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Acceptable noise levels in children ages 10 to 11 years and 14 to 15 years

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ACCEPTABLE NOISE LEVELS IN CHILDREN

AGES 10 TO 11 YEARS AND

14 TO 15 YEARS

by

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ABSTRACT

The present study measured acceptance of background noise in 35 children (age 10-11 and 14-15 years) with normal hearing sensitivity. Acceptance of background noise was measured using the acceptable noise level (ANL) procedure. To obtain an ANL, participants' MCL was first obtained using a running story. Then a competing stimulus (i.e., speech babble or speech spectrum noise) was introduced, and the listeners were asked to adjust the level of the background noise to the most he/she could put up with and follow the story for a long period of time. This level was called background noise level or BNL. The ANL was then determined by the subtracting the MCL from the BNL. Three trials were obtained for each type of background noise distraction (i.e., speech babble and speech spectrum noise). Results demonstrated that acceptable noise levels (ANLs) were reliable in children with normal hearing. Furthermore, the distribution histograms revealed that ANLs were near normally distributed (i.e., slightly skewed to the left) for each age group and type of background noise distraction and for the two age groups combined. Second, results demonstrated that ANLs were not dependent on gender or age, at least for children 10-11 and 14-15 years of age. Lastly, results revealed that ANLs were dependent upon type of background noise distraction. However, since ANLs are measured in 2 decibel (dB) steps, the difference of 1.39 dB was determined to be clinically insignificant. Clinical implications and applications will be discussed.

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Author Krystal S Ware

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CHAPTER I

INTRODUCTION

There are many sources of background noise that can be heard in a classroom; these include but are not limited to traffic, construction, playground noise, air conditioning units, and students talking. In the classroom, these sources of noise are measured using a sound level meter and are compared to the level of the signal, or the teacher. This measurement is called signal-to-noise ratio (SNR). A positive SNR indicates that the level of the signal is louder than the noise; however, a negative SNR indicates that the noise is louder than the signal. Research has revealed that the range of SNRs for a typical classroom is from +5 to -7 dB (Blair, 1977; Finitzo-Hieber & Tillman, 1978; Markides, 1986; Sanders, 1965). It is also known that these minimal SNRs can compromise academic performance, reading and spelling skills, concentration, attention, behavior, auditory discrimination, and memory for some children while affecting other children minimally (Ando & Nakane, 1975; Crook & Langdon, 1974; Green, Pasternak, & Shore, 1982; Hygge, 1993; Ko, 1979; Koszarny, 1978; McCroskey & Devens, 1977; Moch-Sibony, 1984; Sargent, Gidman, Humphreys, & Utley, 1980). The SNRs in the classroom, however, provides no information about how much background noise a specific child is willing to accept before withdrawing from the learning activity. Therefore, the SNR provides little to no information regarding the point at which a breakdown in communication may occur.

In 1991, Nabelek, Tucker, and Letowski introduced a procedure to measure the amount of background noise an individual is willing to listen to while following the words of a story. This procedure is known as acceptable noise level (ANL). To obtain an ANL, the listener adjusts running speech (Arizona Travelogue, Cosmos, Inc.) to their most comfortable listening level. Then, background noise (Revised SPIN, Cosmos, Inc.) is added and adjusted to a level that the listener is willing to "put up with" while listening to and following the words of the story. Originally, this procedure was used to measure how much background noise hearing aid users were willing to accept in order to investigate the relationship between hearing aid use and ANL (Nabelek et al., 1991). Results of the Nabelek et al. (1991) study showed a direct relationship between hearing aid use and ANL in a small number of listeners. Likewise, Nabelek and colleagues (1991) hypothesized that ANL might be a predictor of hearing aid use.

Nabelek, Freyaldenhoven, Tampas, Burchfield, and Muenchen (2006) continued the work of Nabelek et al. (1991) by further investigating the (1) relationship between ANL and hearing aid use and (2) the predictability of hearing aid use based on ANL score. Results revealed that ANLs were related to hearing aid use. Specifically, listeners with small ANLs accepted large amounts of background noise and were more likely to become full-time hearing aid users. Conversely, listeners with large ANLs accepted less background noise and were likely to become part-time or nonusers of hearing aids. Most importantly, the results showed that ANLs could predict hearing aid use with 85% accuracy. Furthermore, ANL research has also shown that ANLs are not related to age, gender, hearing sensitivity, type of background noise distraction, language, reported preference for background noise, pure-tone average, middle ear characteristics, or speech perception in noise performance (Freyaldenhoven & Smiley, 2006; Freyaldenhoven, Smiley, Muenchen, & Konrad, 2006; Harkrider & Smith, 2005; Nabelek et al., 1991; Nabelek et al., 2006; Rogers, Harkrider, Burchfield, & Nabelek, 2003; von Hapsburg & Bahng, 2006). It should be noted that all of the above discussed ANL research has been performed on the adult population.

Therefore, in an effort to determine if ANLs could be measured in the pediatric population, Freyaldenhoven and Smiley (2006) measured ANLs in 32 children aged 8 and 12 years. Results of this study demonstrated that ANLs could be reliably obtained in children age 8 and 12 years. Results further demonstrated that ANLs were not related to age, gender, or type of background noise distraction, at least for children ages 8 and 12 years. More importantly, the results showed that ANLs obtained in children were similar to the results obtained for the adult population. These results indicate that ANLs in children may also be used to predict the success of hearing aid use in children with a hearing loss.

Based on available research, it would be reasonable to speculate that ANLs can be accurately measured in the pediatric population. It would also be reasonable to hypothesize that ANLs in the pediatric population will not be related to gender, age, or type of background noise distraction. However, ANLs must be measured on a larger number of children in order to make these assumptions. Therefore, to aid in the completion of the pediatric ANL data set, ANLs will be measured in children with normal hearing aged 10 to 11 and 14 to 15 years. The following research questions will be addressed:

1) What are typical ANLs in children with normal hearing?
2) Are ANLs dependent on age, gender, or type of noise distraction in children with normal hearing?
3) Are ANLs reliable in children with normal hearing?
4) Is the distribution of ANLs in children normal?

CHAPTER II

REVIEW OF LITERATURE

Acceptable Noise Level

In 1991, Nabelek, Tucker, and Letowski introduced a procedure to quantify the amount of background noise an individual can accept while following the words of a story. The term for this measurement was called tolerated SNR; however, today it is known as acceptable noise level (ANL). To obtain an ANL, the listener adjusts running speech (Arizona Travelogue, Cosmos, Inc.) to their most comfortable listening level (MCL; see Appendix A for MCL instructions for adults). Then, background noise (Revised SPIN, Cosmos, Inc.) is added and adjusted to a level that the listener is willing to "put up with" while listening to and following the words of the story (called BNL; see Appendix A for BNL instructions for adults). The ANL is then calculated by subtracting the individual's BNL from their MCL. For example, if the MCL is 60 dB HL and the BNL is 45 dB HL, then the ANL is 15 dB (i.e., MCL – BNL = ANL).

One purpose of the Nabelek et al. (1991) study was to measure and compare ANLs in five groups of listeners: young listeners with normal hearing, elderly listeners with relatively good hearing, full-time hearing aid users, part-time hearing aid users, and non-users of hearing aids. Full-time hearing aid users were defined as listeners who wore hearing aids whenever they needed them; part-time hearing aid users were defined as listeners who wore hearing aids primarily in difficult listening environments, and nonusers no longer wore hearing aids. Another purpose of this study was to determine the effects of the type of background noise distraction, age, and hearing sensitivity on ANL. ANLs were measured using five types of background noise: multi-talker babble, speech spectrum noise, traffic noise, light music (such as that used in a waiting room) and the sound of a pneumatic drill. For the listeners with impaired hearing, ANLs were obtained monaurally through an earphone with a frequency response shaped to simulate an appropriate hearing aid fitting. Likewise, ANLs were obtained through a monaural earphone for the listeners with normal hearing.

Results of the Nabelek et al. (1991) study showed that full-time hearing aid users accepted significantly higher levels of background noise (i.e., had smaller ANLs) than part-time and non-users of hearing aids; however, part-time and non-users could not be differentiated based on ANL. The results further showed that ANLs were not dependant on age, hearing sensitivity, or type of background noise distraction. It should be noted that most listeners accepted less noise when music was the competing stimuli. These results indicated that ANLs are not related to age, hearing sensitivity, or type of background noise distraction; however, ANLs might be related to hearing aid use.

The reliability and consistency of ANLs over a three-month time period was investigated by Nabelek, Tampas, and Burchfield (2004). Acceptable noise level 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.

Freyaldenhoven and Smiley (2006) expanded the use of ANLs by measuring ANLs in the pediatric population. Mean ANLs, ANL reliability, and ANL distribution were measured in children age 8 (N = 16) and 12 (N = 16) years with normal hearing sensitivity. 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 (See Appendix B for ANL instructions for children). Six experimental ANL trials were completed within one session: three for speech spectrum noise and three for speech babble noise. The results showed that ANLs were reliable and normally distributed. The results further showed that ANLs were not dependant on age (8 years or 12 years), gender, or type of background noise distraction, at least for children 8 and 12 years of age. Lastly, the results demonstrated that mean ANLs obtained on children were similar to mean ANLs for adults. These results indicated that ANLs can be obtained in children age 8 and 12 years. Based on these results, the authors concluded that ANLs should be measured on a larger cohort of children with normal hearing. The authors also suggested that in the future ANLs may provide valuable information regarding children with hearing impairment and their hearing aid acceptance/use.

Characteristics of ANL

The above studies investigated the measurement and reliability of ANLs in both children (Freyaldenhoven and Smiley, 2006) and adults (Nabelek et al., 1991; Nabelek et al., 2004). The following studies investigated the influence of gender, primary language of the speaker, preference for background sounds, and speech presentation level on ANL measurements.

First, Rogers, Harkrider, Burchfield, and Nabelek (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 dependant on the gender of the listener.

Secondly, 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). The results 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).

Thirdly, Freyaldenhoven, Smiley, Muenchen, and Konrad (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) 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. Furthermore, 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 difference in ANLs for speech spectrum and speech babble noises.

Fourthly, Franklin, Thelin, Nabelek, and Burchfield (2006) expanded the understanding of ANL to include measurements of ANL across a wide range of speech presentation levels. Twenty young listeners with normal hearing sensitivity served as the participants. ANLs were obtained at MCL and at five fixed presentation levels (20, 34, 48, 62, and 76 dB HL). Results demonstrated that ANL was dependant on speech presentation level. More specifically, for each 4 dB increase in speech presentation level, ANL increased by 1 dB. These results indicated that as speech presentation level increased, acceptance of noise also increased.

Freyaldenhoven, Plyler, Thelin, and Hedrick (2007) continued the work of Franklin et al. (2006) to determine if the effect of speech presentation level on acceptance of noise was related to the hearing sensitivity of the listener. Twenty-four individuals with normal hearing and 46 individuals with hearing impairment participated in this study. Because acceptance of noise is dependent on speech presentation level, participants with normal and impaired hearing were matched for conventional ANLs (i.e., ANLs obtained at MCL). ANLs were obtained conventionally and at eight fixed speech presentation levels: 40, 45, 50, 55, 60, 65, 70, and 75 dB HL. The effects of speech presentation level on acceptance of noise were analyzed using global ANL and ANL growth. To determine global ANL, ANLs for the fixed speech presentation levels were averaged for each participant. Furthermore, ANL growth was defined as the slope of the ANL function. The results revealed that global ANLs and ANL growth did not differ between listeners with normal and impaired hearing. 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.

Prediction of 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.

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, 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.). The results 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 dependant on pattern of hearing aid use. Specifically, full-time hearing aid users had smaller 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.

Freyaldenhoven, Plyler, Thelin, and Muenchen (2008) recognized the following limitations to ANLs measured conventionally (i.e., at MCL): (1) the model assumes that hearing aid users only listen at one level in all daily listening situations; (2) both part-time and non-users of hearing aids cannot be differentiated based on conventional ANL; and (3) a 15% error rate occurs in the predictive model developed using conventional ANL. Therefore, Freyaldenhoven and colleagues (2008) investigated the effects of speech presentation level on acceptance of background noise in full-time, part-time, and non-users of hearing aids to determine if the effects of speech presentation level on acceptance of background noise could better predict hearing aid use than ANLs measured conventionally (i.e., ANLs at MCL). Sixty-nine adults with hearing impairment were divided into three groups based on pattern of hearing aid use: full-time (N=25); part-time (N=21); and non-use of hearing aids (N=23). ANLs were obtained conventionally (at MCL) and at eight fixed speech presentation levels: 40, 45, 50, 55, 60, 65, 70, and 75 dB HL. While conventional ANLs were obtained for control purposes, the effect of speech presentation level on acceptance of background noise was analyzed using global ANLs (i.e., an average of ANLs for the fixed speech presentation levels) and ANL growth (i.e., the slope of ANL function) for each participant. The results revealed that global ANLs and ANL growth were significantly smaller for full-time hearing aid users than for either part-time or non-users of hearing aids; however, part-time and non-users of hearing aids could not be differentiated. Therefore, the groups were redefined as successful (i.e., full-time) and unsuccessful (part-time and non-users) hearing aid users, and logistic regression analysis was calculated. The results revealed that global ANLs and ANL growth could be used to predict hearing aid use with 62% and 64% accuracy, respectively. The results further revealed that the overall accuracy for global ANL and ANL growth decreased in comparison to ANL measured conventionally (68%). These results indicated that the effects of speech presentation level on ANL differentiated the hearing aid user groups in the same manner as conventional ANL. The authors, however, stated the effects of speech presentation level on ANL may be able to differentiate successful from unsuccessful hearing aid users with mid-range ANLs.

Furthermore, post hoc analyses were conducted to determine if ANL measured at a single fixed speech presentation level could differentiate the three hearing aid groups better than ANLs measured conventionally (Freyaldenhoven et al., 2008). The results revealed that ANLs obtained at 65, 70, and 75 dB HL differentiated the hearing aid groups in the same manner as conventional ANL. The results further revealed that accuracy of the prediction for the fixed speech presentation level slightly increased (74% at 65 dB, 70% at 70 dB, and 69% at 75 dB) in comparison to conventional ANLs (68%). These results indicate that hearing aid use can be accurately predicted when ANLs are measured at fixed speech presentation levels.

Effect of Hearing Aids on ANL

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 dependant on the fitted ear if only one hearing aid is fitted.

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 2 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.

Control Center for 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 indicate that ARTs or CSTEOAEs may not be helpful additions to clinical routines when attempting to determine hearing aid success.

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 small ANLs (i.e., ANLs $\leq$ 6 dB), and 6 listeners had large 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 small 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 indicate that the efferent mechanisms may be enhanced or the afferent mechanisms may be suppressed in females with small versus large ANLs.

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 small (N = 11) or large (N = 10) ANLs. Like Harkrider and Tampas, 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 small ANLs demonstrated a slower rate of growth in ANL (ANL growth = .15 dB/dB) with increasing presentation level than listeners with large ANLs (ANL growth = .44 dB/dB). These results indicate that ANL is mediated in the central auditory nervous system and listeners with large ANLs process background noise differently than those with small 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.

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.

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. Participants with their own custom earmolds used those; however, participants who did not have their own used foam Comply tips (Hearing Components, Inc., Oakdale, Minn). ANLs were obtained using the speech and noise portions from the HINT. Results revealed that ANLs obtained with DNR on 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.

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.

CHAPTER III

METHODS AND PROCEDURES

Participants

The goal of this study was to recruit 32 children (sixteen 10.0 to 11.11 year olds and sixteen 14.0 to 15.11 year olds) with normal hearing sensitivity from Cedar Creek School, A.E. Phillips, and through an email sent to faculty, staff, and students of Louisiana Tech University (Ruston, Louisiana). However, a total of 35 children (nineteen 10.0 to 11.11 year olds [mean age=10.53] and sixteen 14.0 to 15.11 year olds [mean age=14.38]) were recruited to participate in this study. For the 10.0 to 11.11 year old group, eight were male and 11 were female. For the 14.0 to 15.11 year old group, eight were male and eight were female. A letter of recruitment explaining the purposes and procedures of this study was sent home with each child, and interested parents/children contacted the experimenter. Children were also recruited by asking for participation from friends and family of the researchers. The inclusion criteria were as follows:

1. age 10 years, 0 months to 11 years, 11 months OR 14 years, 0 months to 15 years, 11 months,
2. normal hearing sensitivity (pass a pure tone hearing screening at 20 dB HL for 0.5, 1, 2, & 4 kHz in each ear), and
3. placement in a regular classroom setting for the entire school day.

Materials and Procedures

Pure tone hearing screenings were administered and ANLs were measured in a sound-treated booth (IAC; 9'3" by 9'7") with acceptable ambient noise levels (ANSI, S3.1-1991). Speech and noise stimuli were delivered through a compact disk player (Tascam CD-160, Serial #0231289) routed through an audiometer (GSI-61, Serial # AA063067) to an ear-level loudspeaker located at 0° azimuth. A recording of male running speech (Arizona Travelogue, Cosmos Inc.) was used as the primary stimulus, and both speech spectrum noise (generated by the GSI-61 audiometer) and speech babble noise (Revised SPIN, Cosmos Inc) served as the competing stimuli. The output levels for speech and noise stimuli were calibrated at the vertex of the listener and were checked periodically throughout the experiment.

ANLs were measured using the procedures described by Freyaldenhoven and Smiley (2006). Before ANL testing began, the participants were given two indicator buttons, which included the words and a pictorial representation of softer and louder. Each participant was instructed to use the indicator buttons to signal the examiner to manipulate the volume of the story and the background noise.

The initial presentation for both the speech and background noises was 30 dB HL; the MCL and BNL were obtained using a method of adjustments. First, each participant was asked to adjust running speech to their most comfortable listening level (MCL). Specifically, the children were instructed to increase the level of the story until "the level of the story was a little bit too loud." The speech was then decreased until the story was just audible. Lastly, the participant adjusted the level of the story up and down to their MCL (see Appendix B for MCL instructions for children). Then, background noise was introduced, and the participant was asked to adjust the level of the background noise to the maximum he/she was willing to "put up with" while listening to and following the story (called BNL). Specifically, the participant adjusted the background noise up until the story could not be heard, and then down until the story was very clear. Lastly, the participants adjusted the level of the noise to the maximum level of background noise they were willing to accept or 'put-up-with' without becoming tense or tired while listening to and following the words of the story (see Appendix B for BNL instructions for children). The ANL was then calculated by subtracting the BNL from the MCL (i.e., MCL – BNL = ANL).

Three ANL trials were obtained for each background noise (speech spectrum noise and speech babble noise) (Note: ANLs obtained using speech spectrum and speech babble noises were counterbalanced). If ANLs were not within 4 dB of each other, a fourth trial was completed. All experimental trials were completed within one session, lasting approximately 30 minutes. An average of the three or four trials for each background noise served as the mean ANL for that participant in the given condition.

CHAPTER IV

RESULTS

Reliability and Distribution of the Data

One purpose of the present study was to determine if ANLs were reliable in children with normal hearing. To determine the test-retest reliability of ANLs in children using speech babble noise as the competing stimulus, three Single Measure Intraclass Correlation Coefficients based on the consistency definition were calculated. It should be noted that typically, for the behavioral sciences, correlation coefficients of 0.1, 0.3, and 0.5 are interpreted as small, medium, and large, respectively (Green, Salkind, and Akey, 2002). The correlation coefficient for children 10 and 11 years of age (N=19) was r = 0.67 ($p < 0.001$) while the correlation coefficient for children 14 and 15 years of age (N=16) was r = 0.86 ($p < 0.001$)(see Table 1). Finally, the correlation coefficient for all children (N=35) was r = 0.73 ($p < 0.001$); all of these correlation coefficients were high indicating a high test-retest reliability of ANL for all children tested.

To determine the test-retest reliability of ANLs in children using speech spectrum noise as the competing stimulus, three Single Measure Intraclass Correlation Coefficients based on the consistency definition were calculated. The correlation coefficient for children 10 and 11 years of age (N=19) was r = 0.85 ($p < 0.001$) while the correlation coefficient for children 14 and 15 years of age (N=16) was r = 0.82 ($p<0.001$). (see Table 1). Furthermore, the correlation coefficient for all children (N=35) was $r = 0.84$ ($p < 0.001$), indicating a high test-retest reliability of ANL for all children.

Table 1

Single Measure Intraclass Correlation Coefficient Measures obtained using speech babble noise (SBN) and speech spectrum noise (SSN) for 10-11.11 and 14-15.11 year old children separately and together.

	Single Measure Intraclass Correlation Coefficient	
Age	**SBN**	**SSN**
10.0 to 11.11 (N=19)	0.67	0.85
14.0 to 15.11 (N=16)	0.86	0.82
10.0 to 11.11 and 14.0 to 15.11 (N=35)	0.73	0.84

Another purpose of the present study was to determine if ANLs in children with normal hearing were normally distributed. A total of six histograms were created based on the combinations of noise types (speech babble noise and speech spectrum noise) and age groups (10.0-11.11, 14.0-15.11, and both; see Figures 1-6). It should be noted that previous normal ANL distribution histograms centered around 10 dB (Freyaldenhoven & Smiley, 2006; Nabelek et al., 1991; Rogers et al., 2003). The histogram for age group 10.0-11.11 years with speech spectrum noise was normally distributed (see Figure 4). All other histograms were near normal, slightly skewed to the left centering around 5 dB (see Figures 1-3, 5 and 6). Distribution histograms (Figures 1-6) for the present study revealed that ANLs were near normally distributed (i.e., slightly skewed to the left) for each age group and type of background noise distraction and for the two age groups combined.

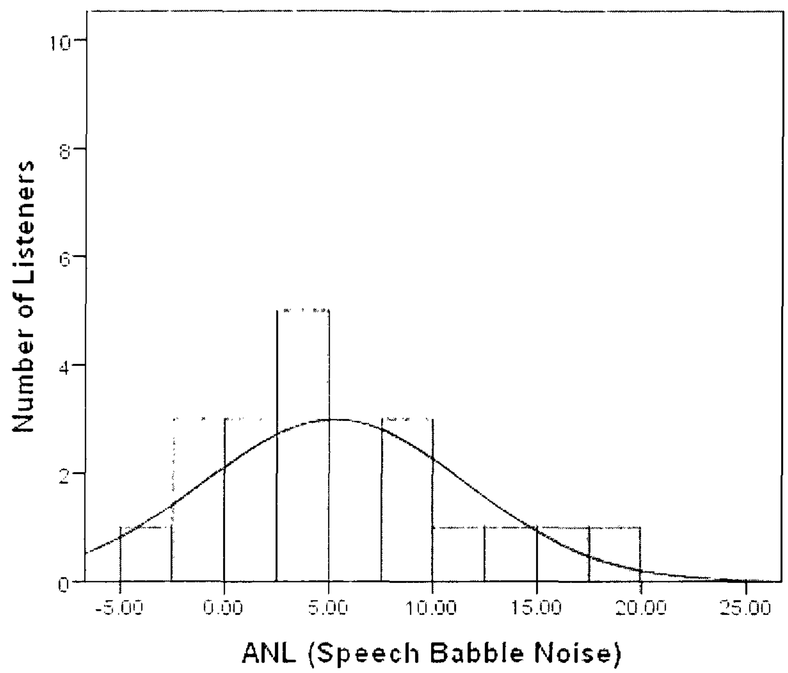

Figure 1: Histogram displaying the frequency distribution of ANLs for children ages 10.0-11.11 years (N = 19) measured using speech babble noise.

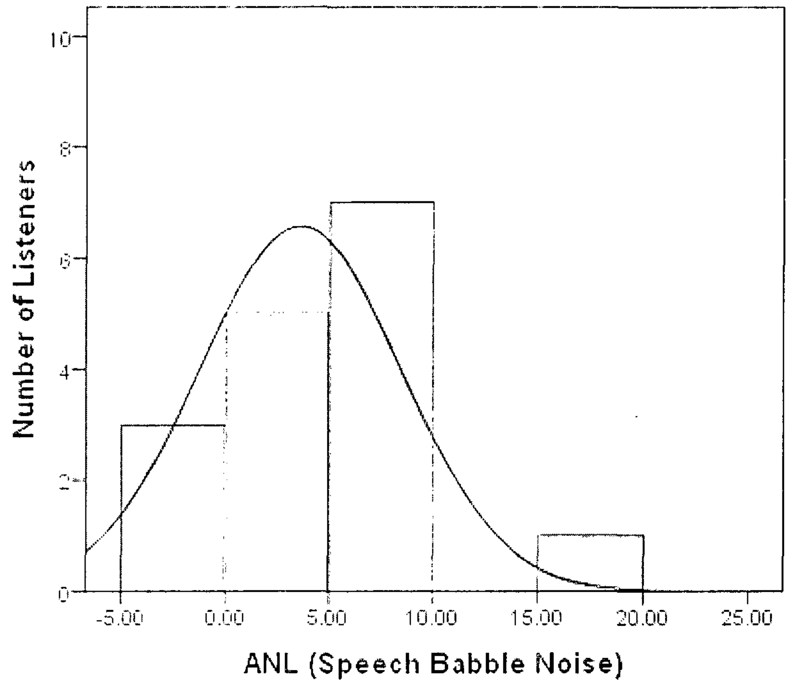

Figure 2: Histogram displaying the frequency distribution of ANLs for children ages 14.0-15.11 years (N = 16) measured using speech babble noise.

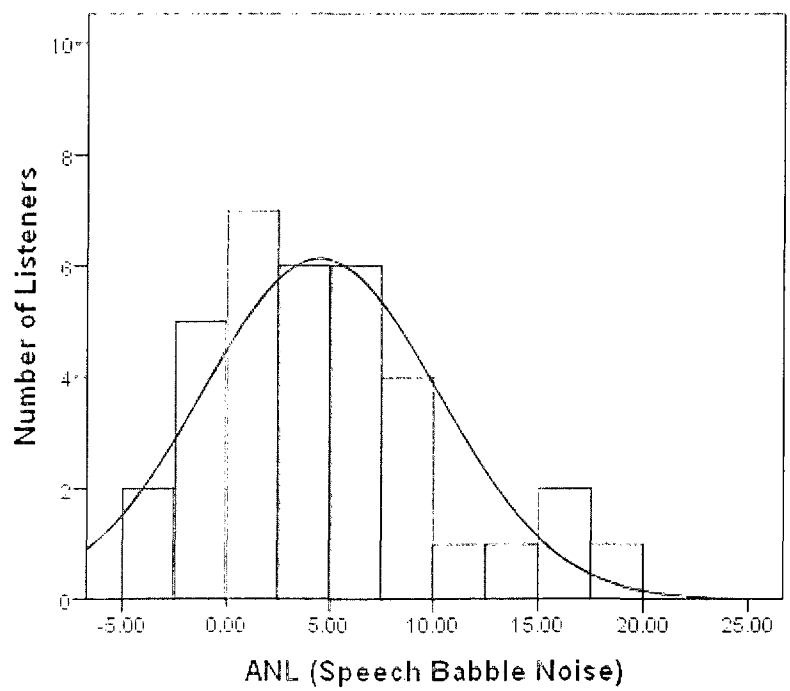

Figure 3: Histogram displaying the frequency distribution of ANLs for all children (age 10.0-11.11 and 14.0-15.11 years; N = 35) measured using speech babble noise.

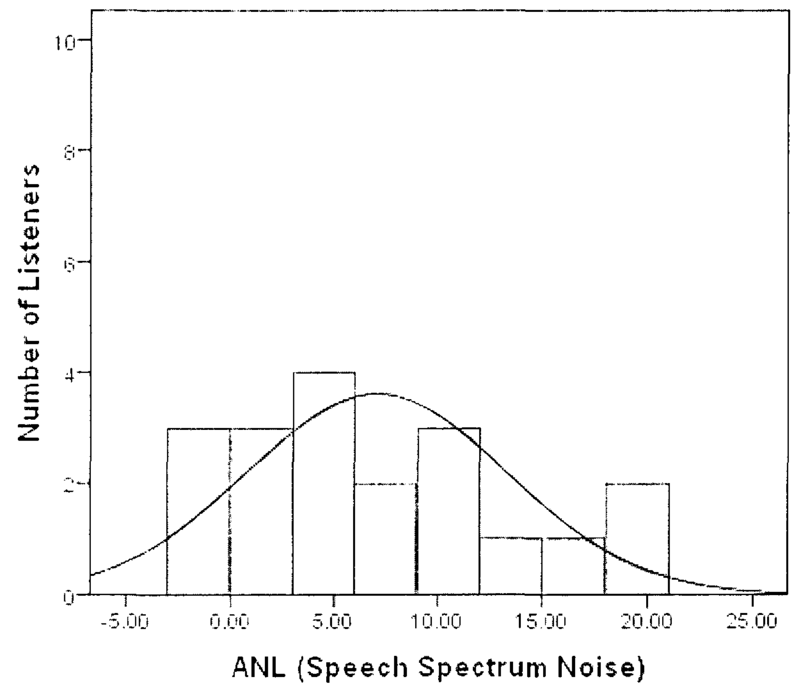

Figure 4: Histogram displaying the frequency distribution of ANLs for children ages 10.0-11.11 years (N = 19) measured using speech spectrum noise.

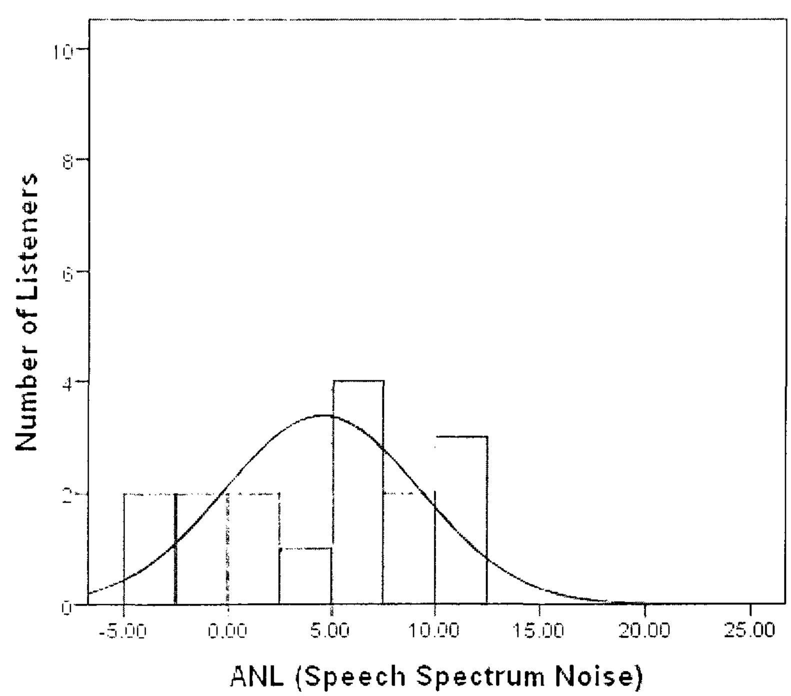

Figure 5: Histogram displaying the frequency distribution of ANLs for children ages 14.0-15.11 years (N = 16) measured using speech spectrum noise.

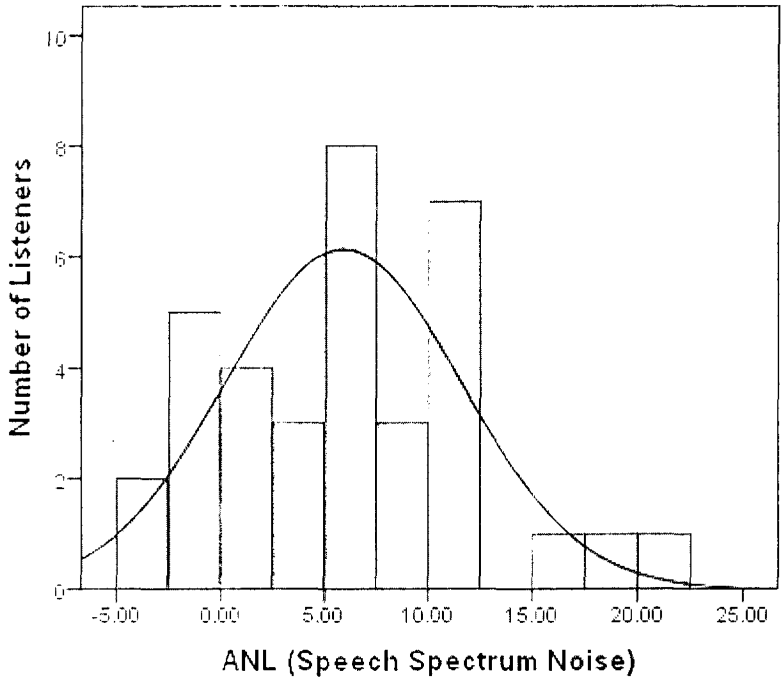

Figure 6: Histogram displaying the frequency distribution of ANLs for all children (age 10.0-11.11 and 14.0-15.11 years; N = 35) measured using speech spectrum noise.

Typical ANL Values

Another purpose of the present study was to determine typical mean ANLs in children age 10 to 15 years. ANLs were obtained three times for each noise type, and a mean ANL was determined for each participant for each type of background noise distraction. Mean ANLs, standard deviations, and ranges for each age group and noise type are shown in Table 2.

A three-way repeated-measures analysis of variance (ANOVA) was completed to determine the effects of age, gender, and type of background noise distraction on ANLs in children with normal hearing. The independent variables were type of background noise distraction, gender, and age. The dependent variable was ANL. The within-subject factor was type of background noise distraction with two levels (speech spectrum noise or speech babble noise), and the between-subject factors were age with two levels (10-11.11 or 14-15.11 years) and gender with two levels (male or female). The analysis revealed a significant main effect for type of background noise distraction (F[1,31] =

6.885, p = 0.13). These results indicated that ANLs in children ages 10.0-11.11 and 14.0-15.11 years were dependent upon type of background noise distraction. Specifically, ANLs measured when speech spectrum noise as the competing stimulus were larger than ANLs measured using speech babble noise as the competing stimulus. The average difference between the two measures was 1.39 dB. These results indicated that children are more willing to put up with background noise when the competing stimulus was speech babble rather than speech spectrum noise. However, it should be noted that this difference is clinically insignificant since ANLs are measured in 2 dB steps.

Table 2

Means (standard deviations) and ranges for ANLs (in dB) obtained using speech babble noise (SBN) and speech spectrum noise (SSN) for 10-11.11 and 14-15.11 year old children separately and all children combined.

	ANL Mean (SD) (in dB)		**Range**	
Age	**SBN**	**SSN**	**SBN**	**SSN**
10.0 to 11.11 (N = 19)	5.26 (6.34)	7.04 (6.28)	-6 22	-2 22
14.0 to 15.11 (N = 16)	3.59 (4.86)	4.52 (4.72)	-6 20	-4 13
10-11 & 14-15 (N=35)	4.50 (5.69)	5.89 (5.69)	-6 22	-4 22

The analysis further revealed no significant main effects for age (F[1,31] = 0.1.174, p = 0.287), gender (F[1,31] = 0.728, p = 0.400), or any of the following interactions: type of background noise distraction by age (F[1,31] = 0.513, p = 0.479), type of background noise distraction by gender (F[1,31] = 0.544, p = 0.466), age by gender (F[1,31] = 0.400, p = 0.532), or type of background noise distraction by age by gender (F[1,31] = 1.733, p = 0.198). These results suggested that ANLs in children were not dependent on gender or age, at least for children 10-11.11 and 14-15.11 years of age. In summary, ANLs in children age 10 to 15 years of age were reliable and nearly normally distributed. Furthermore, ANLs were not related to age, gender, or type of background noise distraction, at least for children age 10 to 15 years.

CHAPTER V

DISCUSSION

The purposes of the present study were (1) to determine if reliable and normally distributed ANLs could be obtained in children with normal hearing and (2) to investigate the affect of age, gender, and type of background noise distraction on ANL for these listeners. Three ANLs were obtained for each child (N=35) using two types of background noise distraction (speech spectrum and speech babble noises). Results of the study revealed that ANLs in children ages 10.0-11.11 and 14.0-15.11 years with normal hearing were reliable. Specifically, ANLs were consistent within a test session and could be obtained in these children in approximately 2 to 4 minutes.

Additionally, ANLs in the tested population were plotted on distribution histograms. These histograms (Figures 1-6) revealed that ANLs were near normally distributed (i.e., slightly skewed to the left) for each age group and type of background noise distraction and for the two age groups combined. It should be noted that histograms from previous studies were centered around 10 dB while histograms from the present study centered around 5 dB, indicating that results from the present study revealed smaller ANLs (Freyaldenhoven & Smiley, 2006; Nabelek et al., 1991; Rogers et al., 2003). The slight skewing of the histograms might be explained by the population of children who volunteered for the study; specifically, these children simply had lower mean ANLs. It should be noted, however, that the range for ANLs was similar to that of previous studies. Mean ANLs for the present study ranged from –6 to 22 dB. Likewise, Rogers et al. (2003) found ANLs to range from 0 to 24.7 while von Hapsburg and Bahng (2006) measured a range from -2 to 20, and Freyaldenhoven and Smiley (2006) measured ANLs ranging from -3 to 22. The similarity between these ranges demonstrates that while mean ANLs were slightly different, the variance in ANLs between the groups of listeners (i.e., children and adults) were similar.

Furthermore, the results revealed that mean ANLs were not related to the age or gender of the participants. Results from the present study were in agreement with the results obtained by Freyaldenhoven and Smiley (2006) on children ages 8 and 12 years with normal hearing. The two studies, both the present study and Freyaldenhoven and Smiley (2006), obtained ANLs on children of similar ages with an equal representation of male and female genders. Only data obtained from these two studies can be directly compared as no other study has obtained ANLs in the pediatric population. Both studies found no effect for age or gender on the measured ANLs, indicating that ANLs are not dependent on age or gender, at least for children ages 8 to 15 years. The present study and Freyaldenhoven and Smiley (2006) found no significant main effect for age, gender, noise distraction by age, noise distraction by gender, age by gender, or noise distraction by age by gender interactions.

Additionally, a statistical difference was found for ANLs obtained using speech spectrum noise versus speech babble noise. Specifically, the mean ANL obtained using speech babble noise was 4.50 dB while the mean ANL obtained using speech spectrum noise was 5.89 dB; therefore, the mean difference between speech babble and speech spectrum noises was 1.39 dB. These results are consistent with Freyaldenhoven and

Smiley (2006) results, who found mean ANLs of 9.7 for speech babble noise and 11.0 for speech spectrum noise (a difference of 1.3 dB). The authors of both the present study and the Freyaldenhoven and Smiley (2006) study determined this difference to be clinically insignificant because measures of ANL are typically performed in 2 dB steps; therefore, this measured difference would not even be detectable clinically.

Table 3

Comparison of research results for mean ANLs, standard deviations (SD), and ranges (in dB) for children with normal hearing.

	Mean ANL (SD) (in dB)		**Range**	
Investigation	**SBANL**	**SSANL**	**SBANL**	**SSANL**
Freyaldenhoven & Smiley (2006) (N=32)	9.7 (6.2)	11.9 (5.7)	-2.7 22	-2.7 21.7
Present Study (N=35)	4.50 (5.69)	5.89 (5.69)	-6 22	-4 22

Conclusions and Clinical Implications

The present study investigated the reliability, distribution, and effect of age, gender, and type of background noise distraction on children ages 10-11 and 14-15 years. Male and female children (age 10.0-11.11 and 14.0-15.11 years) with normal hearing sensitivity served as the participants for this study. The results revealed ANLs were reliable within a session and near normally distributed for these children. The results further revealed that ANLs for the selected population were not related to age or gender. Additionally, the results revealed a statistical difference between ANLs measured using speech babble and speech spectrum noise (i.e., a difference of 1.39 dB), with speech spectrum noise ANLs being larger. Moreover, the authors concluded that this difference was clinically insignificant because ANL measurements are obtained in 2 dB steps.

Furthermore, previous research has revealed that the range of SNRs for typical classrooms ranges from +5 to -7 dB (Blair, 1977; Finitzo-Hieber & Tillman, 1978; Markides, 1986; Sanders, 1965). However, the measured acceptable noise levels in the tested population ranged from -6 to 22 dB. It should be noted that an individual's ANL indicates that person's maximum acceptance for background noise in relation to the stimulus. At the point in which the background noise exceeds the individual's reported acceptance, it is possible that there is a breakdown in communication. It should be noted that ANL is not a measure of speech intelligibility as is SNR; however, both measures display performance in background noise. Therefore, it is possible that ANLs might provide insight into acceptable classroom noise levels for each individual child. In other words, ANLs might aid in determining the point at which certain children in the classroom experience a communication breakdown, which might be directly related to that child's classroom performance and/or academic excellence. These hypotheses warrant further investigation.

Further research should also investigate ANLs in a broader age range of children with normal hearing to determine the youngest age that ANLs can be reliably obtained in children with normal hearing. Additionally, ANLs should be measured in children with impaired hearing to determine if these measures can be used as a predictor of hearing aid success for this population. Results from this future research might aid clinicians in determining potential successful and unsuccessful hearing aid candidates and in the fitting of hearing aids for children with impaired hearing.

APPENDIX A

ANL INSTRUCTIONS FOR ADULTS

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 be comes 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

ANL INSTRUCTIONS FOR CHILDREN

Instructions for Establishing MCL

I'm going to play a story for you to listen to through the loudspeaker in front of you. The story is going to be very soft at first. I want you to use these buttons (pointing) to turn the story up until it is at your perfect listening level. For example, if this was a television, and these buttons were your remote control – I want you to turn the story up until you think it's at a perfect level for you. Remember if it gets too loud, you can turn it down a little by pushing the softer button. When it gets just right, give me a thumbs-up. Then I'll tell you what else we are going to do.

Instructions for Establishing BNL

Now I'm going to put some noise through the same speaker. The lady that was telling you the story is going to stay at the same loudness level that she was before the noise was introduced. The noise is going to be very soft – like the lady's voice when I first turned it on. I want you to turn it up until you think, "I could 'put up with' that noise for a long time if I had to, but if it is any louder then it would probably get on my nerves." It is important that you can also still follow the story that the lady is telling you through the speaker

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