Acceptable Noise Levels and Speech Perception in Noise for Children With Normal Hearing and Hearing Loss

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The purpose of this study was to evaluate acceptable noise levels in children with and without hearing loss as well as to explore a relationship between acceptable noise levels and speech understanding in noise in children. A between subjects design was used. Sixteen children with normal hearing served as the control group and sixteen children with hearing loss served as the experimental group. Results indicated no significant differences for acceptable noise levels between children with normal hearing and children with hearing loss. No significant relationship was found between acceptable noise levels and speech reception threshold for sentences in children with and without hearing loss. The results of the present study are consistent with results found in previous adult acceptable noise level studies. Overall, results suggest that acceptable noise levels in children with normal hearing and in children with hearing loss are similar to acceptable noise levels in adults with normal hearing and in adults with hearing loss.

INTRODUCTION

Noise can negatively affect the ability to detect critical aspects of speech in both adults and children. The ability to understand speech accurately in the presence of noise is critical for children in light of learning educational skills and speech and language development (Mowrer, 1958). Background noise, resulting in a poor signal to noise ratio (SNR), can impede an individual's ability to hear speech, regardless of age and/or hearing status. Children, regardless of hearing status, tend to perform poorer on speech in noise tasks, compared with adults (Papso & Blood, 1989; Nittrouer & Boothroyd, 1990; Johnson et al., 1997; Fallon et al., 2000; Johnson, 2000; Fallon et al., 2002; Hall et al., 2002; Wightman & Kistler, 2005; Nishi et al., 2010; Corbin et al., 2016). The ability to understand speech in noise is affected by maturation variables (e.g. life experience, vocabulary, neurologic immaturity, etc.) (Flexer, 2005). Studies have found that younger children perform poorer on speech in noise tasks than older children (Elliott, 1979; Fallon et al., 2000; Johnson, 2000; Fallon et al., 2002; Jamison et al., 2004; Neuman et al., 2010; Corbin et al., 2016). It appears that a child's ability to perform some speech in noise tasks reaches adult performance levels by age 14 years (Johnson, 2000; Corbin et al., 2016).

Acceptable noise levels (ANLs) are a possible alternative way to measure the effects of noise on children. ANLs, first studied by Nabelek et al. (1991), are used to measure an individual's acceptance of noise while listening to speech. ANLs are calculated by obtaining the listener's most comfortable listening (MCL) level minus the background noise level (BNL). BNL is defined as the highest level of background noise deemed acceptable while listening to speech discourse. ANL research has suggested that low ANLs (< 7 dB) indicate greater acceptance of noise; therefore, these individuals are predicted to have greater success with hearing aids. Likewise, high ANLs (> 12 dB) indicate lower acceptance of noise; thus, individuals with high ANLs are predicted to have less success with hearing aids (Nabelek, et al., 2006). Previous research has generally found that age, hearing sensitivity (pure-tone average [PTA]), gender, locus of control, background noise, acoustic reflex thresholds, contralateral suppression of otoacoustic emissions, reverberation, and speech understanding are not related to the measure of ANL (Nabelek et al., 1991; Rogers et al., 2003; Nabelek et al., 2004; Harkrider & Smith, 2005; Freyaldenhoven & Smiley, 2006; Nabelek et al., 2006; von Hapsburg & Bahng, 2006; Freyaldenhoven et al., 2007; Plyler et al., 2007; Gordon-Hickey & Moore, 2007; Plyler et al., 2008; Johnson, et al., 2009). ANL has been found to be variable, normally distributed, reliable over time, and can predict hearing aid success with about 85% accuracy (Nabelek et al., 1991; Nabelek et al., 2004; Nabelek et al., 2006; Plyler et al., 2007). Variables that contribute to a person's ANL are low-frequency hearing thresholds (the better the low-frequency thresholds, the higher the ANL), personality traits (the more openness a person exhibits, the lower the ANL; the more conscientious a person exhibits, the higher the ANL), self-control (the higher the self-control, the lower the ANL), speech presentation level (the lower the speech presentation level, the lower the ANL), and speech intelligibility (used as a cue to set ANL) (Franklin et al., 2006; Freyaldenhoven et al., 2007; Nichols & Gordon-Hickey, 2012; Recker & Edwards, 2013; Brännström & Olsen, 2017; Recker & Micheyl, 2017).

The first research study to examine ANLs in children was reported by Freyaldenhoven and Smiley (2006). They measured ANLs for thirty-two normal hearing children (sixteen 8 year olds and sixteen 12 year olds). The purpose of the study was to demonstrate that ANLs could be reliably obtained in younger children with child-friendly instructions. The results showed that these age groups could provide reliable ANLs in 2 to 4 minutes, similar to test time for adults, and the ANLs were normally distributed in these age groups. Freyaldenhoven and Smiley (2006) found that ANLs for this group of participants were not related to type of noise, gender, or age of the child and indicated that ANL results for children with normal hearing were similar to those found in adults; however, no statistical analyses were conducted to examine the similarities between the ANL results for children and adults.

Moore et al. (2011) compared ANLs in thirty-four children (ages 8 to 10 years) and thirty-four young adults (ages of 19 and 29 years) with normal hearing. Significant main effects were found between groups for MCL and BNL measures, but not for ANL. Further analysis revealed that MCL and BNL measures were significantly lower in children than adults. Statistical analyses of the ANL results for the two populations found that there was no significant difference in ANLs between children and adults. Moore et al. (2011) concluded that ANLs may not change from childhood to adulthood. The significant differences between MCL and BNL measures suggest a developmental change occurs from childhood to adulthood, but ANLs remain the same. ANL may not be related to age; therefore, maturation variables in the auditory system, which change over time, do not affect the variance of ANL.

Previous studies did not compare ANL results in children with normal hearing with ANLs in children with hearing loss (Freyaldenhoven & Smiley, 2006; Moore et al., 2011). Also, a comparison of ANLs and speech perception in noise results has not been reported in children. While most ANL studies in adults did not find a significant relationship between the presence of hearing loss or speech perception ability and ANL (Nabelek, et al., 2004; Nabelek et al., 2006; von Hapsburg & Bahng, 2006; Plyler, et al., 2008), Ahlstrom, et al. (2009) found a positive correlation between unaided Hearing in Noise Test (HINT) sentence thresholds and unaided ANL scores with speech babble presented at 0 degree azimuth. Ahlstrom, et al. (2009) also found positive correlations between aided HINT sentences with spatial benefit and aided ANLs with spatial benefit. It has been documented that children need higher SNRs to understand speech in noise (Papso & Blood, 1989; Nittrouer & Boothroyd, 1990; Johnson, et al., 1997; Fallon et al., 2000; Johnson, 2000; Fallon et al., 2002; Hall et al., 2002; Wightman & Kistler, 2005; Nishi et al., 2010; Corbin et al., 2016). Consequently, children may accept less noise on an ANL task in order to achieve higher SNRs.

The purpose of the present study was to assess ANLs in children with hearing loss to study the possible usefulness of ANL in the pre-fitting hearing aid evaluation of pediatric patients. While the authors recognize there are many different variables that contribute to the successful use of hearing aids in the pediatric population, there is very little published research on these factors. This project is the first step to identify if ANLs are viable option in the pediatric population with hearing loss. It was hypothesized that ANLs would not be significantly different between the two groups of children. Additionally, the relationship between ANLs and speech perception in children were evaluated since there are significant differences in performances on speech perception tasks between the pediatric and adults populations. It was hypothesized that there would be a significant relationship between ANL and speech perception with higher SNRs being related to higher ANL scores. Lastly, the test-retest reliability and normality of ANLs in the both pediatric populations were examined. These two factors were evaluated to determine if ANLs could be reliably determined as well as normally distributed in children with and without hearing loss. It was hypothesized that ANLs would be able to be reliably determined in this population and that ANLs would be normally distributed following the same pattern that ANLs do in the adult population. While the present study does reproduce and corroborate research conducted in the adult population literature, it adds data from the pediatric population to which there are very few published studies.

METHOD

Participants

Thirty-two children, ages of 6-12 years, served as participants. Sixteen participants had normal hearing with hearing threshold levels 10 dB HL or better (ANSI S3-6-1996). Participants with hearing thresholds equal to or less than 10 dB HL at 500Hz, 1000 Hz, 2000 Hz, and 4000 Hz were included in the normal hearing group. Mean hearing thresholds for the children with normal hearing are shown in Figure 1. Range, mean, and standard deviations of all thresholds are shown in Table 1. Sixteen participants had bilateral hearing impairment with unaided hearing thresholds greater than 25 dB HL (ANSI S3.6-1996). Mean unaided thresholds for the children with hearing loss are shown in Figure 2. Range, mean, and standard deviations of all thresholds are shown in Table 1. The participants with hearing loss wore binaural hearing aids with mean length of use of 4 years (SD = 3 years). The mean age for the participants with normal hearing was 9 years and 8 months (SD = 1 year and 9 months). Participants for the normal hearing group ranged in age from 6 years and 11 months to 12 years and 9 months. The mean age for the participants with hearing impairment was 10 years and 2 months (SD = 1 year and 8 months). Participants for the hearing impaired group ranged in age from 7 years and 3 months to 12 years and 7 months. All participants were approximately equally distributed across the age range. Parents or guardians provided case history information. There was no history of tinnitus, active middle ear disorders, neurologic disorders, or use of central nervous system (CNS) stimulant medications for all participants. Participants read and signed a Statement Assent approved by the Internal Review Board at the University of South Alabama. If a participant was too young to read independently the Statement of Assent, the document was read to them. The parent or guardian of each child read and signed the Statement of Consent for their child's participation in the study.

Apparatus and Test Materials

Audiometric testing, ANL tasks, and Hearing in Noise test – Children (HINT-C) tasks were completed in a sound treated booth that met the American National Standards Institute (ANSI) guidelines for permissible ambient noise (ANSI S3. 1-1999). Audiometric testing was performed using an audiometer (Grason-Stadler Instruments GSI-61) calibrated in accordance with the ANSI (1996) specifications for a Type 2 audiometer. Pure tones were presented through TDH 50P earphones.

The primary stimulus for all ANL tasks was running discourse by a recorded male voice (Arizona Travelogue, Comos Distributing) used in previous ANL studies (i.e., Nabelek et al., 2004; Freyaldenhoven et al., 2005a; Freyaldenhoven et al., 2005b; Franklin, et al., 2006; Nabelek et al., 2006; Gordon-Hickey and Moore, 2007). The background noise was the twelve-talker babble from the R-SPIN test (Bilger, et al., 1984). The background noise used within the HINT Pro 7.2 Audiometric System was filtered white noise. Testing for both ANL and HINT-C was conducted using a loudspeaker placed at zero degree azimuth (both speech and noise) relative to the participant, and the participant was seated one meter away from the loud speaker. Stimuli for the ANL tasks were delivered via a Sony compact disc player (Model CDP-CD345) through the audiometer to the loudspeaker. Stimuli for the HINT-C (Nilsson et al., 1996) were presented through the HINT Pro 7.2 Audiometric System to the loudspeaker.

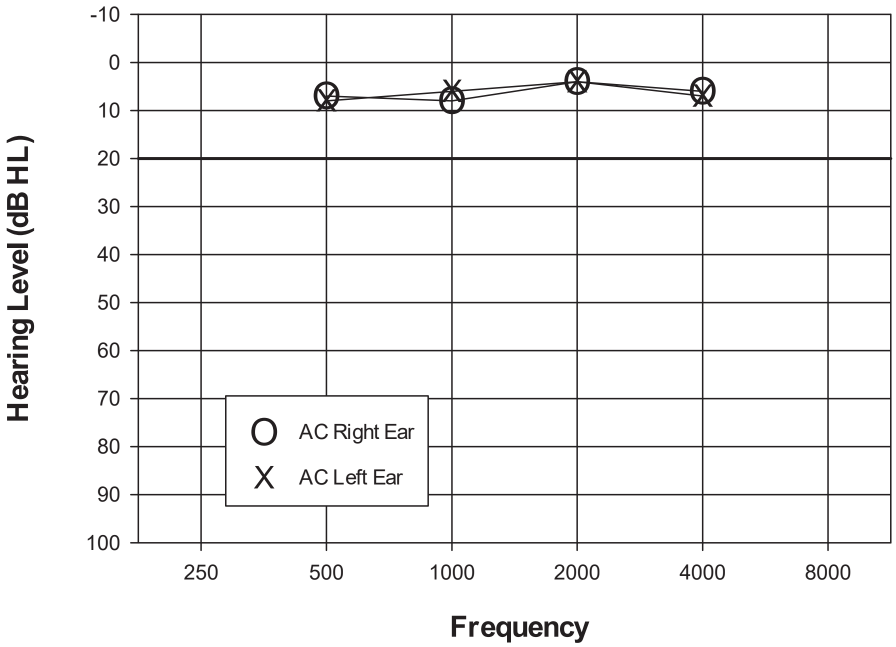

Figure 1. Mean threshold levels (dB HL) for 16 participants with normal hearing.

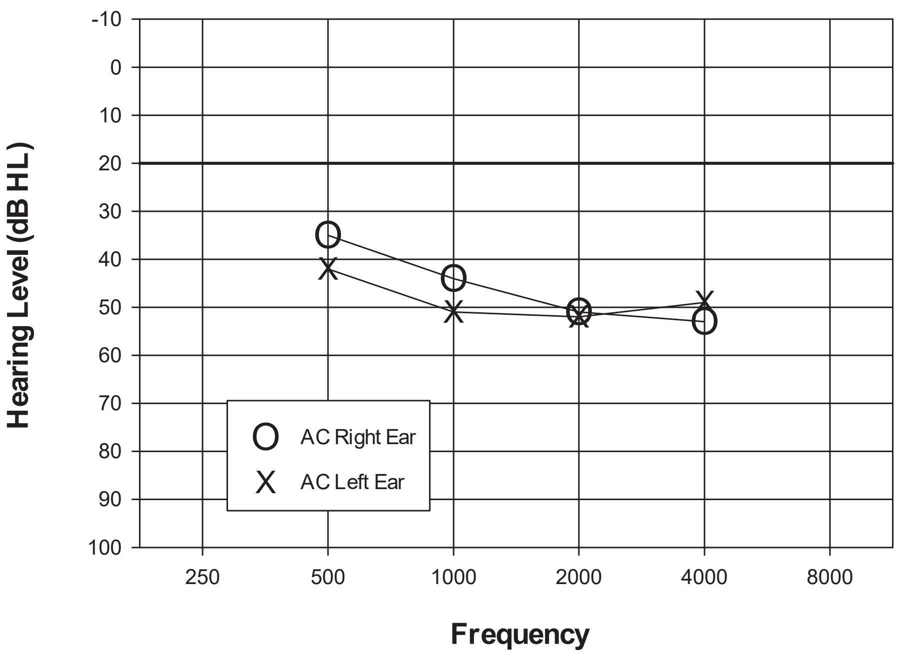

Figure 2. Mean unaided threshold levels (dB HL) for 16 participants with hearing loss.

Table 1. Range, mean, and standard deviation of hearing thresholds for participants with normal hearing and for participants with hearing loss.

	Participants with Normal Hearing			Participants with Hearing Loss		
Frequency	**Range**	**Mean**	**Standard Deviation**	**Range**	**Mean**	**Standard Deviation**
500 Hz Right Ear	10	7	4	55	35	18
500 Hz Left Ear	5	8	3	95	42	23
1000 Hz Right Ear	5	8	3	60	44	19
1000 Hz Left Ear	10	6	3	60	51	17
2000 Hz Right Ear	10	4	4	80	51	20
2000 Hz Left Ear	10	4	3	70	52	20
4000 Hz Right Ear	10	6	4	75	53	24
4000 Hz Left Ear	10	7	4	80	49	24
PTA Right Ear	8	7	3	52	44	17
PTA Left Ear	8	6	3	67	48	18

* All numbers are in dBHL.

** PTA=Pure tone average using 500Hz, 1000Hz, 2000Hz, and 4000Hz.

Procedures

All testing was completed in one 90-minute session with rest breaks provided as needed. The session included obtaining consent from the child and parent or guardian, obtaining a case history, audiometric testing, and completing two experimental tasks (speech perception testing using the HINT-C and ANL). The experimental tasks were counterbalanced. All experimental tasks were completed unaided for the participants with hearing loss.

ANL procedures for this study were similar to those used in previous ANL studies with children (Freyaldenhoven and Smiley, 2006; Moore et al., 2011) using modified instructions with appropriate vocabulary and language for children. The Appendix A shows the modified ANL instructions. Measures of MCL and BNL were obtained in order to calculate ANL. Participants were instructed to make intensity adjustments of the primary stimulus and background noise by using thumbs-up, thumbs-down, and flat palm signals. The thumbs-up signal was used to signal an increase in the intensity, thumbs-down to signal a decrease in the intensity, and flat palm to stop adjustments. This procedure was demonstrated to the participants. If a participant had any difficulty with this task, the testing was halted and the participant was reinstructed to ensure understanding of the task.

MCL was the intensity level at which the participant preferred to listen to the primary stimulus. In order to obtain MCL for each participant, the primary stimulus was presented at 30 dB HL and the level of the stimulus was adjusted in 5 dB steps, based on the participants hand signals described above. The participant was instructed to adjust the level of the story up "until the story is louder than you would want to listen to on the radio." Then the participant was instructed to adjust the level of the story down "until the story is softer than you would want to listen to on the radio." Finally, the participant was instructed to adjust the level of the story up and down to "where you would want to listen to the story on the radio." During this final adjustment, the level was adjusted in 2 dB steps. Once the participant was satisfied with the level of the stimulus, the tester recorded the intensity of the speech stimulus as the participant's MCL. MCL was measured three times, and the results were averaged.

BNL was the highest level of background noise acceptable to the participant while listening to speech. In order to measure BNL, the primary stimulus was presented at the participant's averaged MCL, and the secondary stimulus was presented as background noise. The secondary stimulus was introduced at 30 dB HL and adjusted in 5 dB steps, based on the hand signals previously described. The participant was instructed to increase the level of the background noise to a level where the story could not be heard clearly. Then the participant was instructed to decrease the level of the background noise to a level where the story could be heard very clearly. Finally, the participant was instructed to adjust the level of the background noise up or down "to the most noise that you would be willing to listen to and still be able to listen to the story for a long time." During the final adjustment, the level was adjusted in 2 dB steps. Once the participant was satisfied with the level, the tester recorded the intensity as the BNL. BNL was measured three times and the results were averaged. ANL was the difference value between average MCL and average BNL (ANL = MCL-BNL).

For the HINT-C, sentences were presented in quiet and noise conditions. The participants completed a practice list in quiet, completed one test list in quiet to obtain the HINT threshold, and then completed three lists in the noise condition. Each list contained 10 sentences. The level of the speech was presented at 65 dBA with the noise presented at the recommended 65 dBA for the initial sentence. The participant was instructed to repeat the entire sentence as presented. If the participant correctly repeated the sentence, then the level of the speech was decreased 4 dB. If the participant could not correctly repeat the sentence, the level of the speech was increased 4 dB. After the first four sentences, the same procedure was followed for the remaining sentences by increasing or decreasing the speech in 2 dB steps, depending upon correct or incorrect repetitions of the entire sentence. The results of the two best reception thresholds for sentences (RTS) were averaged and recorded as a dB threshold for signal-to-noise (S/N), based on the protocol recommended by Nilsson et al. (1996).

RESULTS

Test-Retest Reliability Analysis

The test-retest reliability of each measure was analyzed to ensure consistency. The mean MCL, mean BNL, ANL, mean RTS in quiet, and RTS in noise for each participant are displayed in Tables 2 and 3. MCLs and BNLs were measured three times and averaged for each participant. The average BNL was subtracted from the average MCL to calculate ANL for each participant. Overall reliability of the three MCL and BNL measurements for the group with normal hearing and the group with hearing loss (unaided) were evaluated with Pearson product-moment correlations. All correlation coefficients were significant ($p < 0.01$); r-values for MCL ranged from 0.943 to 0.992; and r-values for BNL ranged from 0.953 to 0.990, indicating strong reliability of both measures (see Table 4). Overall reliability of the two best RTS in noise measurements for the participants with normal hearing and the participants with hearing loss (unaided) were evaluated with Pearson product-moment correlations. The correlation coefficients were significant ($p < 0.01$) and r-values ranged from 0.821 to 0.903, which indicated strong reliability (see Table 4).

Statistical Analysis of ANL and Speech Perception

To test the hypothesis that there would not be significant group differences measured for participants with normal hearing and participants with hearing loss, a one-way multivariate analysis of variance (MANOVA) was conducted. Significant group differences were found (Wilks's $\Lambda = .31$, $F [5, 26] = 11.36$, $p < 0.01$, $\eta2 = .70$). Analyses of variances (ANOVA) were conducted for MCL, BNL, ANL, RTS in quiet, and RTS in noise. The Holm-Bonferroni method was used to control for familywise error rates. Results showed significant group differences for MCLs ($F [1, 30] = 6.45$, $p = 0.02$, $\eta2 = .18$) and for BNLs ($F [1, 30] = 10.59$, $p < 0.01$, $\eta2 = .26$). MCLs and BNLs were significantly higher for the participants with hearing loss. Results showed no significant group differences for ANLs ($F [1, 30] = 0.56$ $p = 0.50$, $\eta2 = .02$). Results showed significant group differences for RTS in quiet ($F [1, 30] = 65.45$, $p < 0.01$, $\eta2 = .69$), and for RTS in noise ($F [1, 30] =33.93$, $p < 0.01$, $\eta2 = .53$). Participants with hearing loss had higher thresholds in quiet, and required higher SNRs in noise than the participants with normal hearing. Figures 3 and 4 show the results from above.

Correlation Analysis

It was hypothesized that there would be a significant relationship found between ANLs and RTS in noise, and a Pearson product-moment correlation was conducted between ANLs and RTS in noise in each group. No significant relationship was found between ANLs and RTS in noise for children with normal hearing ($r = 0.20$, $p = 0.46$) or children with hearing loss ($r = -0.07$, $p = 0.79$). Pearson product-moment correlations were also conducted to assess a possible relationship between ANLs and pure tone averages (PTAs). No significant relationship was found between ANL and the PTA for each ear for the participants with normal hearing (Right Ear: $r = -0.06$, $p =$

Table 2. Mean MCLs, mean BNLs, ANLs, RTS in quiet, and RTS in noise for participants with normal hearing.

Participant Number	Mean MCL (dB HL)	Mean BNL (dB HL)	ANL (dB)	RTS in Quiet (dBA)	RTS in Noise (dB S/N)
1	53	51	2	37.0	-0.7
2	61	48	13	26.6	-1.4
3	46	47	-1	30.0	-0.2
4	64	53	11	27.6	1.0
5	45	47	-2	26.2	-1.9
6	53	49	4	21.0	-0.7
7	54	44	10	27.7	-1.6
8	42	26	16	14.8	-2.4
9	55	47	8	18.2	-2.4
10	45	43	2	22.5	-1.2
11	54	45	9	22.6	-0.2
12	79	73	6	22.9	-1.2
13	45	46	-1	20.1	-2.3
14	54	48	6	16.3	-2.7
15	51	39	12	16.1	2.2
16	57	37	20	15.9	-0.6
Mean (S.D.*)	53.63 (9.11)	46.44 (9.54)	7.19 (6.38)	22.84 (6.09)	-1.02 (1.31)

*S.D. = Standard Deviation

Table 3. Unaided mean MCLs, mean BNLs, ANLs, RTS in quiet, and RTS in noise for participants with hearing loss.

Participant Number	Mean MCL (dB HL)	Mean BNL (dB HL)	ANL (dB)	RTS in Quiet (dBA)	RTS in Noise (dB S/N)
17	65	52	13	67.1	5.0
18	57	47	10	51.4	3.2
19	67	63	4	63.9	5.8
20	54	47	7	40.7	-0.2
21	76	69	7	60.7	4.3
22	49	51	-2	40.2	1.6
23	65	39	26	29.8	0.2
24	54	54	0	39.7	-0.5
25	85	71	14	55.1	2.0
26	59	61	-2	56.5	1.8
27	59	59	2	67.4	4.4
28	42	47	-5	33.1	1.6
29	81	74	7	43.5	3.2
30	61	67	-6	57.5	3.0
31	68	61	7	73.0	8.4
32	63	61	2	68.4	7.4
Mean (S.D.*)	62.81 (11.24)	57.69 (10.01)	5.25 (8.12)	53.00 (13.61)	3.95 (2.63)

*S.D. = Standard Deviation

Table 4. MCL, BNL, and RTS in noise measurement correlation coefficients (r) for the participants with normal hearing and hearing loss (unaided).

Measures	Normal Hearing	Hearing Loss-Unaided
MCL1 and MCL2	r = 0.965	r = 0.992
MCL1 and MCL 3	r = 0.943	r = 0.971
MCL2 and MCL3	r = 0.948	r = 0.981
BNL1 and BNL2	r = 0.984	r = 0.982
BNL1 and BNL3	r = 0.953	r = 0.985
BNL2 and BNL3	r = 0.964	r = 0.990
RTS1 and RTS2*	r = 0.821	r = 0.903

*Two best of three RTS in Noise

0.83; Left Ear: r = 0.05, p = 0.87) and participants with hearing loss (Right Ear: r = -0.49, p = 0.052; Left Ear: r = 0.04, p = 0.88).

Normality Analysis

The authors hypothesized that the ANL measurements would be normally distributed for children with normal hearing and children with hearing loss, and the Shapiro-Wilk Test of Normality was completed. The Shapiro-Wilk Test of Normality was not significant for children with normal hearing (W = 0.97, p = 0.80) or children with hearing loss (W = 0.94, p = 0.29), suggesting that ANL was normally distributed for both groups of children. These results follow the same pattern found in adults with and without hearing loss.

DISCUSSION

The purpose of this study was to examine ANLs in children with hearing loss. Additionally, the authors examined if a relationship exists between ANLs and speech perception in children with and without hearing loss, the reliability of ANLs in children with and without hearing loss, and the normality of the distribution of ANLs in children with and without hearing loss. The present study found that there were no significant differences in ANLs for children with normal hearing and children with hearing loss. Additionally, the present study found that there was not a significant relationship between ANLs and speech perception in noise in children with and without hearing loss, that ANLs were able to be obtained reliably in the pediatric population for both children with and without hearing loss, and that ANLs are normally distributed in children with and without hearing loss. These findings replicate the patterns found in ANLs studies for adults with and without hearing loss.

Only 1 out of 6 previous adult ANL studies revealed a significant relationship between ANL and speech understanding in noise tasks (Nabelek et al., 2004; Mueller et al., 2006; Nabelek et al., 2006; von Hapsburg et al., 2006; Plyler et al., 2008; Ahlstrom, et al., 2009). It was hypothesized that there could be a relationship between these two measures for children due to the fact that children younger than 13 years of age perform poorer on speech understanding tests than adults due to immaturity of the auditory system, smaller vocabulary, and reduced ability to use acoustic cues (Papso & Blood, 1989; Nittrouer & Boothroyd, 1990; Nilsson et al., 1996; Johnson et al., 1997; Fallon et al., 2000; Johnson, 2000; Fallon et al., 2002; Smaldino & Crandell, 2005). In this study, no significant correlation was found between ANL and RTS in noise, consistent with past findings in adult listeners (Nabelek et al., 2004; Mueller et al., 2006; Nabelek et al., 2006; von Hapsburg et al., 2006; Plyler et al., 2008).

Reasons for the different outcomes of this study in comparison to the Ahlstrom, et al. (2009) study might include the configuration of the participants hearing loss. The configuration for participants' in this study overall had a more flat shape when compared to participants' in the Ahlstrom et al. (2009) study where those participants had a more steeply sloping configuration shape. The linear regression in that study showed that a low unaided ANL score indicated a better performance on the unaided HINT measure. While most studies to date have not found a correlation between hearing thresholds and ANL, those research studies have only correlated hearing thresholds to ANL using the PTA (Nabelek et al., 1991; Nabelek et al., 2006; von Plyler et al., 2007; Plyler et al., 2008). Brännström and Olsen (2017) found that low frequencies (125 Hz, 250 Hz, and 500Hz)

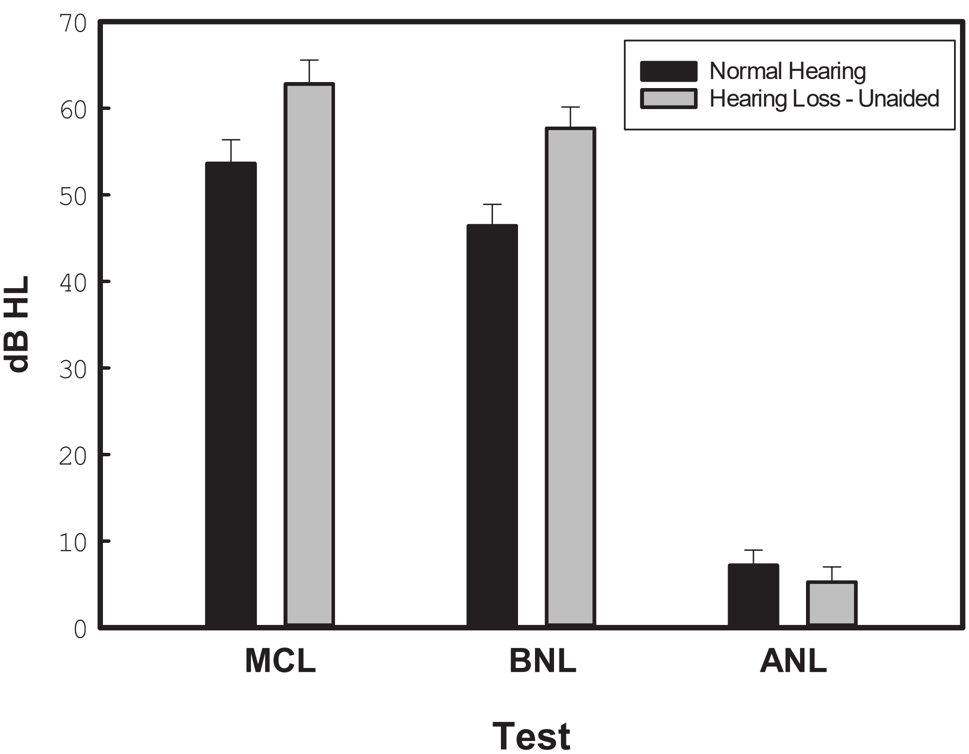

Figure 3. Mean and standard error for each group for the measures of MCL, BNL, and ANL.

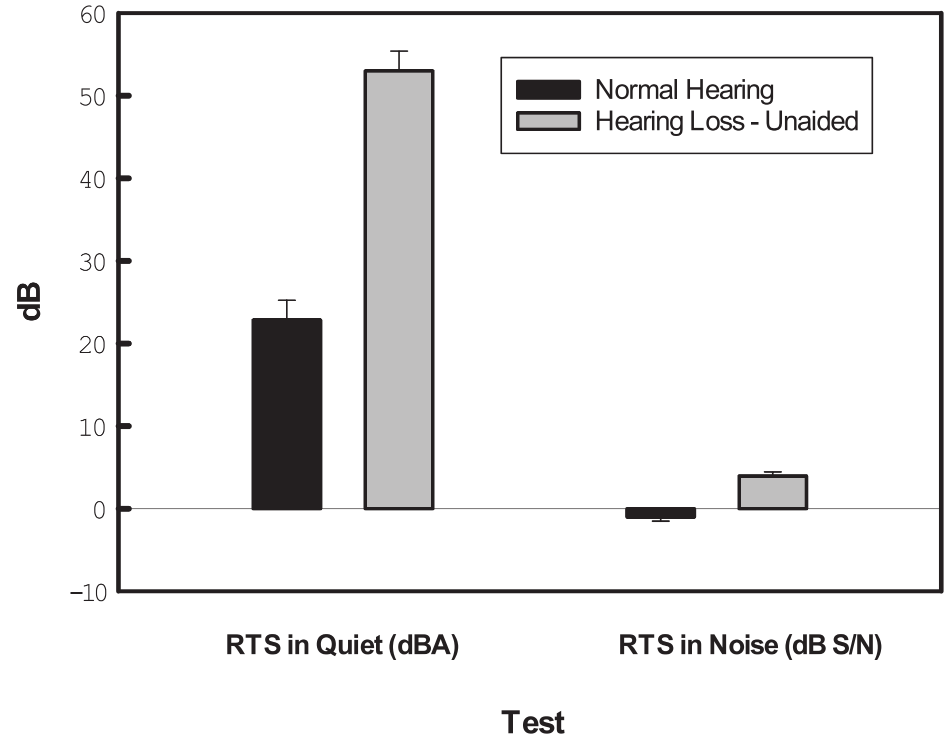

Figure 4. Mean and standard error for each group for the measures of RTS in quiet and RTS in noise.

were correlated to ANL and that the magnitudes of differences between the PTA for the low frequencies (average of 125 Hz, 250 Hz, and 500Hz) and PTA for the high frequencies (average of 1000 Hz, 2000 Hz, and 4000Hz) were correlated to ANL. The participants with poorer low frequency thresholds were more likely to have a lower ANL (< 7 dB), suggesting that they accepted more levels of noise. High ANLs (> 12 dB) were found in participants with a large difference between the PTA for low frequencies and PTA for high frequencies, suggesting that that a sloping hearing loss may contribute to those who are willing to accept less amounts of background noise. It is important to note that the Brännström and Olsen (2017) study did not use the traditional English version of ANL, but one developed by Brännström et al. (2012) utilizing Danish, Swedish, and non-semantic speech materials and different background noise (speech-weighted amplitude-modulated noise and multitalker babble noise).

Findings in the present study were compared to the two pediatric ANL studies. Means reported by Freyaldenhoven and Smiley (2006) were similar to those found in the present study. For example, the present study yielded mean ANL of 7.19 dB for children with normal hearing similar to the mean ANL of 9.7 dB previously reported. Results indicated children 6 to 12 years of age could complete the ANL task in a similar amount of time as an adult. The results of the present study were compared with findings from the Moore et al. (2011) study. Moore et al. (2011) reported a mean ANL of 8.50 dB for adults and a mean ANL of 7.82 dB for children, which were similar to mean ANLs in this study. The results of Moore et al. suggest that ANLs do not change throughout a person's life (from childhood to adulthood). A further comparison of the means and ranges of ANLs from various ANL studies are shown in Table 5. Freyaldenhoven and Smiley (2006) also reported a high re-test reliability ($r = 0.87$ $p < 0.001$) of ANLs in the pediatric population and that ANLs were normally distributed. The present study also found a high re-test reliability of ANLs in children with and without hearing loss. The present study examined the re-test reliability of MCL and BNL too since those are the measures used to obtain ANL, where Freyaldenhoven and Smiley (2006) calculated test-retest reliability using the ANL score only.

Limitations of this study include the lack of variability among the shape of the hearing loss configuration of the participants. Future studies should include a wide range of hearing loss configurations. Additionally, the language level of the Arizona Travelogue is unknown, which might have contributed to the non-significant findings in this population. Children may have been willing to accept more noise if the story was more kid-friendly. Future studies should examine the development of pediatric ANL test material to address this concern. Future directions of this research should include studies on aided ANL in the pediatric population, examining the effects of noise reduction algorithms on aided ANLs in the pediatric population, and assessing whether there is a relationship between ANL and hearing aid success in the pediatric population.

Summary

All ANL results for this study with pediatric listeners were consistent with ANL findings for adults with normal hearing and hearing loss. The results from this study support no significant relationships between ANLs and age, PTA, and speech perception in children with normal hearing and hearing loss. The findings also support that ANLs can be reliably obtained in children with and without hearing loss.

Table 5. Comparison of ANLs across multiple published studies.

Study	Mean ANL (SD) (in dB)	Range
Nabelek et al. (1991) N = 15 (elderly)	11.7 (7.6)	0.0-27.0
Nabelek et al. (1991) N = 15 (young adults)	15.9 (8.5)	5.0-37.0
Rogers et al. (2003) N = 50 (young adults)	10.9 (7.1)	0.0-24.7
Nabelek et al. (2004) N = 50 (adults)	9.6 (3.5)	Not reported
Freyaldenhoven et al. (2006) N = 30 (young adults)	12.9 (5.2)	4.0-24.0
Freyaldenhoven & Smiley (2006) N = 32 (children)	9.7 (6.2)	-2.7-21.7
Nabelek et al. (2006) N = 69 (older adults with HL & full-time HA users)	7.7 (3.0)	2.0-16.0
Nabelek et al. (2006) N = 69 (older adults with HL & part-time HA users)	13.5 (3.9)	9.0-26.0
Nabelek et al. (2006) N = 53 (older adults with HL & HA non-users)	14.4 (4.0)	9.0-27.0
von Hapsburg & Bahng (2006) N = 10 (young adults)	6.4 (6.3)	-2.0-20.0
Moore et al. (2011) N = 34 (young adults)	8.5 (6.7)	-2.7-24.7
Moore et al. (2011) N = 34 (children)	7.8 (5.1)	-1.3-17.3
Nichols & Gordon-Hickey (2012) N = 70 (young adults)	7.6 (6.9)	-4.0-26.0
Lowery & Plyler (2013) N = 30 (adults with HL)	13.3 (8.0)	-6.0-32.0
Gordon-Hickey & Morlas (2015) N = 44 (older adults)	5.4 (6.9)	Not reported
Present Study N = 16 (children with normal hearing)	7.2 (6.3)	-2.0-20.0
Present Study N = 16 (children with hearing loss)	5.3 (8.1)	-6.0-26.0

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Appendix A

PARTICIPANT INSTRUCTIONS FOR ANL TASKS

Instructions for establishing Most Comfortable Listening Level: "I'm going to play a story for you to listen to through the headphones. The story is going to be very soft at first. I want you to turn the volume of the story up by giving me a thumb up sign. Turn the sound up until it is where you can hear the story like on a radio. Remember, if it gets too loud, you can turn down the volume by using a thumb down sign."

Instructions for establishing Background Noise Level: "You will listen to the same story. Now, I'm going to add noise at the same time. The story will stay at the same volume. The noise will start out soft and then you turn the noise up or down to the most noise that you would be willing to listen to and still be able to listen to the story for a long time."

PARTICIPANT INSTRUCTIONS FOR HINT-C TASKS

I am now going to play a list of sentences. Please repeat the whole sentence. At first the sentences will be easy to hear and understand, but then I will add noise in the background. The sentences may become harder to hear and understand. Please repeat the sentences back to me the best you can and it is okay if you miss some of the words. We will first do a practice list.