs. These results indicated that responses were being produced in the central auditory nervous system. Specifically, it is thought that wave V of the ABR is generated in the SOC, lateral lemniscus (LL), and inferior colliculus (IC). Na of the MLR is thought to be generated at the level of the IC and temporal lobe, and Pa of the MLR is generated in the auditory thalamo-cortical projections and the cortex. Collectively, these findings suggest that ANLs are generated from more centralized regions of the auditory system (Harkrider & Tampas, 2006).

Tampas and Harkrider (2006) continued this work through the examination of how ANLs are affected by presentation level in females with low versus high ANLs. The participants consisted of 21 females ages 19-37 years with normal hearing (i.e., thresholds of 15 dB HL or lower at 0.5, 1, 2, 3, 4, 6, & 8 kHz in both ears), normal middle ear function, and right handedness. The subjects were split into two groups; one group had 11 subjects with low ANLs (i.e., 6 dB or less) while the second group had 10 subjects with high ANLs (i.e., 16 dB or greater). ANLs were measured in a sound treated booth using recorded materials (i.e., running speech using a male voice and eight person multi-babble as competing stimuli) at three presentation levels (35 dB HL, MCL, 70 dB HL). The physiological measures tested were: absolute latencies of waves I, III, and V of the ABR; amplitude and absolute latencies between waves Na and Pa of the MLR, and amplitude and absolute latencies between waves P1 and N1 and N1 and P2 of the LLR. All auditory evoked potentials (AEPs) were recorded using a four-channel electrode and a tone burst at 500 and 3000 Hz at a 35 dB HL and 70 dB HL level with negative polarity and a rate of 1.1 seconds.

The results showed a significant difference in the ANL and ANL growth between the two groups of participants; however, as the presentation level increased, all listeners preferred less background noise. Specifically, as the presentation level increased from 35 to 70 dB HL, the ANL growth rate was 11-28 dB for the high ANL group and 1-6.5 dB in the low ANL group. Furthermore, waves III (i.e., mediated at the level of the cochlear nucleus) and V (i.e., mediated at the level of the SOC and/or the LL) of the ABR showed longer latencies and slower neural transmission times in the low ANL group versus the high ANL group. The low ANL group also had smaller amplitudes of waves Na-Pa, P1-N1, and N1-P2 than the high ANL group. These findings suggested that the low ANL group have stronger central efferent mechanisms or less activity in the central afferent mechanisms than the high ANL group. Overall, these results suggest that ANL is mediated in the central auditory nervous system. Specifically, the authors hypothesized that ANL may be mediated beyond the SOC (Tampas & Harkrider, 2006).

More recently, Rishiq, Harkrider, and Hedrick (2012) investigated the differences in responses between subjects with low and high ANLs using simultaneous, backward, and forward masking conditions. The authors hypothesized that if the performances between the two ANL groups were similar for all masking conditions, the responses were most likely coming from the afferent cortical responsiveness. However, if the low ANL group has better responses than the high ANL group, the efferent cortical responsiveness is benefitting from selective attention of the stronger inhibitory system. Nineteen normal hearing subjects between the ages of 19 to 35 years served as participants for this study. Ten of the subjects had low ANLs (i.e., <6 dB), while the other nine had high ANLs (i.e., >16 dB). ANL was obtained using the procedures of Nabelek et al. (1991) with the exception that if the two measured ANLs differed by 4 dB or more, a third ANL was obtained and the two closest ANLs were averaged. Next, each subject was asked to detect a tonal signal which was presented for 20ms at 1 KHz within the presence of masking noise. The masking noise consisted of three conditions including simultaneous masking (i.e., the tonal signal was presented in the center of the masking noise), backward masking (i.e., the tonal signal is presented before the masking noise is turned on at 0, 20, & 40 ms), and forward masking (i.e., the tonal signal is presented after the masking noise is turned off at 0, 20, 40, & 80 ms).

The results of this study revealed no significant differences in responses between the low and high ANL groups for all three masking conditions (i.e., simultaneous, backward, and forward). These results indicated that ANL differences are not due to selective attention or temporal processing abilities. In other words, because the performances between the two ANL groups were similar for all masking conditions, the authors believe that the responses were most likely being generated from afferent cortical responsiveness above the brainstem, suggesting that ANL was mediated in the central auditory system (Rishiq et al., 2012).

Lastly, Brannstrom, Zunic, Borovac, and Ibertsson (2012) investigated a possible correlation between the Swedish version of ANL, working memory capacity (WMC), and AEPs. The authors hypothesized that high ANLs (i.e., >16 dB) were related to larger AEP amplitudes, shorter latencies, and poorer WMC. The subjects consisted of 14 females and seven males, ages 20-39 years, with normal hearing sensitivity (i.e., better than 15 dB HL at .5, 1, 2, and 4 kHz). ANL, AEPs, and WMC were administered for all subjects. A Swedish ANL test was performed monaurally using female speech from an audio recording of a book (*The Prize of Water in Finistere,* CD 1, track 6) and the American ANL multi-talker babble noise. All testing was conducted in a sound treated booth. All AEPs were recorded using a four-channel electrode array and a tone burst at 500 and 3000 Hz with negative polarity and a rate of 1.1 seconds. ABRs, MLRs, and LLRs were also measured. WMC was measured using a Swedish version of a reading span task, where the subject had to respond yes or no to whether or not a sentence was semantically acceptable.

Results of this study showed an average score of 66.5% on the WMC, indicating subjects recalled 47.9 of the 72 words. To further examine WMC, the subjects were split into two groups – those that scored lower than average on WMC (low WMC) and those that scored higher than average on WMC (high WMC). Subjects with higher WMC had low ANLs (i.e., <6 dB). Similarly, subjects with high ANLs had lower WMC. There were not any other significant associations between the latencies and amplitudes of AEPs and other variables. In conclusion, there was no relationship between the behavioral measures (i.e., ANL & WMC) and AEPs. Furthermore, MCL, BNL, and ANL were related to WMC in that those with high WMC could accept larger amounts of background noise and vice versa (Brannstrom et al., 2012).

Asymmetrical Hearing Loss

Currently there is no accepted definition of a significant asymmetrical hearing loss. According to Dillon (2012), asymmetrical hearing can be defined by using pure tone averages, the shape of the audiogram, speech intelligibility testing, dynamic range, and/or discomfort level. Dillon (2012) also stated that the binaural advantage reduces as the thresholds between the right and left ears differ by 15 dB or more in a four frequency average. Furthermore, Segal et al. (2007) defined asymmetrical hearing loss as a 10 dB or more difference between ears at any one frequency.

Effects of asymmetrical hearing loss on communication. The following studies investigated how subjects with asymmetrical hearing loss separate two speech signals, communicate in the presence of noise, and if aiding the poorer ear is beneficial or detrimental. First, Arkebauer, Mencher, and McCall (1971) investigated the effects of bilateral asymmetrical hearing loss on an individual's ability to separate or integrate two speech signals. Ten subjects with bilateral asymmetrical hearing loss, but enough residual hearing in the poorer ear to obtain a speech reception threshold (SRT) were split into two groups based on their degree of hearing loss. Group 1 had borderline normal/mild hearing loss in the better ear, and Group 2 had a mild to moderate hearing loss in the better ear. In the poorer ear, the hearing loss was moderately-severe to severe for both groups. SRT and speech discrimination were obtained for four conditions: (a) poorer ear – under earphone, (b) better ear – under earphone, (c) soundfield – ears unoccluded, and (d) soundfield – poorer ear occluded.

The results showed that 90% of the subjects had better speech discrimination scores in the better ear – under earphone condition than in the soundfield – ears unoccluded condition, indicating that individuals with bilateral asymmetrical hearing loss were affected in their ability to separate or integrate two speech signals, which can reduce speech discrimination. When comparing the soundfield – ears unoccluded condition to the soundfield – poorer ear occluded condition, the results showed that soundfield – poorer ear occluded condition had a 2 – 18% improvement in speech discrimination scores. These results indicated that individuals may perform better in a natural environment by occluding the poorer of the two ears. The results further showed that when speech discrimination was measured in the soundfield with the poorer ear occluded and compared to the better ear – under earphones condition, 80% of subjects performed better or similar in the soundfield – poorer ear occluded condition, indicating that subjects with asymmetric hearing loss can perform better when the poorer ear is occluded. To conclude, bilateral asymmetrical hearing loss can affect one's ability to separate or integrate two speech signals. Furthermore, some individuals can benefit from occluding the poorer ear in everyday situations to improve speech discrimination scores (Arkebauer et al., 1971).

In a similar study, Karsten and Turner (2000) investigated the following two areas in subjects with asymmetrical hearing loss: (1) does "centering" during speech recognition testing provide an advantage or is another position is better; and (2) does providing speech to the poorer ear increase or decrease subjects benefit. This study consisted of 12 adult subjects with bilateral asymmetrical sensorineural hearing loss (SNHL) between the ages of 39 to 79 years old. The criteria for asymmetrical hearing loss included: thresholds poorer than 20 dB from 1 – 4 KHz in each ear; an interaural difference of 20 – 60 dB at any frequency from .5 – 4 KHz; and/or a word recognition score of 15% or greater between ears. The speech stimuli used for this study included 16 vowel-constant-vowel /VCV/ syllables recorded by two males and two females. The stimuli were presented to each subject via insert earphones.

The listener's most comfortable level (MCL) was determined binaurally by having each subject rate the /VCV/ syllables as "too loud, high end of comfortable, comfortable, or too soft". Then, the poorer ear's MCL was determined while no masking noise was present. Next, the authors decreased the level of the volume by 3 to 5 dB for binaural summation. Furthermore, the signal level for the poorer ear was held at a constant speech level while the same speech signal was being presented to the better ear at different levels. Each subject was instructed to listen for two to three syllables at each level in the better ear and report whether the sound was center, right, or left. Using these responses, a center baseline position was determined.

Then, the speech recognition score was determined by instructing the subjects to press a button corresponding to the constant sound. Nine conditions were analyzed: 1) no signal in the better ear, with the poorer ear at fixed center; 2) -20 dB signal in the better ear, with the poorer ear at fixed center; 3) -15 dB signal in the better ear, with the poorer ear at fixed center; 4) -10 dB signal in the better ear, with the poorer ear at fixed center; 5) -5 dB signal in the better ear, with the poorer ear at fixed center; 6) 0 dB signal in the better ear, with the poorer ear center; 7) +5 dB signal in the better ear, with the poorer ear at fixed center; 8) +10 dB signal in the better ear, with the poorer ear at fixed center; and 9) 0 dB signal in the better ear, with the poorer ear signal off. The better ear was held at center position for all nine conditions and the poorer ear varied 5 dB steps from the center. The monaural poorer ear scores were measured without masking noise to determine if cross-over had taken place. If cross-over occurred, then masking noise was added to obtain the score. Each subject had three runs (64 items per run) in each condition. The speech recognition score was obtained by averaging the three runs. Then, the subjects were asked if the sound was in the center, right, or left in each condition.

First, the results showed that there was no significant level effect for the speech recognition scores, suggesting that when the signal level changes by 30 dB in the better ear, speech recognition did not change even though the score for two ears were different. The results also revealed no significant difference for speech recognition when comparing the center position to either the best or worst condition for each subject. However, the results found that when the better and poorer ears were balanced at the center condition, the signal level presented to the better ear was above the threshold. When the sound level was reduced by 20 dB, the speech level did not go below threshold. These results indicate that the subject did not experience a decrease in audibility except when the better ear was fully attenuated. The results further revealed that the speech recognition scores were constant for all subjects, indicating that when the signal level varies in the better ear from -20 to +10 dB of the center position, it does not change the speech recognition scores. However, the subjects reported the center position was preferred over any other condition, thus, indicating the subjects have enhanced ease of listening when the sound is centered. Furthermore, the results showed no significant difference in advantage or disadvantage when adding in the poorer ear, thus, indicating no evidence of binaural interference when comparing the best binaural and center condition to the monaural better ear condition.

To conclude, the authors found that varying the signal level in the better ear did not change the speech recognition scores. The results further found that the poorer ear did degrade the signal when obtaining speech recognition scores. Therefore, a subject's awareness and lateralization of sounds in a binaural situation appear to be separate from information transmitted by the sounds to the listener (Karsten & Turner, 2000).

Third, in 2004, Noble and Gatehouse examined how a self-developed Handicap Questionnaire and the Speech, Spatial, and Qualities of Hearing Scale (SSQ, Gatehouse & Noble, 2004) responses reflect one another. The SSQ was developed to measure binaural functions and determine the advantages of binaural hearing. The SSQ consists of 14 items on hearing speech in a wide range of listening conditions, 17 items on components of spatial hearing (i.e., direction, distance, and movement), and 18 items on qualities of hearing (i.e., segregation of sound, identifications, naturalness, clarity, and the effort needed in listening). The overall SSQ score has a range of 0 to 10, with 10 being the greater handicap experienced. All subjects also completed a self-developed Handicap Questionnaire prior to the study. The questionnaire contained questions about the limitations on activity, social withdrawal, and emotional disturbances due to hearing loss. The overall Handicap Questionnaire score has a range of 0 – 100, with 100 being the greater handicap experienced. The subjects for this study included 103 adults with symmetrical hearing loss and 50 adults with asymmetrical hearing loss (i.e., difference between ears of 10 dB or more at 500, 1000, 2000, and 4000 KHz). All subjects had not used hearing aids prior to this study.

The overall results of the Handicap Questionnaire showed that the subjects with symmetrical hearing scored better compared to the subjects with asymmetrical hearing in almost all the categories (i.e., speech-hearing, spatial hearing, and qualities), indicating that the subjects with asymmetrical hearing were more disabled than the subjects with symmetrical hearing in almost every item of the Handicap Questionnaire. Furthermore, the results for the Handicap Questionnaire revealed that the subjects with asymmetrical hearing loss have a harder time listening in background noise and decreased spatial awareness compared to the subjects with symmetrical hearing. Furthermore, the results for listening items (e.g., identifying people, music, and natural voices) showed both groups had to use a large amount of effort and concentration to listen. The results further showed that the subjects with asymmetrical hearing loss had significantly more difficulty when being a passenger in the car compared to the subjects with symmetrical hearing.

Furthermore, the SSQ scores were significantly different between the two groups. Specifically, subjects with asymmetrical hearing loss scored lower than the subjects with symmetrical hearing loss on the overall SSQ; thus, indicating that subjects with asymmetrical hearing loss reported more difficulties with speech, spatial, and qualities of hearing than those with symmetrical hearing loss. The results for the three subtests of the SSQ are as follows. Subjects with asymmetrical hearing loss scored lower on the spatial and speech items compared to subjects with symmetrical hearing loss, suggesting that subjects with asymmetrical hearing loss had more trouble when trying to localize or communicate in a group situation. In addition, the two groups were similar when asked to rate qualities of hearing (e.g., naturalness, clarity, and segregation items).

In conclusion, subjects with symmetrical and asymmetrical hearing loss have shown considerable differences in rating abilities and the ways in which those disabilities drive the handicap. Subjects with asymmetrical hearing loss reported having a poorer ability across all domains (i.e., speech spatial, and qualities of hearing items) addressed in the SSQ. Furthermore, the subjects with asymmetrical hearing loss reported the most difficulties processing spatial cues and speech compared to the subjects with symmetrical hearing. Results for the Handicap Questionnaire revealed that all subjects reported having a similar degree of handicap. The results are thought to be due to the fact that the subjects with asymmetrical hearing loss adjust for the differences between ears and work to improve the signal-to-noise ratio (SNR) (Noble & Gatehouse, 2004).

In summary, the effects of asymmetrical hearing loss on communication can affect a listener's ability to discriminate speech, separate two speech signals, communicate in groups, and communicate in background noise (Arkebauer et al., 1971; Noble & Gatehouse, 2004). Listeners with asymmetrical hearing also have a decreased ability to separate or integrate two speech signals, which can also reduce speech discrimination (Arkebauer et al., 1971; Noble & Gatehouse, 2004). Furthermore, listeners with severe asymmetrical hearing loss have a harder time with speech discrimination compared to listeners with a mild asymmetrical hearing loss (Arkebauer et al., 1971). Additionally, regardless of the better or poorer ear, when listening to a sound source directly in front of the listener "ease of listening" is increased compared to listening to a sound source behind or to the side (Karsten & Turner, 2000). However, when listeners are communicating in groups, regardless of the listeners hearing loss, both those with asymmetrical and symmetrical hearing have difficulties following and understanding the conversation (Noble & Gatehouse, 2004).

Unilateral Hearing Loss: Definition and Effects on Communication

Unilateral hearing loss is defined by normal hearing sensitivity in one ear and some degree of hearing loss in the other ear (ASHA, 2011). The following studies investigated the effects of unilateral hearing loss on communication, speech recognition, listening in background noise, social interactions, and speech understanding. First, Welsh, Welsh, Rosen, and Dragonette (2004) investigated the impact of unilateral hearing loss on communication by examining the speech discrimination in noise and recognition of compressed sentences in adult subjects. Subjects for this study were split into three groups: Group A included 19 subjects (mean age = 40 years) with normal hearing; Group B included 16 subjects (mean age = 48 years) with unilateral hearing loss (UHL), and Group C included 20 subjects (mean age = 71 years old) with a high frequency asymmetrical SNHL. Speech recognition in noise was assessed using the Speech in Noise (SIN, Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004) test while recognition of compressed sentences was assessed using the Compressed Sentence Test (Keith, 2002). The SIN testing was completed using single words presented at 50 dB HL with competing speech babble presented at a +10 dB SNR. All sentences used were compressed by 30%.

The results of the SIN testing revealed that when noise was introduced listeners with normal hearing had speech discrimination scores that declined approximately 14%. Listeners with UHL had speech discrimination that declined about 34% when noise was introduced, and when noise was introduced for listeners with asymmetrical SNHL, speech discrimination declined about 42%. These results revealed that speech discrimination was highly related to the subjects' degree of hearing loss. Overall, the results of the SIN testing confirmed the authors' hypothesis that subjects with both UHL and asymmetrical SNHL had significantly impaired speech recognition abilities in background noise compared to the listeners with normal hearing.

The results for the Compressed Sentences test revealed that for listeners with normal hearing and those with UHL, their ability to recognize sentences did not degrade significantly. This was not the case for listeners with asymmetrical SNHL. Overall, this suggested that speech recognition was not significantly degraded for listeners with normal hearing or those with UHL; however, recognition for those with asymmetrical SNHL was significantly degraded when speech was compressed (Welsh et al., 2004).

Second, Wie, Pripp, and Tvete (2010) studied the effects of communication in adults and adolescence with unilateral deafness. Specifically, they examined (1) the effect of unilateral deafness on social interaction; (2) the frequency which communication strategies are used in these listeners; (3) the correlation between self-reported speech perception in noise ability and measured outcomes of the test; and (4) the likelihood that communication in noise is a learned process with experience. Subjects included 16 women and 14 men between the ages of 14 – 75 years with a profound unilateral deafness (i.e., poor ear thresholds were worse than 60 dB HL from 250 – 6000 Hz & better ear was within normal limits). Then, 30 subjects with normal hearing were used as a reference group for the speech perception in noise testing and were made experimentally deaf for this research. Data was collected by using three to five interview questions (for hearing impaired listeners only) and the speech perception in noise test (for all subjects). Questions involved communication experiences, coping strategies, speechreading techniques, positioning strategies, and speech perception in different environments. The SIN test was performed for all subjects (i.e., unilateral deaf & normal subjects) under three conditions: (1) unilateral audiovisual, (2) unilateral auditory only, and (3) visual only.

The results of the interview questions revealed that 90% of the subjects with unilateral deafness had a hard time interacting with other people. Second, the results showed that the areas of communication difficulties for the subjects with unilateral deafness included communicating in background noise and in highly reverberated areas. Next, the authors found that subjects with unilateral deafness had a significant improvement when communicating with familiar talkers. Furthermore, when listening strategies (e.g., head turn & speech reading) were introduced, 97% of subjects with unilateral deafness reported using visual cues to enhance speechreading abilities, especially in noise. However, 40% of the subjects with unilateral deafness avoided using listening strategies that could have helped improve communication. Additionally, the results showed that all subjects with unilateral deafness turn their better ear towards the speaker in background noise to achieve better understanding. Furthermore, the results for the SIN test revealed no significant difference between the subjects with unilateral deafness and the subjects with normal hearing when a unilateral deafness was simulated.

These results further showed that when adding visual cues to auditory cues all subjects had a significant improvement for speech perception in noise testing. The results indicated that having more experience with UHL did not give the subjects with unilateral deafness an advantage on the speech perception in noise test over the subjects with normal hearing that had a temporary UHL.

To conclude, unilateral deafness causes a significant disability in communication, speech perception, and social interaction. The results from this study indicated that the subjects with unilateral deafness experience the most difficulties communicating in noise. Furthermore, the subjects with unilateral deafness reported having feelings of exclusion, reduced well-being, and wanting to avoid social situations especially when background noise was present. However, the subjects with unilateral deafness that use listening strategies reported an increase in hearing and communication in all environments. Lastly, the results indicated that the subjects with unilateral deafness did not have an advantage of communicating compared to the normal hearing group that experienced temporary deafness. Both groups did show an improvement communicating when visual cues were added (Wie et al., 2010).

Rothpletz, Wightman, and Kistler (2012) measured spatial cues in subjects with UHL to compare the following in subjects with UHL and normal hearing: (1) performance for monaural listening with masking noise, (2) speech understanding in soundfield, and (3) localization of wide band noise burst on a horizontal plane. The subjects for this study consisted of 11 subjects with UHL and 12 subjects with normal hearing between the ages of 18 – 64 years. The study was divided into three parts.

Experiment One measured the monaural listening condition with a speech target and masking noise present using the Coordinate Response Measure (CRM; as cited in Rothpletz et al., 2012) paradigm. The CRM is a closed-set test with little linguistic context where the subject is to attend to the target and ignore the masking noise. The target was delivered monaurally via headphones. For the subjects with UHL the target was presented to the better ear, and the target was presented to the right ear for the subjects with normal hearing. The subjects were positioned in front of a computer in a sound-treated booth. The computer screen had a start button and 32 response buttons arranged in four color matrices (i.e., red, white, green, and blue) with eight buttons that were numbered 1 – 8. Subjects were instructed to click the start button and to respond to only the speech target by clicking the corresponding button of the color and number that they heard. There was a 60 trial block with the masking noise held at a constant 60 dB SPL. The target level was randomized for each trial and encompassed a span of 20 dB; the typical target level was between 30 and 55 dB SPL. This experiment consisted of two conditions: (1) a target a masker sentence presented at the same time, and (2) a target sentence combined with speech spectrum noise as the masker. The results for Experiment One showed no significant differences between those with UHL and those with normal hearing in either monaural noise condition, indicating that the subjects with UHL performed similar to the subjects with normal hearing when listening monaurally through the better hearing ear. The results further showed that the UHL subjects have "normal" monaural speech understanding in the presence noise.

Experiment Two measured speech understanding in the soundfield. The target and maskers were the same as in Experiment One; however, the target and masker did not overlap in this experiment. The target was presented at ear level with speakers at -90, 0, and +90 degrees azimuth relative to the subject. The target was always presented at 0 degrees azimuth while the masker was presented at 0, -90, and +90 degrees azimuth. The masker was held at a constant 55 dB SPL. The subjects were instructed to verbally respond to the loudspeaker that they heard the stimulus and noise coming from. The subjects with UHL were tested in three conditions: (1) the target and masker presented from the front (i.e., 0 dB azimuth; collocated); (2) the target presented from front (0 degrees azimuth) and the masker presented at 90 degrees azimuth on the side of the subjects impaired ear (i.e., masker impaired); and (3) the target was presented from the front (0 degrees azimuth) and the masker from 90 degrees azimuth on the subjects normal ear (i.e., masker normal). The subjects with normal hearing were measured in the collocated and the masker normal condition on the left ear. The subjects completed 300 trials in each condition. Results for Experiment Two showed a significant difference between the subjects with normal hearing and UHL in the collocated condition, with the subjects with normal hearing performing better. Relative to the collocated condition, the subjects with UHL performed better in the masker impaired condition and poorer in the masker normal condition. However, the overall performance for all three conditions was still better for the subjects with normal hearing than the subjects with UHL. These results indicated that subjects with normal hearing have binaural cues for understanding and localizing sound that the subjects with UHL do not have.

Lastly, Experiment Three measured the subjects with UHL ability to localize. The target was a noise burst with a mean level at 65 dB SPL and was presented to a signal speaker or positioned between two speakers. The speakers were spaced 30 degrees apart from -90 to +90 degrees azimuth. The subjects were seated facing the speaker at 0 degrees azimuth in a sound-treated booth. The target noise was presented randomly to one of the speakers. The subjects were instructed to verbally say the number of which speaker or speakers they heard the target noise from while facing 0 degrees azimuth. Each subject completed 195 trials. In Experiment Three subjects with UHL performed poorer than the subjects with normal hearing. Furthermore, some of the subjects with UHL had little to no ability to localize sound. However, most of the subjects with UHL performed better when the noise was presented on the side of their better ear. The results also found that there was not a significant relationship between localization performance and the use of spatial cues on a speech task for the subjects with UHL.

In conclusion, subjects with normal hearing have binaural abilities that allow them to have better speech understanding and localization than listeners with UHL. Also, the subjects with UHL have deficits when trying to understand speech in noise as compared to the subjects with normal hearing because they are not able to use spatial cues to differentiate the target and masking noise. These results indicated that subjects with UHL appear to have trouble achieving spatial release from masking noise, possibly due to the inability to maximize the head shadow effect (Rothpletz et al., 2012).

In summary, subjects with UHL/unilateral deafness have decreased speech discrimination in noise, decreased localization abilities, a difficult time communicating in highly reverberant environments, and a decreased number of social interactions compared to the subjects with normal hearing (Welsh et al., 2004; Wie et al., 2010; Rothpletz et al., 2012). However, when subjects with UHL use visual and auditory cues along with listening strategies to help with speechreading, they had better results communicating, especially in background noise (Wie et al., 2010). Furthermore, subjects with UHL report turning their better ear toward the sound source for better communication.

Mediation of Hearing Loss

The following studies examined if unilateral/asymmetrical hearing loss is mediated in the central auditory system or peripheral auditory system and if gender and age effect the mediation. The studies also investigated how a unilateral/asymmetrical hearing loss can affect the auditory cortex organization. First, Scheffler, Bilecen, Schmid, Tschopp, and Seelig (1998) examined responses of the primary auditory cortex in unilateral deaf subjects from blood oxygenation level dependent (BOLD) functional magnetic resonance imaging (fMRI). Ten adult subjects with normal hearing and five subjects with unilateral deafness were used in this study. fMRI was used to visualize the anterior and posterior commissure of the brain. The acoustic stimulus consisted of a pulsed sine tone at 1000 Hz delivered through headphones in an on-off cycle. The "on" cycle was presentation of a pulsed sine tone and the "off" cycle was the presentation of no acoustic stimulus. During the on-off cycles a series of five images with nine slides were collected in each subject. The measurements for all subjects consisted of binaural, monaural right, and monaural left stimulations.

The results revealed that all subjects had a BOLD cortical response in the superior temporal gyrus. For the subjects with normal hearing, both temporal lobes of the primary auditory cortex showed significant activation for all subjects. The results further revealed that all of the normal hearing subjects had a significant shift in cortical activation volume to the right hemisphere when the left ear was stimulated. Similarly, when the right ear was stimulated, there was a significant shift of cortical activation volumes for the left hemisphere. The results further showed that the monaural stimulus was significantly smaller than the binaural stimulation in volume for 90% of the normal hearing subjects, thus, indicating that there is an interaural interaction at some level in the auditory pathway because of the differences found between the monaural and binaural responses. For the subjects with unilateral deafness, a strong cortical response in both hemispheres was identified when stimulating the healthy ear. The results also showed that when the deaf ear was stimulated, there was little to no cortical activation present. These results collectively indicate that an adaptation or change in the auditory pathway was present for those with unilateral deafness. Furthermore, all subjects had bilateral cortical responses when stimulated binaurally, indicating bilateral stimulation can lead to bilateral activation of the auditory cortex regardless if the subject is unilateral deaf (Scheffler et al., 1998).

Secondly, Ponton et al. (2001) investigated if a late-onset profound unilateral hearing loss changes the activation of the central auditory system. The subjects consisted of two groups: one group with UHL and the other group had subjects with normal hearing. The first group had 15 teenagers and adults between the ages of 17 – 67 years old (mean age = 43 years) with unilateral hearing loss due to an acoustic neuroma, meningitis, otologic disorders, or a sudden SNHL. Of the 15 subjects, eight of them had UHL for less than two years and seven had UHL for more than two years. The second group had nine adults with normal hearing between the ages of 20 – 38 years old (mean age = 32 years). AEP were recorded with 30 electrodes for all subjects. The stimulus was delivered monaurally to the right and left ears for the normal hearing group and only the intact ear for subjects with UHL. The AEP amplitudes were compared between the ipsilateral and contralateral hemispheres. The inter-hemispheric timing was assessed by the point-to-point cross-correlation with a time lag of zero. Also assessed was the inter-hemispheric amplitude by using the linear regression of peak-to-peak (i.e., P_1-N_1 and N_1-P_2) and peak amplitudes (i.e., P_1, N_1, and P_2).

The results of the inter-hemispheric amplitude differences showed that those with UHL had significantly larger ipsilateral AEP amplitudes than those with normal hearing. However, the inter-hemispheric amplitudes in the contralateral hemisphere were not significantly different for two groups. These results indicated that the central auditory system had an increase of activity from the ipsilateral pathway to the intact ear. Next, the results showed that those with UHL had increased ipsilateral amplitudes that altered the ratio of the ipsilateral and contralateral amplitudes, thus, indicating that subjects with UHL have asymmetry due to the decreased inter-hemispheric amplitudes. Subjects with UHL had larger ipsilateral amplitudes when the stimulus was presented to the ipsilateral ear.

The results of the inter-hemispheric timing for AEPs revealed a significant difference between the two groups. Specifically, the authors found that both UHL groups had significantly lower inter-hemispheric AEP timing over the frontal cortex compared to the normal hearing group. In addition, the less than two year UHL group had significantly higher inter-hemispheric AEP timing over the central cortex compared to the normal hearing group. However, the inter-hemispheric AEP timing for the normal hearing group was significantly higher in the central cortex compared to the UHL group with more than two years of loss. The results collectively indicate that a late-onset of UHL can gradually change the activity in the central auditory system.

The results of the inter-hemispheric and individual peak-to-peak amplitude correlations showed a significant correlation for all groups between the ipsilateral and contralateral amplitudes. Next, the results showed that all the groups had an increase of inter-hemispheric correlations for the peak-to-peak amplitude of P_1-N_1 and N_1-P_2. In addition, the UHL group with more than two years of loss had stronger inter-hemispheric peak-to-peak amplitude in the P_1-N_1 and N_1-P_2than the UHL group with less than two years of loss. The results also revealed that the inter-hemispheric amplitude of N_1-P_2 is significantly stronger in the UHL groups compared to the group with normal hearing subjects. These results indicate the inter-hemispheric amplitude continues to increase in strength for at least two years after the onset of UHL. Collectively, these results indicate that as the length of time from onset of hearing loss increases for the subjects with UHL, the inter-hemispheric peak-to-peak amplitudes continue to increase.

In conclusion, normal hearing subjects have contralateral amplitudes that are larger and earlier than the ipsilateral amplitudes for the central auditory system, and the UHL subjects have the opposite with more symmetrical and synchronous activity in the central auditory system. Furthermore, subjects with UHL can have gradual changes in the cortical activity for at least two years after the onset of the UHL. Overall, Ponton et al. (2001) found that there are changes in the plasticity of the central auditory system in the adult brains following the onset of a profound UHL (Ponton et al., 2001).

Khosla et al., (2003) continued this work through examination of the activation of the central auditory system in relationship to the profound unilateral deafness (right versus left ear). The subjects were divided into two groups: one group consisted of 19 (12 females and 7 males) adults with unilateral deafness (i.e., 10 right sided deafness and 9 left sided deafness) between the ages of 16 to 68 years (mean age = 47 years), and the second group had eight (4 females and 4 males) adults with normal hearing sensitivity (i.e., thresholds of 25 dB HL or better at .25, .5, 1, 2, and 4 KHz).

AEP were recorded via 31 electrode sites on all subjects. On the subjects with normal hearing, AEPs were measured monaurally while on the subjects with unilateral deafness, AEPs were measured from the intact ear. The amplitudes of N_{1b}/P_2 and T_a/T_b complexes were measured for both ipsilateral and contralateral sources. Next, the interhemispheric amplitude differences (IHAD) were recorded; a positive IHAD represents a larger contralateral response and a negative IHAD represents a larger ipsilateral response. Lastly, the interhemispheric latency differences (IHLD) were recorded for each peak (i.e., N_{1b}, P_2, T_a, and T_b).

The results of this study revealed that the IHLD for the right and left stimulated ear had no significant differences for either the subjects with normal hearing or the subjects with UHL. The results further revealed that the peak latencies (i.e., N_{1b}, P_2, T_a, and T_b) were all early in the contralateral hemisphere for the group with normal hearing (mean IHLD: N_{1b} = 14.4, P_2 = 7.7, T_a = 8.3, and T_b = 6.8ms); however, the peak latencies were similar but earlier in both hemispheres for the group with unilateral deaf subjects (mean IHLD: N_{1b} = 1.9, P_2 = 0.2, T_a = 0.9, and T_b = 0.4ms). Next, the results revealed the IHADs were all larger in the contralateral hemisphere for the group with normal hearing subjects (mean IHAD: = 24.5%, N_{1b}-P_2 = 31.0%, and T_a-T_b= 20.6%) compared to the group with unilateral deafness (mean IHAD: = 12.6%, N_{1b}-P_2 = 17.0%, and T_a-T_b = 7.1%). The results further showed no differences for IHAD between the right and left stimulated ears for the group with normal hearing; however, the IHAD for the group with unilateral deaf subjects showed significant differences for the RMS of the N_{1b}/P_2 and T_a/T_b complexes between monaural right and left stimulated ears. Lastly, the study showed that subjects with a left unilateral deafness (right ear monaural stimulation) have a decreased N_{1b}/P_2in IHADs when compared to the group with normal hearing subjects (stimulation of either ear) and subjects with right unilateral deafness group (left ear monaural stimulation).

Collectively, these results showed that regardless of the stimulus ear, the subjects with normal hearing showed a significant difference for the IHAD with the contralateral waves being larger and peak earlier compared to the ipsilateral waves. The subjects with UHL had reduced IHAD that were ear dependent. The results indicate that the subjects with normal hearing had auditory activation changes in the patterns that were asymmetrical/asynchronous; whereas, the subjects that had unilateral deafness have more symmetrical/synchronous auditory activation. Based on these results, the authors hypothesized that there are differential effects on the central auditory system, which are dependent on the unilateral deaf side. Specifically, left unilateral deafness (stimulation of the right ear) produces effects on the cortical activation in both hemispheres, but right unilateral deafness (stimulation of the left ear) produced normal asymmetry. Overall, the results from this study indicated evidence of reorganization occurring in the central auditory system because of left profound unilateral deafness (Khosla et al., 2003).

Next, Hwang, Chao, Ho, & Hsiao (2008) investigated the relationship between gender, age, and hearing asymmetry to determine the effect on the interaural differences of the ABR. More specifically, they examined waves III and V intervals and how they relate to the degree of hearing asymmetry in subjects with asymmetrical SNHL. One hundred and thirty nine females (mean age = 51.9 years) & 106 males (mean age = 49.6 years) with asymmetrical SNHL (i.e., 15 dB or greater at two or more frequencies) participated in this study. All subjects were cleared of a history of brain tumors or vestibular schwannoma, and any neurological medical illness. The ABR was obtained using a four-channel electrode with a 90 dB nHL broad-band click at a rate of 11-12 seconds per click. Pure-tone average (PTA) and interaural differences of the ipsilateral ABR were measured for the right and left ears.

The results showed that gender and age did not significantly affect waves III and IV, but PTA had a positive effect on the waves. Thus, indicating that as the asymmetry between the ears increased the latencies of waves III and V also increased. Furthermore, the results showed that gender, age, and PTA did not have an effect on wave III-V interval; however, for the females younger than 50 years, the wave III-V interval was significantly affected by PTA by way of a negative correlation (i.e., as PTA increased, latencies decreased). These results indicated that as hearing got more asymmetrical, these females' interaural differences decreased. This could be due to the plasticity of the auditory brainstem in young females and/or estrogen may affects the plasticity of the auditory brainstem. Furthermore, the results of this study showed that the neural transmission time remained constant for waves III and V in both ears for all groups besides the younger female adults (Hwang et al., 2008).

Lastly, in 2009, Hanss et al. sought to determine if the auditory cortex was affected by the side of deafness when responding to speech and non-speech stimuli. Eighteen adults with UHL and 16 adults with normal hearing served as the subjects. All subjects were between the ages of 27 – 59 years, and all subjects were right-handed. The subjects were divided into four groups based on the stimulus ear: (1) subjects with normal hearing, tested on the left side; (2) subjects with a right UHL, tested on the left side; (3) subjects with normal hearing, tested on the right side; and (4) subjects with a left UHL, tested on the right side. Long latency AEPs were recorded with an electrode cap of 29 electrodes. Then, six series of 100 stimuli (e.g., 50 non-speech & 50 speech) were repeated three times each. The series were presented randomly to the stimulus ear at 50 dB SL. The stimulus consisted of 1 KHz tone burst (i.e., non-speech stimuli) and /pa/ (i.e., speech stimuli) voice-less consonant-vowel. Each stimulus recorded measurements for latency, amplitude, and inter-hemispheric differences (i.e., IHLD & IHAD) for each subject.

The results for both groups with normal hearing showed a short contralateral N_1 mean latency and large contralateral N_1-P_2 amplitude with strong contralateral IHAD when compared to the ipsilateral responses. The results indicate an early and strong activation in the contralateral cortex for both the 1 KHz tone burst and the /pa/ stimuli. The results for the subjects with a right UHL showed no differences for the measurements of latency, amplitude, IHLD, and IHAD for either stimulus when compared to the normal hearing groups. These results indicate a normal asymmetry pattern in the temporal lobe for the subjects with a right UHL.

The results for the subjects with a left UHL showed no difference in the IHLD responses when the stimulus was a 1 KHz tone burst compared to all other groups, thus, indicating that the right and left auditory cortexes are synchronized. Furthermore, when the stimulus was the /pa/, the subjects with a left UHL had a more pronounced auditory evoked potentials. Specifically, the results showed the subjects with a left UHL had an

IHLD ipsilateral response that was significantly shorter when compared to the subjects with a right UHL and both subjects with normal hearing. The IHLD and IHAD responses also showed synchrony between the right and left temporal lobes for the subjects with a left UHL. Also, the results found that the subjects with a left UHL had mean values of the IHAD that reflected strong ipsilateral responses compared to the subjects with normal hearing, tested on the left side. The subjects with a left UHL had mean values of the N1-P2 amplitudes from a combination of contralateral decreases and ipsilateral increases compared to the subjects with normal hearing, tested on the right side. Lastly, the results for the subjects with a left UHL showed a significant reversal asynchrony of the ipsilateral cortex compared to the subjects with a right UHL when the 1 KHz tone burst stimulus was used and the subjects with normal hearing, tested on the right side and subjects with a right UHL when the stimulus used was the /pa/. These results indicate that the neurophysiological changes observed oriented from the posterior temporal part of the brain for the left UHL group.

To conclude, the authors found that subjects with a left UHL have more cortical reorganization than the subjects with right UHL. The author's findings are consistent with previous data from Khosla et al. 2003. Additionally, the authors also found that the loss of asymmetry in the subjects with left UHL may also lead to consequences on the perception of acoustic features by the intact ear. Lastly, these results indicated that the subjects with right UHL had more anatomical and functional plastic changes than the subjects with left UHL (Hanss et al., 2009).

In summary, the subjects with normal hearing have contralateral amplitudes that are larger and earlier than the ipsilateral amplitudes for the central auditory system, and the UHL subjects have the opposite with more symmetrical and synchronous activity in the central auditory system. Furthermore, the central auditory system is deprived when an adult experiences a late-onset of UHL. Results show that changes in the plasticity of the central auditory system in adults brains following the late-onset of a profound UHL. Khosla et al. (2003) further revealed evidence of reorganization occurring in the central auditory system in subjects with left profound UHL. Furthermore, Hanss et al. (2009) found that subjects with a left UHL have more cortical reorganization than subjects with a right UHL. There are differences that affect the time course and amplitude of the auditory cortex for the subjects with left UHL compared to the subjects with right UHL. However, subjects with right UHL had more anatomical and functional plastic changes than the left UHL. Overall, the research suggests the asymmetrical/unilateral hearing loss is mediated beyond the level of the SOC.

Chapter III

Methods and Procedures

Participants

Fifteen adults, nine with unilateral SNHL and six with bilateral asymmetrical SNHL, served as participants for this study. Subjects were recruited from an Ear, Nose, and Throat Center in Indiana. Unilateral hearing loss was defined as one ear being within the normal range for hearing (i.e., 25 dB HL or better at all octave frequencies from 250 – 8000 Hz) with the other ear having a mild to severe SNHL. Figure 1 shows the mean pure tone thresholds at the octave frequencies 250 to 8000 Hz for subjects with unilateral hearing loss. Asymmetrical hearing loss was defined as at least 20 dB HL difference between the average thresholds of 500, 1000, 2000, and 4000 Hz. Figure 2 shows the mean pure tone thresholds at the octave frequencies 250 to 8000 Hz for subjects with asymmetrical hearing loss. All subjects were native English speaking with no known neurological, cognitive, or learning deficits. Furthermore, all participants had to have word recognition scores of at least 50% bilaterally.

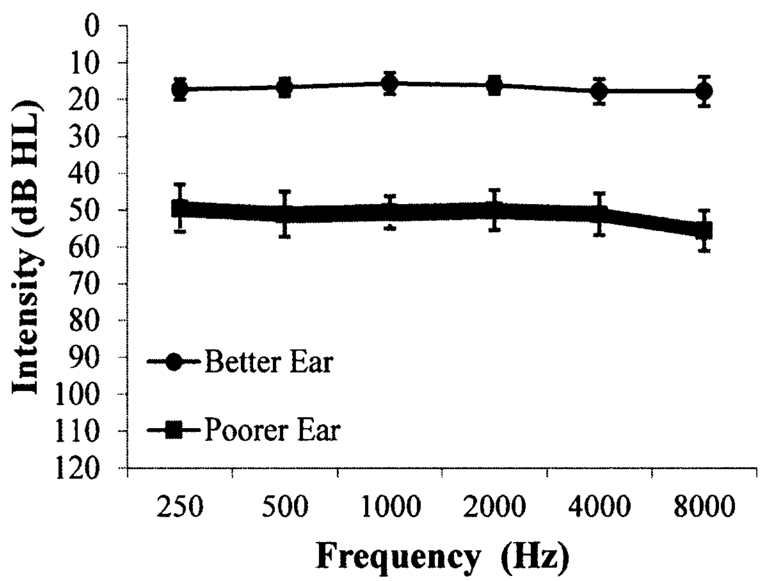

Figure 1. Mean pure tone thresholds and standard deviations for octave frequencies 250 to 8000 Hz for subjects with unilateral hearing loss.

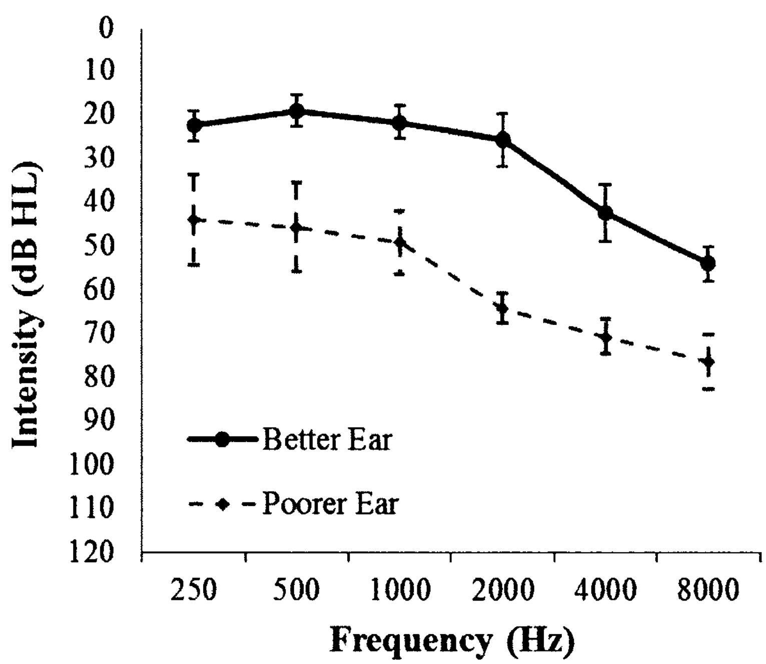

Figure 2. Mean pure tone thresholds and standard deviations for octave frequencies 250 to 8000 Hz for subjects with asymmetrical hearing loss.

Materials

Qualification and experimental testing was conducted at an Ear, Nose and Center in Indiana. A sound-treated examination booth (IAC, Model 402-a) with ambient noise levels appropriate for testing unoccluded ears (ANSI S3.1, 1999) was used for all testing. Otoscopy was performed using a P4 R.A. Bock Diagnostics otoscope to confirm no outer ear pathology. Air and bone conduction testing and speech testing was performed using a Grason-Sadler GSI-16 audiometer, which was confirmed to be in good working order via current electroacoustic calibration and daily biologic checks (ANSI S3.6, 2004). Spondee words were used as the stimuli to measure speech recognition thresholds (SRT) via monitored live speech. The Northwestern University Auditory Test No. 6 (NU-6) was used as the stimuli to measure word recognition ability/score (WRS). The NU-6 word list was delivered through a GSI-16 audiometer coupled to a GPX- CD player. EARTone 3A insert earphones were also used for presentation of all audiometric testing. Furthermore, a portable screening Grason-Sadler GSI-17audiometer was used to present the masking level to the non-test ear when ANL was tested using masking noise. Furthermore, acceptance of background noise was measured using traditional ANL procedures (see Appendix A for ANL instructions). ANL has been shown to have good reliability and validity over a three month period (Nabelek et al. 2004).

Procedures

Qualification procedures. Upon arrival, each participant was given a verbal description of the study and required to read and sign an informed consent (see Appendices B and C for Human Subjects Consent Form and Approval Documentation). All subjects completed an audiological evaluation including otoscopy, air and bone conduction threshold testing, SRT, and WRS. The main purpose of completing SRT testing was to document reliability and obtain an initial masking level, when masking the non-test ear. All subjects also had word recognition scores of at least 50% bilaterally.

Test conditions. ANL was tested in the following four conditions: (a) binaural ANL (i.e., using both the right and left ears) in soundfield from zero degrees azimuth; (b) ANL in the better ear only using insert earphones; (c) ANL in the poorer ear only without masking noise presented to the better ear (called ANL poorer ear unmasked) using insert earphones; and (d) ANL in the poorer ear with masking noise presented to the better ear at a level of SRT +30 (called ANL poorer ear masked).For the fourth condition only, masking noise was delivered using a portable screening audiometer with a super-aural (TDH-39) headphone to the non-test ear and an insert earphone in the poorer ear. Two ANLs were measured for each condition (i.e., both ears, better ear, poorer ear unmasked, poorer ear masked); however, if the difference between the two ANLs exceeded 4 dB, a third ANL was measured for that condition. The four conditions were randomized for each subject.

Experimental procedures. ANL testing was performed for all subjects. First, the subjects were given two buttons with the words and pictures of louder and softer on them. When the subject touched the button, this signaled the examiner to adjust the audiometer up or down based on the subject's response. Initial presentations level of 30 dB HL were used to obtain most comfortable listening level (MCL) and background noise level (BNL).

To obtain most MCL, all subjects listened to a story and were asked to first adjust male running speech (Arizona Travelogue, Frye Electronics). First, the subjects were asked to turn the loudest level up until it was too loud. Second, the subjects were asked to turn the loudness level of the story down until the story was at the softest loudness level where they could still hear the story. These two adjustments were completed using a 5 dB step size. Lastly, the subjects were asked to adjust the loudness of the story to his or her MCL; the signal was adjusted in 2 dB increments to find MCL. Please note that the subject did not adjust the levels for MCL themselves; instead they hit a button, which signaled the examiner to adjust the audiometer according to the subject's response. Next, multi-talker speech babble background noise (Revised SPIN; Bilger et al., 1984) was added. The subjects were first asked to turn the background noise up until they could not hear the story. Then, the subjects were asked to turn the level of the background noise down until the story became very clear. These adjustments were made in 5 dB increments. Lastly, the subjects were asked to adjust the signal of the background noise to the maximum level of background noise that they were willing to accept but could still follow the story for a long period of time (called background noise level or BNL); these adjustments were made in 2 dB increments. Again, please note that the subject did not adjust the levels for BNL themselves; instead they hit a button, which signaled the examiner to adjust the audiometer according to the subject's response. The BNL was subtracted from the MCL to obtain the ANL (ANL = MCL – BNL).

Chapter IV

Results

To determine whether the mediation point of ANLs is a central or peripheral phenomenon, ANL was obtained between ears within subjects with unilateral or asymmetrical SNHL. Four ANL conditions were tested: (a) binaural ANL (i.e., using both the right and left ears) in soundfield from zero degrees azimuth; (b) ANL in the better ear only using insert earphones; (c) ANL in the poorer ear only without masking noise presented to the better ear using insert earphones (called ANL poorer ear unmasked); and (d) ANL in the poorer ear with masking noise presented to the better ear at a level of SRT +30 (called ANL poorer ear masked).ANL was obtained twice for each condition unless the two ANLs were not within 4dB, then a third ANL was obtained. A third ANL was completed 10 times out of the 60 ANL trials (60 = 15 participants x 4 ANL trials). Furthermore, a mean ANL was obtained for each condition which required two ANL trials, and the median ANL was used when three trials were required. Next, a mean ANL was calculated for all subjects with unilateral and asymmetrical hearing for each condition. Figure 3 shows the mean ANLs in each condition for both subjects with unilateral and asymmetrical SNHL.

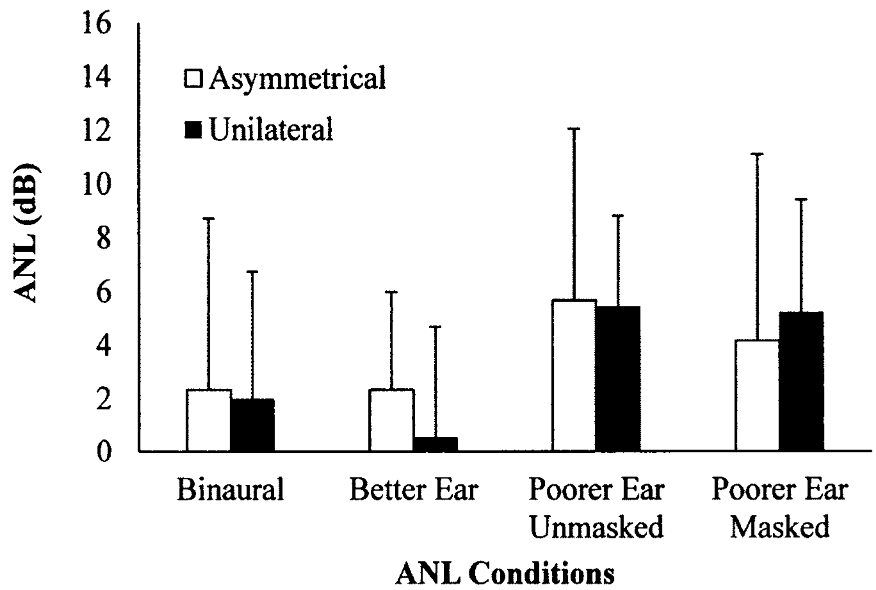

Figure 3. Mean ANLs and standard deviations in the four conditions for all subjects with unilateral and asymmetrical SNHL.

A two-way repeated measure analysis of variance (ANOVA) was conducted to determine the effect of condition and hearing loss on ANL. The within subjects variable was condition with 4 levels (binaural, better ear, poorer ear unmasked, and poorer ear masked). The between subjects variable was group with two levels (unilateral and asymmetrical). The results showed a significant main effect for condition ($F[3,39] = 8.42$, $p < 0.001$); however, there was no significant effect for group ($F[1,13] = 0.02$, $p = 0.892$) or the ANL by group interaction ($F[3,39] = 0.73$, $p = 0.542$). These results indicate a significant difference between ANL in the four conditions (i.e., binaural, better ear, poorer ear unmasked, and poorer ear masked); however, the subjects with unilateral and asymmetrical SNHL behaved similarly throughout the testing.

Pairwise comparisons were completed to further explore the difference in the four ANL conditions; a Bonferroni adjustment was completed for multiple comparison. The results showed a significant difference between both the binaural ANL (M =2.17) and better ear ANL (M = 1.44) conditions and the poorer ear unmasked ANL (M = 5.56) condition. There was, however, no significant difference between the binaural (M = 2.17) and better ear ANL (M = 1.44) conditions or the poorer ear unmasked (M = 5.56) and the poorer ear masked (M = 4.69) conditions. The results further showed that both the binaural ANL (M = 2.17) and better ear ANL (M = 1.44) conditions versus the poorer ear masked ANL (M = 4.70) condition approached significance. These results indicate that ANLs were lower when measured in the binaural or better ear compared to the poorer ear, which presented with higher ANLs. Furthermore, the results indicated that ANLs were similar among subjects with unilateral and asymmetrical SNHL.

Chapter V

Discussion

One way to determine if ANLs are truly mediated at the level of the central auditory cortex or in the peripheral auditory pathway is to test individual ANLs at each ear in listeners with unilateral and asymmetrical SNHL. Therefore, the purpose of this study was to determine if ANLs differ between ears within subjects with unilateral or asymmetrical SNHL. The results revealed a significant difference in the four ANL conditions (i.e., binaural, better ear, poorer ear unmasked, and poorer ear masked); however, subjects with asymmetrical and unilateral SNHL performed similarly. The results further revealed a significant difference between both the binaural ANL (M = 2.17) and the better ear ANL (M = 1.44) conditions and the poorer ear unmasked ANL (M = 5.56) condition. The results further showed that both the binaural ANL (M = 2.17) and better ear ANL (M = 1.44) conditions versus the poorer ear masked ANL condition approached significance. Furthermore, there was no significant difference between the binaural (M = 2.17) and better ear ANL (M = 1.44) conditions or the poorer ear unmasked (M = 5.56) and the poorer ear masked (M = 4.69) conditions. These results indicate that lower ANLs were obtained in the binaural and better ear conditions compared to the high ANLs that were obtained in the poorer ear. These results further indicated that when the better of the two ears was being used, subjects had lower ANLs and when the poorer ear was being used subjects had higher ANLs. The results suggest that the peripheral auditory system is at least in part contributing to the meditation point of ANL.

Previous research conducted on the mediation point of ANL focus on individuals with normal hearing with high and low ANLs. The previous studies (Harkrider & Smith, 2005) found results that are suggestive that ANL is mediated at levels beyond the SOC. For example, Harkrider and Smith (2005) showed ANLs were unrelated to PRN, ARTs, or TEOAEs in normal hearing individuals. Additionally, Harkrider and Tampas (2006) and Tampas and Harkrider (2006) showed no differences between high and low ANL groups at the level of the cochlea (i.e., CEOAEs), 8th nerve, and the lower brainstem (i.e., waves I & III of the ABR); however, there were differences in those with high and low ANLs for more centralized regions of the auditory system (i.e., wave V of the ABR and MLR and LLR findings). More recently, Rishiq et al. (2012) investigated subjects with low and high ANLs using different masking conditions. They found similar performances between those with low and high ANLs in all masking conditions, which they stated indicates that ANL is mediated from the central auditory cortex (Rishiq et al., 2012). The results of the current study were, however, somewhat in disagreement with previous research. Specifically, results from the current study showed that ANL is at least in part mediated in the peripheral auditory system because subjects had lower ANLs in the binaural and better ear conditions and higher ANLs during the poorer ear unmasked and poorer ear masked conditions. These results indicated that when subjects were able to use the better ear, they obtained lower ANLs compared to when the poorer ear was being used. Therefore, the peripheral auditory system may in part be contributing to the mediation point of ANL.

Alternatively, the seemingly peripheral phenomenon maybe caused by auditory deprivation over time in the poorer ear. Therefore, the higher ANLs obtained in the poorer ear conditions are, in fact, due to auditory deprivation instead of peripheral hearing impairment. Likewise, ANL is a listening task where the listener is asked to "follow" the story. To this end, the auditory cortex is needed to process the signal. If auditory deprivation resulted from a peripheral hearing impairment this would give the impression that the peripheral hearing system mediated ANL when it was, in fact, a central consequence to a peripheral problem.

Clinical Implications

The hearing aid research on ANL suggests that it is a test of acceptance of background noise and is directly related to a person's willingness to wear hearing aids (Nabelek et al., 2006). Specifically, hearing aid users with low ANLs are more willing to wear hearing aids and hearing aid users with high ANLs are less likely to wear hearing aids. The current study found subjects obtained lower ANLs during the better ear and binaural conditions and higher ANLs during the poorer ear conditions. This may suggest that subjects with unilateral and/or asymmetrical hearing loss would be more willing to wear a hearing aid in their better hearing ear and less likely to wear a hearing aid in their poorer hearing ear. Furthermore, lower ANLs were also obtained in the binaural condition. This seems to indicate that the binaural ANL is unaffected by the poorer ear; therefore, patients may accept hearing aids binaurally even when presented with a unilateral and/or asymmetrical hearing loss. Please note, however, this could be patient specific; therefore, it would be best practice to measure ANLs for both ears independently and binaurally in those with unilateral and/or asymmetrical hearing loss.

Limitations and Future Research

One limitation of the current study is the small sample size where there were only 9 subjects with unilateral SNHL and 6 subjects with asymmetrical SNHL. Follow-up studies should have at least 12 subjects in each group. Furthermore, the current study showed that both the binaural ANL and better ear ANL conditions versus the poorer ear masked ANL condition was approaching significance. The author believes that if the current study had a larger sample size (i.e., at least 12 in each group), significance may have been reached.

Furthermore, in the literature in the field, there is not a clear definition of unilateral and asymmetrical SNHL, causing a limitation to the study. Specifically, by not having exact guidelines to determine hearing loss groups, the results of this study might not be comparable to other similar studies. Therefore, developing a standard definition for unilateral and asymmetrical SNHL would help distinguish the listeners with these types of hearing loss.

Appendix A

Acceptable Nosie Level Instructions

Acceptable Noise Level Instructions

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 background noise that is the most you would be willing to accept or "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 B

Human Subjects Consent Form

Human Subjects Consent Form

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

TITLE OF PROJECT: Ear Specific ANL Measurements in Individuals with Unilateral and Asymmetrical Sensorineural Hearing Loss.

PURPOSE OF STUDY/PROJECT: The purpose of this purposed research project is to determine if acceptable noise levels (ANLs) differ between ears within subjects with unilateral or asymmetrical sensorineural HL. Results will provide indications whether ANLs are a central or peripheral mediated phenomenon.

PROCEDURE: In order to take part in this study, you must consent to a full hearing evaluation, which will be provided at no charge to you. The hearing evaluation will include otoscopy, air/bone conduction, speech recognition test, and word recognition testing. This will take about 30 minutes. If you do not meet the qualification guidelines of the study, you will be excluded from further participation. If you meet the qualification guidelines, you will be asked to perform the following procedure.

Acceptable Noise Level (ANL) – While listening to a story subjects will be asked to set the listening level to their most comfortable level. Then background noise will be introduced and subjects were instructed to determine the maximum level of background noise that they were willing to accept and still follow the story. The noise is not supposed to be too loud as to cause any tension or anxiety to the participant. Completion of this portion of the project will take approximately 1 hour. Therefore, completion of the entire project will take about 1.5 hours.

INSTRUMENTS: The subject's identity will not be used in any form in the analysis or representation of the data. Only numerical data such as percent correct will be used in the presentation of the results.

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 hearing evaluation.

I, ____________________________, attest with my signature that I have read and understood the above description of the study, "Ear Specific ANL Measurements in Individuals with Unilateral and Asymmetrical Sensorineural Hearing Loss," and its purposes and methods. I understand that my and 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 or Louisiana Tech Speech and Hearing Center. Furthermore, I understand that I may withdraw at any time or refuse to answer any 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 Bryan, Ph.D., CCC-A; Rebecca Howard, B.S. Department of Speech

Members of the Human Use Committee of Louisiana Tech University may also be contacted if a problem cannot be discussed with the experimenters: Dr. Stan Napper; Dr. Mary Livingston; Barbara Talbot.

Appendix C

Human Subjects Approval Documentation

LOUISIANA TECH
UNIVERSITY

MEMORANDUM

OFFICE OF UNIVERSITY RESEARCH

TO: Ms. Rebecca Howard, Dr. Matthew Bryanearch & Deve
Dr. Melinda Fredyaldenhoven Bryan

FROM: Dr. Stan Napper, Vice President Research & Development

SUBJECT: HUMAN USE COMMITTEE REVIEW

DATE: May 28, 2014

In order to facilitate your project, an EXPEDITED REVIEW has been done for your proposed study entitled:

"Ear Specific ANL Measurements in Individuals with Unilateral and Asymmetrical Sensorineural Hearing Loss"

HUC 1218

The proposed study's revised procedures were found to provide reasonable and adequate safeguards against possible risks involving human subjects. The information to be collected may be personal in nature or implication. Therefore, diligent care needs to be taken to protect the privacy of the participants and to assure that the data are kept confidential. Informed consent is a critical part of the research process. The subjects must be informed that their participation is voluntary. It is important that consent materials be presented in a language understandable to every participant. If you have participants in your study whose first language is not English, be sure that informed consent materials are adequately explained or translated. Since your reviewed project appears to do no damage to the participants, the Human Use Committee grants approval of the involvement of human subjects as outlined.

Projects should be renewed annually. ***This approval was finalized on May 28, 2014 and this project will need to receive a continuation review by the IRB if the project, including data analysis, continues beyond May 28, 2015.*** Any discrepancies in procedure or changes that have been made including approved changes should be noted in the review application. Projects involving NIH funds require annual education training to be documented. For more information regarding this, contact the Office of University Research.

You are requested to maintain written records of your procedures, data collected, and subjects involved. These records will need to be available upon request during the conduct of the study and retained by the university for three years after the conclusion of the study. If changes occur in recruiting of subjects, informed consent process or in your research protocol, or if unanticipated problems should arise it is the Researchers responsibility to notify the Office of Research or IRB in writing. The project should be discontinued until modifications can be reviewed and approved.

If you have any questions, please contact Dr. Mary Livingston at 257-2292 or 257-5066.

A MEMBER OF THE UNIVERSITY OF LOUISIANA SYSTEM

P.O. BOX 3092 • RUSTON, LA 71272 • TEL: (318) 257-5075 • FAX: (318) 257-5079

AN EQUAL OPPORTUNITY UNIVERSITY

References

American Speech-Language-Hearing Association. (2011). Type, degree, and configuration of hearing loss. *Audiology Information Series*. Retrieved from http://www.asha.org/uploadedFiles/AIS-Hearing-Loss-Types-Degree-Configuration.pdf

Arkebauer, H., Mencher, G., & McCall, C. (1971). Modification of speech discrimination in patients with binaural asymmetrical hearing loss. *Journal of Speech and Hearing Disorders, 36*, 208-212.

Bilger, R., Nuetzel, J., Rabinowitz, W., & Rzeczkowski, C. (1984). Standardization of a test of speech perception in noise. *Journal of Speech, Language, and Hearing Research*, 27, 32-48.

Brannstrom, K., Zunic, E., Borovac, A., & Ibertsson, T. (2012). Acceptance of background noise, working memory capacity, and auditory evoked potentials in subjects with normal hearing, *23(7)*, 542-552.

Dillon, H. (2012). *Hearing aids*. (2nd ed.). New York, NY: Thieme.

Freyaldenhoven, M., Plyler, P., Thelin, J., & Hedrick, M. (2007). The effects of speech presentation level on acceptance of noise in listeners with normal and impaired hearing. *Journal of Speech, Language, and Hearing Research, 50,* 878-885.

Freyaldenhoven, M., Smiley, D., Muenchen, R., & Konrad, T. (2006). Acceptable noise level: Reliability measures and comparison to preference for background sound. *Journal of the American Academy of Audiology, 17*(9), 640-648.

Gordon-Hickey, S., Adams, E., Moore, R., Gaal, A., Berry, K., & Brock, S. (2012). Intertester reliability of the acceptable noise level. *Journal of the American Academy of Audiology, 23*(7), 534-541.

Hanss, J., Veuillet, E., Adjout, K., Besle, J., Collet, L., & Thai-Van, H. (2009). The effect of long-term unilateral deafness on the activation pattern in the auditory cortices of french-native speakers: influence of deafness side. *BMC Central, 10*(23), 1-11.

Harkrider, A., & Smith, S. (2005). Acceptable noise level, phoneme recognition in noise, and measures of auditory efferent activity. *Journal of the American Academy of Audiology, 16*(8), 530-545.

Harkrider, A., & Tampas, J. (2006). Differences in responses from the cochlea and central nervous systems of females with low versus high acceptable noise levels. *Journal of the American Academy of Audiology, 17*(9), 667-676.

Hwang, J. H., Chao, J. C., Ho, H. C., & Hsiao, S. H. (2008). Effects of sex, age and hearing asymmetry on the interaural differences of auditory brainstem responses. *Audiology & Neurotology, 13*, 29-33.

Karsten, S., & Turner, C. (2000). Binaural speech recognition and the stenger effect. *Journal of Speech, Language, and Hearing Research, 43*, 926-933.

Keith, R. (2002). Standardization of the time compressed sentence test. *The Journal of Educational Audiology, 10*, 15-20.

Khosla, D., Ponton, C., Eggermont, J., Kwong, B., Don, M., & Vasama, J. (2003). Differential ear effects of profound unilateral deafness on the adult human central auditory system. *Journal of the Association for Research in Otolaryngology, 4*, 235-249.

Killion, M., Niquette, P., Gudmundsen, G., Revit, L., & Banerjee, S. (2004). Development of a quick speech-in-noise test for measuring signal-to-noise ratio loss in normal-hearing and hearing-impaired listeners. *Journal of the Acoustical Society of America, 116*(4), 2395-2405.

Nabelek, A., Freyaldenhoven, M., Tampas, J., Burchfield, S., & Muenchen, R. (2006). Acceptable noise level as a predictor of hearing aid use. *Journal of the American Academy of Audiology, 17*(9), 626-639.

Nabelek, A., Tampas, J., & Burchfield, S. (2004). Comparison of speech perception in background noise with acceptance of background noise in aided and unaided conditions. *Journal of Speech, Language, and Hearing Research, 47*, 1001-1011.

Nabelek, A., Tucker, F., & Letowski, T. (1991). Toleration of background noises: Relationship with patterns of hearing aid use by elderly persons. *Journal of Speech and Hearing Research, 34*, 679-685.

Noble, W., & Gatehouse, S. (2004). Interaural asymmetry of hearing loss, speech, spatial and qualities of hearing scale (ssq) disabilities, and handicap. *International Journal of Audiology, 43*, 100-114.

Ponton, C., Vasama, J., Tremblay, K., Khosla, D., Kwong, B., & Don, M. (2001). Plasticity on the adult human central auditory system: evidence from late-onset profound unilateral deafness. *Hearing Research, 154*, 32-44.

Rishiq, D., Harkrider, A., & Hedrick, M. (2012). Acceptable noise level and psychophysical masking. *American Journal of Audiology, 21*, 199-205.

Rothpletz, A., Wightman, F., & Kistler, D. (2012). Informational masking and spatial hearing in listeners with and without unilateral hearing loss. *Journal of Speech, Language, and Hearing Research, 55*, 511-531.

Scheffler, K., Bilecen, D., Schmid, N., Tschopp, K., & Seelig, J. (1998). Auditory cortical responses in hearing subjects and unilateral deaf patients as detected by functional magnetic resonance imaging. *Cerebral Cortex*, *8*(2), 156-163.

Segal, N., Shkolnik, M., Kochba, A., Segal, A., & Kraus, M. (2007). Asymmetric hearing loss in a random population of patients with mild to moderate sensorineural hearing loss. *The Annals of Otology, Rhinology, and Larynology*, *116*(1), 7-10.

Tampas, J., &Harkrider, A. (2006). Auditory evoked potentials in female with high and low acceptance of background noise when listening to speech. *Acoustical Society of America*, *119*(3), 1548-1561.

Welsh, L., Welsh, J., Rosen, L., & Dragonette, J. (2004). Functional impairments due to unilateral deafness. *The Annals of Otology, Rhinology, and Laryngology*, *113*(12), 987-993.

Wie, O., Pripp, A., & Tvete, O. (2010). Unilateral deafness in adults: Effects on communication and social interaction. *Annals of Otology, Rhinology, & Laryngology*, *119*(11), 772-781.