The relationship between acceptable noise level and electrophysiologic auditory brainstem and cortical signal to noise ratios

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Abstract

The following objectives of the study were formulated: i) to investigate differences in measured signal to noise ratios while recording speech-evoked auditory brainstem response (cABR) and cortical late latency response (LLR) in low and high acceptable noise level (ANL) groups; and ii) to compare peak to peak amplitude of cABR (V-A) and LLR (N1-P2) in low and high ANL groups. A total of 23 normal hearing participants was included in the study. One shot replicative and partly exploratory research design was utilized to study the effect of signal to noise ratio in a recorded waveform on afferent mechanism, assessed by cABR and LLR on participants having values of ANL of ≤7 (low ANL group) and ≥13 (high ANL group). There were no differences in signal to noise ratio in the recorded waveforms of cABR and LLR between low and high ANL groups at both brainstem and cortical levels. However, the peak to peak amplitude of V-A of cABR and N1-P2 of LLR were both statistically larger in the high ANL group compared to their counterpart. The signal to noise ratio in recorded waveforms did not differentiated cABR (V-A) or LLR (N1-P2) in low and high ANL groups. However, Larger peak to peak amplitudes in the high ANL group suggests differences higher processing centers in the upper brainstem to the auditory cortex. The findings of the study may be useful in determining the patient acceptability of noise.

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Key words: signal to noise ratio, auditory brainstem response, late latency response

Contributions: HNS, study design, data collection and analyzing and interpretation of data; SM, DV, study design, collecting data, analyzing and interpretation of the results.

Conflict of interests: the authors declare no potential conflict of interests.

Acknowledgements: the authors would like to thank the Director, All India Institute of Speech and Hearing for granting permission to carry out the study. The authors would also like to thank HOD, Department of Audiology for permitting us to use instruments in collecting data and all the participants of the study for their co-operation. The authors would also like to extend gratitude to reveiwers for their valuable comments.

Received for publication: 29 November 2013.
Revision received: 7 March 2014.
Accepted for publication: 11 March 2014.

Audiology Research 2014;4:93
doi:10.4081/audiores.2014.93

Introduction

Acceptable noise level (ANL) is the measure of a subject's willingness to accept /or put up with noise while listening to speech. ANL purports to directly quantify the real world hearing aid benefit. In this procedure, the listeners adjusted the background noise level (BNL) until they are able to put up with noise without any annoyance while listening to recorded passage presented at their most comfortable level (MCL). The ANL is calculated by substracting the maximum BNL from the MCL *i.e.*, ANL = BNL - MCL. Listeners with low ANL (≤7) group can tolerate more noise while listening to speech (*e.g.*, poor signal to noise ratios). However, the higher ANL group (≥13) tolerates less noise while listening to speech (*e.g.*, better signal to noise ratios).

Though subjects were homogenous in hearing sensitivity, inter-subject variability noted in the literature for ANL.[1] ANL is not related to age and language,[2] gender[3] and type and preference of noise.[4] Nabelek *et al*.[4] demonstrated that the clinical consequences of ANL with hearing impaired individuals with low ANLs tend to accept more noise, with high potential to become successful hearing aid users. Conversely, hearing impaired individuals with high ANL tend to accept less noise relative to their counterparts. They are less likely to become successful hearing aid users and are considered as problematic with the usage of hearing aid. In the successive research reports Harkrider and Smith[5] and Tampas *et al*.[6] investigated the possible cause for differences in the ANL score among different groups. They suggested that there may be variability in the afferent and efferent auditory processing mechanism.

Harkrider and Tampus[7] conducted a study on the role of afferent mechanism in individuals who accept noise (low ANL) from those who do not accept more noise (high ANL). In all 13 participants with normal hearing, oto-acoustic emission (OAE) auditory brainstem response (ABR) and middle latency response (MLR) were recorded. The authors inferred that variability in the two ANL groups did not come from contributions in the cochlea (OAE), the distal part of the auditory nerve (wave I of ABR), the proximal part of the auditory nerve (wave II of ABR) and cochlear nucleus (wave III of ABR). However, a significant difference between the two groups was noted in lateral lemiscus (wave V of ABR) and auditory thalmo-cortical area (Na-Pa components of MLR), suggesting that acceptance of background noise is mediated by more of higher processing centers in the upper brainstem to the cortex.

In yet another similar study by Tampas and Harkrider,[8] investigated acceptance of noise in aggregate physiological responses at different levels of the auditory nervous system. They recorded ABR, MLR and LLR for the two tone bursts (0.3 kHz and 0.5 kHz) presented at lower (35 dB nHL) and higher (70 dB nHL) intensities on 21 female subjects with normal hearing classified into low and high ANL groups. The result revealed a smaller amplitude in the low ANL group compared to their counterparts in each part of the auditory afferent pathway. These differences in the amplitudes of wave V of ABR, Na –Pa of MLR and N1-P2 of LLR were found significant. They attributed these findings to stronger central efferent mechanism and/or less active central afferent mechanism in the low ANL group. To summarize, the auditory physiological mechanism at the higher processing centers in the upper brainstem to the auditory cortex mediated the willingness of noise. The smaller amplitudes of peak V (ABR) and N1-P2 (LLR) were noted in the low ANL group compared to the high ANL group. These findings were documented from the electro-physiological studies, which neurally encode the acoustic cues in an ongoing speech stimulus. From the literature report it was noted that the larger activity of noise [electroencephalogram (EEG)] obscures signal strength (response time locked to stimulus), which reflected in the amplitude of the response waveform.[9] In this context the signal to noise ratio is defined as the difference in electro-physiological response strength (ABR/LLR) to noise (EEG). Thus, it is hypothesized that signal to noise ratios might influence the response amplitudes of V-A of cABR at the auditory brainstem level and N1-P2 of LLR at cortical level in individuals of low and high ANL groups.

The purpose of the present study was to investigate the influence of signal to noise ratios on the physiological response obtained at the auditory brainstem and cortical levels between low and high ANL groups. Has the signal to noise ratio (SNR) contributed to the differences in the amplitudes of V-A of cABR at auditory brainstem level and N1-P2 component of LLR at cortical level reported in the low and high ANL groups? In order to solve this research question, there is a need to investigate the influence of SNRs on the amplitudes of V-A of cABR and N1-P2 of LLR obtained from subjects of the low and high ANL groups. In addition, the study of Harkrider and Tampas[7,8] discrepancy was noted in the stimulus used to obtain ANL and electro-physiologic response at the auditory brainstem and cortical levels. To overcome procedural variability in the study of Harkrider and Tampas[7,8] the present study is taken up, in which the speech passage is utilized to determine the ANL, and consonant vowel (CV) speech syllable is used to record the auditory brainstem response (cABR) and late latency response (LLR).

The aim of the study is to investigate the relationships between acceptable noise level and electrophysiologic auditory brainstem signal to noise ratio; and cortical signal to noise ratio. The following objectives of the study were formulated: i) to investigate differences in measured signal to noise ratios while recording speech-evoked cABR and cortical LLR in low and high ANL groups; and ii) to compare peak to peak amplitude of cABR (V-A) and LLR (N1-P2) in low and high ANL groups.

Materials and Methods

A total number of 23 normal hearing subjects were included in the study. One shot replicative and partly exploratory research design was utilized to study the inflence of signal to noise ratios in a recorded waveform obtained at each level of afferent pathway (cABR at brainstem level and LLR at cortical level) on subjects with different values of ANL. Those subejcts with ANL value of less than 7 were classified into low ANL group (14 participants) and those with an ANL value of 13 or above were classified into high ANL group (9 participants). ANL was determined by adopting the method of Nabelek.[10] It is the subject's willingness to accept/put up with background noise in the presence of speech delivered at the most comfortable level (ANL = BNL - MCL).

Electro-physiologic responses at different levels of the afferent auditory system were recorded by far field recording using Intelligent Hearing System (IHS) instrument. Three electrodes were placed on the test ear mastoid (inverting), forehead (ground) and vertex (non-inverting) such that each electrode and inter-electrode impedance was 1 k Ohms. Each participant was instructed to watch audio muted video and to avoid body movement during the test. Synthetic stimulus /da/[11] of 40 ms. duration was used as the test stimulus. It evokes an ABR followed by FFR components and is assumed to engage the language centers of the auditory system. The stimulus was delivered through insert earphone in alternating polarity at 65 dBnHL to record ABR in 15 ms. of post-stimulus time window and 5 ms. of pre-stimulus time window. Sweeps of 2000 were presented at the repetition rate of 7.1/s. Further, each epoch elicted was filtered online by 100 Hz to 3000 Hz. The epoch was rejected if the amplitude exceeded ±23 µV. Finally epochs which were free from artifacts was averaged.

Additionally, the LLR was recorded in the similar montage of cABR except activating ocular channels to remove eye blinks. Synthetic stimulus /da/ of 40 ms. duration was delivered through insert earphone in alternating polarity at 65 dBnHL to record LLR in 500 ms. of post-stimulus time window and 50 ms of pre-stimulus time window. Sweeps of 200 were presented at the repetition rate of 1.1/s. Each epoch elicted was filtered online by 0.1 Hz to 30 Hz. The epoch was rejected if the amplitude exceeded ±75 µV. Finally epochs which were free from artifacts was averaged.

Analysis

The waveforms of cABR and LLR were accepted for further analysis only if the artifact rejections were less than 2% from the total sweeps. Peak to peak amplitude in the waveforms of cABR (V-A) and LLR (N1-P2) were measured. Peak-to-peak amplitude is the difference between the maximum positive and the maximum negative amplitudes of a waveform.[12] Additionally, signal to noise ratios were computed from the responses of cABR and LLR using an IHS instrument.

Table 1. Mean, standard deviation, /U/, and P-values of signal to noise ratio in the response waveforms at barainstem and cortical levels.

Groups (no. of particpants)	SNR at brainstem level (mean±SD)	/U/	P-value	SNR at cortical level (mean±SD)	/U/	P-value
Low ANL group (N=14)	0.79±0.31	61.50	0.925	0.82±0.39	57.50	0.729
High ANL group (N=9)	0.77±0.22			0.72±0.40		

SNR, signal to noise ratio; ANL, acceptable noise level.

Before recording each evoked potential, the desired start time and end time to which SNR is to be calculated should be specified in the evoked potential instrument. In our study, signal to noise ratio was calculated in the entire time window of post stimulus response [*i.e.*, in cABR (0-15 ms) and in LLR (0-500 ms)]. In each buffer the corresponding array was selected at the start time (A) and at the end time (B) of post stimulus response based on sampling rate. Split sweep technique was used to calculate a signal estimate (S=buffer A + buffer B) and noise estimate (N=buffer A - buffer B). The total number of data points was calculated in signal estimate and noise estimate. A uV conversion factor was used to convert numerical values from the system (analoge to digital) A/D to uV values, where AD Volts is the range of the A/D which is 10 Volts and AD range is the numeric range of the A/D which is 32767. In signal estimate, the uV in each data point was summed and squared (Sss). Similarly, in noise estimate, the uV in each data point was summed and squared (Nss). The following formula was used to compute signal to noise ratio:

$$SNR = 0.5 * \sqrt{Sss}/\sqrt{Nss} \quad (1)$$

where:
SNR, signal to noise ratio;
Sss, signal sum square;
Nss, noise sum square.

Results

Data of signal to noise ratios in cABR and LLR waveforms, peak to peak amplitude of V-A of cABR, N1-P2 peak to peak amplitude of LLR from the low and high ANL groups were subjected to Mann-Whitney U test. The result revealed that there was no significant difference between the low and high ANL groups in the mean SNR of response waveform obtained at the brainstem level. This was true even at the cortical level (Table 1). From Figure 1, it was noted that peak to peak amplitude of V-A in cABR was larger in the high ANL group than the low ANL group. The peak to peak amplitude obtained from low and high ANL groups were subjected to Mann-Whitney U test. The result indicated a significant difference in the mean peak to peak amplitude of V-A of cABR, such that peak to peak amplitude was larger in the high ANL group than the low ANL group (Table 2).

Further, the N1-P2 peak to peak amplitude of LLR obtained from low and high ANL groups were subjected to Mann-Whitney U test. From Figure 2 the N1-P2 peak to peak amplitude of LLR was larger in the high ANL group than the low ANL group, such that this difference was found statistically significant (Table 3).

Discussion

The aggregate of neural response from auditory brainstem and cortical levels were measured to determine differences in physiologic activity in the low and high ANL groups. The SNRs in response waveforms obtained at different levels of the auditory pathway in the low and high ANL groups revealed no difference. The results of the present study inferred that SNR did not influence the amplitude differences in the recorded waveforms obtained at the brainstem and cortical levels of the auditory pathway between the low and high ANL groups.

In an excitation, the membrane threshold of the neuron reduces at the synaptic junction. This resulted in the release of neurotransmitter by which firing rate increases. Conversely, in an inhibition, the mem-

Table 2. Mean, standard deviation, /U/, and P-values of peak to peak amplitude of V-A (cABR) obtained from the low and high acceptable noise level groups.

Groups (no. of particpants)	Peak to peak Amplitude V-A (μV) (mean±SD)	/U/	P-value
Low ANL group (N=14)	0.45±0.24	16.50	0.002
High ANL group (N=9)	1.00±0.42	16.50	0.002

ANL, acceptable noise level.

Table 3. Mean, standard deviation, /U/, and P-values of N1-P2 peak to peak amplitude of late latency response obtained from the low and high acceptable noise level groups.

Groups (no. of particpants)	Peak to peak Amplitude V-A (μV) (mean±SD)	/U/	P-value
Low ANL group (N=14)	-2.95±1.52	11.50	0.001
High ANL group (N=9)	-2.95±1.52	11.50	0.001

ANL, acceptable noise level.

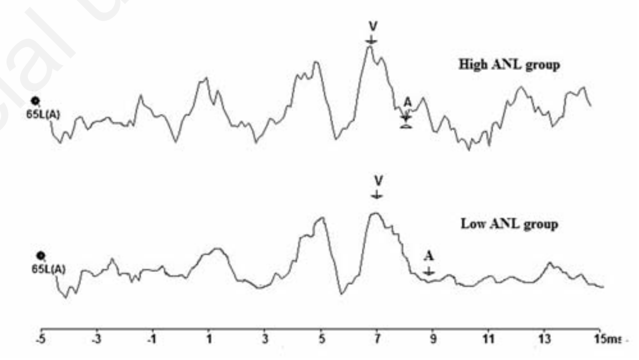

Figure 1. Grand avearged waveform of cABR obtained from the low and high acceptable noise level (ANL) groups. The peak to peak amplitude of V-A of cABR is larger in the high ANL group than the low ANL group.

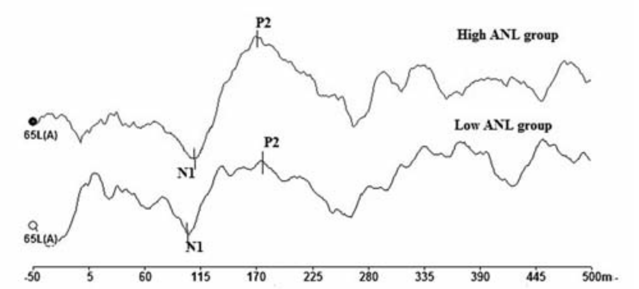

Figure 2. Grand averaged waveform of late latency response (LLR) obtained from the low and high acceptable noise level (ANL) groups. The N1-P2 peak to peak amplitude of LLR is larger in the high ANL group than the low ANL group.

brane threshold of the neuron increases, which in turn reduces the firing rate.[13] This mechanism continues until the generation site.[14] Thus, the amplitude variation in the evoked potential is attributed to the excitatory and inhibitory mechanisms of the neurons. In the present study, the peak to peak amplitude of V-A of cABR was reduced in the low ANL group compared to their counterpart, and this difference was found significant. It suggests that the neuron excitatory mechanism at the brainstem level in the low ANL group is relatively lesser than in the high ANL group. This mechanism might have been supported by the efficient efferent system, which balances the inhibitory mechanism to help them communicate in background noise as well to tolerate background noise. The results of the research report of Harkrider and Tampas[7,8] are in accordance with the present study. The amplitude of V in the present study was relatively lesser than in the previous research report in both the low and high ANL groups. This could be because the stimulus used and its intensity in the present study differed from the previous study. In the present study synthetic speech stimulus /da/ was delivered at 65 dB nHL. A tone of 3 kHz was presented at 70 dB nHL in the previous study. However, the explanation regarding the difference in V peak elicited by a tone (utilized in the previous study) and speech stimulus (present study) is not the scope of this article, which is reported elsewhere.[15] At the cortical level, the peak to peak amplitude of N1-P2 components of LLR was reduced in the low ANL group than the high ANL group. The results of the present study are in accordance with the research report of Harkrider and Tampas.[7,8] The reason is similar to what was explained previously. That is, central efferent mechanisms are stronger in the low ANL group such that sensory inputs are suppressed more than in the high ANL group. Thus, peak to peak amplitude differences between the low and high ANL groups at the brainstem level (V-A of cABR) and at the cortical level (N1-P2 of LLR) suggest that the acceptance of noise might be mediated by higher processing centers in the upper brainstem to the cortex.

Clinically, measuring ANL at hearing assessment stage helps to know the patient's acceptability towards noise. Knowledge regarding patient reaction to noise is advantageous because in the hearing aid a constant background noise will be present, such that there might be a high chance of rejection. Hence, the ANL score obtained from the patient directs the clinician to prescribe an appropriate hearing device. That is, patients having an ANL value greater than 13, may be better served with a device with directional microphones and/or noise reduction circuits, which improves can aid in the improvement of acoustic signal to noise ratio in the listening environment.

Conclusions

Signal to noise ratio did not influence the findings of peak to peak amplitude of V-A of cABR and peak to peak amplitude of N1-P2 components of the LLR between low and high ANL groups. However, the high ANL group had larger V-A and N1-P2 peak to peak responses than their counterpart. The physiological findings continue to suggest that the higher processing centers in the upper brainstem to the cortex is involved in the behavioral acceptance of more noise (low ANL) compared to those who are not willing to accept noise (high ANL) and is not a reflection of the signal to noise inherent in the evoked potential averaging process.

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