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ACCEPTABLE NOISE LEVELS AND ELECTROPHYSIOLOGICAL
MEASURES IN LISTENERS WITH HEARING IMPAIRMENT

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Abstract

Acceptable noise level (ANL) is a measure of a listener's acceptance of background noise when listening to speech. A consistent finding in research on ANL is large intersubject variability in the acceptance of background noise. This variability is not related to age, gender, hearing sensitivity, type of background noise, speech perception in noise performance, cochlear responses, or efferent activity of the medial olivocochlear bundle pathways. Moreover, across ANL studies, young and elderly individuals with both hearing impairment and normal-hearing sensitivity display equivalent means and ranges for ANLs, indicating that acceptance of background noise may be an inherent characteristic of the individual that does not change with age, or the development of hearing loss. In the present study, auditory evoked potentials and encephalography (EEG) were examined in 40 adults with mild-to-moderately-severe sensorineural hearing impairment with low, mid-range, and high ANLs to determine whether or not differences in judgments of background noise are related to differences measured in aggregate physiological responses from the auditory nervous system. Group differences in the auditory brainstem response, auditory middle latency, cortical, auditory late latency, and EEG responses indicate that differences in more central regions of the nervous system contribute to the variability in the willingness of a listener with hearing impairment to accept background noise when listening to speech.

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INTRODUCTION

Hearing loss is one of the most prevalent chronic health conditions in the United States, affecting people of all ages, in all segments of the population, and across all socioeconomic levels. There are over 28 million Americans with hearing loss, 10% of the US population [National Institute on Deafness and Other Communication Disorders (NIDCD), 1996]. One of the most common complaints among individuals with sensorineural hearing impairment is the inability to follow speech in the presence of background noise (Plomp, 1978; Dubno, Dirks, and Morgan, 1984; Festen and Plomp, 1990; Souza and Turner, 1994; Needleman and Crandell 1995; Killion, 1997). The treatment of choice for these complaints and most types of hearing loss is hearing aids. Despite scores of recent technological advances in hearing aids, a major complaint of many hearing-aid users continues to be difficulty listening in background noise (Kochkin 2002 a, b; Cord, Surr, Walden, and Dyrland, 2004). These problems contribute to frustration with, and an underutilization of, hearing aids. The NIDCD reports that only one out of five people who could benefit from a hearing aid actually wears one (1996). Furthermore, it is estimated that 16-30% of hearing aids that are issued in the United States are not used (Popelka, Cruikshanks, Wiley, et al., 1998; Kochkin, 2000a). These issues have prompted the investigation of various methods to predict hearing-aid outcome (Cox and Gilmore, 1990; Crowley and Nabelek 1996; Cox and Alexander, 2000; Hosford-Dunn and Halpern, 2000, 2001; Humes, 2003; Walden and Walden, 2004). This research has provided valuable insight into subjective satisfaction and benefit, but has not produced an accurate method of predicting success with hearing aids.

Despite the fact that difficulty understanding speech in the presence of background noise is a frequent complaint of hearing-aid users, speech perception performance in background noise does not accurately predict whether an individual will become a successful or unsuccessful hearing-aid user (Bentler, Niebuhr, Getta, and Anderson, 1993; Humes Halling, and Coughlin, 1996; Nabelek, Tampas, and Burchfield, 2004). This paradox led Nabelek, Tucker, and Letowski (1991) to investigate the hypothesis that an individual's willingness to listen to speech in background noise is more indicative of hearing-aid use than speech discrimination in background noise.

Nabelek et al. (1991) developed a procedure to quantify the maximum amount of background noise that listeners are willing to accept while listening to speech. In this procedure, the listener adjusts the background noise level (BNL) to the highest intensity they deem acceptable while listening to and following the words of a recorded story at their most comfortable listening level (MCL). This measure, which has become known as acceptable noise level (ANL), evaluates the willingness of an individual to accept noise while listening to speech (Nabelek et al., 2004). ANL is computed by subtracting the maximum acceptable background noise level from the speech presentation level (e.g., $ANL = MCL - BNL$). Therefore, individuals with low ANLs (e.g., 6 dB) are willing to accept larger amounts of background noise than individuals with high ANLs (e.g., 16 dB). It is reported that, on average, successful hearing-aid users accept more background noise (i.e., have lower ANLs) than unsuccessful hearing-aid users, and that ANL predicts hearing-aid outcome with 85% accuracy (Nabelek, Freyaldenhoven, Tampas, Burchfield, and Muenchen, 2006).

Listeners' reactions to background noise are not uniform. Investigations of ANL have attempted to identify the variables contributing to the wide range of differences exhibited among individuals in their acceptance of background noise. Although ANLs have been found to be highly reliable within and between test sessions in individuals (Nabelek et al., 2004), studies report large between-subject differences in the acceptance of background noise among homogeneous populations. These investigations have failed to explain the large range of ANLs on the basis of age, hearing sensitivity (Nabelek et al., 1991), amplification with hearing aids (Nabelek et al., 2004), gender (Rogers, Harkrider, Burchfield, and Nabelek, 2003), type of background noise (Nabelek et al., 1991, Crowley and Nabelek, 1996), cochlear responses (Harkrider and Smith, 2005; Harkrider and Tampas, 2006), efferent activity of the medial olivocochlear bundle pathway, middle ear characteristics (Harkrider and Smith, 2005), and speech perception in noise performance (Nabelek et al., 2004). Moreover, across ANL studies, young and elderly individuals with both hearing impairment and normal-hearing sensitivity display the equivalent means and ranges for ANLs, indicating that acceptance of background noise may be an inherent characteristic of the individual that does not change with age, or the development of hearing loss.

Previous research suggests that differences in background noise acceptance may be related to individual variations in the afferent and/or efferent function of the central auditory nervous system (CANS), as measured with auditory evoked potentials (AEPs) (Harkrider and Smith, 2005; Harkrider and Tampas, 2006; Tampas and Harkrider, 2006). Studies in young females with normal hearing indicate that central regions of the auditory

nervous system account for, at least in part, the large variability in listeners' willingness to accept background noise. Specifically, females with low ANLs (i.e., greater background noise acceptance) exhibit smaller amplitudes and longer latencies in select AEP components relative to females with high ANLs (i.e., lower background noise acceptance) (Harkrider and Tampas, 2006; Tampas and Harkrider, 2006). In addition, the presentation level of the stimuli has been shown to interact with ANL group to influence behavioral judgments of background noise acceptance, as well as AEPs when measured from females with low versus high ANLs. As speech presentation level increases, females with low ANLs demonstrate a slower rate of ANL growth than females with high ANLs. Furthermore, females with low ANLs exhibit less of a decrease in latency with an increase in stimulus level for waves III and V of the auditory brainstem response (ABR) than females with high ANLs. These results are consistent with reduced responsiveness in the afferent auditory nervous system, or greater inhibitory activity from the central efferent system of individuals with low ANLs as compared to high ANLs. It may also be the case that both the afferent and efferent pathways are involved resulting in decreased excitatory and increased inhibitory response in the low versus high ANL groups.

The physiological data in young females with normal hearing support the theory that acceptance of background noise is mediated from central regions of the auditory system. The electroencephalograph (EEG) may prove to be a useful technique in distinguishing the physiological mechanisms underlying differences in acceptance of background noise exhibited among individuals. EEG measures the spontaneous electrical

activity produced by the cerebral cortex in the absence of sensory stimuli; thereby it is a more direct measure of cortical activity than AEPs which have multiple cortical and subcortical generators. Furthermore, EEG records complex patterns of neural activity occurring within seconds that may be masked by the averaging processes used to acquire AEPs that occur over a matter of minutes (Norton, Brown, and Howard, 1992). Quantitative EEG utilizes Fast Fourier Transformation (FFT) techniques to break down complex brain waves into their constituent components to examine how the different frequency bands compare among groups in power/amplitude. A deficiency, excess, or abnormal distribution of these frequencies may account for changes in sensory processing and/or performance and may prove to be a useful technique in understanding the physiological characteristics contributing to differences in acceptance of background noise exhibited among individuals; however, this possibility has not been explored.

To date, the evidence for central mediation of background noise acceptance has been documented primarily in young normal-hearing females with extreme ANL values. Considering the accuracy with which ANL predicts successful hearing-aid outcome, an understanding of the physiological characteristics contributing to background noise acceptance in listeners with hearing impairment is essential for the development of auditory habilitation/rehabilitation strategies and may have important implications for the prescriptive hearing-aid test battery of a patient. In addition, the lack of ANL differences reported between young and elderly individuals with both normal hearing sensitivity and hearing impairment suggest that similar processing mechanisms are present among the groups. Furthermore, listeners with the most commonly occurring ANL values (7- 13

dB) have not been included in physiological investigations of ANL. Research also has been unable to distinguish the mid-range ANL group from the high ANL group. For example, ANLs for full-time hearing-aid users are significantly smaller than ANLs for part-time and non-users, but ANLs for part-time and non-users are not significantly different from each other (Nabelek et al. 2004, 2006; Freyaldenhoven, Plyler, Thelin, and Muenchen., 2006); this point has led researchers to collapse the part-time (mid-range ANLs) and non-users (high ANLs) into one “unsuccessful” group. Therefore, physiological investigations incorporating the mid-range ANL group may aid in the differentiation of the part-time and non-user hearing-aid groups. Including listeners with impaired hearing and mid-range ANLs in the current study may further elucidate the neurophysiologic mechanisms contributing to acceptance of background noise.

The aim of the current study was to examine differences in the physiological responses of hearing-aid users with mild-to-moderately-severe sensorineural hearing impairment who fell into the following three groups: 1) Low ANL group (ANLs ≤ 6 dB), 2) Mid-range ANL group (ANLs = 7 - 13 dB); 3) High ANL group (ANLs ≥ 14 dB). The following research questions were addressed:

- 1) Are differences in peak-to-peak amplitudes and absolute latencies of waves I, III, and V of the ABR, waves Na and Pa of the auditory middle latency response (MLR), and waves P1, N1, and P2 of the cortical, auditory late latency response (LLR) exhibited among the groups?
- 2) Are the behavioral and physiological responses of these groups differentially affected by the presentation level of the stimuli?

3) Do these groups exhibit differences in EEG activity?

Based on data from normal-hearing females, it is hypothesized that the low ANL group will have smaller amplitude and longer latency ABR, MLR, and LLR peaks, and decreased slow-wave and increased fast-wave EEG activity relative to the mid-range and high ANL groups. Next, the mid-range ANL group is hypothesized to have smaller amplitude and longer latency ABR, MLR, and LLR peaks, and decreased slow-wave and increased fast-wave EEG activity relative to the high ANL group. This pattern of responses could be indicative of reduced responsiveness in the afferent auditory nervous system and/or greater inhibitory activity from the central efferent system in the low ANL group versus the mid-range and high ANL groups. Furthermore, if low ANLs are associated with less responsive afferent auditory nervous systems and/or greater inhibitory activity from the central efferent system, it is predicted that increases in presentation level will cause less of an increase in AEP amplitudes and less of a decrease in AEP latencies in groups with low versus high ANLs. Accordingly, it is expected that ANL growth rate will not be as steep in individuals with low versus mid-range or high ANLs.

The overall objective of this research was to identify physiological differences contributing to the large range of ANLs observed in listeners with hearing impairment. This may aid in the development of appropriate strategies to increase listeners' acceptance of background noise, thus improving their chances of becoming successful hearing-aid users.

REVIEW OF LITERATURE

Acceptable Noise Level

Nabelek et al. (1991) developed a procedure to quantify an individual's willingness to listen to speech in the presence of background noise. Initially called allowable signal-to-noise ratio, this method is currently referred to as acceptable noise level (ANL) (Nabelek et al., 2004). In this procedure, listeners adjust the background noise level (BNL) to the highest intensity they deem acceptable while listening to and following the words of a recorded story at their most comfortable listening level (MCL). ANL is calculated by subtracting the maximum acceptable BNL an individual is willing to accept from the speech presentation level (e.g., $ANL = MCL - BNL$, in dB). Therefore, individuals with low ANLs (e.g., 6 dB) are willing to accept larger amounts of background noise than those with high ANLs (e.g., 16 dB).

Nabelek et al. (1991) examined the relationship between hearing-aid use and toleration of background noise in young and elderly listeners with normal and impaired hearing using different types of background noise in the measurement of ANL. For the impaired hearing groups, pattern of hearing-aid use was defined as follows: 1) full-time users who wore their hearing aids whenever they needed them, 2) part-time users who wore their hearing aids occasionally, and 3) non-users who had completely stopped wearing their hearing aids. ANLs for full-time hearing-aid users (mean = 7.5 dB) were significantly lower than part-time (mean = 14.0 dB) and non-users (mean = 14.5 dB); however, there was no difference between ANLs obtained from part-time and non-users. These findings signify that although ANLs were not related to age, hearing status, or type

of background noise, they were related to patterns of hearing-aid use. Subsequent studies have validated the Nabelek et al. (1991) results suggesting that ANL may have the ability to predict hearing-aid outcome (Lytle, 1994; Crowley, 1994; Crowley and Nabelek, 1996; Nabelek et al., 2004, 2006; Freyaldenhoven, Plyler, Thelin, and Hedrick, in press), acceptance of noise is not related to age (Freyaldenhoven and Smiley, 2001; Nabelek et al., 2006; Freyaldenhoven, Plyler, Thelin, and Hedrick, in press), hearing sensitivity (Nabelek et al., 2004, 2006) and ANLs are not dependent on type of noise distraction (Freyaldenhoven and Smiley, 2006).

The ability of ANL to predict hearing-aid outcome was established by Nabelek et al. (2006) in the investigation of hearing-aid users divided into three groups based on self-reported patterns of hearing-aid use: full-time, part-time, or non-use (see Appendix A for the pattern of hearing-aid use questionnaire). Results demonstrated that ANLs were not related to individual subject characteristics (e.g., age, gender, audiometric configuration) or speech in noise scores. ANLs were, however, related to hearing-aid use. Specifically, full-time hearing-aid users accepted more background noise (Mean ANL = 7.5 dB) than part-time (Mean ANL = 13.3 dB) or non-users (Mean ANL = 14.5 dB), but part-time and non-users could not be differentiated. Thus, a predictive model of hearing-aid outcome was determined by combining part-time and non-users into one group (redefined as unsuccessful hearing-aid users) and comparing them to the full-time users (redefined as successful hearing-aid users). Logistic regression analysis determined that unaided ANLs could predict success with hearing aids with 85% accuracy.

ANLs observed in older adult listeners with normal and impaired hearing range

from 0 dB to 37 dB (Nabelek et al., 1991; Nabelek et al., 2004, 2006). Similarly, the range observed for younger adult listeners with normal hearing is -3 dB to 27 dB (Rogers et al., 2003; Harkrider and Tampas, 2006; Tampas and Harkrider, 2006). In an attempt to explain the large range of variability observed in the acceptance of background noise, investigations have also focused on relating ANL to other factors. Studies determined that acceptance of noise is not related to gender (Rogers et al. 2003; Freyaldenhoven and Smiley, 2006), preference for background noise (Freyaldenhoven, Smiley, Muenchen, and Konrad, 2006), or native-language patterns (von Hapsburg and Bahang, 2006).

To obtain a further understanding of acceptance of noise, several investigators (Franklin et al., 2006; Tampas and Harkrider, 2006; Freyaldenhoven, Plyler, Thelin, and Muenchen, in press) have measured ANL to speech stimuli presented at various presentation levels (range: 20 dB HL to 80 dB HL) in addition to MCL, which is conventionally used. The results have generally demonstrated that as speech presentation level increases, the level of acceptable background noise decreases, resulting in increased ANLs. However, this change in ANL with increasing speech presentation level is not the same among the listeners. Individuals with low ANLs tend to have a slower rate of growth in ANLs with increases in speech presentation level than individuals with high ANLs (Tampas and Harkrider, 2006).

There is a body of non-physiological research that has proposed ANL is influenced by factors beyond the peripheral auditory system. Madix and Plyler (2005) measured ANLs with speech and background-noise stimuli that were low-pass (2, 4, and 6 kHz) and notch filtered (0.5 to 1 kHz, 1 to 2 kHz, 2 to 4 kHz, and 4 to 6 kHz). The

results revealed that manipulation of acoustic stimuli does not significantly affect ANLs, leading the authors to suggest that acceptance of background noise is not mediated at the level of the peripheral auditory system. More convincingly, Freyaldenhoven, Thelin, Plyler, Nabelek, and Burchfield (2005) examined the effect of stimulant medication on acceptance of background noise in young adults with attention deficit/hyperactivity disorder (ADHD). Methylphenidate is the primary medication used to treat ADHD and is a central nervous system (CNS) stimulant. The results demonstrated that the medication significantly increases the listeners' willingness to accept background noise (i.e., decreased ANLs). This not only suggests that acceptance of noise can be manipulated with the use of pharmacological intervention but is further indication that ANL is influenced by more central auditory structures.

At the same time that these behavioral studies were being conducted, the relations between an individual's willingness to accept noise and physiological responses arising from the peripheral to the central auditory system were being investigated (Harkrider and Smith, 2005; Harkrider and Tampas, 2006; Tampas and Harkrider, 2006). Results of each of these studies were consistent with a more centrally-mediated influence on ANL. However, before reporting the findings of these studies in detail, an overview of the physiological responses assessed, the anatomic structures believed to generate these responses, and their contributions to human behavior is warranted.

Relations Between Physiological Measures of the Auditory System and ANL

Physiologic Measures of the Auditory System

Otoacoustic emissions (OAEs), auditory evoked potentials (AEPs) and electroencephalography (EEG) are useful techniques that allow gross measurement of the peripheral and central auditory systems, detected by measuring sound pressure levels in the outer ear and by placing electrodes on the scalp. OAEs are very low-level, narrowband acoustic signals found in the external auditory canal (EAC) that are thought to be a by-product of non-linear mechanical activity of the outer hair cells within the cochlea (i.e., cochlear amplifiers) (Davis, 1983). These sounds may occur spontaneously or in response to acoustic stimulation and are measured using a sensitive probe-microphone assembly placed in the EAC (for review, see Robinette and Glatcke, 1997). Investigators have demonstrated that presenting sound to the ear results in a decrease in the amplitude of OAEs (e.g., Collet, Kemp, Veuillet et al., 1990; Tavartkiladze, Frolenkov, Kruglov, and Artamasof, 1997). This phenomenon is called OAE suppression and is mediated through the medial olivocochlear (MOC) system (Kujawa, Glatcke, Fallon, and Bobbin, 1993; Warren and Liberman 1989). Several studies have provided evidence that activation of the medial efferents serves a protective function in the auditory periphery against high-level auditory stimuli. For example, the MOC system has been implicated in protecting the ear from acoustic injury: stimulation of the MOC bundle (MOCB) reduces temporary threshold shifts (TTSs) (for review, see Rajan, 1991), and severing the MOCB increases permanent threshold shifts (PTSs) (Kujawa and Liberman, 1997).

The auditory brainstem response (ABR) is a type of AEP consisting of a series of waveforms occurring approximately 1-7 ms following the onset of a transient stimulus. Typically, five to seven peaks are observed in a human scalp recording. These successive peaks are described relative to their absolute latencies and designated by roman numerals (I-VII), with the most prominent being waves I, III, and V (Hall, 2007). Although the exact generators of the ABR are not completely understood, approximations of its generation have been given. Wave I has been confirmed to be generated by the peripheral portion of the auditory nerve (Chiappa, 1997), while wave II is thought to be generated by the intracranial portion of the auditory nerve (Hashimoto, Ishiyama, Yoshimoto, and Nemoto, 1981). Other studies suggest that wave III is generated in the cochlear nucleus (Moller and Janetta, 1983), while wave IV is believed to arise from the superior olivary complex (SOC) (Moller, Jho, Yokoto, and Janetta, 1994). Wave V of the ABR is thought to be generated in the tracts of the lateral lemniscus, particularly those contralateral to the stimulated ear (Moller and Janetta, 1983).

The middle-latency response (MLR) is composed of a series of negative and positive peaks (Na, Pa, and Nb) that occur within approximately 10-75 ms of stimulus onset and immediately following the ABR (Picton, Hillyard, Krausz, and Galambos, 1974; Jerger, Oliver, and Chmiel, 1988). Researchers have identified the underlying neuronal generators of wave Na (the first negative peak occurring at approximately 18ms) to include contributions from the inferior colliculi (Hashimoto, 1982), temporal lobe (Jacobson, Privitera, Neils, Grayson, and Yeh, 1990), and possibly other subcortical generators. The Pa waveform is the most constant and reliable component of the MLR

(Deiber, Ibanez, Fischer, Perrin, and Mauguiere, 1988; Krauss and McGee, 1988; Tucker and Ruth, 1996), occurring as a positive deflection at approximately 25 to 30 ms post-stimulus onset (Picton et al., 1974; Moller, 1994). The Pa component has been found to originate from portions of the primary auditory pathway, including both cortical and subcortical structures and probably represents the auditory projections from the thalamus to the auditory cortex. The generators of the Nb component are less clear, however, and appear to also result from contributions of the reticular activating system and other multi-sensory structures outside the primary auditory pathway. Therefore, it is affected by a subject's level of arousal and attention and not present as consistently as waves Na and Pa.

The cortical, auditory late latency response (LLR) occurs within 300 ms after stimulus onset. Typically, three to four peaks in a human scalp recording are reported in the literature and named by their polarity and sequence: P1 (sometimes labeled as Pb of the MLR), N1, P2, and N2. LLR generators include the primary auditory cortex, auditory association areas, the frontal cortex, and subcortical areas (for review, see Stapells, 2002). The LLR is referred to as an obligatory response because it is primarily determined by the physical properties of the stimulus. However, the later components of the LLR are affected by both arousal level and attention and therefore should be recorded when the subject is awake and alert (Hall, 2007). N1 and P2 are reported to be the most stable waves of the LLR with peak latencies of approximately 100 ms and 175 ms, respectively (Näätänen and Picton, 1987).

The EEG measures the spontaneous electrical activity produced by the cerebral cortex in the absence of sensory stimuli. The EEG waveform reflects states of attention, sleep, arousal, and various other conditions of the CNS (Kandel, Schwartz, and Jessell, 2000). The greatest advantage of EEG is that it can record complex patterns of neural activity occurring within seconds that may be masked by the averaging processes used to acquire AEPs that occur over a matter of minutes (Norton, Brown, and Howard, 1992). The EEG waveforms are analyzed using a Fast Fourier Transformation (FFT), which quantifies the power/amplitude at each frequency and expressed as the power spectrum (Thatcher, 1998). The normal human EEG shows activity over the range of 1-30 Hz with amplitudes in the range of 20-100 μ V. The observed frequencies are divided into several groups: delta (0.5-4 Hz), theta (4-7 Hz), alpha (8-13 Hz), beta (14-30 Hz), and gamma (31-70 Hz). Delta and theta waves are normal during drowsiness and early slow-wave sleep and have the largest amplitudes of all EEG waves. Alpha waves of moderate amplitude are typical of relaxed wakefulness and are most prominent over the parietal and occipital electrode sites. The typical EEG of the awake adult is primarily composed of lower-amplitude beta activity and is characterized by an irregular pattern (Kandel et al., 2000). Gamma rhythms appear to be involved in higher mental activity, including perception, and seem to be associated with consciousness (e.g., it disappears with general anesthesia). A deficiency, excess, or abnormal distribution of these frequencies reflect changes in sensory processing and/or performance. For example, the human brain uses 13 Hz (high alpha or low beta) for "active" intelligence. Often individuals who exhibit learning disabilities and attention problems having a deficiency of 13 Hz activity in

certain brain regions that effect the ability to easily perform sequencing tasks and math calculations (Klimesch, 1999). Relationships have been found between EEG and behavior, personality factors, mental disorders (e.g., Gale and Edwards, 1986; Smit, Eling, and Coenen, 2004), and pharmacological effects (e.g., Harkrider and Champlin, 2001).

Physiological Contributions to Behavior

The human brain provides both inhibitory and excitatory input to maintain performance in various types of tasks by means of waves of neuronal hyperpolarization and depolarization. At synaptic junctions, these actions trigger the release of neurotransmitters to exert one of two effects on post-synaptic membranes: excitation, which decreases membrane thresholds and increases the probability of neuronal firing or inhibition, which raises membrane thresholds and decreases the probability of neuronal firing (for review, see Kandel et al., 2000). These processes result in a progressive and sequential order of informational processing along the auditory afferent pathways, from the auditory nerve to the cerebral cortex. These ascending pathways are reciprocally connected, meaning that the auditory system is rich in efferent, descending projections. Therefore, the function of a given auditory nucleus can be influenced by feedback from higher auditory nuclei, ultimately the auditory cortex. AEP and EEG measures can be employed to describe shifts in the balance between neural excitation and inhibition (e.g., Ashmore, 1991; McDowd and Fillion, 1992; Dustman, Emmerson, Shearer, 1996; Chao and Knight, 1997; Knight, Staines, Swick, and Chao, 1999; Lei-Zhang, Cohen, Porjesz, and Begleiter, 2001).

Inhibition is a major component of selective attention and is manifested in the suppression of task-irrelevant stimuli. The process of selective attention is one in which an individual “selectively attends to some stimuli, or aspects of stimuli, in preference to others” (Kahneman, 1973), and is a vital component of one’s ability to function in the environment. There are numerous studies emphasizing the important role the cortex plays in this ability to effectively suppress stimuli that are not relevant to the task at hand (e.g., Glosser and Goodglass; 1990; Knight et al., 1999; Reuckert and Grafman, 1996; Stern, Sherman, Kirchhoff, and Hasselmo, 2001). Reviews of literature in cognitive functioning emphasize that individual differences in behavioral performance might best be explained by underlying differences in cortical inhibition (e.g., Dempster, 1992; Harnishfeger and Bjorkland, 1994). Furthermore, electrophysiologic studies interpret enhanced EEG and AEP responses to be indicative of increased brain excitability or a reduced capacity for inhibition, relative to controls (Ahveninen, Jaaskelainen, Pekkonen et al., 1999; Lei-Zhang et al., 2001).

Variability among listeners in their willingness to listen in background noise may be due to their ability to perceive sensory input. Neurophysiological augmentation/reduction is a phenomenon defined as the systematic translation of sensory input: individuals who are “augmenters” amplify their perceptions, while “reducers” subjectively attenuate or dampen them. Petrie (1967) originally posed this theory in Kinesthetic Figural Aftereffect (KFA) tests measuring the perceived width of a wooden block by tactile exposure. Petrie suggested that the difference between augmenting and reducing appeared to underlie differences in the ability to perceive sensory input. These

perceptual differences were reflected in visual and auditory event-related potentials (Spilker and Callaway, 1960; Buchsbaum and Silverman, 1968), in which individuals were presented stimuli at low and high stimulus intensities. At higher stimulus levels, the amplitudes of the evoked responses increased in augmenters, while the amplitudes of the reducers showed little change. Blenner and Yingling (1993) propose that augmenting and reducing may reflect inhibitory processes within the prefrontal cortex. Likewise, the functioning of the dopaminergic and serotonergic neurotransmitter systems, which are primarily inhibitory in nature, are less efficient in people who augment stimuli compared to those who reduce the effects of more intense stimuli (Bruneau, Barthelemy, Joubert, and Lelord, 1986). Consequently, several studies have suggested central inhibition is weaker for 'augmenters' than for 'reducers' (von Knorring, Monakhov, and Perris, 1978; Dustman et al., 1990; Alain and Woods, 1999). Based on these studies, individuals with low ANLs may behave like reducers (i.e., able to accept more intense noise by subjectively attenuating their perception of it), while those with higher ANLs function like augmenters.

Physiological Measures and ANL

Harkrider and Smith (2005) examined the contribution of the auditory efferent system to ANL. Monotic (i.e., speech and noise presented to only one ear) and dichotic (i.e., speech presented to one ear and noise presented to the other ear simultaneously) ANLs were measured for 31 adults with normal hearing and compared to monotic phoneme recognition in noise, contralateral suppression of click evoked OAEs (CEOAEs), middle ear impedance measures, and ipsilateral and contralateral acoustic

reflex thresholds (ARTs). ANLs were found to be unrelated to middle ear impedance measures, ARTs evoked by tonal or broad band noise stimuli, phoneme recognition in noise, or contralateral suppression of CEOAEs. These authors concluded that variability in ANLs was not due to middle-ear characteristics or activity levels of acoustic reflex or MOC systems. However, monotic (typically-recorded) ANL was correlated with dichotic ANL (story in one ear, background noise in opposite ear) implying ANL must be mediated, in part, at or beyond the level of the superior olivary complex where binaural processing first occurs in the auditory system.

Harkrider and Tampas (2006) measured physiological responses including CEOAEs, ABRs, and MLRs in females with normal hearing with low ($n = 6$) versus high ($n = 7$) ANLs. No differences were found in OAEs, or waves I and III of the ABR. However, group differences did emerge between the groups for ABR wave V and MLR waves Na and Pa such that, overall, the low ANL group tended to demonstrate smaller amplitudes than the high ANL group. Considering the structures from which these waves originate, the results of Harkrider and Tampas (2006) indicated that physiological differences in the central, but not peripheral, auditory system were a potential variable contributing to the inter-subject variability in background noise acceptance. Owing to the exploratory nature of this study, it was concluded that these findings needed to be replicated with a larger number of participants.

In a subsequent study, Tampas and Harkrider (2006) continued investigating the physiologic contributions to ANL by measuring ABRs, MLRs, and LLRs in two groups of young females with normal hearing [one with low ANLs ($n = 11$) and one with high

ANLs ($n = 10$) to low- and high-level stimuli. In accord with the results of Harkrider and Tampas (2006), differences in AEPs between the two groups were absent for the early ABR waves and emerged for waves III and V of the ABR, as well as for MLR and LLR peaks. Females with low ANLs had longer wave III and V latencies and smaller Na-Pa, P1-N1, and N1-P2 amplitudes than females with high ANLs. Moreover, there was a differential effect of stimulus level on the two groups such that P1-N1 amplitudes for the low ANL group increased less with an increase in stimulus level than those for the high ANL group, a finding that mirrored behavioral ANL growth with increasing speech presentation level in the two groups. The pattern of group differences indicated that more central regions of the auditory system account, at least in part, for variability in normal-hearing females' willingness to accept background noise. Smaller amplitudes, longer latencies, and smaller increases in amplitude or decreases in latency with increasing level in females with low versus high ANLs, may be indicative of reduced responsiveness in the afferent auditory nervous system, greater inhibitory activity from the central efferent system, or both.

Although differences in the ANLs of young, normal-hearing females have been reflected in differences for waves III and V of the ABR, as well as for MLR and LLR peaks, this has not been investigated in hearing-impaired populations of both genders and various ages and ANLs, one goal of the current study. Identification of the physiological variables contributing to the large range of ANLs in this population (Nabelek et al, 1991; Crowley and Nabelek, 1996; Nabelek et al, 2004) may have important implications for the prescriptive hearing-aid battery of these patients, including predictions of successful

hearing-aid use and subsequent decisions regarding aural rehabilitation. ABRs, MLRs, and LLRs have been measured in groups of males and females with mild-to-moderate hearing impairment ranging in age from 40 – 79 years (e.g., Tremblay, Piskosz, and Souza, 2002, 2003; Harkrider, Plyler, and Hedrick, 2005, 2006) and the AEP measures have been sensitive enough to result in significant differences when addressing the relative research questions. In the current study, ABRs, MLRs, and LLRs evoked by low- and high-level stimuli and EEG were used to examine physiological differences among three groups of listeners with mild-to-moderately-severe hearing impairment [listeners with high background noise acceptance = low ANLs (≤ 6 dB); listeners with moderate background noise acceptance = mid-range ANLs (7-13 dB); listeners with low background noise acceptance = high ANLs (≥ 14 dB)].

Identification of the physiologic characteristics of the auditory system and/or brain contributing to the large range of ANLs in the hearing-impaired population may have important implications for auditory rehabilitation of a patient. For example, when treating a patient with a high ANL (e.g., 20 dB) that has been unsuccessful with hearing aids in the past, it may be possible to lower that individual's ANL to a level associated with full-time hearing-aid use (e.g., < 7 dB) by targeting certain areas of the auditory system with physiological training (bio/neurofeedback) or pharmacological agents. Furthermore, it may be possible that objective physiological measures could be used to predict the likelihood of full-time hearing-aid use in infants, young children, and other populations in which behavioral testing is difficult or impossible.

METHODS

Participants

Participants consisted of forty adults (47-85 years, mean age = 72 years; 9 females) with mild-to-moderately-severe sensorineural hearing loss separated into three groups according to acceptance of background noise. Group 1 consisted of listeners with low ANLs less than or equal to 6 dB ($n = 14$) with a mean pure-tone average (PTA) of 38.4 dB HL [standard deviation (SD) = 10.8]. Groups 2 and 3 consisted of listeners with mid-range ANLs (7-13 dB) ($n = 13$) with a mean PTA of 39.2 dB HL (SD = 7.1) and high ANLs greater than or equal to 14 dB ($n = 13$) with a mean PTA of 39.9 dB HL (SD = 11.0), respectively. Mean audiograms for each group are presented in Figure 1. The number of participants in each group was determined by a power analysis (Cohen, 1988; Borenstein, Rothstein, and Cohen, 1997) computed with SPSS software. The analysis was based on a repeated measures fixed analysis of variance. The power analysis set the criterion for significance at the level of 0.05, power at 0.80, and effect size at 0.61.

Initially, all participants were interviewed and screened before continuing with the experimental session. First, a description of the study, including the general purpose, nature of participation, and risks and benefits were given. Then, an informed consent statement was read and signed and a case history given, asking specific questions about past and present ear infections, other otologic diseases, and neurological or learning deficits. For subjects ≥ 60 years, cognitive function was screened (28 out of 30 correct responses required) using the Mini Mental State Examination (MMSE) (Folstein, Folstein, and McHugh, 1975; Tremblay et al., 2002, 2003) (See Appendix B for MMSE

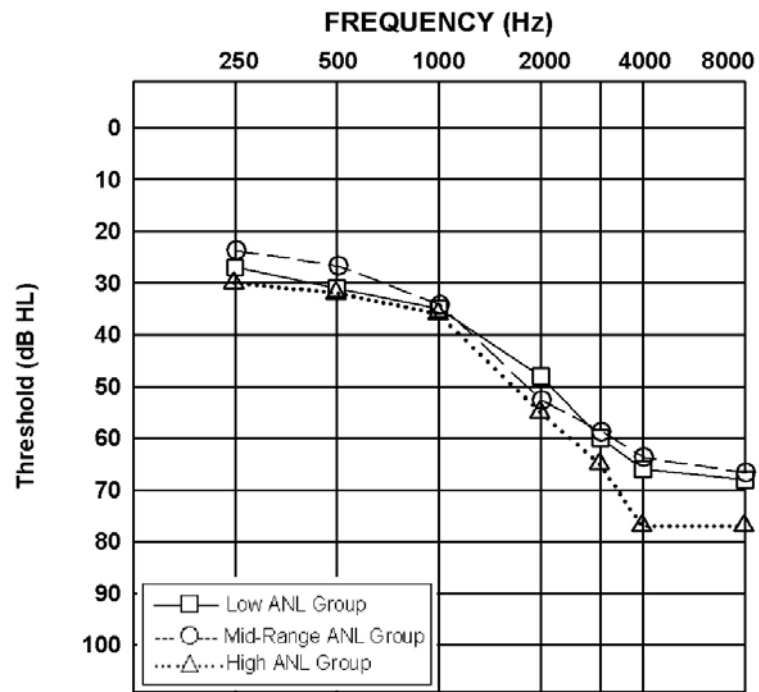


Figure 1: Mean audiograms for low, mid-range, and high ANL groups

exam). A hearing evaluation, including audiometric testing, tympanometry, and otoscopy, was conducted on each participant and ANL measured at MCL was assessed to determine group assignment.

All participants met the following criteria: normal middle-ear function as determined by immittance testing (i.e., type A tympanograms); right handed and footed to minimize possible hemispheric differences in AEPs or EEG; and no known otological, neurological, cognitive, or learning deficits as reported by subjects and/or performance on the MMSE. Potential participants were excluded if they were taking any CNS active medication (e.g., anti-depressants). Each listener's pattern of hearing-aid use also was determined based on a questionnaire developed by Nabelek et al. (2004) (See Appendix A for questionnaire). The pattern of hearing-aid use was determined as either 1) full-time use, wore hearing aids whenever needed, 2) part-time use, wore hearing aids occasionally, or 3) non-use, rejected and no longer wear hearing aids. Participants were excluded from the study if the rationale for hearing aid use/non-use and/or dissatisfaction was due to cost of the hearing aids, cosmetics, or other complaints not related to hearing benefit/hearing-aid performance. At the completion of the interview-screening session, the qualifying participants continued on with the experimental testing. Each participant received \$25 for their participation in the study.

Procedures

ANL Behavioral Procedure

The test materials and procedure for establishing ANL in the interview and screening session were based on the Nabelek et al. (2004; 2006) methods. 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.¹) as the primary stimulus against a multi-talker speech-babble recording (Revised Speech Perception in Noise Test; Kalikow, Stevens, and Elliot, 1977) as the competing background signal. The stimuli were presented from a compact disc to a Grayson Stadler (GSI-61) audiometer and delivered binaurally via insert earphones (Etymotic ER-3A).

To establish ANL, first, the participant's MCL was determined. The listener signaled 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 earphones. After a few moments, select the loudness of the story that is most comfortable for you, as if listening to a radio. 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 adjusted in steps of 10 dB when establishing the maximum and minimum loudness levels. Once the listener indicated the story was “too soft”, the level of the story was adjusted in 2-dB increments. To establish BNL, the speech was presented at MCL (for group assignment), 55 dB HL, 75 dB HL, or 85 dB HL, and then the background noise was added. As with the

¹ Cosmos, Inc. is owned and operated by Robert McClocklin. A copy of the ANL CD can be obtained by contacting Robert McClocklin at email (rmcclock@shaw.ca), phone (204-957-1328), or by mailing a request to 4744 West Ridge Dr., Kelowna, British Columbia, V1W3B5.

MCL adjustment, the listener signaled the examiner to adjust the volume of the background noise up or down. The verbal and written instructions for measuring BNL in reference to these three speech presentation levels 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 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 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 adjusted in steps of 10 dB when establishing the maximum and minimum loudness levels. Once the listener indicated the story was “very clear”, the level of the story was adjusted in 2-dB increments.

The ANL was calculated by subtracting the BNL from the speech presentation level (e.g., $ANL = MCL - BNL$). The ANL measured at the MCL was used in assigning participants to one of the three groups, and then ANLs at 55, 75, and 85 dB HL were measured in random order. The ANL at each speech presentation level was measured twice and the average of the two trials served as the mean ANL for that condition. All testing was performed without hearing aids.

Physiological Procedures

Physiological measures included ABR, MLR, LLR, and EEG. The stimuli and procedures for obtaining AEPs were based on methods from Tampas and Harkrider (2006). For obtaining EEG, methods were similar to those in Harkrider and Champlin (2001). For all physiological measures, participants were seated in a sound-treated booth, comfortably reclined in an armchair with their heads and necks well supported, while they watched a silent videotaped movie with closed captioning or read quietly. The order of the AEP acquisition was randomized across subjects.

Stimulus generation

Auditory Evoked Potentials

The AEPs were recorded to 500-Hz, Blackman-gated, tone-burst stimuli of negative polarity. They had rise/fall times of 2 cycles and a plateau of 1 cycle (Davis, Hirsch, Popelka, and Formby, 1984; Gorga and Thornton, 1989), and presented at a rate of 1.1/sec at levels of 55 dB nHL and 85 dB nHL for recording “low” and “high” AEPs, respectively. The stimuli were delivered diotically via electrically shielded insert earphones (Etymotic Research, model ER-3A). Weekly calibrations with a sound level meter (Bruel and Kjaer, type 2230) set to impulse 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 diotically via electrically shielded insert earphones (Etymotic Research, model ER-3A).

Recording procedures

Auditory Evoked Potentials and Electroencephalography

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 5k Ω , and within 1k Ω of each other. The non-inverting 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 non-inverting electrodes were randomly assigned to channels one, two, and three. Using the fourth electrode channel, the electro-oculogram (EOG) was measured to develop an eye-blink rejection rule for each subject. 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 for the ABRs and MLRs, and at DC-30 Hz for the LLRs. The total time window for the ABRs and MLRs was 145 ms, with a

70-ms pre-stimulus period. The total time window for the LLRs was 750 ms, which included a 350-ms pre-stimulus period. Each response was digitized via a 16-bit analog-to-digital converter (Tucker-Davis Technologies, model AD1). A total of 1000 sweeps were presented for ABR and MLR recordings. For LLRs, 250 sweeps were presented at each recording. The sampling rate was set at 10 kHz for all AEPs.

For all stimuli, the ABR and MLR waveforms were obtained simultaneously. One ABR/MLR and one LLR waveform was obtained from each of three channels, unless a replication was needed for identification of particular components. AEPs were evoked to two stimulus levels (55 dB nHL and 85 dB nHL) at a tone-burst frequency of 500 Hz. Thus, for ABR and MLR recordings, 6 waveforms (3 electrodes x 2 levels) per subject were acquired; For LLR recordings, there were also 6 waveforms (3 electrodes x 2 levels) per subject were acquired. Overall, a total of 12 waveforms were obtained for each subject.

Data Analysis

Auditory Evoked Potentials and Electroencephalography

Each AEP waveform was analyzed using Tucker-Davis Technologies software (BioSig[®]). Peaks were selected based on latencies, which are expected to fall within a certain time frame (Harkrider et al., 2005, 2006). ABR amplitude (peak to following trough) and absolute latency was 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. LLR amplitude (peak-to-peak) was measured between waves P1 and N1 and N1 and P2. The absolute latency was measured for waves P1, N1

and P2. 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 (e.g., Kavanagh, Harker, and Tyler, 1984). 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-ms delay and the amplifier causes a 2-ms group delay. Thus, 2.9 ms in addition to the time between sweep onset and stimulus onset for a given set of AEPs were subtracted from the raw latency values.

During off-line analyses, a FFT using a Hanning window was performed on each of the participants' EEG responses. The FFT results for the 10 waveforms acquired from C_z were averaged and then divided into the five standard EEG bands; delta (<4.0 Hz); theta (4.0-7.9 Hz); alpha (8-13.9 Hz); beta (14-30.9 Hz); and gamma (31-70 Hz). The frequency (Hz) with the highest power (μ V) and the value of the highest power were noted in each band. The EEG was analyzed using custom software developed in the LabView 3.1 (National Instruments) programming environment. The FFT frequency resolution was 0.95 Hz. There were 1900 sampling points for each EEG waveform, which were padded to 2048 points prior to FFT.

All data were coded so that the experimenter was blind to each participant's name and ANL during analysis. Data presented and analyzed in this paper are from the C_z electrode. The data from the C_5 and C_6 electrodes will be analyzed for hemispheric differences among groups in subsequent manuscripts as this was not a topic addressed in the current study.

RESULTS

Acceptable Noise Level

Figure 2 shows bivariate plots of the individual ANL data as a function of speech presentation level. The left panel shows the data for low ANL group, the middle and right panels display the data for the mid-range and high ANL groups, respectively. The lines fit to the data in each panel are the linear functions of speech presentation level for each group. The regression equations that describe each function are indicated in the upper left corner for each group. Individual ANL data for each speech presentation level, ANL growth rate (i.e., slope), and standard deviations for each group are reported in Table I. When obtained at MCL, the mean ANL was 3.9 (SD = 1.2), 9.8 (S.D. = 1.7), and 17.3 dB (SD = 3.1) for the low, mid-range, and high ANL groups, respectively. Average MCL was 59.4 (SD = 6.2), 60.7 (SD = 5.9), and 58.9 dB (SD = 3.5) for the low, mid-range, and high ANL groups, respectively. Mean BNL was 55.4 (SD = 5.8), 50.8 (SD = 6.9), and 42.3 (SD = 5.0) for the low, mid-range, and high ANL groups, respectively. The ANL growth rate for each group was calculated by dividing the difference of the ANLs at 55 dB HL and 85 dB HL by 30, the difference between 85 and 55. Therefore, the following equation was used to calculate the ANL growth rate: $(\text{ANL at 85 dB HL} - \text{ANL at 55 dB HL}) / 30$.

To evaluate the effect of speech presentation level on ANL, a two-factor, repeated measures analysis of variance (ANOVA) was conducted on ANL. The factors were ANL group (three levels: low, mid-range, and high) and speech presentation level (repeated

measures on four levels, 55 dB HL, MCL, 75 dB HL, and 85 dB HL. Significant main effects were found for speech presentation level ($F_{3,35} = 20.06, p < 0.001$) and group ($F_{2,37} = 102.33, p < 0.001$). The speech presentation level by group interaction also was significant ($F_{6,70} = 2.25, p = 0.049$). Post-hoc analyses revealed that listeners with hearing impairment in the low and mid-range ANL groups had less of an increase in ANL with increasing speech presentation level versus listeners from the high ANL group (Figure 3). The rate of ANL growth as a function of speech presentation level was calculated to be 0.12 (SD = 0.15), 0.13 (SD = 0.11), and 0.27 dB/dB (SD = 0.17) for the low, mid-range, and high ANL groups, respectively.

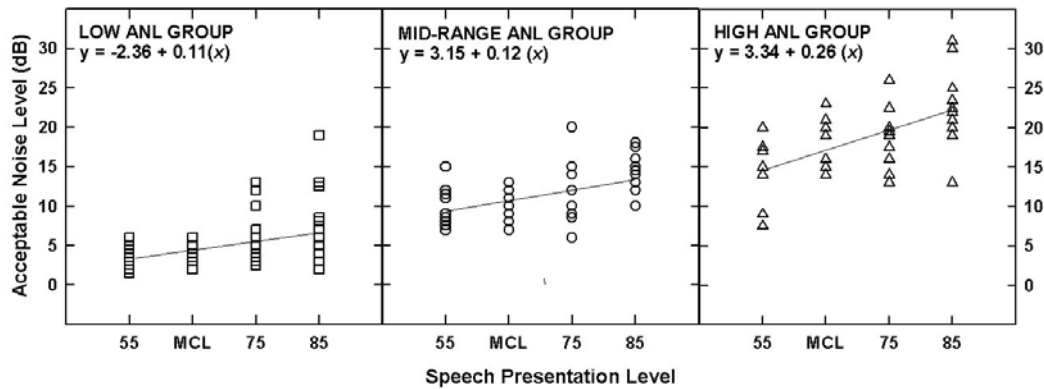


Figure 2. Bivariate plots of individual ANL data as a function of speech presentation level for low (left panel, $n = 14$), mid-range (middle panel, $n = 13$), and high ANL (right panel, $n = 13$) groups.

Table I. Individual and group data of mean ANLs for 55 dB HL, MCL, 75 dB HL, and 85 dB HL speech presentation levels, and ANL growth rate for three groups of participants.

	Participant	Speech Presentation Level				Growth Rate
		55	MCL	75	85	
Low ANL Group (N=14)	2	4.0	4.0	5.0	8.0	0.13
	4	4.0	4.0	3.0	6.0	0.07
	5	4.5	3.5	2.5	5.0	0.02
	12	2.0	2.0	3.0	2.0	0.00
	15	6.0	6.0	7.0	6.0	0.00
	16	2.0	2.0	7.0	13.0	0.37
	20	4.0	4.0	10.0	8.5	0.15
	24	5.0	6.0	5.0	5.0	0.00
	30	3.0	5.0	3.0	3.0	0.00
	32	1.5	3.5	4.0	6.0	0.15
	35	3.5	4.0	3.5	7.0	0.12
	37	6.0	4.0	13.0	19.0	0.43
	39	3.0	3.0	12.0	12.5	0.32
	40	6.0	4.0	6.0	4.0	-0.07
	Mean	3.9	3.9	6.0	7.5	0.12
	SD	1.4	1.2	3.4	4.6	0.15
Mid-range ANL Group (N=13)	1	8.0	8.0	8.5	10.0	0.1
	3	8.5	10.0	14.0	13.0	0.2
	6	9.0	9.0	12.0	14.5	0.2
	8	7.0	7.0	6.0	13.0	0.2
	9	12.0	12.0	15.0	18.0	0.2
	10	7.0	8.0	9.0	10.0	0.1
	11	11.0	11.0	12.0	14.0	0.1
	14	11.5	11.0	10.0	12.0	0.0
	17	8.5	11.0	10.0	15.0	0.2
	22	7.5	9.0	20.0	17.5	0.3
	23	11.5	9.0	10.0	17.5	0.2
	25	15.0	13.0	14.0	16.0	0.0
	31	15.0	10.0	8.5	12.0	-0.1
	Mean	10.1	9.8	11.5	14.0	0.13
	SD	2.8	1.7	3.6	2.7	0.11
High ANL Group (N=13)	7	15.0	16.0	19.0	25.0	0.33
	13	9.0	19.0	16.0	19.0	0.33
	18	15.0	14.0	16.0	21.0	0.20
	19	14.0	14.0	19.5	22.5	0.28
	21	20.0	21.0	26.0	31.0	0.37
	26	20.0	20.0	22.5	30.0	0.33
	27	14.0	14.0	14.0	19.0	0.17
	28	7.5	20.0	17.5	25.0	0.58
	29	15.0	15.0	16.0	22.0	0.23
	33	14.0	14.0	19.0	25.0	0.37
	34	17.5	23.0	20.0	20.0	0.08
	36	14.0	19.0	26.0	23.5	0.32
	38	17.0	16.0	13.0	13.0	-0.13
	Mean	14.8	17.3	18.8	22.8	0.27
	SD	3.5	3.02	3.9	4.75	0.17

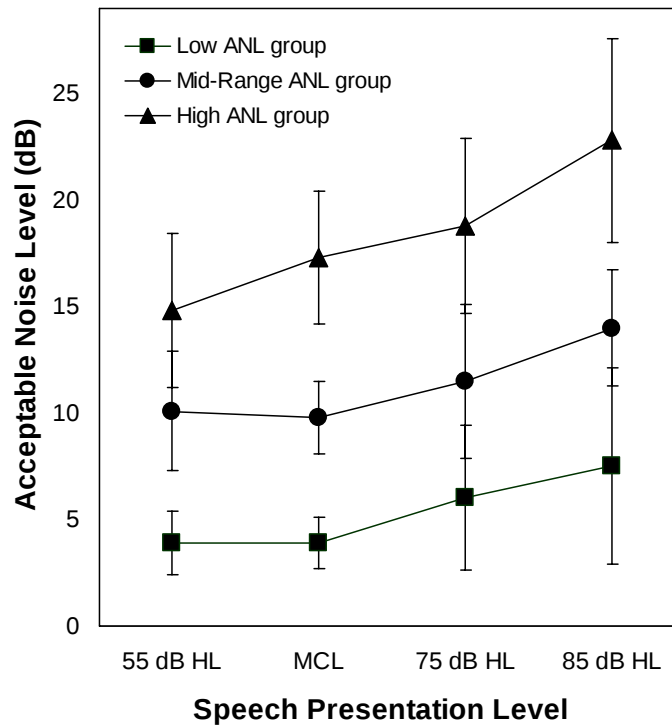


Figure 3: Mean ANLs for low (n = 14), mid-range (n = 13), and high (n = 13) ANL groups as a function of speech presentation level.

Auditory Evoked Potentials and Electroencephalography

Mean data comparing ABR, MLR, and LLR amplitudes and latencies measured for the three groups in response to the 55 dB nHL and 85 dB nHL 500-Hz stimuli are presented in Tables II and III, respectively. The independent variables of greatest interest were group (low versus mid-range versus high ANL) and stimulus level (55 dB nHL versus 85 dB nHL). Generally, all components of the AEP responses were present for

Table II. Means and (standard deviations) for the 55 dB nHL and 85 dB nHL, 500-Hz toneburst AEP peak-to-peak amplitudes (μV) measured at C_z for the three groups.

Wave	Group	55 dB nHL		85 dB nHL	
		n	Amplitude	n	Amplitude
Wave I	Low	0	0.00 (0.00)	9	0.10 (0.09)
	Mid	0	0.00 (0.00)	10	0.15 (0.14)
	High	0	0.00 (0.00)	9	0.12 (0.10)
Wave III	Low	5	0.05 (0.08)	12	0.17 (0.10)
	Mid	3	0.03 (0.07)	13	0.22 (0.11)
	High	3	0.03 (0.10)	11	0.17 (0.10)
Wave V	Low	14	0.44 (0.24)	14	0.59 (0.23)
	Mid	13	0.47 (0.25)	13	0.73 (0.35)
	High	13	0.40 (0.10)	13	0.60 (0.20)
Wave Na - Pa	Low	14	0.98 (0.27)	14	1.58 (0.48)
	Mid	13	1.04 (0.53)	13	1.70 (0.95)
	High	13	1.63 (0.10)	13	1.96 (1.10)
Wave P1 - N1	Low	14	3.02 (1.58)	14	3.70 (1.74)
	Mid	13	3.56 (2.36)	13	4.74 (3.23)
	High	13	3.86 (2.10)	13	5.48 (3.60)
Wave N1 - P2	Low	14	3.12 (1.51)	14	4.66 (2.23)
	Mid	13	3.40 (4.03)	13	5.61 (3.93)
	High	13	3.22 (1.80)	13	5.63 (2.80)

Table III. Means and (standard deviations) for the 55 dB nHL and 85 dB nHL, 500-Hz tone burst AEP peak latencies (ms) measured at C_z for the three groups.

Wave	Group	<u>55 dB nHL</u>		<u>85 dB nHL</u>	
		n	Latency	n	Latency
Wave I	Low	0	NP	9	1.77 (0.39)
	Mid	0	NP	10	1.70 (0.81)
	High	0	NP	9	1.85 (0.40)
Wave III	Low	5	4.86 (0.58)	12	4.35 (0.53)
	Mid	3	4.94 (0.52)	13	3.97 (0.70)
	High	3	4.79 (0.70)	11	4.30 (0.70)
Wave V	Low	14	7.18 (0.33)	14	6.38 (0.59)
	Mid	13	7.23 (0.46)	13	6.41 (0.47)
	High	13	7.00 (0.30)	13	6.48 (0.50)
Wave Na	Low	14	18.67 (2.10)	14	16.82 (2.70)
	Mid	13	19.35 (2.57)	13	16.78 (2.17)
	High	13	19.07 (3.10)	13	16.85 (2.28)
Wave Pa	Low	14	32.71 (3.48)	14	27.93 (5.00)
	Mid	13	32.78 (5.13)	13	27.67 (4.55)
	High	13	32.77 (5.20)	13	29.63 (4.97)
Wave P1	Low	14	51.43 (13.82)	14	39.65 (9.80)
	Mid	13	45.95(10.71)	13	45.08 (10.01)
	High	13	52.28 (12.20)	13	48.05 (10.22)
Wave N1	Low	14	90.62 (16.10)	14	76.66 (16.42)
	Mid	13	91.80 (15.82)	13	87.43 (12.27)
	High	13	99.47 (17.95)	13	93.39 (10.48)
Wave P2	Low	14	154.08 (22.54)	14	139.13 (20.35)
	Mid	13	161.55 (21.21)	13	149.65 (19.19)
	High	13	153.06 (32.46)	13	141.47 (13.91)

Notes. NP = wave not present.

each listener except for waves I and III of the ABR elicited by the 55 dB nHL stimuli.

The presence of these waves (I, III) are generally more variable in individuals with high-frequency sensorineural hearing losses (Hall, 2007), therefore, this finding was not unexpected. To emphasize group differences in individual AEP components, amplitude and latency data collapsed across level are presented in Figures 4 and 5, respectively.

To examine differences in AEP responses among the groups, repeated measures, two-factor ANOVAs were conducted on ABR amplitudes (waves I, III, and V), ABR latency (wave V), MLR and LLR amplitudes (Na-Pa, P1-N1, N1-P2), and MLR and LLR latencies (Na, Pa, P1, N1, P2). The factors were group (3 levels, low, mid-range, and high ANL), and level (repeated measures on 2 levels, 55 dB nHL versus 85 dB nHL). Waves I and III of the ABR were typically absent in response to the 55 dB nHL stimulus, therefore two one-factor repeated-measures ANOVAs were conducted on latencies of ABR waves I and III obtained with the 85 dB nHL stimulus. The factor was group (3 levels, low, mid-range, and high ANL). Group differences for the frequency and power for each EEG band were tested with one-factor repeated measures ANOVAs. The factor was group (3 levels, low, mid-range, and high ANL).

Previous research has reported difficulty in distinguishing the mid-range ANL group from the high-ANL group (Nabelek et al., 2004, 2006); therefore, it was anticipated that the mid-range group may be difficult to parse from the extreme ANL groups. Based on this expectation, and to allow for a more direct comparison with previous physiological investigations of ANL conducted with young females with.

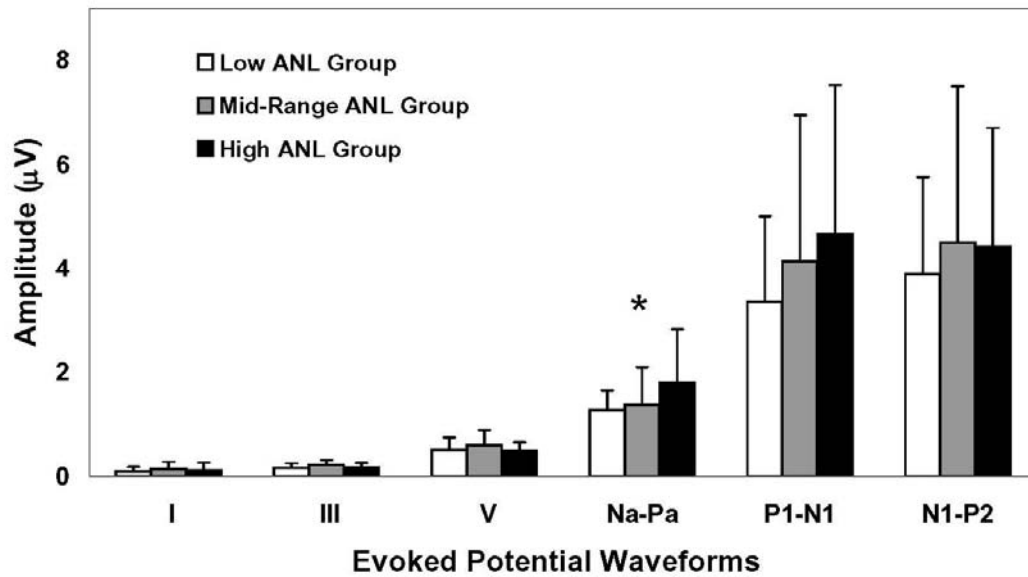


Figure 4. Evoked potential amplitude data collapsed across stimulus presentation level for all AEP waveforms. Significant group differences are noted by *.

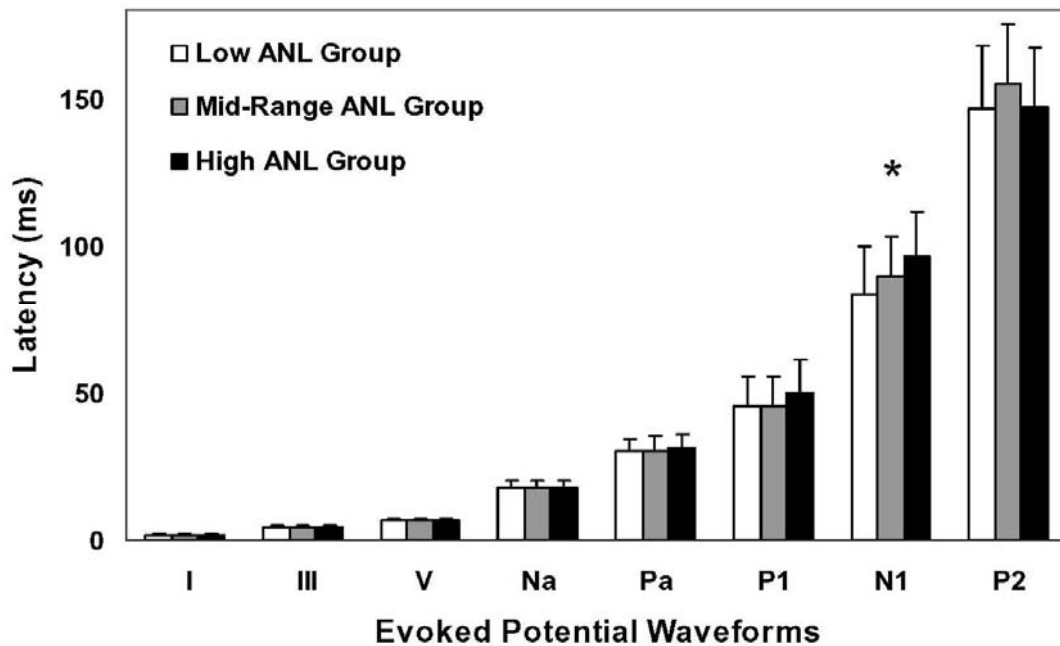


Figure 5. Evoked potential latency data collapsed across stimulus presentation level for all AEP waveforms. Significant group differences are noted by *.

normal hearing (Harkrider and Tampas, 2006; Tampas and Harkrider, 2006), secondary analyses on the extreme groups (low ANL group versus high ANL group) were conducted to maximize visualization of group differences. The results of these ANOVAs on the two extreme groups will immediately follow those from the ANOVAs on all three groups

ABR amplitude and latency

The two-factor repeated-measures ANOVAs conducted on ABR amplitude revealed that the main effect for group was not significant for waves I ($F_{2,37} = 0.52, p = 0.60$), III ($F_{2,37} = 0.54, p = 0.59$), and V ($F_{2,37} = 0.80, p = 0.46$). Significant main effects were found for level for waves I ($F_{1,37} = 39.89, p < 0.001$), III ($F_{1,37} = 85.59, p < 0.001$), and V ($F_{1,37} = 68.47, p < 0.001$), indicating that, as expected, ABR amplitudes increased with an increase in stimulus level. In other words, the ABR responses were smaller for the 55 dB nHL stimuli than for the 85 dB nHL stimuli. No significant interactions were observed. Similarly, comparisons of the data from low and high ANL groups (excluding the mid-range ANL group) using two-factor repeated-measures ANOVAs revealed no significant main effects for group for wave I ($F_{1,25} = 0.36, p = 0.56$), wave III ($F_{1,25} = 0.09, p = 0.76$), or wave V ($F_{1,25} = 0.05, p = 0.83$). As with the ANOVAs on all three groups, significant main effects were found for level for waves I ($F_{1,25} = 24.53, p < 0.001$), III ($F_{1,25} = 46.21, p < 0.001$), and V ($F_{1,25} = 43.34, p < 0.001$).

The one-factor repeated-measures ANOVAs conducted on latency revealed no significant main effect for group for wave I ($F_{2,25} = 0.17, p = 0.84$) or wave III ($F_{2,33} = 1.45, p = 0.25$). The two-factor ANOVA on ABR wave V latency revealed no significant

main effect for group ($F_{2,37} = 0.05$, $p = 0.96$). Significant main effects were found for level ($F_{1,37} = 79.90$, $p < 0.001$). As expected, ABR latencies were longer for the 55 dB nHL stimuli than for the 85 dB nHL stimuli. No significant interactions were observed.

MLR and LLR Amplitude and Latency

The two-factor repeated measures ANOVAs performed on MLR and LLR peak-to-peak amplitudes revealed no significant main effect for group for waves Na-Pa ($F_{2,37} = 2.32$, $p = 0.11$), P1-N1 ($F_{2,37} = 1.05$, $p = 0.36$), and N1-P2 ($F_{2,37} = 0.21$, $p = 0.81$). The main effect for level was significant for waves Na-Pa ($F_{1,37} = 19.83$, $p < 0.001$), P1-N1 ($F_{1,37} = 17.14$, $p < 0.001$), and N1-P2 ($F_{1,37} = 42.55$, $p < 0.001$), indicating that MLR and LLR amplitudes increased with an increase in stimulus level. No significant interactions were observed. The two-factor repeated measures ANOVAs comparing data from the low and high ANL groups only demonstrated a significant main effect for group for MLR wave Na-Pa ($F_{1,25} = 4.24$, $p = 0.05$), indicating that MLR amplitudes were significantly smaller for listeners with hearing impairment in the low ANL group compared to those in the high ANL group. No main effects were observed for LLR waves P1-N1 ($F_{1,25} = 2.49$, $p = 0.13$) and N1-P2 ($F_{1,25} = 0.52$, $p = 0.48$). The main effect for level was significant for MLR wave Na-Pa ($F_{1,25} = 9.34$, $p = 0.005$), and LLR waves P1-N1 ($F_{1,25} = 9.20$, $p = 0.06$) and N1-P2 ($F_{1,25} = 31.32$, $p \leq 0.0001$).

The two-factor repeated measures ANOVAs conducted on MLR and LLR latencies displayed a significant main effect for group for wave N1 ($F_{2,37} = 3.15$, $p = 0.05$). The absolute latency for LLR wave N1 was earlier for the low ANL group versus the mid-range and high ANL group. There was not a main effect for group on the

latencies of waves Na ($F_{2,37} = 0.84$, $p = 0.92$), Pa ($F_{2,37} = 0.49$, $p = 0.62$), P1 ($F_{2,37} = 1.54$, $p = 0.23$), or P2 ($F_{2,37} = 1.05$, $p = 0.36$). The main effect for level was significant for waves Na ($F_{1,37} = 25.11$, $p < 0.001$), Pa ($F_{1,37} = 25.39$, $p < 0.001$), N1 ($F_{1,37} = 12.67$, $p = 0.001$), and P2 ($F_{1,37} = 10.32$, $p = 0.003$) indicating that MLR and LLR latencies were longer for the 55 dB nHL stimuli than for the 85 dB nHL stimuli. The main effect for level was not significant for LLR wave P1 ($F_{1,37} = 3.43$, $p = 0.07$). No significant interactions were observed. The ANOVAs conducted on the data from the extreme ANL groups also revealed a significant main effect for group for LLR wave N1 ($F_{1,25} = 5.63$, $p = 0.03$). No group effects were exhibited for MLR wave Na ($F_{1,25} = 0.08$, $p = 0.78$), wave Pa ($F_{1,25} = 0.87$, $p = 0.36$), LLR waves P1 ($F_{1,25} = 2.99$, $p = 0.10$), or P2 ($F_{1,25} = 0.01$, $p = 0.93$). As expected, the main effect for level was significant for MLR wave Na ($F_{1,25} = 10.65$, $p = 0.003$), Pa ($F_{1,25} = 18.78$, $p \leq 0.0001$), LLR waves N1 ($F_{1,25} = 17.04$, $p \leq 0.0001$), and P2 ($F_{1,25} = 6.21$, $p = 0.02$). There were no significant interactions.

AEP Data Reduction

To underscore group differences in individual AEP components, responses for each presentation level were grand averaged to create composite peak-to-peak amplitudes (Figure 4) and absolute latencies (Figure 5) for each ABR, MLR, and LLR wave, respectively. One-factor ANOVAs were conducted on AEP peak-to-peak amplitudes (ABR waves I, III and V, MLR waves Na-Pa, and LLR waves P1-N1 and N1-P2) and absolute latencies (ABR waves I, III and V, MLR waves Na and Pa, and LLR waves P1, N1, P2). The factor was group (three levels, low, mid-range and high ANLs).

The ANOVAs comparing the three groups on peak-to-peak amplitudes revealed that the main effect for group was not significant for ABR waves I ($F_{2,37} = 0.51, p = 0.61$), III ($F_{2,37} = 0.52, p = 0.60$), and V ($F_{2,37} = 0.80, p = 0.46$), MLR waves Na-Pa ($F_{2,37} = 2.33, p = 0.11$), LLR waves P1-N1 ($F_{2,37} = 0.23, p = 0.79$), or N1-P2 ($F_{2,37} = 0.47, p = 0.63$). The ANOVAs conducted on the extreme ANL groups (low versus high) revealed a significant main effect for group for peak-to-peak amplitude of MLR wave Na-Pa ($F_{1,25} = 4.20, p = 0.05$). The amplitude of MLR wave Na-Pa was smaller for listeners in the low ANL group than for those in the high ANL group. No significant main effects were observed for the amplitude of ABR waves I ($F_{1,25} = 0.37, p = 0.55$), III ($F_{1,25} = 0.10, p = 0.76$), V ($F_{1,25} = .06, p = 0.81$), LLR waves P1-N1 ($F_{1,25} = 0.24, p = 0.63$), or N1-P2 ($F_{1,25} = 0.90, p = 0.35$).

ANOVAs performed on absolute latencies of the three ANL groups revealed a significant main effect for group for LLR wave N1 ($F_{2,37} = 4.84, p = 0.01$). Post-hoc testing revealed that N1 latency for low ANL group was significantly smaller ($p = 0.004$) than the high ANL group. No significant main effect for group was found for ABR waves I ($F_{2,25} = 0.17, p = 0.84$), III ($F_{2,33} = 1.39, p = 0.26$), V ($F_{2,37} = 0.04, p = 0.96$), MLR waves Na ($F_{2,37} = 0.09, p = 0.92$), Pa ($F_{2,37} = 0.49, p = 0.62$), LLR wave P1 ($F_{2,37} = 2.46, p = 1.00$), or P2 ($F_{2,37} = 1.23, p = 0.30$). The ANOVAs conducted on the extreme ANL groups (low versus high) revealed a significant main effect for LLR waves P1 ($F_{1,25} = 4.75, p = 0.04$) and N1 ($F_{1,25} = 8.76, p = 0.01$) latencies, such that the low ANL group exhibited shorter latencies for LLR waves N1 and P1 than the high ANL group. No main effect for group was found in any of the other AEP components [ABR wave I (F

$_{1,16} = 0.18$ $p = 0.67$), III ($F_{1,21} = 0.08$ $p = 0.78$), V ($F_{1,25} = 0.01$ $p = 0.98$), MLR wave Na ($F_{1,25} = 0.08$, $p = 0.78$), Pa ($F_{1,25} = 0.87$, $p = 0.36$), LLR wave P2 ($F_{1,25} = 0.12$ $p = 0.74$)].

Electroencephalography

The average dominant frequency (Hz) of each of the five bands of EEG (delta, theta, alpha, beta, and gamma) and the maximum power (μV) in each band for the three groups are presented in Table IV. The one-factor ANOVAs performed on EEG frequencies revealed a significant main effect for group for the alpha frequency band ($F_{2,37} = 3.47$, $p = 0.04$). Post-hoc testing revealed that the mid-range group was significantly different from the high ANL group ($p = 0.05$) such that the dominant frequency in the alpha band was lower for the mid-range ANL group than for the high ANL group. No significant main effect for group was found for the delta ($F_{2,37} = 1.25$, $p = 0.30$), theta ($F_{2,37} = 0.40$, $p = 0.67$), beta ($F_{2,37} = 1.25$, $p = 0.30$), or gamma ($F_{2,37} = 3.04$, $p = 0.06$) frequency bands. ANOVAs conducted on the low and high ANL groups demonstrated a significant main effect for group for gamma frequency band ($F_{1,25} = 7.13$, $p = 0.01$). Examination of the mean data revealed that the dominant frequency in the gamma band was greater in the low ANL group than the high ANL group. No significant group effects were observed for the delta ($F_{1,25} = 0.56$, $p = 0.46$), theta ($F_{1,25} < 0.001$, $p = 1.0$), alpha ($F_{1,25} = 0.16$, $p = 0.69$), or beta ($F_{1,25} = 2.03$, $p = 0.17$) frequency bands.

The ANOVA conducted on the maximum power of each of the five EEG bands revealed no significant main effects for group for delta ($F_{2,37} = 0.29$, $p = 0.75$), theta ($F_{2,37} = 1.83$, $p = 0.18$), alpha ($F_{2,37} = 2.60$, $p = 0.09$), beta ($F_{2,37} = 0.11$, $p = 0.90$),

Table IV . Means and (standard deviations) for frequency[†] (Hz) and power[‡] of each EEG band measured at C_z for the three groups.

EEG band	Group	frequency	power
delta	Low ANL group	3.02 (0.33)	1.28 (0.20)
	Mid-Range ANL group	2.81 (0.30)	1.34 (0.41)
	High ANL group	2.90 (0.39)	1.16 (0.22)
theta	Low ANL group	6.57 (0.35)	1.45 (0.25)
	Mid-Range ANL group	6.73 (0.32)	1.77 (0.43)
	High ANL group	6.66 (0.64)	1.84 (0.19)
alpha	Low ANL group	10.47 (0.61)	1.58 (0.40)
	Mid-Range ANL group	9.97 (0.63)	1.82 (0.49)
	High ANL group	10.63 (0.78)	1.92 (0.23)
beta	Low ANL group	18.94 (1.51)	1.21 (0.27)
	Mid-Range ANL group	18.30 (1.28)	1.41 (0.51)
	High ANL group	18.14 (1.35)	1.32 (0.25)
gamma	Low ANL group	41.95 (3.99)	0.56 (0.10)
	Mid-Range ANL group	40.94 (4.68)	0.39 (0.25)
	High ANL group	38.10 (3.82)	0.56 (0.39)

Notes. frequency[†] = the frequency in Hz with highest power, power[‡] = the value of the highest power (mV).

or gamma ($F_{2,37} = 1.93$, $p = 0.16$) EEG frequency bands. Similarly, the ANOVAs conducted on the extreme ANL groups demonstrated no significant main effects for group in the delta ($F_{1,25} = 0.29$, $p = 0.60$), theta ($F_{1,25} = 2.67$, $p = 0.12$), alpha ($F_{1,25} = 2.32$, $p = 0.14$), beta ($F_{1,25} = 0.04$, $p = 0.84$), or gamma ($F_{1,25} = 0.44$, $p = 0.51$) frequency bands.

Relationship between ANLs, AEPs, and Hearing-Aid Outcome

In order to determine the relationship between ANLs, AEPs, and hearing-aid outcome, Pearson product-moment correlations were calculated and are displayed in Table V. Only those AEP components that demonstrated statistical group differences were included in the analysis. In order to minimize the chances of making a Type I error,

only correlations with a p -value less than 0.05 and a correlation coefficient greater than 0.30 were considered to be significant. Downie and Heath (1965) suggest the following guidelines for interpreting the magnitude of correlation coefficients: 1) very high correlation- 0.9 to 1.0, 2) high correlation- 0.7 to 0.9, 3) moderate correlation, 0.5 to 0.7, 4) low correlation- 0.3 to 0.5, and 4) little to no correlation- coefficient below 0.3. Results of the correlation analyses confirmed that all significant correlations were positive, statistically significant at $p < 0.05$ (2-tailed) level, and greater than 0.30. As can be seen from Table V, every behavioral measure of ANL was correlated with each other, with ANL growth rate, and with hearing-aid use. Some AEP measures were correlated with each other, but only a few were significantly correlated with behavioral ANL measures.

Table V. Pearson product-moment correlation coefficients between ANLs obtained at each speech presentation level, AEPs, and pattern of hearing-aid use

	1	2	3	4	5	6	7	8	9	10
1. ANL-55	--	0.86*	0.78*	0.78*	0.12	0.72*	0.22	0.17	0.24	0.33*
2. ANL-MCL		--	0.85*	0.83*	0.35*	0.70*	0.45*	0.21	0.29	0.38*
3. ANL-75			--	0.92*	0.59*	0.69*	0.36*	0.21	0.25	0.36*
4. ANL-85				--	0.71*	0.77*	0.40*	0.21	0.24	0.38*
5. ANL Growth rate					--	0.41*	0.38	0.13	0.25	0.12
6. Hearing-aid use						--	0.19	0.11	0.28	0.38*
7. NaPa-55							--	0.55*	0.13	0.24
8. NaPa-85								--	-0.05	-0.15
9. N1-55									--	0.42*
10. N1-85										--

Note: * $p < 0.05$ (two-tailed)

DISCUSSION

The goal of the current study was to examine differences in the physiological responses of listeners with mild-to-moderately-severe sensorineural hearing impairment who differ in their willingness to listen to speech in the presence of background noise and their patterns of hearing-aid use. By this, a better understanding of the underlying mechanisms contributing to ANLs was sought. Specifically, ABR, MLR, LLR, and EEG responses are reported from individuals with low, mid-range, and high ANLs, representing physiologic activity from the auditory nerve to the cerebral cortex. Results suggest that differences in the responsiveness of more central regions of the auditory nervous system are related to differences in willingness to listen in background noise. The findings in the current study are consistent with others reporting a central influence on willingness to listen in background noise (Freyaldenhoven et al., 2005; Harkrider and Smith, 2005; Harkrider and Tampas, 2006; Tampas and Harkrider, 2006).

One purpose of the present study was to determine if differences in peak-to-peak amplitudes and absolute latencies of the ABR, MLR, and/or LLR components exist among hearing-impaired listeners with low, mid-range, and high ANLs. Figure 4 represents the combined peak-to-peak amplitudes for the 55 db nHL and 85 db nHL 500-Hz stimuli. This composite demonstrates that the low ANL group, overall, exhibited smaller amplitudes than the mid-range or high ANL groups and reveals a developing trend across AEP types. ABR waves I, III, and V are comparable among the three groups, but the amplitude differences are notable between low and high ANL groups in MLR wave Na-Pa and LLR waves P1-N1 and N1-P2 (although P1-N1 and N1-P2 mean

differences lack statistical significance). The mid-range ANL group varies in its relationship to the extreme groups but the amplitude generally fell between the two extreme groups. This finding is in accord with the first hypothesis in the current study and with results from that of Harkrider and Tampas (2006) and Tampas and Harkrider (2006). In these studies, no differences in OAEs or ABR amplitude among young normal-hearing listeners with low and high ANLs were found, but significant differences emerged beginning with the MLR, and persisting through the LLR, such that the low ANL group displayed smaller amplitudes than the high ANL group. Figure 6 compares peak-to-peak amplitudes for ABR wave V, MLR wave Na-Pa, and LLR waves P1-N1 and N1-P2 reported for the two studies. It should be noted that the standard deviations for the amplitudes of the LLR waves for the current study were much greater (range: 1.51 – 4.03) compared to the previous physiological data (range: 0.1- 1.30); this may have contributed to the lack of statistical significance result.

LLR latency differences are also reported in the present study. Comparisons among the three groups revealed that latencies of LLR waves N1 and P1 were significantly shorter for the low ANL group than for the high ANL group. It was hypothesized, however, that the mid-range and high ANL groups would demonstrate shorter latencies compared to the low ANL group. The prediction was based, in part, on Tampas and Harkrider (2006) reports of group differences for ABR waves III and V latency, such that the low ANL group exhibited longer latencies than the high ANL group. In summary, the current data for latency do not support the original hypothesis that individuals with higher ANLs exhibit faster neural conduction times than those with

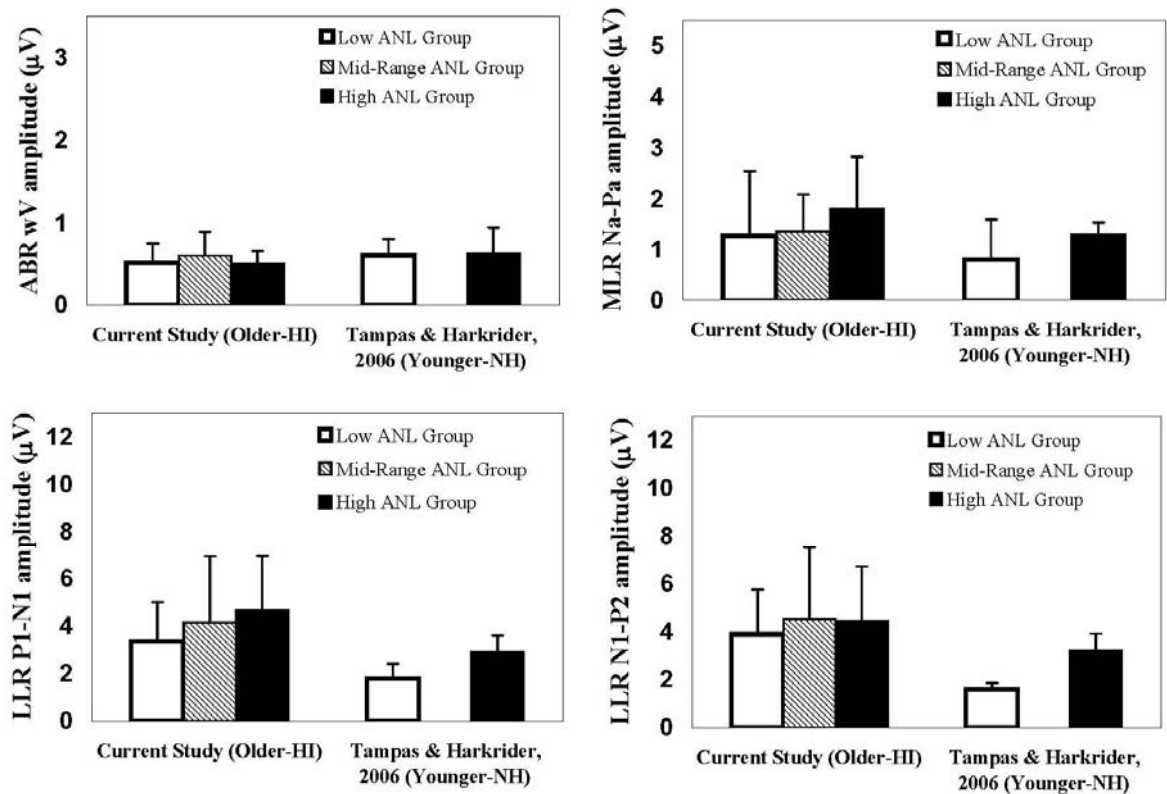


Figure 6. Composite evoked potential amplitude comparisons between the current study (older subjects with hearing impairment; 55 and 85 dB nHL stimuli) and Tampas and Harkrider, 2006 (young, normal hearing females; 35 and 70 dB nHL stimuli), elicited by 500-Hz tone-burst stimuli.

lower ANLs, which may suggest that latency is of little value in differentiating willingness to listen in background noise, at least among older listeners with hearing impairment.

The present study is the first research attempt to investigate the physiological mechanisms of background noise acceptance in listeners with the most common (i.e., mid-range) ANLs and listeners with hearing impairment. Like with young, normal-hearing listeners, differences were found among the groups for Na-Pa amplitude. However, these amplitude differences did not persist into the LLR range. Further, the latency difference among the groups of older, hearing-impaired subjects for N1 was in the opposite direction of the ABR wave III and V latency differences reported between groups of younger, normal-hearing listeners. The disparities between the electrophysiological results (amplitude and latency) for the current study compared to Tampas and Harkrider (2006) may be the result of participant and methodological differences. The subject pool from which the current participants were selected consisted of primarily elderly male subjects, resulting in 31 males (9 females) with a mean age of 72 years. This is in stark contrast to previous investigations that have focused on young females with normal hearing (mean age = 24 years). Results of electrophysiological investigations of gender, hearing sensitivity, and the aging auditory system shed light on the inconsistencies observed among the AEP studies of ANL. Additionally, characteristics of the AEP responses and the way they may interact with participant factors must be considered. Further, differences in stimulus conditions between the studies may explain, in part, some of the discrepancies in the data obtained from young,

normal-hearing individuals versus older, hearing-impaired ones.

Published research has consistently reported significant gender effects on AEPs. Particularly, ABR, MLR, and LLR waveforms recorded from females are more robust (i.e., greater in amplitude) than those of males (Jerger and Hall, 1980; Woods and Clayworth, 1986; Tucker, Dietrich, Harris, and Pelletier, 2002; Hall, 2007). Some authors have also described shorter latencies for selected AEP components in females versus males (Jerger and Hall, 1980; Patterson, Michalewski, Thompson, Bowman, and Litzelman, 1981; Amenendo and Diaz, 1998). These male-female differences prompted researchers (Harkrider and Tampas, 2006; Tampas and Harkrider, 2006) to initially explore physiological contributions to background noise acceptance in young females with normal hearing. Because females have larger amplitude AEPs than males, their responses often have better signal-to-noise ratios making them easier to analyze. Thus, using female listeners increased the likelihood of visualizing even small differences in responses from peripheral to central levels of the auditory system that may have existed between the groups. The group differences that were documented (Harkrider and Tampas, 2006), replicated, and extended (Tampas and Harkrider, 2006) using female participants were clear and robust. Because of this and the fact that the female advantage for larger, earlier AEPs is fairly subtle, it was expected that similar AEP differences in males with low, mid, or high ANLs could be visualized if they were present. Furthermore, the majority of the subjects in the current study were male, with females spread equally among the three groups (three in each group). Thus, comparisons across groups of primarily male listeners should still have allowed for group differences, like the

one for Na-Pa amplitude or alpha power, to be seen. While gender cannot be ruled out as having an effect on the current findings, the explanation as to why group differences were not found for more AEP measures may arise from other factors, like participant age and hearing sensitivity.

With stimuli well above threshold, older listeners with normal and impaired hearing demonstrate larger amplitude MLRs and LLRs versus younger listeners with normal hearing (e.g., Woods and Clayworth, 1986; Harkrider, Plyler and Hedrick, 2005; Harris, Mills and Dubno, 2007). A comparison of AEP data from young females with normal hearing versus older males and females with hearing-impairment (Figure 6) delineates these aging effects. MLRs and LLRs from the older listeners in the current study are larger in amplitude than those from younger listeners (Tampas and Harkrider, 2006). The fact that AEPs were larger in amplitude and, so, in a more favorable signal-to-noise ratio for the older listeners, if anything, should have made group differences more obvious. Furthermore, there was no real age discrepancy among the three groups of older subjects. The mean age was 70, 73, and 73 for the low, mid-range, and high ANL groups, respectively. This makes it unlikely that age accounts for the lack of group differences within the current data. Thus, the primary explanation as to why group differences were not found for more AEP or EEG measures may arise from other factors, like participant hearing sensitivity.

Electrophysiological studies provide insight into changes in brain processes that occur when audibility is reduced, as with hearing loss. To gain a better understanding of the physiological underpinnings of ANL, the current study extended its investigations to

the hearing impaired population. Sensorineural hearing loss may alter the timing (i.e., latency) and amplitude of AEP responses. Data demonstrate that as the degree of hearing loss increases, latencies of AEPs may increase and amplitudes may be reduced or absent (Coates, 1978; Oates, Kurtzberg, and Stapells, 2002). Tremblay, Piskosz, and Souza (2003) report longer LLR latencies for older participants with hearing loss compared to younger listeners with normal hearing. They interpreted these changes in the temporal response properties of the CANS to be a result of age and age-related hearing loss. Even though gender, age, and hearing loss are not related to behavioral measures of ANL, it is possible that one or a combination of these factors had an affect on the AEP data.

An additional explanation for a lack of group differences in the LLR data for the older versus the younger listeners may have to do with the intrinsic and extrinsic characteristics of the AEP responses. Examination of AEPs across many tasks demonstrate that consecutive EP components (i.e., ABR, MLR, LLR) are related to successive stages of information processing by the listener, from primarily sensory (exogenous) to the higher integrative levels (endogenous) . Unlike the shorter latency ABRs or MLRs that are primarily determined by the physical properties of the stimulus, the later components of the LLR are highly affected by the state of arousal of the listener and the level of attention to the signal. This is thought to be due to the fact that the generators of the LLR are primarily the auditory cortex and include contributions from the reticular formation (Näätänen and Picton, 1987). It is difficult to control for consistency of arousal and/or attention across subjects. The inter-subject variability in arousal and attention is often cited as the cause for greater variability in LLR versus ABR

or MLR amplitude measures. Furthermore, the LLR literature reports decreases in N1 amplitude with gradual reductions in a subject's wakefulness and attention to the signal. This reduction is greater for older subjects than younger subjects (Fisher, Hymel, Cranford, and DeChicchis, 2000). Conversely, during this transition from wakefulness to sleep and diminished attention to the signal, P2 amplitudes may increase (Campbell, Bell, and Bastien, 1992). The ability of the CNS to inhibit the response to auditory stimuli that require no attentional effort is reported to diminish in older listeners. Subjects were directed to watch a silent video with closed captioning or read quietly to control for subject arousal and attention level, however the confounding effects of these factors could not be ruled out, especially in the data from the older participants in this study compared to the younger subjects for Tampas and Harkrider (2006).

The differences in mean ANLs between older and younger listeners also may have contributed to the lack of significance among groups in the LLR in older listeners. The mean ANLs for the current study were 4, 10, and 17 dB for the low, mid-range, and high ANL groups, respectively, whereas ANLs for the younger listeners (Tampas and Harkrider, 2006) were 2 and 21 dB for the low and high ANL groups, respectively. In other words, the younger listeners exhibited larger ANL differences between the low and high ANL groups as compared to the groups of older listeners with impaired hearing. If the degree of difference between low versus high ANLs correspond to differences in excitation and/or inhibition in the CANS as hypothesized, then smaller differences in ANLs among groups would minimize the differences observed in AEPs in the current study.

The finding of group differences for the amplitudes and latencies difference for some AEP components and not others is not unusual (e.g., McFadden and Champlin, 2000; Harkrider and Tampas, 2006; Tampas and Harkrider, 2006). Sorting out these differences will involve more understanding than currently is available regarding the generators of the various AEP waves, as well as the impending effects of subject and methodological differences and their relationship to the physiological mechanisms involved in mediating acceptance of background noise. There is not a one-to-one association between individual AEP components and single generator sites within the brain. Instead, researchers have identified the involvement of multiple generator sources from various levels of the nervous system, especially for the later waves (Perrault and Picton, 1984; Näätänen and Picton, 1987). Identifying the exact neural populations responsible for the group differences observed in the AEPs is beyond the scope or intent of this paper.

Another purpose of the present study was to investigate whether or not the ANLs measured from these three groups were differentially affected by the presentation level of the stimuli. Results indicate that presentation level interacts with ANL group to influence behavioral judgments of background noise acceptance. For the 55 dB HL speech presentation level, the ANLs did not change in reference to MCL for the low and mid-range ANL groups, but ANLs decreased for the high ANL group. In other words, listeners with high ANLs were more willing to accept noise when the level of the speech decreased below MCL whereas there was no change for listeners with low and mid-range

ANLs. For the 75 and 85 dB HL presentation levels, the ANLs increased in reference to the presentation at MCL for each group, with the high ANL group exhibiting a higher growth rate than the low and mid-range ANL groups. In other words, all listeners were less willing to accept noise when the intensity of the speech increased. Further, there was an interaction between speech presentation level and ANL group. Specifically, the rate of ANL growth was much steeper for individuals with high ANLs as speech presentation level was increased from 55 dB HL to 85 dB HL, compared to listeners with low and mid-range ANLs who demonstrated a minimal rate of ANL growth. Thus, an individual's ANL growth rate appears to be dictated by his/her ANL measured at MCL.

The ANL growth results for the present study were similar to the growth rates observed for other studies in listeners with normal and impaired hearing (Franklin et al., 2006, Tampas and Harkrider, 2006; Freyaldenhoven, Plyler, Thelin, and Muenchen, in press) (Table VI). Young listeners with high ANLs (Tampas and Harkrider, 2006) demonstrated a higher rate of ANL growth compared to older impaired hearing participants with high ANLs. It is also important to note the similarities in growth rates for the low and mid-range ANL groups in the present study. The differences in mean ANLs per group between older and younger listeners, discussed previously with regard to AEP measures, also may have contributed to the growth rate patterns observed among groups in this dissertation. Examination of the individual ANLs measured at MCL (Table I) revealed a number of listeners in the high ANL group were just above the cut-off between mid-range and high ANLs. The differences exhibited in growth rate patterns between the low and mid-range ANLs versus the high ANLs suggest differences in the

Table VI. Comparison of studies that have examined ANL as a function of speech presentation level in listeners with normal (NH) and impaired (IH) hearing.

Study	Presentation Level Range (dB HL)	ANL Growth Rate
Franklin et al., 2006 (NH) n = 20	20 – 76	0.25
Tampas and Harkrider, 2006 (NH) n = 21	35 – 70	
Low ANL Group		0.15
High ANL Group		0.46
Freyaldenhoven et al., 2007 (NH+IH) n = 30	40 – 75	0.17
Present Study (IH) n = 40	55 – 85	
Low ANL Group		0.12
Mid-range ANL Group		0.13
High ANL Group		0.27

auditory processing mechanisms contributing to background noise acceptance.

Stimulus level did not significantly interact with any of the AEP components for the three ANL groups. Tampas and Harkrider (2006) described a stimulus level by ANL group interaction for LLR P1-N1 amplitude such that P1-N1 amplitudes for the low ANL group increased less with increased stimulus level than from the high ANL group. The greater variability in P1-N1 amplitudes in the older versus younger subjects may decrease the likelihood of finding an interaction. Also, methodological differences between the current study and Tampas and Harkrider (2006) may explain its absence. AEPs in the current study were recorded to 500-Hz tone bursts presented at 55 and 85 dB nHL, whereas Tampas and Harkrider (2006) elicited responses with 500- and 3000-Hz

tonebursts at 35 dB nHL and 70 dB nHL. The hearing status of the participants precluded the use of the 3000-Hz tone burst in the current study. As a general rule, AEP latencies are longer, and amplitudes larger, for low-frequency stimuli compared to high-frequency stimuli (Alain, Woods, and Covarrubias, 1997). Although LLR amplitudes were larger for the 500-Hz versus the 3000 Hz stimuli, the level by group interaction seen in the young listeners (Tampas and Harkrider, 2006) was not significantly effected by stimulus frequency. Studies have demonstrated that changes in the stimulus frequency may prove to be a useful method for detecting sensory processing differences among groups (Genmoto, Urasaki, and Yokata, 2004), therefore, this possibility should be explored further in future studies. The relative differences between the “low” and “high” stimuli [55 and 85 dB nHL in the present study, and 35 and 70 dB nHL in Tampas and Harkrider (2006)] are more likely to explain the absence of a stimulus level by group interaction for the AEPs. In the auditory nervous system, low sound presentation levels are coded by a small number of neural responses. Increasing stimulus levels above threshold leads to an increase in neuronal activity; the stronger the stimulus in reference to threshold, the greater the number of receptors that are activated (Kandel et al., 2000). The PTA for young normal hearing subjects (Tampas and Harkrider) was ≤ 15 dB HL while the PTA for the current hearing impaired subjects was 39 dB HL. The smaller dynamic range of the current participants limited the ability to explore a wider range of presentation levels, and may have contributed to the lack of level by group interaction for AEPs.

Relationship between ANLs, AEPs, and Hearing-Aid Outcome

High correlations were found among ANLs obtained at each of the four speech presentation levels, indicating that each provides similar information regarding willingness to listen in background noise. ANLs at each level were also highly correlated with pattern of hearing-aid use, supporting the established theory that willingness to accept background noise is associated with hearing-aid outcome (Nabelek et al., 2006; Freyaldenhoven et al., in press). Interestingly, the ANL measured at 85 dB HL, not at MCL, had the strongest correlation with hearing-aid use. This may suggest that clinical measurements of ANL should occur at a level higher than MCL in order to achieve the greatest accuracy in predicting success with hearing aids. ANL growth rate was also correlated with pattern of hearing aid use, but not as strongly as any one of the individual ANL measures. This is consistent with Freyaldenhoven, Plyler, Thelin, and Muenchen (in press) who reported that the effects of speech presentation level on ANL did not considerably increase the accuracy of predicting hearing-aid outcome compared to ANL measured at MCL. Further, ANL growth rate was correlated with ANLs measured at all but the lowest speech presentation levels, suggesting that a person's ANL growth rate can be predicted by their ANL. This was particularly true for ANLs measured at 85 dB HL, which were most strongly correlated with ANL growth rates. For these reasons, ANL growth does not appear to provide additional information about potential success with hearing aids beyond that provided by ANL at a single speech presentation level and does not need to be added to the clinical ANL test battery.

As would be expected, many of the AEP measures were correlated with one

another. More importantly, a significant but low correlation was observed among MLR Na-Pa amplitude at 55 dB nHL and ANLs measured at MCL, 75, and 85 dB nHL, validating the group effects reported by the ANOVAs. It also suggests that MLRs measured at low levels may provide valuable insight into background noise acceptance, but may not be reliable as tools for prediction hearing-aid outcome at this point, limiting its clinical usefulness in this regard.

The final purpose of this project was to investigate group differences in EEG activity. Results revealed that the dominant frequency in the alpha EEG band of the high ANL group was higher than the mid-range ANL group, suggesting enhancement in brain activity (Basar, Schurmann, Basar-Eroglu, and Karakas, 1997) and faster processing of sensory stimuli (Knott, 1989) in this EEG band. In addition, the dominant frequency of the gamma EEG band was greater in the low ANL group than the high ANL group. Gamma rhythms are involved in higher mental activity, including perception, problem solving, and consciousness (Haenschel, Baldeweg, Croft, Whittington, and Gruzelier, 2000). Studies have indicated that gamma band synchronization may be an essential mechanism of information processing, reflecting integration of various features of an object. Furthermore, gamma-range synchronization is thought to depend on the relationship between excitatory projection neurons and inhibitory neurons utilizing γ -aminobutyric acid (GABA) (Kwon, O'Donnell, Wallenstein, et al., 1999). These differences in the current study provide further evidence that influences of central origin mediate the willingness to listen in background noise.

Unlike the visual and somatosensory pathways, the auditory system lacks any

direct pathway from peripheral receptors to the cortex or vice versa. Rather, information ultimately reaching and returning from the auditory cortex undergoes significant reorganization as it is processed (Moore, 1994). A general conclusion reached from work on the anatomic and chemical composition of the auditory pathway is that inhibition plays an extremely important role at all levels of the system in shaping the exquisitely precise responses of central neurons (for review, see Jackler and Brackmann, 1994).

Inhibition is also a major component of selective attention and is manifested in the suppression of task-irrelevant stimuli. The process of selective attention is one in which an individual “selectively attends to some stimuli, or aspects of stimuli, in preference to others” (Kahneman, 1973), and is a vital component of one’s ability to function in the environment. There are numerous studies emphasizing the role of the cortex in this ability to effectively suppress stimuli that are not relevant to the task at hand (e.g., Glosser and Goodglass; 1990; Knight et al., 1999; Reuckert and Grafman, 1996; Stern, Sherman, Kirchhoff, and Hasselmo, 2001). Reviews of literature in cognitive functioning emphasize that individual differences in behavioral performance might best be explained by underlying differences in cortical inhibition (e.g., Dempster, 1992; Harnishfeger and Bjorkland, 1994). Furthermore, electrophysiologic studies interpret enhanced EEG and AEP responses to be indicative of increased brain excitability or a reduced capacity for inhibition, relative to controls (Ahveninen, et al., 1999; Lei-Zhang et al., 2001; Harkrider and Champlin, 2001a, b). These complexities of central organization seem to relate to the phenomenon of background noise acceptance. Results from the current study agree with theories and findings related to individual differences in

perceptual responses to similar sensory stimulation, and that there are distinct excitatory and inhibitory mechanisms that interact to maintain sensitivity to background noise. Specifically, it appears that individuals with high ANLs have weaker inhibitory feedback from the cortex leading to greater levels of afferent and cortical excitability to repetitive stimuli like background noise.

Limitations of the Study and Future Research

Given the pervasive influence of gender and aging effects on AEPs, future studies investigating the physiological aspects of ANL must balance the number of male and female participants among defined age groups to statistically evaluate and factor out the influence of gender and age. Future research must also incorporate more cognitive-based responses. Thus far, electrophysiological responses have been limited to “obligatory” AEPs that rely on the physical properties of the stimulus and provide limited information regarding memory, attention, and cognition. Event-related potentials (ERPs) provide a window into the regions of the brain underlying the sensory and perceptual processes of the auditory system and give insight into the physiological/psychological demands of the situation. Addressing these issues would provide more understanding about the physiological and cognitive processes contributing to background noise acceptance. Research suggests that attention is a system of cognitive control with different components having distinctive anatomic and physiologic bases. The highest levels of attentional control are based in the frontal lobes and act to inhibit irrelevant stimuli (Shimamura, 1995). Given that listeners with high ANLs lack the ability to inhibit task irrelevant distractions (i.e., background noise) it is expected that ERPs hold great

potential in documenting the processing characteristics contributing to the intersubject variability of ANL.

Finally, the stimulus differences between the behavioral and electrophysiological measures also must be recognized. The ANL procedure was measured with running speech and multitalker-babble stimuli, whereas the AEPs were elicited with brief tone bursts. It is essential to point out that the current study sought to characterize fundamental differences in physiological activity exhibited among individuals with a wide range of perceptual patterns of background noise acceptance. The inherent differences between the stimuli prohibit any cause-and-effect conclusions regarding the neural processes responsible for the willingness of an individual to accept background noise. The group differences in the electrophysiological responses are better interpreted as an indication that differences in the responsiveness of central regions of the auditory system are related to the variability in ANL. Future research should use more analogous behavioral and physiological stimuli to contribute to a more precise identification of the neural mechanisms responsible for the amount of background noise an individual is willing to accept.

CONCLUSIONS

One goal of this study was to investigate the possibility that differences in judgment of background noise exhibited among individuals may have underlying physiological significance in listeners with impaired hearing. Thus far, the differences in behavioral performance of ANL have not been attributed to differences in age, hearing thresholds/sensitivity, gender, type of background noise, efferent activity of the medial olivocochlear bundle pathway, middle ear characteristics, or speech perception in noise performance. Physiological responses from three groups of participants (low, mid-range, and high ANLs), including auditory brainstem responses, middle latency evoked potentials, long latency evoked potentials, and EEG were obtained. It was hypothesized that individual ANL differences in older listeners with impaired hearing are related to differences measured in aggregate physiological responses from the auditory nervous system. Differences in AEPs among the low, mid-range and high ANL groups were absent for the ABR and emerged for MLR peak-to-peak amplitude between the low and high ANL groups. Specifically, low ANLs had smaller Na-Pa amplitudes than high ANLs. The dominant frequency in the alpha EEG band of the high ANL group was higher than the mid-range ANL group, and the dominant frequency of the gamma EEG band was greater in the low ANL group than the high ANL group.

A second goal of this study was to determine whether or not the presentation level of the stimuli had differential effects on background noise acceptance and AEPs when measured from listeners with impaired hearing with low, mid-range and high ANLs. Results indicate that presentation level interacts with ANL group to influence behavioral

judgments of background noise acceptance, but not the physiological measures. Hearing impaired listeners with low and mid-range ANLs demonstrated a slower rate of ANL growth with increasing stimulus presentation level than those with high ANLs. Overall main effects of group on the AEP data and the interactions between group and stimulus presentation level are consistent with previous investigations purporting the theory that reduced responsiveness of the central afferent auditory nervous system and/or increased strength of cortical inhibition contributes to greater acceptance of background noise (i.e., lower ANLs).

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APPENDICES

Appendix A

Pattern of Hearing-Aid Use Questionnaire

Pattern of Hearing-Aid Use Questionnaire

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

1. I wear my hearing aids whenever I need them _____
Approximately how many hours? _____
2. I only wear my hearing aids occasionally _____
Approximately how many hours? _____
Why? Briefly describe the situations _____

3. I do not wear my hearing aid _____
Why do you not wear them? _____

Appendix B

Mini Mental State Examination (MMSE), Instructions, and Scoring

Mini-Mental State Exam

To begin the test, say: "Now I would like to ask you some questions to check your memory and concentration. Some of them may be easy and some may be hard.

	Correct	Incorrect
1. What is the year?	1	0
2. . . . the season of the year?	1	0
3. . . . the date?	1	0
4. . . . the day of the week?	1	0
5. . . . the month?	1	0
6. Can you tell me where we are? (e.g., what state are we in?)	1	0
7. What country are we in?	1	0
8. What city are we in?	1	0
9. What floor of the building are we on?	1	0
10. What is the name or address of this place?	1	0
11. I am going to name 3 objects. After I have said them, I want you to repeat them. Remember what they are because I will ask you to name them again in a few <i>minutes</i> :		
Apple	1	0
Table	1	0
Penny	1	0
Please repeat the names for me.		
(Score the first try only. If the patient is not successful on the first try, repeat the list up to two additional times.)		
12. Turn to the second page of the booklet and say: Here is a drawing. Please copy this drawing on the same paper.	1	0
Now, what were the three objects I asked you to remember?		
13. (Apple)	1	0
14. (Table)	1	0
15. (Penny)	1	0
16. Now, I am going to give you a word and ask you to spell it forwards and backwards.		
The word is "WORLD."		
First, spell it forwards: - - - -		
Now, spell it backwards: - - - -		

Correct Incorrect

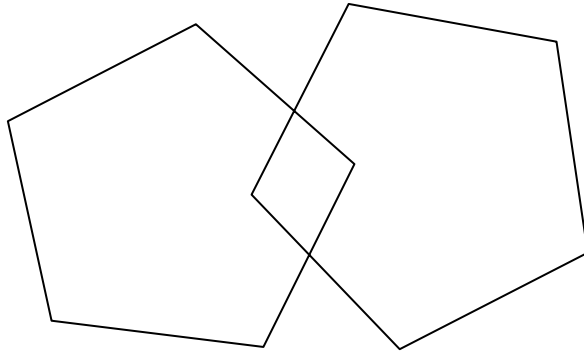
17. Show the subject your wrist watch. Say: What is this called?	1	0
18. Show the subject a pencil. Say: What is this called?	1	0
19. I would like you to repeat a phrase after me. The phrase is "no ifs, ands or buts" (allow only one trial.)	1	0
20. Show the subject the page stating " Close you eyes" Say: Read the words on this page and then do what it says.	1	0
21. Say: I am going to give you a piece of paper. When I do, take the paper in your right (or left) hand, fold the paper in half with both hands, and put the paper down on your lap. Read the full statement, then hand over the paper. Do not repeat or coach.		
Right hand	1	0
Folded	1	0
In lap	1	0
22. Write any complete sentence on that piece of paper for me.	1	0

Total for all 22 items; be sure to include item 16.
Range 0-30.

Total: _____

Mini-Mental State Instructions and Scoring

- 1) The MMSE is a screener of impaired mental status.
- 2) For questions 1-11, ask the participant to verbally answer each question.
- 3) For question 12, give them half of a sheet of paper and instruct them to copy the following drawing:



- 4) For questions 13-19, read the instructions as printed on the form and mark down the response. For question 20, use the card that says "Close your eyes" and read the question as printed. For question 21, read the directions to the participant and then hand them a piece of paper so that they can complete the three-step command. For question 22, have the participant write a complete sentence on the piece of paper.
- 4) Scoring: Each correct answer is worth 1 point and noted on the questionnaire. For item 12, score correct only if both of the following criteria are met: i) the two five-sided figures intersect to form a four-sided figure, and ii) all angles in the five-sided figures are preserved.
- 5) For item 16, there are a number of possible errors. These include letter omission, letter transposition, letter insertion, and letter misplacement. Count one point off for each of these errors.
- 6 Total the score for all 22 items. The range is 0-30. For the purposes of this study, a score of 28 out of 30 is required for subjects ≥ 60 years.

Appendix C

Informed Consent for Participants

INFORMED CONSENT STATEMENT

Physiological Contributions to Noise Acceptance

You are being asked to participate in a study of the acceptance of background noise. We would like to investigate physiological responses in comparison to the amount of background noise you can accept when listening to a story.

General Information:

To take part in this study, you must ≥ 19 years of age and consent to a hearing evaluation, which will be provided at no charge to you. The hearing evaluation will include a case history, test of hearing sensitivity, tests of eardrum and ear canal health, and a measure of the amount of background noise you are willing to listen to while listening to speech. **If you do not meet the study criteria for each part of the hearing exam you will be excluded from further participation.** If you qualify for the study you will receive monetary compensation of \$25 for the 2-hour session. This will be mailed to you approximately 2 weeks after your participation, in the form of a check from The University of Tennessee.

Procedures

If you have none of the exclusionary criteria and agree to participate in the study, you will undergo several tests of auditory function. These procedures are all tests that are commonly performed in standard audiological evaluations. The following steps are involved in these procedures:

Case History-Answer questions regarding your general health and hearing status, including a Mini Mental State Examination to assess cognitive function if you are ≥ 60 years of age.

Hearing Evaluation-Respond to tones presented at various frequencies to each ear.

Immittance Screening-Your ear canals will be examined to make sure they are free from obstruction. A soft earplug will be placed at the entrance to your ear canal and you will hear a tone. You will also feel pressure in your ear canal and may experience a brief, mild sensation of aural fullness, but you should not feel pain or discomfort.

Acceptable Noise Level- You will be asked to adjust the loudness of a story to your most comfortable listening level. Next, background noise will be added to the story. You will then be asked to adjust the level of the background noise to the highest level at which the story can still be followed without the noise creating tension or causing you to become tired.

Hearing Aid Questionnaire – You will be asked questions to determine your pattern of hearing aid use.

Auditory Evoked Response- Surface electrodes will be applied to your scalp and ears using an electrode cap. A small amount of an electrically conductive gel will be injected into the hole of each electrode mount. The experimenter will use a small stick to work the gel onto your scalp with the goal of obtaining a good electrical connection between your scalp and the electrodes. The electrodes will allow for non-invasive monitoring of electrical activity produced by your nervous system in response to auditory signals. The auditory signals will include tones that you will hear through earphones. The stimuli will be presented at comfortable loudness levels and will not be uncomfortably loud. During testing (approximately 1.25 hours), you will be seated comfortably in a reclining chair in a sound booth and will be asked to sit quietly and relax.

Potential risks or discomfort

For all tests, you will be seated comfortably in a chair in a sound treated room and given breaks, as needed. Completion of all tests will take approximately 2 hours. None of the sounds you will hear pose any risk of damaging your hearing. There are no known psychological, social, legal, or physiological risks or side effects associated with participation in this study. Although it is not expected, you should inform the investigator immediately if you experience any discomfort of any kind during the experiment.

Benefits

Benefits of the study include a free hearing evaluation and a free examination of the outer and middle ear. The results of the tests will be explained by the investigator. Based on the results of the tests you will be counseled regarding any needed medical/audiological follow-up. The scientific and clinical communities will benefit from greater understanding of the physiological mechanisms involved in acceptance of noise.

Voluntary Participation

Participation in this research experiment is voluntary. You may refuse to participate or quit at any time. If you quit or refuse to participate, then the benefits to which you are entitled will not be affected and you will be paid for the time served in the experiment at a rate of \$10/hour.

Confidentiality

Under federal regulations, you have the right to determine who has access to your personal health information (called “protected health information” or PHI). PHI collected in this study may include test results from the above procedures, as well as basic demographic information. By signing this consent form, you are authorizing the research team at the University of Tennessee to have access to your PHI collected in this study. In addition, your PHI may be shared with other persons involved in the conduct or oversight of this research. The Institutional Review Board (IRB) at the University of Tennessee may review your PHI as part of its responsibility to protect the rights and welfare of research subjects. Your PHI will not be used or disclosed to any other person or entity, except as required by law, or for authorized oversight of this research study by other regulatory agencies, or for other research for which the use and disclosure of your PHI has been approved by the IRB. Your PHI will be used only for the purposes described in this consent form. Your PHI will be kept in a locked filing cabinet on the UT campus for three years and then destroyed. In addition, any experimental data obtained from you during the session will be kept in a locked filing cabinet on the UT campus for five years and then destroyed. These data may be disseminated via presentation or publication, but will never be done so in association with your name or any other identifying information. If you have any questions, please ask them at this time. Your decision whether or not to participate will not affect your future relations with the Department of Audiology and Speech Pathology or The University of Tennessee. Your signature indicates that you have read the information provided here and that all of your questions have been answered. You may withdraw from participation in this study at any time after signing this form, without penalty. You may cancel this authorization at any time by contacting the principal investigator listed on this consent form. If you cancel the authorization, continued use of your PHI is permitted if it was obtained before the cancellation.

However, PHI collected after your cancellation may not be used in the study. If you refuse to provide this authorization, you will not be able to participate in the research study. If you cancel the authorization, you will be withdrawn from the study.

Signature of Participant

Date

Investigator's Assurance

The individuals named here are responsible for carrying out this research program. They assure all questions are answered to the best of their abilities. They will assure that you are informed of any changes in the procedure or risks and benefits if any should occur. They assure all information remains confidential.

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VITA

Joanna Webster Tampas was born in Knoxville, Tennessee on October 13, 1975, the daughter of Joe and Diana Webster. Joanna graduated from Jefferson County High School in 1993 and continued her education at the University of Tennessee, Knoxville, receiving a Bachelor of Science in Biology in 1997. Joanna received her Master of Arts in Audiology in 2002 and her Doctor of Philosophy in Speech and Hearing Science in 2007 from the University of Tennessee. She married James Gregory Tampas, son of George of Charlotte Tampas, with daughters Alexandra and Victoria Tampas. Joanna's research has concentrated on electrophysiological measures of the auditory system and its relationship to the Acceptable Noise Level (ANL) procedure.