

Differences in Responses from the Cochleae and Central Nervous Systems of Females with Low versus High Acceptable Noise Levels

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Abstract

Studies of acceptable noise level (ANL) consistently report large intersubject variability in acceptance of background noise while listening to speech. This variability is not related to age, gender, hearing sensitivity, type of background noise, speech perception in noise performance, or efferent activity of the medial olivocochlear pathway. An exploratory study was conducted to determine if differences in aggregate responses from the peripheral and central auditory system can account for intersubject variability in ANL. Click-evoked otoacoustic emissions (CEOAEs), binaural auditory brainstem responses (ABRs), and middle latency responses (MLRs) were measured in females with normal hearing with low ($n = 6$) versus high ($n = 7$) ANLs. Results of this preliminary study indicate no differences between the groups for CEOAEs or waves I or III of the ABR. Differences between the two groups emerge for the amplitudes of wave V of the ABR and for the Na-Pa component of the MLR, suggesting that physiological variations arising from more central regions of the auditory system may mediate background noise acceptance.

Key Words: Acceptable noise level, auditory brainstem response, auditory evoked potentials, click-evoked otoacoustic emissions, middle latency response

Abbreviations: ABR = auditory brainstem response; ANL = acceptable noise level; BNL = background noise level; CEOAEs = click-evoked otoacoustic emissions; MCL = most comfortable level; MLR = middle latency response; MOCB = medial olivocochlear bundle

Sumario

Los estudios del nivel aceptable de ruido (ANL) reportan consistentemente gran variabilidad inter-sujeto en la aceptación del ruido de fondo mientras escuchan lenguaje. Esta variabilidad no se relaciona con la edad, el género, la sensibilidad auditiva, el tipo de ruido de fondo, el desempeño en cuanto a percepción del lenguaje en ruido o a la actividad eferente de la vía olivo-coclear medial. Un estudio exploratorio se condujo para determinar si las diferencias en las respuestas agregadas del sistema auditivo central o periférico, podían explicar las variaciones inter-sujeto en el ANL. Se midieron las emisiones otoacústicas evocadas por clic (CEOAE), las respuestas auditivas binauriculares del tallo cerebral (ABR) y las respuestas de latencia media (MLR) en mujeres con audición normal, con ANL bajos ($N = 6$) versus altos ($n = 7$). Los resultados de este estudio preliminar no encontraron diferencias entre los grupos para las CEOAE, o para las ondas I y III de los ABR. Las diferencias entre los dos grupos emergen para la amplitud de la onda V de los ABR y para el componente Na-Pa de las MLR, sugiriendo que las variaciones fisiológicas que surgen de regiones más centrales del sistema auditivo puede mediar en la aceptación del ruido de fondo.

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Data in this paper were presented at the 147th Meeting of the Acoustical Society of America, New York, May 24–28, 2004.

Palabras Clave: Nivel aceptable de ruido; respuesta auditiva del tallo cerebral; potenciales evocados auditivos; emisiones otoacústicas evocadas por clic; respuestas de latencia media

Abreviaturas: ABR = respuesta auditiva del tallo cerebral; ANL = nivel aceptable de ruido; BNL = nivel de ruido de fondo; CEOAEs = emisiones otoacústicas evocadas por clic; MCL = nivel más comfortable; MLR = respuesta de latencia media; MOCB = fascículo olivo-coclear medial

Aceptable noise level (ANL) is a procedure developed to quantify the maximum amount of background noise that listeners are willing to accept while listening to speech (Nabelek et al, 1991). Individuals with low ANLs are willing to accept more background noise than individuals with high ANLs, a phenomenon that has been found to be highly reliable within and between test sessions in individuals (Nabelek et al, 2004). However, studies report large between-subject differences in the acceptance of background noise that has not been explained by age, hearing sensitivity (Nabelek et al, 1991), gender (Rogers et al, 2003), type of background noise (Crowley and Nabelek, 1996), efferent activity of the medial olivocochlear bundle (MOCB) pathway, middle ear characteristics (Harkrider and Smith, 2005), or speech perception in noise performance (Crowley and Nabelek, 1996; Nabelek et al, 2004).

Although neither low nor high ANLs in listeners with normal hearing have been found to have any apparent clinical consequences, Nabelek et al (this issue) demonstrated that listeners with impaired hearing who exhibit high ANLs (≥ 14 dB) are characterized by problematic hearing aid use. Listeners with impaired hearing who have low ANLs (≤ 8 dB) tend to be successful with amplification, while people with ANLs between 8 and 14 dB may be either successful or unsuccessful. Identification of the variables contributing to the large range of ANLs in listeners with normal hearing would result in an overall improved understanding of the processes contributing to this behavioral phenomenon. The wide spectrum of judgment differences may be related to individual variations in the function of the cochleae and/or auditory nervous systems of these participants, but this possibility has not been explored fully.

In a study by Harkrider and Smith (2005), ANLs were found to be unrelated to middle ear impedance measures, acoustic reflex thresholds evoked by tonal or broadband noise stimuli, or contralateral suppression of click-evoked otoacoustic emissions (CEOAEs). These results suggest that variability in ANLs is not due to middle ear characteristics or activity levels of the MOCB system. However, monotic ANL

(story and background noise in same ear) was correlated with dichotic ANL (story in one ear, background noise in opposite ear), implying ANL must be mediated, in part, beyond the level of the superior olivary complex where binaural processing first occurs in the auditory system.

The purpose of the current, exploratory study was to determine if individual differences in physiological activity measured from the cochleae to the peripheral and central auditory nervous systems of young female adults with normal hearing can, in part, account for the variability observed in ANL. Physiological responses from two groups of females (one with low ANLs and one with high ANLs) including CEOAEs, auditory brainstem responses (ABRs), and middle latency responses (MRLs) were obtained. Because of the exploratory nature of the study, only participants who fell within either the low or high ANL groups (Nabelek et al, this issue) were used in order to maximize visualization of group differences on physiological responses. Any differences in physiological responses between the two groups will contribute to our understanding of (1) the role the auditory system plays in the acceptance of background noise and (2) which parts of the auditory system contribute to differences in noise acceptance within a homogeneous population of young, female adults.

METHOD

Participants

Participants consisted of two groups of young female adults (20–37 years of age). Females were chosen due to previous research that reported more robust responses in females than males for the proposed measures (e.g., Onishi and Davis, 1968; Jerger and Hall, 1980; Shucard et al, 1981; McFadden, 1998). Participants not on oral contraception were tested one week prior to menses because this time has been shown to have the least effect on the ABR (Elkind-Hirsch et al, 1992). One group consisted of seven participants with low ANLs of 6 dB or less, while the second group contained six participants with high ANLs of

16 dB or greater, for a total of 13 participants.

Each participant met the following criteria: normal hearing (air-conduction thresholds of 15 dB HL or less for pure tones at 0.5, 1, 2, 3, 4, 6, and 8 kHz in both ears); normal middle-ear function (i.e., type A tympanograms with the admittance maximum at ear canal pressures between ± 30 daPa re: ambient pressure and static admittance between 0.3 and 1.4 mmhos); right-hand dominant to minimize possible hemispheric effects; no known otological, neurological, or learning deficits as reported by participants; and an ANL that fell within the range of one of the two defined groups. Fifteen participants were excluded from the study because their ANLs were between 7 and 15 dB. A written consent form was read and signed, and the University of Tennessee Institutional Review Board approved the protocols.

ANL Behavioral Procedure

The test materials and method for establishing ANL in the interview-screening session were based on the Nabelek et al (2004) procedures. Acceptance of background noise was measured in a sound-treated booth with a recording of running speech with a male voice (Arizona Travelogue, Cosmos, Inc.) as the primary stimulus and a competing stimulus of multitalker babble from the revised SPIN test (Bilger et al, 1984). The stimuli were presented from a compact disc to a Grason Stadler (GSI 61) audiometer and delivered diotically via insert earphones (Etymotic, ER-3A). Diotic presentation (versus monotic) enables comparison of current data with data collected in the sound field on normal or hearing-impaired individuals, as well as more closely approximating a "real world" listening situation (speech in the presence of background noise reaching both ears) in a laboratory setting.

To establish ANL, first, the participant's most comfortable level (MCL) was determined. The listener was given two handheld buttons to signal the examiner to adjust the volume of the speech up or down. The verbal and written instructions for measuring MCL were as follows:

You will listen to a story through headphones. 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.

The loudness level of the running speech began at 0 dB HL and was increased in steps of 10 dB until the listener indicated that it was "too loud." It was then decreased by 10 dB until the listener indicated that it was "too soft." At this point, the level of the story was adjusted up and down in 2 dB increments until the listener's MCL was found.

Once the participant's MCL was established, the speech continued at that level while the background noise was added to establish the background noise level (BNL). As with the MCL, the listener was given two handheld buttons to signal the examiner to adjust the volume of the background noise up or down. The verbal and written instructions for measuring BNL were as follows:

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 maximum level of the background noise that you would be willing to accept or "put up with" without becoming tense and tired while following the story. First, turn the noise up until it is too loud and then down until the story becomes very clear. Finally, adjust the noise (up and down) to the highest level that you would "put up with" for a long time while following the story.

The loudness level of the noise began at 0 dB HL and was increased in steps of 10 dB until the listener indicated the noise was "too loud" to accept while following the story. The level of the noise was then decreased by 10 dB until the listener indicated that the noise was soft enough that the story was "very clear." At this point, the level of the noise was adjusted up and down in 2 dB increments until the listener indicated that it had reached the highest level that could be accepted while following the story without becoming tense or tired. This level became the participant's BNL.

The ANL was calculated by subtracting the BNL from the MCL ($ANL = MCL - BNL$). The MCL and BNL procedures were repeated three times, and the average of the three ANLs was used.

Physiological Procedure

Stimulus Generation

CEOAEs were collected for condensation clicks of 100 μ sec duration at a level of 65 dB peak equivalent SPL (SPL re 20 μ Pa). This

presentation level was selected to ensure that the CEOAE responses reflected both nonlinear active (cochlear amplification) and linear passive processes in the cochlea. At levels greater than 75–80 dB SPL, cochlear amplification is overcome by passive cochlear mechanics (for review, see Pickles, 1988). The presentation rate of the clicks was nominally 10/sec, but the sound level in the ear canal was monitored continually, and no click was presented until the noise level was below a pre-established criterion value of 45–52 dB pSPL). Clicks were delivered monaurally to the right ear with an Etymotic ER-2 miniature earphone.

To more closely match the diotic presentation of the ANL stimuli and enhance the response amplitude (Jewett, 1970; Blegvad, 1975; Woods and Clayworth, 1985), binaural ABRs and MLRs were recorded simultaneously to 3000 Hz Blackman-gated toneburst stimuli of negative polarity generated with a 16-bit digital-to-analog converter (Tucker-Davis Technologies, model DA1). The gated tone bursts had rise/fall times of two cycles with no plateau (Davis et al, 1984; Gorga and Thornton, 1989). The toneburst stimuli were presented at a rate of 8.1/sec and levels of 35 dB nHL (70 dB peak SPL) and 70 dB nHL (104 dB peak SPL), for recording a “low” ABR/MLR and “high” ABR/MLR, respectively. Weekly calibrations with a sound level meter (Bruel and Kjaer, type 2230) set to “peak hold” capability and a 2-cc coupler (Zwislocki type) confirmed the accuracy of the signal level, which was kept within 1 dB peak SPL. The stimuli were delivered via electrically shielded insert earphones (Etymotic Research, model ER-3A).

Recording Procedures

CEOAEs were assessed using an Otodynamics ILO 88/92-v5 system connected to an Etymotic RA-10A microphone system. The output was fed to an analog-to-digital converter where the CEOAE waveform was digitized (with 16-bit resolution) at a sampling rate of 48,000 sample points per second. The responses to 250 clicks were averaged as follows: Beginning 4 msec after click offset, a 40 msec sample of the microphone response was collected and summed with the responses from the previous clicks in that sequence. (Data collection was delayed by 4 msec to avoid the acoustic ringing in the ear canal and the middle ear system produced by the click.) Incoming noise was updated dynamically during the recording. If the noise in the external auditory canal exceeded the pre-established rejection level of 45–52 dB p SPL,

the recording paused and resumed once the noise level dropped back below the rejection level. If the accepted number of sweeps was below 85%, the CEOAE waveform was rerecorded. CEOAEs were measured in the right ear of all participants and then replicated.

Binaural auditory evoked potentials (AEPs) were acquired with a four-channel electrode configuration using gold-plated electrodes applied to the surface of the scalp and held in place with medical tape. Electrode impedances were measured at 30 Hz, were below 5 k Ω , and were within 1 k Ω of each other. The noninverting electrodes were placed along the center of the head (C_z , C_5 , C_6), with linked reference electrodes on both ears and the ground electrode on the forehead (F_{pz}) (Jasper, 1958). Among participants, the noninverting electrodes were randomly assigned to channels one, two, and three to ensure that any differences seen between electrode recordings could not be attributed to differences between the three amplifier channels. Using the fourth electrode channel, the electro-oculogram (EOG) was measured to develop an eye-blink rejection rule for each participant. The EOG was recorded between electrodes above and below one eye and amplified (gain: 1×10^4). Artifact rejection, used to exclude samples collected during eye blinks or other muscular contractions, was set at a level equivalent to that of the smallest recorded EOG during a series of 10 blinks performed just prior to data collection. Accordingly, an artifact rejection algorithm was applied to the on-line averaging waveform. If the peak voltage within a sweep exceeded $\pm 80 \mu V$, that sweep was excluded from the averaged waveform. The ongoing average of the AEP waveform was monitored. Tucker-Davis Technologies SigGen[®] and BioSig[®] software was used for data acquisition. The AEPs were differentially amplified (gain: 2×10^5) (Tucker-Davis Technologies, model DB4) and filtered. The rejection rate of these filters was -6 dB/octave, and the bandwidth was set at 10–3000 Hz. Each response was digitized via a 16-bit analog-to-digital converter (Tucker-Davis Technologies, model AD1). A total of 1000 sweeps were presented at each recording. The sampling frequency was set at 10 kHz with a sampling window of 145 msec with a 70 msec pre-stimulus period. The sampling rate was 0.1 msec.

One ABR and MLR waveform was obtained simultaneously from each of three channels, unless a replication was needed for identification of particular components. Thus, a total of six AEP waveforms (three electrodes x two levels) per participant were acquired.

Participants were seated in a sound-treated

booth, comfortably reclined in an armchair with their heads and necks well supported. They were instructed to sit quietly but not sleep. For each participant, CEOAEs were collected first. The order of the stimulus levels (low versus high) used to acquire the AEPs was randomized across participants.

Data Analysis

For each averaged CEOAE waveform, a root mean square (rms) value was calculated in volts and then converted to dB SPL. For each participant, two SPL values (one from each replication) were averaged to summarize the mean strength of the response. The mean amplitude (expressed in dB SPL) of the CEOAEs served as the dependent variable in a one-factor analysis of variance (ANOVA). The factor was group (two levels: low ANL, high ANL).

Each ABR and MLR waveform recorded from Cz was analyzed separately using Tucker-Davis Technologies software (BioSig®). (Data from C5 and C6 are being used to investigate hemispheric differences among groups with high and low acceptance of background noise when listening to speech, a topic not addressed in the current manuscript.) All data were coded so that the experimenter was blind to each participant's name and ANL during analysis. Peaks were selected based on latencies, which were expected to fall within a certain time window (e.g., Harkrider et al, 2001; Harkrider and Champlin, 2001). ABR amplitudes (peak to following trough) and absolute latencies were measured for waves I, III, and V. MLR amplitude (peak-to-peak) was measured between waves Na and Pa, and absolute latency was measured for waves Na and Pa. If a waveform was not present, the peak-to-peak amplitude was recorded as 0 μ V, and the absence of a latency was noted. For the purpose of presentation and for comparison with the results of other studies, AEP response latencies were corrected for delays imposed during data acquisition. The length of the tubes for the insert earphone causes a 0.9 msec delay, and the four-channel amplifier/filter causes a 2 msec group delay. Thus, 2.9 msec in addition to the time between sweep onset and stimulus onset were subtracted from the raw latency values.

It should be noted that binaurally evoked ABR/MLR data may differ from traditional monaural recordings. Generally, response amplitudes are greater with binaural versus monaural stimulation (e.g., Jewett, 1970; Blegvad, 1975; Woods and Clayworth, 1985). Reports of latency differences in ABR/MLR components with binaural versus monaural

stimulation are less consistent, with some authors reporting no statistical difference (e.g., Dobie and Norton, 1980) and others finding latencies to be shorter for binaural versus monaural conditions (e.g., Kelly-Ballweber and Dobie, 1984; Woods and Clayworth, 1985).

Group differences for peak latencies and peak-to-peak amplitudes of waves I, III, and V of the ABR, and peak latencies and peak-to-peak amplitudes of Na and Pa recorded at Cz were tested with two, two-factor repeated-measures multivariate analyses of variance (MANOVA), one on peak latency and one on peak-to-peak amplitude. The factors were group (two levels: low and high ANL) and stimulus level (two levels: 35 and 70 dB nHL). The F-value from Pillais was reported as an *approximate F*. Because of the exploratory nature of the study and the conservative, multivariate statistical approach, individual ANOVAs were used to follow up on all main effects or interactions having a *p* value of 0.1 or less.

RESULTS

Behavioral

The average individual and group MCL, BNL, and ANL data are reported in Table 1. The mean ANL was 3.0 and 19.7 dB for the low and high ANL groups, respectively.

Physiological

Otoacoustic Emissions

Individual and group mean CEOAE amplitude data are displayed in Table 2. The mean CEOAE levels were 5.4 (SD = 2.4) and 6.5 dB SPL (SD = 3.9) for the low and high ANL females, respectively. A one-factor ANOVA was conducted on mean CEOAE levels. The factor was group (two levels; low versus high ANL). The ANOVA revealed no main effect of group ($F_{1,12} = 0.346, p = 0.568$).

Auditory Evoked Potentials

Mean amplitudes and latencies of ABR and MLR waves from females with low versus high ANLs are presented in Table 3. Binaural AEP responses were present for all listeners with the exception of wave I of the ABR, which was absent to the 35 dB nHL tone bursts. It is not unusual for wave I to disappear into the noise floor at such low stimulus levels (Hall,

1992). Because wave I was absent to the 35 dB nHL tone bursts, a one-factor ANOVA was conducted on wave I latency obtained with the 70 dB nHL tone burst. The factor was group (two levels). The ANOVA indicated no main effect of group ($F_{4,8} = 1.363, p = 0.328$).

The repeated measures MANOVA conducted on the latencies of waves III, V, Na, and Pa revealed no main effect for group ($F_{4,8} = 1.363, p = 0.328$). The interaction was not significant. As expected, a main effect for level was found ($F_{4,8} = 10.439, p = 0.003$). Post hoc univariate testing indicated that the latencies of waves III ($F_{1,11} = 10.599, p = 0.008$), V ($F_{1,11} = 36.193, p < 0.001$), Na ($F_{1,11} = 5.280, p = 0.042$), and Pa ($F_{1,11} = 17.144, p = 0.002$) contributed to the main effect of level reported

in the MANOVA. All latencies were longer when evoked by 35 dB nHL versus 70 dB nHL tone bursts.

The repeated-measures MANOVA conducted on the peak-to-peak amplitudes of waves I, III, V, and Na-Pa revealed a main effect for group ($F_{4,8} = 2.736, p = 0.10$) and level ($F_{4,8} = 9.827, p = 0.004$). The interaction was not significant. Post hoc univariate testing indicated that the amplitudes of waves V ($F_{1,11} = 4.381, p = 0.060$) and Na-Pa ($F_{1,11} = 3.265, p = 0.098$) contributed to the main effect of group found in the MANOVA, such that amplitudes were smaller in the females with low versus high ANLs (Figure 1). Additionally, the amplitudes of waves I ($F_{1,11} = 28.317, p < 0.001$), V ($F_{1,11} = 24.294, p < 0.001$), and

Table 1. Means and Standard Deviations (SD) for Individual and Group Data on Most Comfortable Listening Levels (MCL), Background Noise Levels (BNL), and Acceptable Noise Levels (ANL) While Listening to Speech for the Two Groups of Participants

	Participant	MCL (dB HL) Mean (SD)	BNL (dB HL) Mean (SD)	ANL (dB) Mean (SD)	
Low ANL Group (n = 7)	S1	46 (2.0)	46 (2.0)	0 (0.0)	
	S3	54 (1.5)	51 (2.5)	3 (1.2)	
	S5	50 (2.0)	47 (2.3)	3 (1.2)	
	S7	49 (1.2)	44 (0.0)	5 (1.2)	
	S8	50 (2.0)	47 (3.1)	3 (1.2)	
	S9	53 (1.2)	48 (0.0)	5 (1.2)	
	S13	49 (1.2)	47 (2.3)	2 (2.0)	
		Group Mean SD	50.0 2.7	47.1 2.1	3.0 1.7
High ANL Group (n = 6)	S2	50 (0.0)	31 (1.2)	19 (1.2)	
	S4	53 (3.1)	26 (2.0)	27 (1.2)	
	S6	50 (0.0)	29 (1.2)	21 (1.2)	
	S10	62 (2.0)	46 (3.5)	16 (2.0)	
	S11	43 (1.2)	27 (1.0)	16 (1.5)	
	S12	51 (1.2)	32 (2.0)	19 (1.2)	
		Group Mean SD	51.5 6.2	31.8 7.3	19.7 4.1

Table 2. Individual and Mean CEOAE Amplitudes (dB SPL) for the Two Replications in Females with Low and High ANLs

	Participant	Replication 1	Replication 2	Mean	
Low ANL Group (n = 7)	S1	4.8	4.7	4.8	
	S3	2.8	2.0	2.4	
	S5	7.5	8.2	7.9	
	S7	9.0	9.2	9.1	
	S8	3.5	3.0	3.3	
	S9	5.3	4.5	4.9	
	S13	5.8	4.8	5.3	
		Group Mean Standard Deviation	5.5 2.2	5.2 2.6	5.4 2.4
High ANL Group (n = 6)	S2	10.7	11.5	11.1	
	S4	6.8	6.9	6.9	
	S6	10.9	11.7	11.3	
	S10	5.5	5.2	5.4	
	S11	4.1	3.7	3.9	
	S12	0.5	0.1	0.3	
		Group Mean Standard Deviation	6.4 3.6	6.5 4.1	6.5 3.9

Na-Pa ($F_{1,11} = 18.387, p = 0.001$) contributed to the main effect of level reported in the MANOVA. Amplitudes were smaller when evoked by 35 dB nHL versus 70 dB nHL tone bursts. Representative ABR and MLR tracings from two females (one with a low ANL and one with a high ANL) are displayed in Figure 2.

DISCUSSION

Aggregate responses from the cochlea to the cortex were measured to determine if, and at what level, differences in physiologic activity exist from females with normal hearing with low versus high ANLs. Conclusive interpretations of the data are limited somewhat by the exploratory nature of the study, which precluded fine-tuned, extensive measures at a given level of the auditory system. Moreover, the sample population was relatively small in comparison to the number of dependent variables analyzed, decreasing the statistical power of the study. Thus, a larger sample size may reveal group differences in components that were not found to be significantly different in this preliminary

report, as well as larger group differences for components that were found to be significant (e.g., Tampas and Harkrider, 2006). That said, both qualitatively and quantitatively, trends in the data indicate that differences between the two groups of females were lacking in responses generated at the level of the cochlea, 8th nerve, or lower brainstem but emerged in responses produced by more central regions of the auditory nervous system (Figure 1). Specifically, no differences between the groups were found in CEOAE amplitudes or in the amplitudes or latencies of waves I or III of the ABR. However, group differences were found in the amplitudes of wave V of the ABR and Na-Pa component of the MLR.

The lack of differences for the mean OAE amplitudes between the low and high ANL groups indicates that differences in cochlear activity are not contributing to intersubject variability in ANL. Previous investigations have reported ANL distributions that are similar between populations with normal hearing and hearing impairment (e.g., Nabelek et al, 1991; Rogers et al, 2003; Nabelek et al, 2004). Furthermore, ANL distributions are similar between hearing-impaired populations

Table 3. Means and Standard Deviations (in parentheses) for AEP Latencies (msec) and Peak-to-Peak Amplitudes (μ V) from Cz to 3000 Hz Tone Bursts at 35 and 70 dB nHL in Females with Low and High ANLs

Latencies of AEP components (msec)			
Wave	Group	Binaural 3000 Hz tone burst	
		35 dB nHL	70 dB nHL
I	Low ANL	NP	1.5 (1.73)
	High ANL	NP	1.6 (0.8)
III	Low ANL	4.6 (0.47)	3.8 (1.00)
	High ANL	4.9 (1.23)	3.9 (0.49)
V	Low ANL	7.0 (0.27)	6.0 (0.12)
	High ANL	6.8 (0.87)	5.9 (0.21)
Na	Low ANL	17.9 (2.82)	16.6 (0.94)
	High ANL	17.9 (1.75)	16.8 (1.10)
Pa	Low ANL	26.0 (0.92)	24.6 (1.60)
	High ANL	27.6 (2.79)	25.5 (1.80)
Amplitudes of AEP components (μ V)			
Wave	Group	Binaural 3000 Hz tone burst	
		35 dB nHL	70 dB nHL
I	Low ANL	0.00 (0.00)	0.14 (0.08)
	High ANL	0.00 (0.00)	0.10 (0.05)
III	Low ANL	0.05 (0.34)	0.10 (0.08)
	High ANL	0.12 (0.09)	0.11 (0.05)
V	Low ANL	0.33 (0.14)	0.62 (0.15)
	High ANL	0.69 (0.40)	0.89 (0.37)
Na-Pa	Low ANL	0.65 (0.23)	1.09 (0.32)
	High ANL	1.11 (0.52)	1.45 (0.64)

Note: NP = Not present.

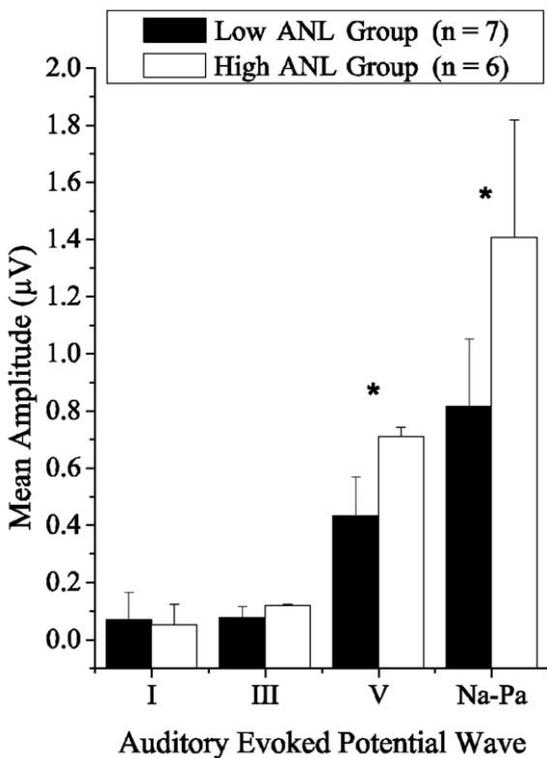


Figure 1. Mean amplitudes of ABR waves I, III, and V and MLR wave Na-Pa for females with low (mean = 3.0 dB) versus high (mean = 19.7 dB) ANLs. Error bars denote one standard deviation from the mean. The asterisk indicates a main effect of group at $p < 0.1$. Data are recorded from Cz.

with versus without amplification (Nabelek et al, 2004). Cumulatively, these findings suggest that background noise acceptance is not influenced by the status of the peripheral auditory structures (i.e., cochlear hearing loss) or by habilitation with amplification devices.

A lack of group differences in the amplitudes and latencies of waves I and III of the ABR in the current study suggest that, like the cochlea, activity at the level of the 8th nerve and cochlear nucleus, respectively (Moller and Janetta, 1982; Moller and Janetta, 1983), also does not influence ANL. Wave V is thought to be generated in the superior olivary complex, the lateral lemniscus, and the inferior colliculus (Moller and Janetta, 1983); wave Na from the inferior colliculus (Hashimoto, 1982) and temporal lobe (Jacobson et al, 1990); and Pa primarily from the auditory thalamo-cortical projections and cortex (Kraus et al, 1982; Woods et al, 1987). Thus, group differences in the amplitudes of waves V and Na-Pa indicate that differences in activity levels of successive nuclei from the upper brainstem to the temporal lobe may account for dissimilarities

in acceptance of background noise while listening to speech. Consistent with this, Harkrider and Smith (2005) found that the amount of background noise listeners were willing to accept while listening to speech in a monotic condition correlated with the amount of background noise they were willing to accept while listening to speech in a dichotic condition, suggesting that ANL is mediated at a level beyond the superior olivary complex where binaural processing begins.

Interestingly, females with low ANLs (i.e., greater background noise acceptance) had smaller amplitude wave V and Na-Pa peaks relative to females with high ANLs (i.e., lower background noise acceptance). Smaller amplitudes and longer latencies of various

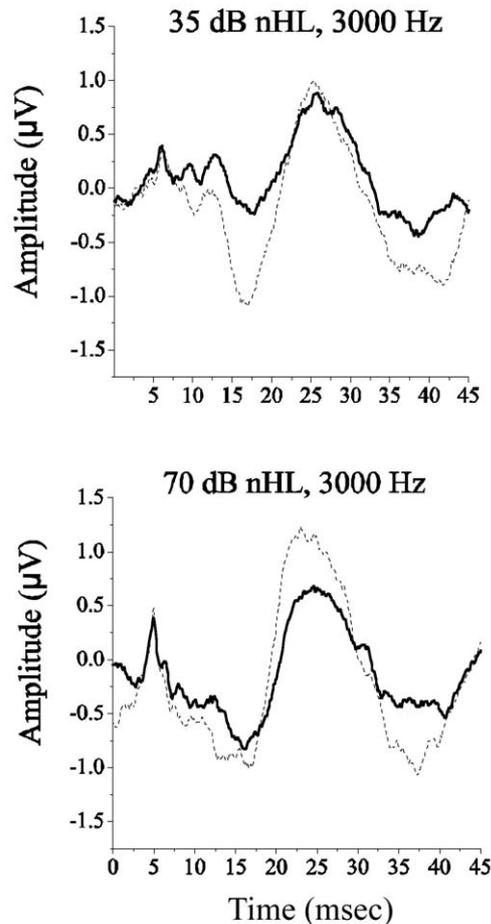


Figure 2. Representative ABR and MLR waveforms for a female participant from each ANL group (solid = low ANL; dashed = high ANL). Note: In order to better visualize the ABR and MLR on the same graph, the time window of the responses has been truncated to 0–50 msec, excluding EEG data from pre-stimulus and post-MLR time frames. Data are recorded from Cz.

AEP components are indicative of less efficient afferent transmission while larger amplitudes and shorter latencies are indicative of more efficient afferent transmission (e.g., Ahveninen et al, 1999; Harkrider et al, 2001; Lei-Zhang et al, 2001). Due to the far-field nature of recordings obtained from human participants, it is impossible to pinpoint the exact neural populations or physiologic factors that determine response amplitude. However, it is known that transmembrane ionic current flow of a neuron creates the voltage potentials that underlie AEPs. Transmembrane current flow is linked to an action potential traveling along the axon of a neuron. This positive voltage potential forms the leading edge of propagated neural transmission and flows in a peripheral to central direction (for review, see Hall, 1992). AEP latencies reflect conduction time of action potentials through the system, with shorter latencies indicative of faster conduction time. AEP amplitudes reflect CNS excitability, with larger AEP amplitudes indicating heightened excitation, resulting from greater depolarization and increased production of action potentials.

In the current study, therefore, the smaller amplitude AEPs found in females with low versus high ANLs likely reflect a lesser amount of neuronal depolarization and action potential generation in the neural populations responsible for generating the wave V and Na-Pa responses. This could be caused by either less efficient afferent, excitatory pathways or inhibitory actions upon the afferent neurons by more active central efferent mechanisms. Thus, one might speculate that (1) central efferent mechanisms are stronger in the group with low ANLs such that sensory inputs are suppressed more than in the high ANL group and/or (2) that central afferent mechanisms are enhanced in the high ANL group. This is in agreement with electrophysiologic studies reporting enhanced AEPs to be indicative of increased central nervous system (CNS) excitability and the reduced capacity for inhibition (Ahveninen et al, 1999; Harkrider and Champlin, 2001; Harkrider et al, 2001; Lei-Zhang et al, 2001).

Determining the levels and functions of the auditory system that are associated with low versus high ANLs will contribute to our understanding of the processes underlying this behavioral phenomenon and could have important clinical implications. Nabelek et al (this issue) report that individuals with hearing impairment who have low ANLs are likely to be successful hearing-aid users. Thus, strategies to decrease an individual's ANL could increase his/her chances of benefiting from amplification. Based on the preliminary

data from this study, influencing more central regions of the auditory system, perhaps by pharmacological intervention (e.g., Freyaldenhoven et al, 2005) or auditory retraining therapy, may prove to be the most effective rehabilitative approach.

Future research on the identification of physiological variables contributing to differences in background noise acceptance should focus on AEPs from levels of the central auditory nervous system beyond the lower brainstem (e.g., Tampas and Harkrider, 2006). Varying the levels and frequencies of the stimuli used to evoke the AEPs should shed some light on whether differences between the two groups of females are due to stronger auditory afferent activity, weaker auditory efferent activity, or both. Additionally, extending the participant pool to include males and individuals with hearing impairment is necessary before generalizing the findings of this study to those populations.

CONCLUSIONS

The goal of this exploratory study was to investigate the possibility that differences in judgment of background noise exhibited among individuals may be due to differences in physiological activity in the auditory system. Aggregate physiological responses from two groups of females with normal hearing (one with low ANLs and one with high ANLs), including OAEs, ABRs, and MLRs, were obtained. No differences were found between the groups for CEOAEs or waves I or III of the ABR. However, differences between the groups were reported for the amplitudes of wave V of the ABR ($p = 0.06$) and Na-Pa of the MLR ($p = 0.098$), with more robust responses obtained from females with high versus low ANLs. These preliminary data suggest that (1) more central regions of the auditory system may account for variability in listeners' willingness to accept background noise and (2) central efferent mechanisms may be stronger or central efferent mechanisms may be weaker in females with low versus high ANLs. Due to the exploratory nature of this study, these findings need to be replicated in a larger group of participants.

Acknowledgments. The authors would like to thank Drs. Anna K. Nabelek, Samuel B. Burchfield, Patrick N. Plyler, James W. Thelin, and their anonymous reviewers for comments on earlier drafts of this manuscript.

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