Spring 2011

The effects of hearing aid circuitry and speech presentation level on acceptance of background noise

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THE EFFECTS OF HEARING AID CIRCUITRY AND SPEECH PRESENTATION LEVEL ON ACCEPTANCE OF BACKGROUND NOISE

by

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

COLLEGE OF LIBERAL ARTS
LOUISIANA TECH UNIVERSITY

May 2011

LOUISIANA TECH UNIVERSITY

THE GRADUATE SCHOOL

March 25, 2011

Date

We hereby recommend that the dissertation prepared under our supervision by Ashley P Boynton, B S

entitled

The Effects of Hearing Aid Circuitry and Speech Presentation Level on Acceptance of Background Noise

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

Doctor of Audiology

Supervisor of Dissertation Research

Head of Department

Speech

Department

Recommendation concurred in

Advisory Committee

Approved

Director of Graduate Studies

Dean of the College

Approved

Dean of the Graduate School

GS Form 13a
(6/07)

ABSTRACT

The present study investigated the effects of hearing aid circuitry and speech presentation level on ANL and hearing in noise in 19 adult, bilateral hearing aid users The acceptable noise level (ANL) procedure was used to assess acceptance of background noise Conventional ANLs (i e , measured at the participant's most comfortable listening level (MCL)) and ANLs at eight fixed speech presentation levels were obtained Then global ANLs (i e , ANLs averaged over eight fixed speech presentation levels) and ANL growth (i e , the slope of the ANL function) were calculated Each measure was obtained in three conditions unaided, aided with wide dynamic range (WDRC) circuitry, and aided with output limiting compression (dSC) circuitry Results revealed that conventional ANLs are not significantly different when obtained using any of the three levels of hearing aid circuitry However, results demonstrated that global ANLs may be affected by hearing aid circuitry in that listeners are able to accept more background noise when in the unaided or dSC circuitry condition compared to using WDRC Finally, results showed that ANL growth for each type of hearing aid circuit was not significantly different, indicating that ANL growth is stable for all three types of circuitry

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GS Form 14
(5/03)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

I would like to acknowledge all of the individuals who provided me with support throughout the preparation of this dissertation A special thank you is given to the Director of my Dissertation Committee, Melinda F Bryan, Ph D , CCC-A for all of her time and dedication to my dissertation In addition, I would like to thank Matthew D Bryan, Au D , CCC-A and Steven G Madix, Ph D , CCC-A/SLP for their assistance and support throughout this process Lastly, I would like to thank Brian Thom, Marguerite Landry, Roger Boynton, Rachel Stich, Sarah Johnson, Brittany Brown, and the rest of my family and friends for their support, friendship and love throughout my academic career

CHAPTER I

INTRODUCTION

In the United States, there are 31 5 million individuals with hearing impairment Only 20% of these individuals currently use amplification Of these individuals with amplification, 30% have reported dissatisfaction and 17% have reported they no longer use their amplification Researchers do not have specific reasons why such large percentages of individuals with amplification are dissatisfied with their current hearing instruments or do not use their hearing aids at all This lack of information has lead researchers to investigate how to predict hearing aid usage and how to document the outcome of hearing aid usage (Kochkin, 2005, Walden and Walden, 2004)

Because background noise is a common complaint of hearing aid users and can lead to patients' rejection of hearing aids, acceptance of background noise has been investigated as an alternative method to predict hearing aid usage (Kirkwood, 2005) Acceptance of background noise is typically measured using the acceptable noise level (ANL) procedure, a measure of willingness to accept speech in the presence of background noise ANLs are obtained by measuring most comfortable listening levels (MCLs) and background noise levels (BNLs) First, the participant adjusts running, male speech to their MCL Then, background noise is introduced, and the participant adjusts the background noise to the most noise they are willing to "put up with" and still clearly follow the words of the story without becoming tired or frustrated (see Appendix A for ANL instructions) ANLs are calculated by subtracting the participants BNL from their MCL (i e , MCL-BNL=ANL) This type of ANL measurement is referred to as conventional ANL (Nabelek, Tucker, and Letowski, 1991, Freyaldenhoven, Plyler, Thelin, and Hedrick, 2007)

Previous ANL research has shown that ANL is not affected by age, gender, hearing sensitivity, or type of background stimuli (Nabelek et al , 1991, Rogers, Harkrider, Burchfield, and Nabelek, 2003, Freyaldenhoven, Smiley, Muenchen, and Konrad, 2006) Furthermore, ANL has been shown to be directly related to hearing aid use Specifically, the more noise a listener is willing to accept, the more likely they are to become a successful hearing aid user (i e , full-time hearing aid user) Conversely, those listeners who accept less background noise (i e , have higher ANLs) are more likely to become unsuccessful hearing aid users (i e , part-time or non-users of hearing aids) Moreover, ANL has been shown to predict hearing aid use with 85% accuracy (Nabelek et al , 1991, Nabelek, Freyaldenhoven, Tampas, Burchfield, and Muenchen, 2006) Furthermore, when ANL and two subtests of the Abbreviated Profile of Hearing Aid Benefit (APHAB), Ease of Communication (EC) and Background Noise (BN), are combined, the prediction of hearing aid usage increases to 91% (Freyaldenhoven, Nabelek, and Tampas, 2008)

It should be noted that there are potential limitations to using conventional ANL measurements to predict hearing aid use The first limitation is that conventional ANLs are measured at the listener's MCL This assumes that daily listening environments are always at the listener's MCL, therefore, the effects of a dynamic signal (above or below

MCL) are neglected The second limitation of conventional ANL is that the unsuccessful hearing aid user group is composed of both part-time and non-users of hearing aids because conventional ANL measurements cannot differentiate these two groups Therefore, based on current ANL measurements, part-time hearing aid users cannot be categorized differently than non-users of hearing aids The third limitation of conventional ANL is that it cannot not predict hearing aid use for listeners with the most common ANLs (i e , 10 dB HL) In other words, listeners with conventional ANLs of 10 dB HL are just as likely to become full-time users as they are to become part-time or non-users of hearing aids (Freyaldenhoven, Plyler, Thelin, and Muenchen, 2008)

In an attempt to overcome these limitations, Freyaldenhoven, Plyler et al (2008) measured ANLs at eight fixed speech presentation levels (40, 45, 50, 55, 60, 65, 70, 75 dB HL) Using these eight ANL measurements, two other ANLs measurements were calculated global ANL and ANL growth Global ANLs were calculated by averaging the eight ANLs at each of the fixed speech presentation levels, and ANL growth was calculated using logistic regression analysis Furthermore, ANL growth is the slope of the ANL function Results of this study revealed that global ANLs were able to predict hearing aid use in the same manner as conventional ANLs, meaning that global ANLs were able to differentiate full-time hearing aid users from part-time and non-users of hearing aids, but were not able to differentiate part-time and non-users of hearing aids The results further revealed that ANL growth could differentiate full-time hearing aids users and non-users of hearing aids only, however, part-time users could not be differentiated from either of the other two groups Specifically, full-time users had relatively flat ANL growth functions whereas non-users of hearing aids had steeper ANL growth functions Furthermore, the results revealed that ANLs were directly related to speech presentation level Specifically, as speech presentation level increased ANL scores also increased, indicating that listeners accept less background noise as speech becomes louder (Freyaldenhoven, Plyler et al , 2008)

To date, all previous ANL studies regarding multiple speech presentation levels have been conducted in the unaided condition for listeners with normal and impaired hearing In other words, ANL has never been evaluated using different types of hearing aid circuitry to determine if either circuitry type would allow for greater acceptance of background noise The two most common types of circuitry used in hearing aids currently are wide dynamic range compression (WDRC) and output compression limiting, each amplifying sounds in a different manner The goal of WDRC is to make soft sounds audible, moderate sounds comfortable and loud sounds tolerable This is achieved by providing more amplification for soft sounds than for moderate sounds and compressing loud sounds Conversely, the goal of output limiting compression is to make all sounds audible and to make loud sounds tolerable This is achieved by providing constant gain at all intensities until the output of the hearing aid reaches the designated compression threshold At this level, the compression is then activated so that loud sounds are compressed (Dillon, 2001, Banerjee, 2007)

It is unknown if either type of circuitry will allow for greater acceptance of background noise This information could be valuable to clinicians who fit hearing aids and troubleshoot the problems background noise can cause for hearing aid patients Furthermore, it could be hypothesized that the type of hearing aid circuitry used will affect background noise acceptance, thus increasing or decreasing a listener's acceptance of background noise (i e , hearing aid acceptance) This could change the way audiologists fit circuitry in hearing aids It could also be that neither type of hearing aid circuitry will affect background noise acceptance, indicating that audiologists can continue to fit hearing aids based on other audiological factors, such as comfort, preferred style and cost Additionally, the research has demonstrated that as speech presentation level increases, acceptance of background noise decreases Furthermore, ANL growth is more stable for full-time hearing aid users than for part-time or non-users of hearing aids Therefore, it might be that part-time and non-users of hearing aids may reject hearing aids when speech presentation level reaches a specific intensity level, and they are no longer willing to accept the background noise It is thought that by changing the compression characteristics of the hearing aid, such as lowering the compression threshold and increasing the compression ratio, the hearing aid users may be able to accept more background noise and consequently not reject their hearing aids, especially at louder intensity levels Therefore, the purpose of the present study is to determine the effects of hearing aid circuitry and speech presentation level on acceptance of background noise

CHAPTER II

REVIEW OF LITERATURE

Acceptable Noise Level

In 1991, Nabelek, Tucker, and Letowski introduced a procedure for measuring acceptance of background noise while listening to speech This procedure has become known as acceptable noise level (ANL) (then called tolerated signal to noise ratios [S/Ns]) To obtain an ANL, most comfortable listening levels (MCLs) and background noise levels (BNLs) are obtained First, each participant adjusts running speech to their MCL Then background noise is introduced, and the participant adjusts the background noise to the most noise he/she is willing to "put up with" and still follow the words of the story (see Appendix A for ANL instructions for adults) Finally, the ANL is calculated by subtracting the BNL from the MCL (MCL – BNL = ANL) For instance, if a listener's MCL is 70 dB HL, and his/her BNL is 50 dB HL, the ANL is 20 dB ANLs are typically measured in the sound field with both the speech and background noise presented from 0 degrees azimuth

Nabelek et al (1991) measured ANLs in five groups of listeners (N = 15/group) to determine the effects of type of background noise distraction, age, hearing sensitivity, and self-perceived handicap on ANL Group 1 included young normal hearing listeners (mean age = 21 73 years), and Group 2 (mean age = 70 87 years) was comprised of older listeners with relatively good hearing Groups 3 (mean age = 74 years) was made up of full-time hearing aid users (defined as those who wore hearing aids whenever needed), Group 4 (mean age = 74 80 years) consisted of part-time hearing aid users (defined as those who wore hearing aids occasionally), and Group 5 (mean age = 74 13 years) was composed of non-users of hearing aids (defined as those who had completely stopped using hearing aids) ANLs were measured using five types of background noise multi-talker speech babble, speech-spectrum noise, traffic noise, light music such as that heard in a waiting room, and the sound of a pneumatic drill Additionally, the hearing aid users completed the Hearing Handicap Inventory for the Elderly (HHIE Ventry and Weinstein, 1982) to assess the effects of hearing impairment on everyday hearing aid use All subjects were tested in a sound-treated booth room using a monaural TDH-50 headphone For the hearing impaired listeners, ANLs were obtained using a modified frequency response to simulate an appropriate hearing aid fitting (Nabelek et al , 1991)

Results of the Nabelek et al (1991) study demonstrated that ANLs were not related to age, hearing sensitivity, or background noise distraction for most noises The results also demonstrated that full-time hearing aid users exhibited significantly smaller ANLs than the part-time and non-users of hearing aids for most background noise types Part-time and non-users of hearing aids, however, could not be differentiated based on ANL In other words, full-time users were willing to accept more background noise than the part-time or non-users Lastly, the HHIE scores were not significantly different between the three groups of hearing aid users, however, the full-time haring aid users perceived themselves as less handicapped when they wore hearing aids than when they did not wear hearing aids These results indicate that ANL is not dependent on age, hearing sensitivity, or type of noise distraction The results further indicated that ANL may be related to hearing aid use Lastly, the fact that HHIE scores were not related to hearing aid use indicated that the reason part-time and non-users were not wearing hearing aids was not related to their perception of hearing loss The HHIE may, however, be used as a measure of hearing aid benefit for some listeners (Nabelek et al , 1991)

ANL reliability and consistency over a three-month time period was investigated by Nabelek, Tampas, and Burchfield (2004) ANL scores were also compared to speech perception in noise (SPIN) scores in both aided and unaided listening conditions Forty-one full-time hearing aid users and nine part-time users served as the participants Aided (with hearing aids) and unaided (without hearing aids) ANLs and SPIN scores were measured in three experimental sessions at initial hearing aid fitting, one-month post fitting, and three-months post fitting The results revealed both unaided and aided ANLs and SPIN scores were highly reliable and consistent between the three test sessions The results further revealed that unaided and aided ANLs were not significantly different, however, aided SPIN scores were significantly better than unaided SPIN scores These results indicated that ANLs were reliable and acclimatization to hearing aids does not alter either ANLs or SPIN scores, at least over a three-month time period These results further indicated that ANLs and SPIN scores measure two different reactions to background noise Specifically, ANL may be used as a predictor of successful hearing aid use, and SPIN scores can be used to document hearing aid benefit (Nabelek et al , 2004)

Characteristics of ANL

The following studies investigated the influence of gender, age, primary language of the speaker, preference for background sounds, and speech presentation level on ANL measurements First, Rogers et al , (2003) examined the influence of gender on acceptance of background noise Fifty young adults (25 male and 25 female) with normal hearing sensitivity served as the participants The results demonstrated that males had significantly larger MCLs and BNLs than females, however, ANLs between the two groups were not significantly different These results indicated that MCL and BNL may be dependent on gender, however, ANL is not dependent on the gender of the listener

Secondly, Freyaldenhoven & Smiley (2006) examined if ANLs could be assessed in the pediatric population Thirty-two children (16 eight year olds [mean age = 8 6 years] and 16 twelve year olds [mean age = 12 4 years]) with normal hearing sensitivity served as the participants All participants were placed in a regular classroom for the entire school day, and there were an equal number of males and females in each age group ANLs were obtained using the procedures of Nabelek et al (1991) with one major exception the instructions were altered to adjust for language differences in children Six experimental ANL trials were completed within one session three for speech spectrum noise and three for speech babble noise Results of this study demonstrated that ANLs measured in children were not dependent on gender, age, or type of background noise distraction The results further demonstrated that ANLs were reliable and normally distributed in children age 8 and 12 years These results indicated that ANLs can be obtained reliably in children age 8 and 12 years, and ANLs are not dependent on age, gender, or type of noise distraction in the pediatric population Based on these results, the authors concluded that ANLs should be measured on children with hearing impairment to determine if they could be used as a predictor of hearing aid acceptance/use in the pediatric population (Freyaldenhoven & Smiley, 2006)

Thirdly, von Hapsburg and Bahng (2006) measured ANLs in listeners whose native language was Korean to determine (1) if ANLs could be measured in languages other than English, (2) if Korean ANLs would compare to English ANLs, (3) the dependency of ANL on language in bilingual listeners (Korean-English), and (4) the relationship between speech perception in noise and ANLs in bilingual listeners Thirty participants with normal hearing sensitivity participated in this study The participants were divided into the following three groups monolingual English listeners (N=10), moderately proficient bilingual Korean-English listeners (MPB, N=8, defined as self-reported moderate proficiency in English and passed the University of Tennessee SPEAK test with a score of 50 or higher), and low-proficiency bilingual Korean-English listeners (LPB, n=12, defined as self-reported minimal English language skills) The English ANL was determined in the conventional manner, and the Korean ANL was obtained using a prerecorded story about a ladybug read by a Korean male talker (primary stimulus) and the speech babble noise from the Korean SPIN (competing stimulus) (von Hapsburg and Bahng, 2006)

The results of this study revealed no difference in English ANLs among the three groups of listeners monolingual English ANLs = 6 4 dB, MPB ANLs = 8 0 dB, and LPB ANLs = 6 8 dB Additionally, Korean ANLs were similar to English ANLs for the same listeners Lastly, the results revealed no relationship between speech perception in noise and ANLs in bilingual listeners These results indicated that ANLs are unaffected by changes in language patterns (i e , ANL is language independent), and ANLs may not be affected by language experience However, it should be noted that the range of ANL in bilingual Korean-English listeners showed less variability (range = 4 to 14 dB) when compared to monolingual English listeners (range = -2 to 20 dB) (von Hapsburg and Bahng, 2006)

Fourthly, Freyaldenhoven, Smiley, et al , (2006) investigated the reliability of ANL in adults with normal hearing and the relationship between ANL and preference for background sound Thirty adults (15 male and 15 female, mean age = 23 years) with normal hearing sensitivity served as the participants Participants attended three experimental sessions scheduled approximately one week apart During each session, three ANL measures were obtained for both speech babble and speech spectrum noise Also, a self-developed questionnaire evaluating personal preference for background sounds was completed during each session The results revealed that ANLs were reliable within a session and consistent over a three-week time period In addition, the results of the questionnaire showed that ANLs were not related to listeners' reported preference for background sounds, at least using the questionnaire in this study Lastly, the results revealed that ANLs obtained with speech babble noise were 2 dB smaller than those obtained with speech spectrum noise The results indicated that ANLs do not change over time, at least for a three–week time period The results further indicated that ANLs cannot be determined by asking the listener questions about their preference for background sounds, at least with the questionnaire used in this study Lastly, the authors concluded that ANLs obtained using different background noises should not be directly compared based on the 2 dB dıfference ın ANLs for speech spectrum and speech babble noıses (Freyaldenhoven, Smıley et al , 2006)

Fıfthly, Franklın, Thelın, Nabelek, and Burchfield (2006) expanded the understandıng of ANL to ınclude measurements of ANL across a wıde range of speech presentatıon levels Twenty adults (mean age = 21 8 years) wıth normal hearıng sensıtıvıty served as the partıcıpants ANLs were obtaıned at MCL and at five fixed presentatıon levels (20, 34, 48, 62, and 76 dB HL) Results demonstrated that ANL was dependent on speech presentatıon level More specıfically, for each 4 dB ıncrease ın speech presentatıon level, ANL ıncreased by 1 dB These results ındıcate that as speech presentatıon level ıncreased, acceptance of noıse decreased (Franklın et al , 2006)

More recently, Freyaldenhoven, Plyler, Thelın, and Hedrıck (2007) contınued the work of Franklın et al (2006) to determıne ıf the effect of speech presentatıon level on acceptance of noıse was related to the hearıng sensıtıvıty of the lıstener Twenty-four ındıvıduals wıth normal hearıng and 46 ındıvıduals wıth hearıng ımpaırment partıcıpated ın thıs study Because acceptance of noıse ıs dependent on speech presentatıon level, partıcıpants wıth normal and ımpaıred hearıng were matched for conventıonal ANLs ANLs were obtaıned conventıonally (ı e , at MCL) and at eıght fixed speech presentatıon levels 40, 45, 50, 55, 60, 65, 70, and 75 dB HL The effects of speech presentatıon level on acceptance of noıse were analyzed usıng global ANL and ANL growth To determıne global ANL, ANLs for the fixed speech presentatıon levels were averaged Furthermore, ANL growth was defined as the slope of the ANL functıon The results revealed that global ANLs and ANL growth dıd not dıffer between lısteners wıth normal and ımpaıred hearıng The results further revealed that both global ANLs and ANL growth were related to conventional ANLs Specifically, as conventional ANL increased, both global ANL and ANL growth also increased These results indicated that the effects of speech presentation level on acceptance of noise were not dependent on hearing sensitivity (Freyaldenhoven et al , 2007)

Furthermore, Freyaldenhoven, Plyler, Thelin, and Muenchen (2008) reexamined the data collected during the previous study in order to determine if predictions of full-time, part-time, and non-use of hearing aids could be differentiated based on the effects of speech presentation level on acceptance of background noise, specifically using global ANLs and ANL growth measurements Because conventional ANL measurements are only able to differentiate full-time hearing aid users from part-time and non-users of hearing aids, the researchers sought to determine if the use of these two measurements could make clear differentiations between the three groups of hearing aid users (Freyaldenhoven, Plyler et al , 2008)

The results revealed that ANLs were directly related to speech presentation level Specifically, as speech presentation level increased, ANL scores also increased, indicating that a listener accepts less background noise as the speech presentation level becomes louder The results further revealed that global ANLs were able to predict hearing aid use in the same manner as conventional ANLs, meaning that global ANLs were able to differentiate full-time hearing aid users from part-time and non-users of hearing aids but were not able to differentiate between part-time and non-users of hearing aids ANL growth was able to differentiate between full-time hearing aids users and non-users of hearing aids only This was because full-time users had relatively flat ANL growth where as non-users of hearing aids had steeper ANL growth functions Finally, ANLs obtained at the eight fixed speech presentation levels were unable to predict hearing aid use more accurately than conventional ANLs in that part-time and non-users of hearing aids could not be differentiated Therefore, there continues to be no measure that differentiates between part-time and non-users of hearing aids (Freyaldenhoven, Plyler et al , 2008)

ANL and Music

As stated previously, Nabelek et al (1991) developed a procedure to measure a listener's willingness to accept background noise in the presence of speech An additional finding of this study was that listeners' ANL scores were similar for all types of background noise, except music ANL scores measured when music was the background noise were significantly higher when compared to ANLs measured using all other types of background noise, indicating that the listeners accepted less background noise when music was the competing stimulus More recently, Gordon-Hickey and Moore (2007) sought to determine if ANLs obtained using multi-talker speech babble and different music samples as background noise were different A second purpose of this study was to determine if individual ANLs were related to the listener's preference of the music that served as background noise (Gordon-Hickey and Moore, 2007) Conventional ANLs were obtained at MCL using multi-talker speech babble and six different music samples as background noise All music samples were from the rock genre The participants were also asked to rate their preference for each music sample relative to the other five samples Additionally, the participants completed a questionnaire about their familiarity with the music samples in the experiment, their enjoyment of those music samples, and estimates of their time spent listening to music (Gordon-Hickey and Moore, 2007)

Results of this study revealed that ANL scores obtained when music was the background noise were better than when multi-talker speech babble was used This indicated that the listeners were able to accept more background noise when the background noise was music rather than speech, which were in contrast with the Nabelek et al (1991) study which determined that listeners accepted less background noise when music served as the competing stimulus The discrepancy in results from the two studies could be due to the different types of music that served as background noise The background noise in the Nabelek et al (1991) study was considered to be "light music" whereas the background noise in the Gordon-Hickey and Moore (2007) study was music from the rock genre The researchers in the Gordon-Hickey and Moore (2007) study suggested that the results of their study may not be true for all types of music and that further investigation is needed Another reason for the disagreement in results between the two studies could be due to a difference in the primary stimulus used for each Female running speech served as the primary stimulus in the Nabelek et al (1991) study whereas male running speech served as the primary stimulus in the Gordon-Hickey and Moore (2007) study, suggesting that music as background noise may have a greater effect on female speech than male speech, making acceptance of music background noise more difficult with female speech Results also revealed that preference for music and ANL are not related (Gordon-Hickey and Moore, 2007)

ANL and Hearing Aid Use

As previously stated, in 1991 Nabelek et al introduced a procedure to quantify the amount of background noise an individual could accept while following the words of a story Results of this study revealed that ANLs might be related to hearing aid use In a similar study, Crowley and Nabelek (1996) hypothesized that hearing aid performance may be able to be predicted before the purchase of hearing aids Therefore, Crowley and Nabelek (1996) analyzed 16 unaided variables in 46 participants with acquired, symmetrical, sensorineural hearing loss All participants were first time binaural hearing aid users The 16 unaided variables were age, gender, years of education, number of medications taken per day, percentage of employment time, pure-tone average (PTA), slope of the hearing loss, MCL, dynamic range, revised SPIN scores (Bilger, Neutzel, Rabinowitz, and Rzeczkowski, 1984), ANLs with multi-talker speech babble as the competing stimuli, ANLs with speech spectrum noise as the competing stimuli, Personal Adjustment and Communication Strategies scale scores from the Communication Profile for the Hearing impaired (CPHI Demorest & Erdman, 1986), motivation for pursuing hearing aid use (self-motivation versus encouragement from others), and the difference between the National Acoustic Laboratories' (NAL Byrne & Dillon, 1986) target gain and actual insertion gain The results revealed that the following unaided variables contributed to the prediction of the listeners' perceived hearing aid performance age, slope of hearing loss, MCL, dynamic range of the listener, SPIN scores, ANLs with speech babble, Communication Strategies and Personal Adjustment scores from the CPHI, and the difference between NAL target gain and actual gain These results further indicate that ANLs may be a predictor of success with hearing aids (Crowley and Nabelek, 1996)

To further investigate if ANL could be used as a predictor of hearing aid use, Nabelek, Freyaldenhoven, Tampas, Burchfield, and Muenchen (2006) investigated (1) the relationship between ANL, gender, age, pure-tone average (PTA), and hours of daily hearing aid use, (2) the reliability of the self-developed pattern of hearing aid use questionnaire, and (3) the predictability of hearing aid use based on unaided ANL The criteria for inclusion were binaural hearing aids obtained within the last three years and no known neurological or cognitive listener deficits One hundred ninety-one participants were divided into three categories based on responses to the questionnaire full-time (n=69), part-time (n=69), and non-users of hearing aids (n=53) Unaided ANLs and SPIN scores were obtained for all listeners while aided ANLs and SPIN scores were obtained for 164 participants (Note Twenty-seven participants could not complete the aided testing because they had returned their hearing aids) (Nabelek et al , 2006)

The results of this study demonstrated that aided and unaided ANLs were not related to gender, age or PTA In addition, results revealed that only 3 of the 58 listeners who completed the questionnaire reported less hearing aid use after three months Results further revealed that unaided ANLs were dependent on pattern of hearing aid use Specifically, full-time hearing aid users had lower ANLs than part-time and non-users of hearing aids, however, part-time and non-users of hearing aids could not be differentiated Lastly, the prediction of hearing aid use based on unaided ANL was 85% accurate These results indicated that ANLs are not related to age, gender, or acquired hearing loss The results further indicated that three months appears to be sufficient for a reliable determination of pattern of hearing aid use Most importantly, these results indicated that ANL can be used as a predictor of success of hearing aid use with relatively precise accuracy (Nabelek et al , 2006)

Furthermore, Freyaldenhoven, Nabelek, and Tampas (2008) investigated if the combined use of two common predictors of hearing aid use (ANL and the Abbreviated Profile of Hearing Aid Benefit [APHAB]) could predict hearing aid use more accurately than using the two measures alone The APHAB is a self-reported questionnaire used to determine the effects of hearing impairment on an individual's daily life The ABHAP is divided into four subscales (1) Ease of Communication (EC), (2) Reverberation (RV), (3) Background Noise (BN), and (4) Aversiveness to Sounds (AV) The questionnaire is traditionally completed by the individual before using hearing aids (unaided) and after being fit with hearing aids (aided) The results of the questionnaire are expressed as the percentage of problems in the specific areas defined above Hearing aid benefit is determined by the difference between the aided and unaided scores The APHAB has been shown to be a reliable measure over time and can be beneficial in hearing aid fittings In addition, the APHAB may be able to predict hearing aid use (Cox and Alexander, 1995)

The results of this study showed that unaided and aided ANL scores were not related to any of the aided or unaided APHAB subscale scores or benefit scores This means that the self-reported communication difficulties measured using the APHAB and the acceptance of background noise measured using ANL provide different information about hearing aid success and outcome Additionally, like ANL scores, the APHAB was unable to distinguish between part-time and non-users of hearing aids Moreover, the results of this study showed that two of the four subscales of the APHAB were able to predict hearing aid outcome Both EC and BN were able to predict hearing aid outcome with 60% accuracy, which is 25% lower than the 85% accuracy with which ANL can predict hearing aid outcome The results also revealed that when ANL, EC and BN are combined, prediction of hearing aid outcome increased to 91% from 85% with ANL alone Finally the results of this study showed that three of the four APHAB subscales could determine hearing aid success for listeners with mid-range ANLs (9-10 dB), whereas before listeners with mid-range ANLs were just as likely to become successful as non-successful hearing aid users (Freyaldenhoven, Nabelek et al , 2008)

Effects of Amplification on ANL

Hearing Aids

The following studies investigated the effects of binaural versus monaural amplification and the use of venting and low-frequency gain compensation on ANL First, Freyaldenhoven, Plyler, Thelin, and Burchfield (2006) investigated the effect of monaural versus binaural amplification on speech understanding in noise and acceptance of background noise in 39 current binaural hearing aid users Speech understanding in noise was measured using masked speech recognition thresholds (SRTs), and acceptance of background noise was measured using the conventional ANL procedure The results revealed a significant improvement in masked SRTs with binaural versus monaural amplification, however, there was no improvement in ANL with binaural versus monaural amplification These results indicated that speech understanding in noise improves with binaural amplification, however, ANL is unaffected by monaural versus binaural amplification Based on these results, the authors concluded that listeners should be fitted with binaural hearing aids to improve speech understanding in noise while ANL (i e , hearing aid use) remains unaffected compared to monaural amplification Furthermore, it should be noted that individual data analysis revealed some listeners' best monaural score was better than their binaural score, indicating that some listeners may be more willing to use amplification if fitted monaurally instead of binaurally Individual data analysis further revealed that some listeners exhibited interaural ANL differences, indicating that acceptance of hearing aids/noise may be dependent on the fitted ear if only one hearing aid is fitted (Freyaldenhoven, Plyler, Thelin, Burchfield, 2006)

Second, Freyaldenhoven, Plyler, Thelin, Nabelek, and Burchfield (2006) investigated the effects of venting and low-frequency gain compensation on speech understanding in noise and acceptance of background noise in listeners wearing hearing instruments with directional microphones A secondary goal of this study was to determine if a relationship existed between low-frequency gain compensation and/or venting and degree of low-frequency hearing loss of the listener Nineteen binaural hearing aid users with symmetrical sensorineural hearing loss were included in this study The listeners were separated into two groups one group included listeners with no low-frequency hearing loss, and the other included listeners with a low-frequency hearing loss Each listener was fitted with two behind-the-ear (BTE) Starkey Axent II hearing aids The Hearing in Noise Test (HINT) was used to test speech understanding in noise, and the conventional ANL procedure was used to evaluate acceptance of noise Results revealed that the group with no low-frequency hearing loss performed significantly better than the group with low-frequency hearing loss on the speech understanding in noise test (i e , HINT), however, speech understanding in noise was unaffected by venting or low-frequency gain compensation for either group Results also revealed that ANL was not affected by venting, low-frequency gain compensation, or hearing sensitivity These results indicate that listeners with better low-frequency hearing can be expected to understand speech in the presence of background noise better than those with poorer low-frequency hearing and that this is independent of vent size or amount of gain compensation These results also indicate that a listener's acceptance of background noise, thus their acceptance of hearing aids, may be unaffected by venting or low-frequency gain compensation Taken together, these results indicate that venting and gain compensation can be manipulated For clinical purposes, it is important to note that clinicians can alter the vent size without decreasing speech intelligibility or decreasing the likelihood of the patient's acceptance of the hearing aid (Freyaldenhoven, Plyler, Thelin, Nabelek, Burchfield, 2006)

Cochlear Implants

Plyler, Bahng, and von Hapsburg (2008) investigated ANL scores in adult cochlear implant (CI) users One purpose of this study was to determine if ANL scores obtained for CI users were similar to those obtained for listeners with normal hearing A second purpose of this study was to determine if sentence reception thresholds were related to ANL scores in CI users A third purpose of this study was to determine if ANLs and subjective outcome measures were related in CI users Nine adult CI users and 15 adults with normal hearing sensitivity served as the participants for this study ANLs were obtained using the conventional ANL procedure Speech understanding in noise was evaluated using the HINT Subjective outcome measurements were only obtained for the nine CI users through the use of the APHAB, which was modified for them An additional questionnaire was administered to assess the CI users' satisfaction with previous hearing aid use and satisfaction with their current CI (Plyler et al , 2008)

The results of this study were in agreement with previous research that has shown that ANLs are not significantly different for individuals with normal hearing and those with hearing impairments Stated differently, MCLs and ANLs obtained for CI users were not significantly different from those individuals with normal hearing Also, this research indicated that speech understanding in noise for CI users is significantly poorer than for individuals with normal hearing This suggests that acceptance of noise was unrelated to speech understanding in noise for both groups, and that the measures of ANL and speech understanding in noise were unrelated Finally, the research showed increased overall satisfaction for CI use compared with previous hearing aid use as was reported on the modified version of the APHAB and CI satisfaction questionnaire It should also be mentioned that acceptance of background noise in CI users does not predict satisfaction as it does with hearing aid users This could be due to the small sample size and the surprising finding that CI users with larger ANL scores reported more benefit with their CIs than those with smaller ANL scores (Plyler et al , 2008)

Mediation of ANL

The following studies aimed to determine whether ANL is mediated peripherally or centrally First, Harkrider and Smith (2005) examined the role of the auditory efferent system on ANL Monotic ANLs (i e , ANLs obtained with speech and noise presented ipsilaterally) and dichotic ANLs (i e , ANLs obtained with speech and noise presented in the two ears simultaneously) were measured in 31 adults with normal hearing These were compared to monotic phoneme recognition in noise (PRN, defined as the recognition of phonetically balanced, monosyllabic words presented in the presence of an ipsilaterally competing stimulus), ipsilateral and contralateral acoustic reflex thresholds (ARTs), and contralateral suppression of transient evoked otoacoustic emission (CSTEOAE) The results revealed a direct relationship between monotic and dichotic ANLs Additionally, the results revealed that neither monotic nor dichotic ANLs were related to PRN, ARTs, or CSTEOAEs Because the level of efferent activity in the contralateral AR arc is correlated with the level of efferent activity in the medial olivary cochlear bundle (MOCB) pathway, these results indicated that non-peripheral factors, at or beyond the superior olivary complex, mediate ANL The results also indicated that ARTs or CSTEOAEs may not be helpful additions to clinical routines when attempting to determine hearing aid success (Harkrider and Smith, 2005)

Next, Harkrider and Tampas (2006) measured physiological responses including click-evoked otoacoustic emissions (CEOAEs), auditory brainstem responses (ABRs) and middle latency responses (MLRs) in 13 females with normal hearing sensitivity The females were divided into two groups based on ANL score seven listeners had low ANLs (i e , ANLs $\leq$ 6 dB), and six listeners had high ANLs (i e , ANLs $\geq$ 16 dB) Results of this study revealed no differences between the groups for CEOAEs or the amplitudes and latencies of waves I or III of the ABR, however, differences did exist for the amplitudes and latencies of wave V of the ABR and Na-Pa of the MLR Specifically, listeners with low ANLs had smaller wave V amplitudes and Na-Pa peaks These results further support the hypothesis that ANL is mediated in the more central regions of the auditory nervous system In addition, these results indicated that the females with low ANLs may have suppressed afferent transmission and stronger efferent mechanisms because their sensory inputs are suppressed more than in females with high ANLs, whereas the females with high ANLs may have enhanced afferent transmission and weaker efferent mechanisms because their sensory inputs are restrained less than in females with low ANLs (Harkrider & Tampas, 2006)

Tampas and Harkrider (2006) continued to investigate the effects of auditory evoked potentials on ANLs In addition to ABRs and MLRs, long latency responses (LLRs) were measured in 21 young females with normal hearing Again, the listeners were separated into two groups depending on if they had low (N = 11) or high (N = 10) ANLs Like Harkrider and Tampas (2006), the results revealed no differences between the two groups for the early ABR waves, however, differences emerged for the later waves of the ABR as well as the MLR and LLR peaks The results further revealed that females with low ANLs demonstrated a slower rate of growth in ANL (ANL growth = 15 dB/dB) with increasing presentation level than listeners with high ANLs (ANL growth = 44 dB/dB) These results indicate that ANL is mediated in the central auditory nervous system and listeners with high ANLs process background noise differently than those with low ANLs The authors contributed these differences to differences in responsiveness of central regions of the auditory system, which they explained may account for large inter-subject variability in listeners' willingness to accept background noise (Tampas and Harkrider, 2006)

Ways to Improve ANL

Results from the following studies provide some insight into factors which may improve an individual's ANL using either hearing aid technology or pharmacology First, Freyaldenhoven, Nabelek, Burchfield, and Thelin (2005) investigated the suitability of the ANL procedure for assessing the benefit of directional hearing aids Forty adults, who had been wearing binaural hearing aids for at least three months, participated in this study ANL measurements, masked SRTs, and front-to-back ratio (FBR) were measured utilizing both omnidirectional and directional microphones (Note Masked SRTs were obtained solely for reliability purposes) Results from this study revealed that the directional benefit measured using the ANL, masked SRT, and FBR procedures were similar More specifically, all three measures yielded a directional benefit of approximately 3 dB The investigators also stated that the ANL procedure is typically easier for the listener and requires less time to obtain than either the masked SRT or FBR This indicates that ANL may be an alternative method for measuring directional benefit (Freyaldenhoven, Nabelek et al , 2005)

In a similar study, Mueller, Weber, and Hornsby (2006) investigated the effects of digital noise reduction (DNR) on ANL and aimed to determine if the patient's degree of hearing loss, insertion gain, speech intelligibility in noise, and unaided and aided MCLs could be used to predict ANLs Twenty-two binaural hearing aid users, each with a symmetrical, mild to moderate, sensorineural hearing loss, were included in this study All participants were tested using bilateral Siemens Acuris Model S BTE hearing aids Moreover, if the participants did not have their own earmolds, foam comply tips were provided to the participants ANLs were obtained using the speech and noise portions from the HINT Results revealed that ANLs obtained with DNR activated in the hearing aid were smaller than ANLs obtained with DNR off Results further revealed that ANL is not related to speech understanding in noise abilities, patient's degree of hearing loss, or insertion gain These results indicated that DNR can significantly improve acceptance of background noise, at least when measured using the HINT (Mueller et al , 2006)

To determine if ANLs could be improved using pharmacological intervention, Freyaldenhoven, Thelin, Plyler, Nabelek, and Burchfield (2005) (1) investigated the effect of stimulant medication on ANL in individuals with attention deficit/hyperactivity disorder (ADD/ADHD) and (2) measured the influence of speech presentation level on ANL in persons with ADD/ADHD Fifteen young females who were on stimulant medication for treatment of ADD/ADHD and had normal hearing sensitivity served as the participants for this study Each listener participated in two sessions One session was conducted while the listeners were taking medication for treatment of ADD/ADHD, and the other session was performed after the participants had been off the medication for at least 12 hours The ANLs were measured at 20 dB HL, MCL, and 76 dB HL ANLs measured at MCLs were obtained in the conventional manner For the fixed speech presentation levels (i e , 20 and 76 dB HL), the running speech remained constant while the listener adjusted the background noise to their BNL Results of the Freyaldenhoven, Thelin et al (2005) study revealed that as speech presentation level increased, ANL also increased The results further revealed that ANLs improved while the participants were on stimulant medication for the treatment of ADD/ADHD in comparison to the results with no medication These results indicated that listeners with ADD/ADHD can accept more background noise when taking stimulant medication for the treatment of ADD/ADHD and provided the first evidence that pharmacological intervention could manipulate ANLs (Freyaldenhoven, Thelin et al , 2005)

Hearing Aid Circuitry

Hearing aids are the most common device used to remediate hearing loss Modern devices incorporate various types of technology and features that help to make incoming signals more audible and intelligible for the listener One of the most common features of modern hearing aids is compression circuitry The most basic goal of compression is to condense the range of environmental sounds into the reduced dynamic range of a listener with hearing loss Each type of compression circuitry is implemented based on the position of the compressor, static and dynamic features, and the goal of the compression (Dillon, 2001)

The compressor is an amplifier that is incorporated into the hearing aid that automatically increases or decreases the gain of the signal It can be located before or after the volume control The static features of compression, compression ratio and compression threshold, are those which respond to a steady input while the dynamic features of compression, attack and release times, are those which respond at a specific time interval in response to a change in input Attack and release times can also be adaptive, which means that they respond differently to different types of input Compression threshold (i e , TK) is the level at which the compression is activated, and compression ratio is the change in input level needed to change the output level of the signal by 1 dB Stated differently, compression ratio is how much the signal is being compressed Higher compression ratios, above 5 1, are more aggressive and compress the signal at a faster rate than lower compression ratios (i e , 1 5 1) (Banerjee, 2007) Attack and release times refer to how quickly the compression is activated in response to a sound (Dillon, 2001)

A review of the different types of hearing aid circuitry linear, compression, and alternative technology will be discussed Linear hearing aid circuitry does not utilize any form of compression, but does employ a process called peak clipping to ensure that loud sounds entering the hearing aid do not exceed the maximum power output (MPO) When a loud sound enters the hearing aid that is at or above the MPO, the hearing aid reduces or clips the peaks of the sound so that they are below the MPO The major goals of linear circuitry using peak clipping are to avoid damage and discomfort The major disadvantage of peak clipping is that it introduces distortion (Banerjee, 2007) Furthermore, hearing aids that utilize compression are referred to as nonlinear amplification The different types of compression currently available are compression limiting circuitry, wide dynamic range compression (WDRC), advanced dynamic range optimization (ADRO), and frequency compression (Dillon, 2000)

Compression limiting is a common type of compression that is characterized by automatic application of compression based on the signal level Low level inputs are amplified linearly with a 1 1 compression ratio, however, once the signal reaches the TK, compression is activated Compression limiting can be differentiated based on whether compression is applied to the input or output of the hearing aid Input compression limiting (AGC-I) utilizes a compressor that is located before the volume control so that the input signal is compressed before it is amplified Output compression limiting (AGC-O) utilizes a compressor that is located after the volume control so that the output signal is compressed just before it is presented to the listener In general, compression limiting is characterized by attack times that are less than five milliseconds (ms) and release times that are between 20-100 ms, or adaptive attack and release times which change in response to different sounds Compression ratios for this type of compression are typically 8 1 so that loud signals do not exceed the MPO TKs of 70 dB SPL are common because loud sounds are of concern Likewise, compression limiting circuitry is used to prevent damage, discomfort and distortion for hearing aid wearers without clipping the signal (Banerjee, 2007, Dillon, 2001)

WDRC is a type of compression that provides more gain for soft inputs and more compression for loud inputs so that soft sounds are audible, moderate sounds are comfortable, and loud sounds are tolerable For WDRC circuits, TKs are set relatively low, such as 50 dB SPL, so that soft sounds are audible and more gain is applied to these sounds than for moderate or loud sounds Compression ratios for WDRC are typically less aggressive than those for compression limiting devices because they are applied over a greater number of inputs Most commonly, they are set at 4 1 or below Adaptive attack and release times are utilized in WDRC circuitry to react to a wide range of inputs The goals of WDRC compression circuitry are to restore loudness perception and to optimize the residual dynamic range of the listener (Banerjee, 2007)

ADRO is an alternative circuitry option to traditional compression It is an output based amplification scheme which aims to optimize the reduced dynamic range of the listener First, the dynamic range of the signal is optimized by selecting the most information rich portion of the signal After the dynamic range of the signal is optimized, the information rich portion of the signal is presented at a level within the dynamic range of the listener that is audible and comfortable so that the listener's dynamic range is optimized (Blamey, 2005) Optimization of the dynamic range is achieved by a comparison of the listener's dynamic range and a statistical analysis of the gain of the signal This makes certain that the gain of the signal is kept within the listener's dynamic range (Dynamic Hearing, n d)

It is important to understand that ADRO is not based on compression, but instead based on four "fuzzy logic" rules Fuzzy logic means that these rules are statistically sound, but may not always be true or apply to all situations The four rules are the comfort rule, the audibility rule, the hearing protection rule, and the background noise rule The comfort rule makes sure that the output level of the hearing aid does not exceed the comfort target more than 10% of the time The audibility rule ensures that sounds do not fall below the audibility target more than 30% of the time The hearing protection rule makes sure that the output of the hearing aid never exceeds the maximum output level (MPO) of the hearing aid Finally the background noise rule prevents background noise from being amplified to an annoying level (Blamey, Fiket, and Steele, 2006) These rules guarantee that the information rich portions of the signal are amplified within the dynamic range of the patient to a level that is audible and comfortable Amplification in ADRO is applied based on three targets the audibility target, the comfort target, and the MPO These are the prescribe output targets to which the fuzzy logic rules are applied (Dynamic Hearing, n d) The analysis times for ADRO are measured in seconds rather than milliseconds unlike conventional hearing aids The ADRO technology could be thought of as a linear processor that reacts slowly so that the frequency response and dynamic range are optimized (Blamey, Martin, and Fiket, 2004) There are no other time constants for the signal processing such as attack and release time because compression is not being applied to the signal by the ADRO processor (Blamey, 2005)

Frequency compression is another alternative hearing aid technology Traditional compression, such as WDRC and compression limiting, is used to compress the signal in hearing aids so that it fits into the reduced dynamic range of the listener In comparison, frequency compression compresses the frequency spectrum and bandwidth of the signal This type of circuitry analyzes the incoming signal on the basis voicing If the signal is voiced, indicative of a vowel, normal amplification characteristics are applied to the signal, but if the signal is voiceless, indicative of a consonant, frequency compression is activated For example, if an individual has no residual hearing above 4000 Hz, all incoming sounds above that frequency will be compressed according to a preset compression ratio If a compression ratio of two is used, the 8000 Hz tone is now heard as a 4000 Hz tone and a 4000 Hz tone as a 2000 Hz tone (Auriemmo, Keenan, Korhonen, and Kuk, 2009) Frequency compression and WDRC or compression limiting can be utilized in the same hearing instrument

WDRC and output compression limiting are the most common types of compression circuitry that are currently prescribed by audiologists when fitting hearing aids Much research has been done to determine if either type of circuitry is preferred, provides better speech intelligibility, has better outcome measures associated with it, or provides more benefit for hearing aid patients One such study was conducted by Humes, Christensen, Thomas, Bess, Williams, and Bentler (1999) The researchers sought to determine if binaural performance and benefit were increased using WDRC hearing aids or linear hearing aids Fifty-five current hearing aid users were fit with binaural in-the-canal (ITC) hearing aid using WDRC and linear amplification Binaural performance and benefit were measured using SRT in quiet and in noise and subjective ratings of benefit, sound quality, and listening effort SRT was assessed using the NU-6 word list (Tilman and Carhart, 1966) and Connected Speech Test (CST, Cox, Alexander, Gilmore, and Pusakulich, 1988) in quiet and in noise Subjective measures of benefit were assessed using the Hearing Aid Performance Inventory (HAPI, Walden, Demorest, and Helper, 1984), and sound quality judgments were assessed using the Speech Intelligibility Rating test (SIR, Cox and McDaniel, 1989) Finally, listening effort was assessed by having the participants listen to recorded passages in different signal-to-noise ratio (SNR) conditions and rate the ease of listening based on a 100 point scale The results of this study indicated that both types of circuitry, linear and WDRC, provided significant benefit for the listeners based on SRT scores and the results of the subjective benefit rating scales when compared to using no amplification There were no significant differences for SRT scores using either type of hearing aid circuitry The results also showed an increase in outcome measures and better hearing aid fittings using WDRC compared to linear circuitry, especially for low level inputs The researchers hypothesized that this was the result of WDRC proving more gain for low level inputs than the linear amplification They also hypothesized that if the participants were able to adjust the volume control on the hearing aids, this difference in benefit and performance at low levels would no longer exist (Humes et al , 1999)

Secondly, Hayes and Cormier (2000), conducted a double-blind comparison of linear, output compression limiting, and WDRC circuitry with new hearing aid users The researchers sought to determine if 17 new hearing aid users performed better using either type of circuitry and if the participants preferred one type of circuitry after wearing each type for one month Subjective ratings/questionnaires, speech perception tests, and real ear measurements, were used to determine if any type of circuitry was superior or preferred Participants ranked the hearing aids in order of preference based on overall performance of the hearing aids Speech perception was assessed using the clinical SRT procedure and Four Alternative Auditory Features test (FAAF, Foster and Haggard, 1987), and the participants completed the Communication Profile for the Hearing Impaired (CPHI, Demorest and Erdman, 1986) The results of this study determined that the new hearing aid uses did not prefer or rank any type of circuitry over the other types based on subject ratings In other words, preferences for the three types of circuitry were evenly distributed among the participants The results also determined that performance on speech perception tests in quiet or in noise were not significantly different, and all three types of circuitry performed equally well (Hayes and Cormier, 2000) These results were in agreement with the pervious study conducted by Humes et al (1999)

Another study conducted by Gatehouse, Naylor, and Elberling (2006), outlined the patterns of benefit for hearing aid users achieved using linear, WDRC, and output compression limiting hearing aid circuitry Fifty current hearing aid users were monaurally fit with a BTE hearing aid that implemented all three types of circuitry Speech identification was assessed using the FAAF (Foster and Haggard, 1987) Participants also completed the APHAB (Cox and Alexander, 1995), the Satisfaction with Amplification in Daily Life (SADL, Cox and Alexander, 1999), and the Glasgow Hearing Aid Benefit Profile (GHABP, Gatehouse, 1999) to assess their self-reported benefits using amplification The results of this study revealed that both types of nonlinear circuitry outperformed linear circuitry for both self-reported and SRT for the participants The results also determined that were differences in performance and benefit between the two types of nonlinear circuitry Specifically, the participants rated listener comfort higher with output compression limiting compared to WDRC circuitry, but rated and measured speech intelligibility was higher for WDRC than for output compression limiting These results indicated that neither type of nonlinear circuitry was preferred over the other, however, nonlinear circuitry was preferred over linear circuitry (Gatehouse et al , 2006)

The previous research focused on objective performance and subjective quality ratings for different types of circuitry using speech stimuli Hearing aid users, however, have also reported that signals other than speech, such as music, are of importance in terms of sound quality Therefore, Davies-Venn, Souza, and Fabry (2007) conducted a study to determine if any type of amplification strategy (linear, compression limiting, or WDRC) provided hearing aid users with better sound quality for music Another objective of the study was to determine if any of the amplification strategies allowed for better objective speech recognition in quiet and noise and subjective ratings of sound quality for speech Eighteen adults were binaurally fit with digital, BTE hearing aids that had multi-memory capabilities Each of the three hearing aid memories was programmed with one of the three amplification strategies Speech quality ratings were assessed using the SIR (Cox and McDaniel, 1989), and the subjects rated the quality of speech in different SNR settings based on four aspects overall impression, pleasantness, intelligibility, and loudness Speech recognition was assessed using the HINT (Nilsson et al , 1994) Music quality was rated on five dimensions – loudness, sharpness, fullness, pleasantness, and overall impression – after listening to two, one minute clips of music The results of this study determined that WDRC was preferred over linear amplification for loud sounds, however, for moderate sounds, there was no preference for type of circuitry for speech quality in quiet The ratings for speech quality in noise revealed no preference for type of circuitry The results also determined that no type of circuitry provided better SRT scores Finally, the results revealed that participants preferred WDRC over the other two types of circuitry when rating music quality, especially for the dimensions of pleasantness and overall impression The results of this study suggest that other signals of interest (i e , not just speech) should be considered for each individual patient when choosing the type of circuitry during a hearing aid fitting (Davies-Venn et al , 2007)

In summary, amplification, whether linear or nonlinear, provided vast improvements in speech intelligibility and audibility over no amplification for listeners with hearing loss Furthermore, research has demonstrated that nonlinear circuitry in hearing aids was preferred by hearing aid users over linear circuitry in terms of sound quality and other subjective ratings In terms of speech understating, overall listeners did not have a preference of WDRC or output limiting compression circuitry Because there was no clear preference for one type of compression circuitry preferred, it was suggested that the audiologist should determine the individual listener's signals of interest when choosing the type of compression circuitry for a given patient

CHAPTER III

METHODS

Methods

Participants

Nineteen adults participated in this study The inclusion criteria included participants with any degree or configuration of sensorineural hearing loss at all octave frequencies, native English speakers with no self-reported neurological or cognitive impairments, and have used binaural hearing aids for at least three months prior to this study All qualification and experimental testing was conducted in a sound-treated examination room (IAC, Model 30 9'3" x 9'7") with ambient noise levels appropriate for testing unoccluded ears (ANSI S3 1-1991, American National Standards Institute, 1991)

Materials and Procedures

Hearing Instruments

Two digital behind-the-ear (BTE) hearing instruments with multiple memory capabilities (Phonak Eleva 211 dAZ) were utilized in this study The same two hearing instruments were used for each participant The audiometric data of each participant was used to program each hearing instrument using the National Acoustic Laboratories (NAL-R) fitting strategy (Byrne and Dillon, 1986) The digital hearing instruments were programmed for each participant using the Phonak iPFG fitting software (see Appendix B for hearing aid programming protocol) Program 1 was programmed using wide dynamic range compression (WDRC) circuitry, and Program 2 was programmed using output limiting compression circuitry, called dynamic super compression (dSC) in the Phonak fitting software All other fitting parameters were identical between the two programs Each participant was then fit with one-time use compliance earmolds and the two hearing instruments for the test session

Stimuli and Procedures

Qualifying Procedures

Prior to testing, all participants completed the Pattern of Hearing Aid Use Questionnaire and signed an informed consent (see Appendices C and D) The Pattern of Hearing Aid Use questionnaire categorized each participant as a full-time, part-time, or non-user of hearing aids Full-time users were defined as participants who wore hearing aids whenever they needed them, part-time users were defined as participants who wore hearing aids occasionally, and non-users were participants who had stopped using their hearing aids Additionally, a pure-tone audiogram and the completion of two HINT sentence lists were obtained prior to testing using standard audiometric test procedures for all participants See Figure 1 for audiogram data

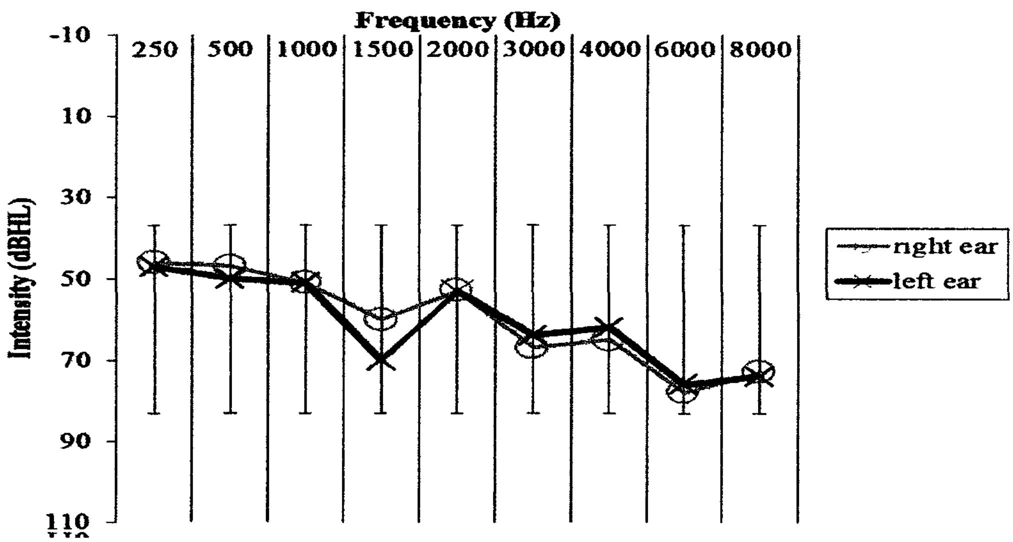

Figure 1 Mean audiometric and standard deviations for 19 participants

Acceptance of Background Noise

Acceptance of background noise was assessed unaided and for each type of hearing aid circuitry (WDRC and output compression limiting) using the ANL procedure Participants were seated 1 meter (m) from a loudspeaker located at 0° azimuth in a sound-treated room Running male speech (Arizona Travelogue, Cosmos, Inc) served as the primary speech stimulus and multi-talker speech babble (Speech Perception in Noise Test, Bilger, Neutzel, Rabinowitz, Rzeczkowski, 1984) served as the background noise in measuring ANL The speech and background noise were produced by a compact-disc player, routed through a clinical audiometer calibrated to specifications, and presented through soundfield loudspeakers The speech and background noise were presented at 0° azimuth

Conventional ANLs were obtained by measuring the participant's most comfortable listening level MCL and background noise level (BNL) First, each participant adjusted running speech to their MCL. MCL was obtained by having the participant increase the intensity level of the stimulus until it was judged to be too loud. Then, the participant decreased the intensity of the stimulus until he/she could no longer follow the story. Finally, the participant increased the intensity level of the speech until it was judged to be at his/her MCL. Then background noise was introduced, and the participant increased the intensity of the background noise until it was loud enough to interfere with the understanding of the running speech stimulus. Next, he/she decreased the intensity of the background noise until it was no longer interfering with his/her understanding of the running speech. Lastly, the participant increased the intensity level of the background noise to the most noise they were willing to "put up with" and still follow the words of the story (see Appendix A for ANL instructions). Conventional ANLs were calculated by subtracting the BNL from the MCL (MCL – BNL = ANL). ANLs were also measured at eight fixed speech presentation levels (40, 45, 50, 55, 60, 65, 70 and 75 dB HL). ANLs at the eight fixed speech presentation levels were calculated by subtracting the BNL from the speech presentation level (45-BNL=ANL). Two ANL trials were conducted for each experimental condition (i.e., unaided, WDRC, and output limiting compression) and for each fixed speech presentation level. An average of the two trials served as the mean ANL for that participant in the given condition. In the event that the two trials were not within 4 dB, a third trial was conducted, and the median score of the three trials was used to calculate ANL.

Prior to data collection, an experimental schedule was generated for each participant listing a completely randomized assignment for each type of hearing aid circuitry. Testing took between two and three hours for each participant.

CHAPTER IV

RESULTS

ANLs were measured twice at MCL (i e , conventionally) and at eight fixed speech presentation levels for each participant in three conditions unaided, aided with wide dynamic range compression (WDRC) circuitry, and aided with output compression limiting (dSC) circuitry Mean ANLs were calculated at each level for each participant in each condition (Note If ANLs from the two trials were not within 4 dB, a third ANL trial was completed and the median ANL was utilized for the analysis The median was utilized a total of 38 times out of 513 trials) Furthermore, the data was analyzed in three different ways (i) conventional ANL, (ii) global ANL, and (iii) ANL growth for all three conditions Conventional ANLs reflected ANLs measured at MCL Global ANLs were determined by averaging ANLs across the fixed speech presentation levels Lastly, ANL growth was determined by conducting linear regression analyses for each participant For each linear regression analysis, the dependent variable was ANL and the independent variable was speech presentation level Each analysis yielded a slope value, which was used to represent ANL growth

Conventional ANL

Table 1 shows mean data for conventional ANLs measured in the three conditions A one-way repeated measures analysis of variance (ANOVA) was performed to compare conventional ANLs for each circuitry type The dependent variable was conventional ANL, and the within subject variable was hearing aid circuitry with three levels (unaided, WDRC, and dSC) The analysis revealed a significant effect for hearing aid circuitry ($F(2, 36)$ = 4 873, p = 0 013) Post hoc testing was performed using pairwise comparisons, a Bonferroni adjustment was used for multiple comparisons Pairwise comparison results showed no significant differences between any of the three circuitry types for conventional ANL More specifically, when comparing conventional ANLs obtained using WDRC circuitry (M = 10 65) to unaided conventional ANLs (M = 7 84) and to conventional ANLs obtained using dSC circuitry (M = 7 95), the results were insignificant but approached significance (p = 0 061 and, p = 0 051, respectively) Furthermore, when comparing unaided conventional ANLs (M = 7 84) to conventional ANLs obtained with dSC circuitry (M = 7 95), the results were insignificant (p = 1 00) These results indicate that conventional ANLs are not significantly different when obtained using any of the three levels of hearing aid circuitry

Table 1 Mean ANLs, global ANLs, ANL growth (all in dB) and standard deviations for three types of hearing aid circuitry (unaided, WDRC, dSC)

Circuitry	Conventional ANL (SD)	Global ANL (SD)	ANL Growth (SD)
Unaided	7 84(4 31)	8 18(3 22)	0 22(0 37)
WDRC	10 65(4 84)	11 47(5 30)	0 42(0 30)
dSC	7 95(3 61)	7 86(3 41)	0 46(0 35)

ANL at Fixed Speech Presentation Levels

Global ANL

Table 1 and Figure 2 show mean data for global ANLs measured in the three conditions A one-way repeated measures ANOVA was performed to compare global ANLs (i e , ANLs averaged over eight fixed speech presentation levels) for each circuitry type The dependent variable was global ANL, and the within subject variable was hearing aid circuitry with three levels (unaided, WDRC, and dSC) The analysis revealed a significant effect for circuitry ($F(2, 36) = 13\ 437$, $p < 0\ 001$) Post hoc testing was performed using pairwise comparisons, a Bonferroni adjustment was used for multiple comparisons Results showed that unaided global ANLs (M = 8 18) and global ANLs obtained using dSC circuitry (M = 7 86) were not significantly different ($p = 1\ 00$) However, when compared to global ANLs obtained using WDRC circuitry (M = 11 47), both unaided global ANLs (M = 8 18) and ANLs obtained with dSC circuitry (M= 7 86) were significantly smaller ($p =$ 008 and $p < 0\ 001$, respectively) These results indicate that global ANLs are affected by hearing aid circuitry in that listeners are able to accept more background noise when in the unaided or dSC circuitry conditions compared to using WDRC circuitry when ANLs are measured over a range of fixed speech presentation levels

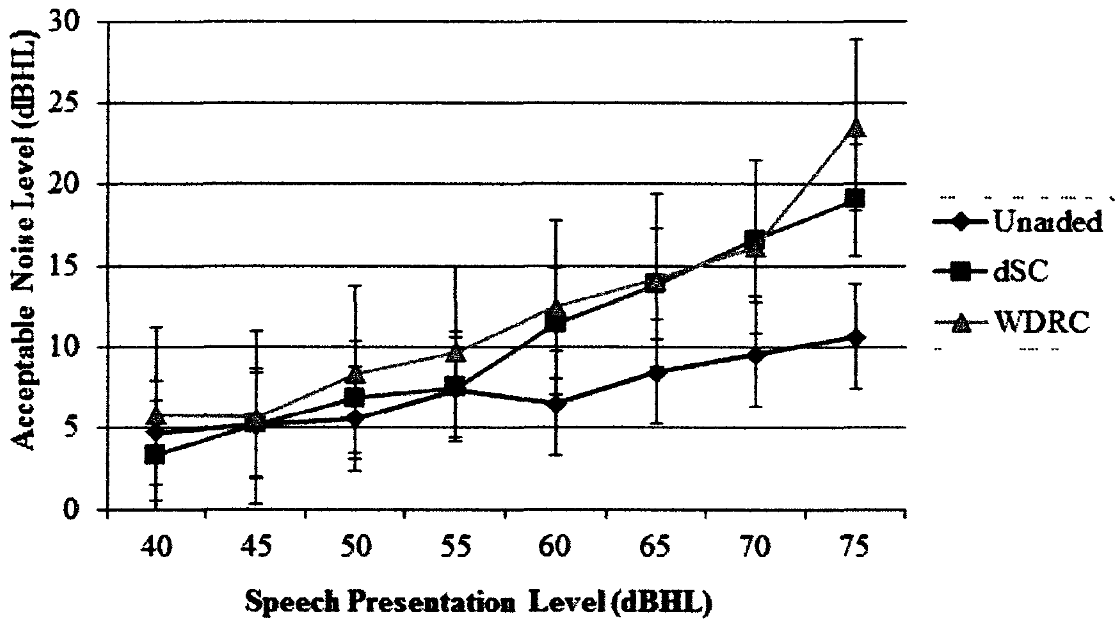

Fıgure 2 ANLs as a functıon of speech presentatıon level for lısteners usıng each type of hearıng aıd cırcuıtry

Secondary Analysis of Global ANL

As can be seen ın Fıgure 2, ANLs at 75 dBHL were greatly ıncreased compared to those obtaıned at the other speech presentatıon levels Furthermore, examınatıon of ındıvıdual data showed that only one subject was able to complete the ANL procedure at 75 dBHL usıng dSC cırcuıtry, and only seven subjects were able to perform the same task usıng WDRC cırcuıtry Therefore, the presentatıon level 75 dBHL was removed from the analysıs, and a second one-way repeated measures ANOVA was completed for global ANL In thıs analysıs, the presentatıon level of 75 dBHL was excluded from the analysıs (ı e , ANLs averaged over seven fixed speech presentatıon levels) Table 2 shows mean global ANL data for the secondary analysıs The dependent varıable was global ANL, and the wıthın subjects varıable was hearıng aıd cırcuıtry wıth three levels (unaıded, WDRC, and dSC) The analysıs revealed a sıgnıficant effect for cırcuıtry ($F(2, 36)$ =

9 235, p < 0 001) Post hoc testing was performed using pairwise comparisons, a Bonferroni adjustment was used for multiple comparisons Results showed that unaided global ANLs (M = 7 66) and global ANLs obtained using dSC circuitry (M = 9 25) were not significantly different (p = 0 148) However, when compared to global ANLs obtained using WDRC circuitry (M = 10 70), both unaided global ANLs (M = 7 66) and ANLs obtained with dSC circuitry (M = 9 25) were significantly smaller (p = 007 and p = 0 011, respectively) These results are not statistically different from the results obtained when 75 dBHL was included in the analysis, therefore, 75 dBHL was included in all further statistical analyses

Table 2 Secondary analysis displaying mean global ANLs (all in dB) and standard deviations for three types of hearing aid circuitry (unaided, WDRC, dSC) This analysis excluded the presentation level of 75 dBHL when calculating global ANL

Circuitry	Global ANL (SD)
Unaided	7 66(3 33)
WDRC	10 70(4 49)
dSC	9 25(4 10)

ANL Growth

Table 1 shows mean data for ANL growth measured in the three conditions A one-way repeated measures ANOVA was performed to compare ANL growth for each circuitry type The dependent variable was ANL growth The within subject factors was hearing aid circuitry with three levels (unaided, WDRC, and dSC) The analysis revealed a significant effect for hearing aid circuitry ($F(2, 36)$ = 4 996, p = 0 012) Post hoc testing was performed using pairwise comparisons, a Bonferroni comparison was performed for multiple comparisons These results showed that ANL growth for each type of hearing aid circuitry was not significantly different, indicating that ANL growth is stable for all three types of circuitry (see Table 3 for pairwise comparison results)

Table 3 Pairwise comparison results for ANL growth for three levels of circuitry

Circuitry	Unaided (SD)	WDRC (SD)	dSC (SD)
Unaided	XXXX	0 083(0 083)	0 085(0 101)
WDRC	0 083(0 083)	XXXX	1 00(0 053)
dSC	0 085(0 101)	1 00(0 053)	XXXX

CHAPTER V

DISCUSSION

The purpose of the present study was to determine the effects of hearing aid circuitry and speech presentation level on acceptance of background noise Nineteen adults who were current bilateral hearing aid users participated in this study Conventional ANLs (i e , ANL measured at MCL), global ANLs (i e , ANLs measured over eight fixed speech presentation levels), and ANL growth (i e , the slope of the ANL function) were measured for each participant using three different levels of hearing aid circuitry unaided, aided with wide dynamic range compression (WDRC) and aided with output compression limiting (dSC)

Results indicated that conventional ANLs obtained with each type of hearing aid circuitry were not significantly different These results agree with previous ANL research which indicates unaided and aided ANLs are highly reliable and not significantly different (Nabelek et al , 2004, Nabelek et al , 2006, Freyaldenhoven, Smiley et al , 2006)

Results from the present study also indicated that ANLs increased as speech presentation level increased Specifically, unaided ANLs at 40 dBHL averaged 4 75 dB while unaided ANLs obtained at 75 dBHL averaged 10 6 dB, this is an increase of 5 85 dB Likewise, ANLs for dSC at 40 dBHL averaged 3 33 dB whileANL means at 75 dBHL averaged 19 dB, this is an increase of 15.67 dB. Finally, mean ANLs for WDRC at 40 dBHL averaged 5.83 while mean ANLs at 75 dBHL averaged 23.58 dB, this is an increase of 17.75 dB. These results are in agreement with previous ANL and multiple speech presentation levels research, which indicate that as speech presentation level increases, ANLs also increase (Franklin et al., 2006, Freyaldenhoven et al., 2007). Specifically, Franklin et al. (2006) found that as speech presentation level increased by 4 dB, ANL increased by 1 dB. For this study, as speech presentation level increased by 4 dB, ANL increased by 0.67 dB for the unaided condition, 1.79 dB for the dSC condition, and 2.03 dB for the WDRC condition. Although statistics were not completed on this data specifically, the above trend shows that different types of circuitry affect ANL across speech presentation levels differently. One possible explanation for this is that when aided with a hearing aid, the output SPL at the eardrum is louder when measuring similar speech presentation levels. Furthermore, as illustrated in Figure 3, ANLs at low and moderate speech presentation levels were very similar for both the unaided and dSC conditions, however, for loud speech presentation levels (i.e., 60 dBHL and louder) ANLs increase dramatically for output compression limiting circuitry versus the unaided condition. Further individual data analysis revealed that at 60 dBHL, average ANLs were 11.42 dB for dSC versus 6.5 dB for the unaided condition. This trend continued for the speech presentation levels of 65, 70, and 75 dBHL. At these loud speech presentation levels, gain should have been applied when using output compression limiting circuitry. The result of this was that ANLs measured at those speech presentation levels were perceived as louder that when unaided, and therefore these ANLs are larger.

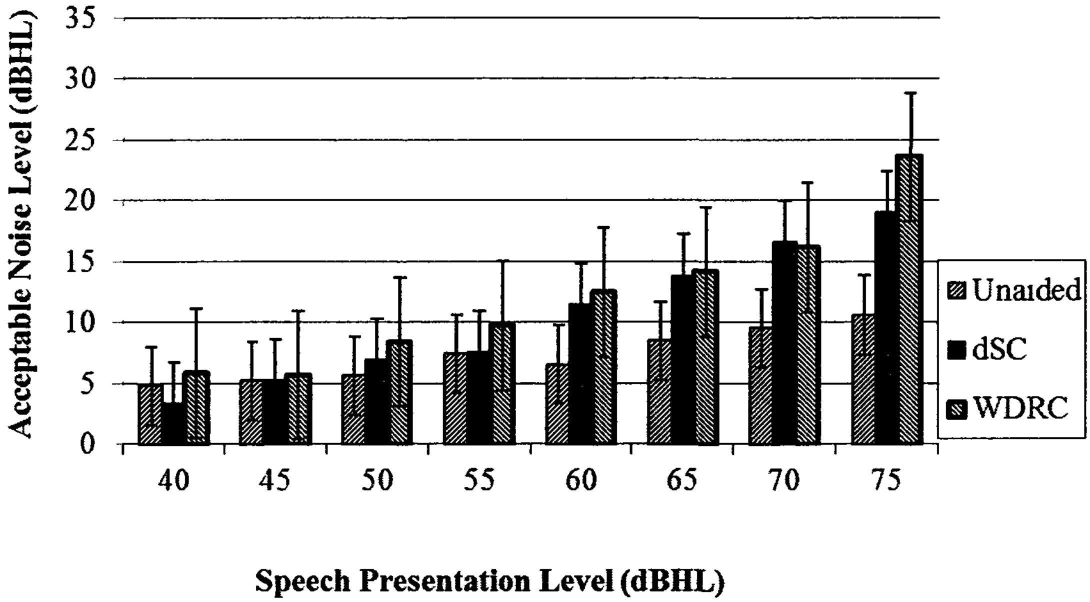

Figure 3 Mean ANL and standard deviation data for each speech presentation level

Furthermore, global ANL results indicated that unaided global ANLs and global ANLs obtained using dSC hearing aid circuitry were not significantly different Interestingly, the results also indicated that global ANLs obtained using WDRC circuitry were significantly different when compared to both unaided global ANLs and those obtained using dSC These findings, could be attributed to the different amplification rationales of dSC and WDRC The goal of output compression limiting (i e , dSC) is to prevent discomfort, distortion, and damage This goal is achieved by amplifying sounds below the compression threshold (TK) linearly, with a 1 1 compression ratio The TK in this type of circuitry are typically set at 70 dB SPL or above, so loud sounds do not exceed the patient's uncomfortable listening level Sounds above the TK are compressed with an aggressive compression ratio of approximately 8 1 (Dillon, 2007) On the other hand, the goal of WDRC is to restore loudness perception and to optimize the residual dynamic range of the listener These goals are achieved by providing more gain for soft inputs while compressing loud inputs This helps to ensure that soft sounds are audible, moderate sounds are comfortable, and loud sounds are tolerable The TK is generally set around 50 dB SPL with compression ratios ranging from 1 5 1 to 4 1 (Banerjee, 2007)

Moreover, for the current study, input/output functions were run in the Audioscan Verifit testbox each time the hearing aids were programmed for experimental testing This was done to ensure the hearing aids were in fact operating in the correct circuitry mode Results of these testbox measures show that for dSC circuitry, the TK was set to approximately 75 dB SPL with a compression ratio of 10 1, while for WDRC circuitry, the TK was set to approximately 45 or 50 dB SPL with a compression ratio of 1 5 1 Therefore, for the present study, more gain was applied to both soft and moderate sounds when using WDRC versus output compression limiting circuitry This, in turn, should have given the hearing aid user the perception that the hearing aid was louder when programmed using WDRC circuitry as compared to output compression limiting circuitry, at least for soft and moderate level presentation levels Thus, higher ANLs would have been expected for these speech presentation levels

Likewise, global ANLs for the unaided condition were similar to global ANLs found using output compression limiting circuitry This could be due to the fact that ANLs at soft and moderate speech presentation levels were very similar (see Figure 2), but once the speech presentation level reached loud levels (i e , 60 dBHL and above) ANLs increased more dramatically for dSC that for unaided

Finally, the results indicated that ANL growth was stable for all three types of circuitry This could be due to the fact that all of the participants in this study were successful hearing aid users These results are in agreement with the results from

Freyaldenhoven, Plyler et al (2008), which determined that ANL growth was stable and relatively flat for successful hearing aid users, but might be steeper for non-successful hearing aid users

Conclusion/Clinical Implications

In conclusion, the results of this study have indicated that bilateral, full-time hearing aid users have larger global ANLs when using WDRC versus dSC hearing aid circuitry or with no amplification These results can be clinically valuable to dispensing audiologists and hearing aid dispensers who strive to increase patient satisfaction with amplification and decrease the number of hearing aids returned As previously stated, in the United States there are 31 5 million individuals with hearing impairment of which only 20% currently use amplification Furthermore, background noise is one common complaint of hearing aid users which can lead to dissatisfaction or rejection of amplification Changing amplification circuitry, from WDRC to output compression limiting, may allow a patient with background noise complaints to accept more background noise over a wide range of speech presentation level therefore potentially increasing satisfaction with amplification

Individual analysis of ANL data indicated that once speech presentation level reached a loud level, specifically 60 dBHL and above, aided ANLs, both WDRC and dSC, increased dramatically when compared to unaided conventional ANLs Therefore, it could be that hearing aid users cannot tolerate hearing aids at loud levels only Decreasing the maximum power output could be one solution to help hearing aid users with complaints in moderate and loud levels of background noise better tolerate loud sounds while increasing satisfaction with amplification This hypothesis should be further investigated

Further aided ANL research needs to be done with part-time hearing aid users and those who have rejected their hearing aids due to reasons other than cost and cosmetics Previous research has indicated that both of these groups of listeners have larger conventional and global ANLs and steeper ANL growth curves than full-time hearing aid users (Freyaldenhoven, Plyler et al , 2008) It would be interesting and beneficial to investigate if either type of hearing aid circuitry, WDRC or dSC, would allow an unsuccessful hearing aid user to become a successful hearing aid user and perceive more benefit and satisfaction from their amplification

APPENDIX A

ANL INSTRUCTIONS

ANL 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* Handheld buttons will allow you to make adjustments First, turn the loudness up until it is too loud and then down until it is too soft Finally, select the loudness level that is most comfortable for you

Instructions for establishing BNL

You will listen to the same story with background noise of several people talking at the same time After you have listened to this for a few moments, *select the level of background noise that is the MOST you would be willing to accept 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 time while following the story

APPENDIX B

HEARING AID PROGRAMMING PROTOCOL

HEARING AID PROGRAMMING PROTOCOL

1 Obtain pure tone thresholds at all octave frequencies using supra-aural headphones for right and left ear

2 Enter thresholds into Phonak IPFG fitting software in NOAH

3 Connect hearing aids using NOAH Link without batteries

4 In IPFG fitting software
- Detect hearing instruments
- Use **Settings from IPFG**
- Set experience with previous HI t= **3mo – 6yrs**
- Former signal processing = **Undefined**

5 Patient Info
- Prescriptive Method = Phonak Adaptive Digital
- Acoustic Properties = Occluded Ear Mold
- Long Term User = 2
- Occlusion Control = Off
- Measured = Headphones

6 Initial Fit
- Programs = Tripilot + Manual program 1-3
- Unclick acoustic telephone
- Change dWDRC to mixed
- Program 1 = Calm Situation (dWDRC)
- Program 2 = Custom(Calm Situations) (dSC)
- Program 3 = Undefined

7 Follow-Up Fit
- Program Options -> Additional Programs and Tripilot
  - Turn off noise canceller
  - Make sure it is on omni directional
  - M for input source

8 Unclick program coupling for auto and manual fine tuning

9 Under Program options for Start Up
- Enable T-Switch
- Unclick Tripilot and mute
- Disable Manual VC
- Start up in Calm Situation (dWDRC program)

10 Program and Save fitting to database and HI

11 Dısconnect aıds, turn off NOAH Lınk, ınsert batterıes, and complete a lıstenıng check

APPENDIX C

PATTERN OF HEARING AID USE QUESTIONNAIRE

PATTERN OF HEARING AID USE QUESTIONNAIRE

How do you use your hearing aids? (Circle 1, 2 or 3)

1 I wear my hearing aids whenever I need them

2 I only wear my hearing aids occasionally

3 I do not wear my hearing aids

APPENDIX D

HUMAN SUBJECTS PERMISSION FORMS

D.1: HUMAN SUBJECTS CONSENT FORM

HUMAN SUBJECTS PERMISSION FORM

Experimental Group

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

TITLE Effect of Circuitry on Acceptable Noise Level Growth Patterns

PURPOSE OF STUDY/PROJECT This research study is designed to determine the effect of circuitry on ANL growth patterns in hearing aid users

PROCEDURES To take part in this study, you must consent to a hearing evaluation, which will be provided at no charge to you The hearing evaluation will include tests of eardrum and ear canal health and a test of hearing sensitivity 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 procedures

If you meet the qualification guideline and agree to participate in the study, you will be fitted with two hearing aids using standard (one-size fits all) earmolds You will be asked to complete a questionnaire to determine your pattern of hearing aid use You will then be presented with a story at various levels and asked to adjust background noise to a level that is deemed acceptable to you (Note This testing will also occur without hearing aids for control purposes only) During this time, you will be seated comfortably in a sound-treated booth All the sounds will be presented at a comfortable loudness level You will be offered frequent breaks 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 subjects All procedures will be conducted at normal conversational speech levels and are similar to clinical audiometric measures Participation is voluntary with informed consent

BENEFITS/COMPENSATION Each participant will receive a free hearing evaluation and a hearing aid check, if applicable

I, ______________________________, attest with my signature that I have read and understood the above description of the study, "Effect of Circuitry on Acceptable Noise Level Growth Patterns," 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 F Bryan, Ph D , CCC-A Department of Speech (318) 257-2146

Members of the Human Use Committee of Louisiana Tech University may also be contacted if a problem cannot be discussed with the experimenters

Dr Les Guice (318)257-4647 Dr Mary Livingston (318)257-2292 Nancy Fuller (318)257-5075

D.2: IRB APPROVAL LETTER

LOUISIANA TECH
U N I V E R S I T Y

OFFICE OF UNIVERSITY RESEARCH

MEMORANDUM

TO Dr Melinda Freyaldenhoven Bryan

FROM Barbara Talbot, University Research

SUBJECT Human Use Committee Review

DATE July 28, 2010

RE Approved Continuation of Study HUC 408

TITLE **"Effect of Circuitry on Acceptable Noise Level Growth Patterns"**

HUC- 408

The above referenced study has been approved as of July 28, 2010 as a continuation of the original study that received approval on July 2 2007 ***This project will need to receive a continuation review by the IRB if the project, including collecting or analyzing data, continues beyond July 28, 2011*** 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 257-4315

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