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COLLEGE OF ARTS AND SCIENCES

**A Comparison of Tone Burst Auditory Brainstem Response (ABR) Latencies
Elicited With and Without Notched Noise Masking**

BY

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Department of Communication Sciences and Disorders
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Abstract

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Objective: The air conduction click is currently the most widespread stimulus used to estimate the pure tone audiogram as part of auditory brainstem response (ABR) testing. The click is characterized by its broad spectral content and rapid onset, which may not make it the best choice for frequency specific ABR testing. An alternative stimulus is a short duration tone burst stimuli with notched noise masking. When obtaining an ABR using standard unmasked tone bursts, the brief stimulus onset may cause excessive spectral splatter producing response contributions from unwanted regions of the cochlea; thus, reducing the frequency specificity of the ABR. Notched noise masking used in conjunction with the tone burst ABR, limits the evoked response to those frequencies within the notch, thereby reducing the likelihood of spectral splatter and increasing frequency specificity. The presence of a sloping sensorineural hearing impairment creates additional difficulties for achieving frequency specificity because of the likelihood that lower frequency cochlea regions, with less sensory damage, will contribute to the evoked response. It is theorized that notched noise masking will reduce the neural contributions from regions of the cochlear outside those within the notch, resulting in more frequency specific results than those achieved with a standard unmasked tone burst stimulus. The present study was designed to investigate the differences in wave V latency between the notched noise ABR and the standard unmasked tone burst ABR as a measure of frequency specificity.

Design: Twenty-five participants with normal hearing in at least one ear and 16 participants with bilateral sensorineural hearing loss participated in this investigation. Each participant was given

an audiological evaluation, a click ABR screening to determine neural synchrony, a standard tone burst ABR and a notched noise tone burst ABR.

Results: An Analysis of Variance (ANOVA) failed to reveal any significant wave V latency differences between the ABRs obtained with unmasked tone bursts versus ABRs obtained with a notched noise tone burst.

Conclusion: The results of this study do not support the use of notched noise tone bursts for improved ABR frequency specificity. This finding is contrary to previously reported results (Stapells et al., 1990), which indicated improved frequency specificity when obtaining a tone burst ABR in notched noise versus a standard unmasked tone burst ABR.

Introduction

The auditory brainstem response (ABR) has several clinical applications. Among them is estimating the frequency specific hearing sensitivity of patients who cannot perform conventional pure-tone behavioral audiometry (Hood, 1998). It is important to determine hearing threshold sensitivity in patients who cannot provide valid or reliable thresholds using behavioral audiometry methods. Measurement of ABR is one way to estimate frequency specific hearing thresholds in these patients. Frequency specificity, as defined by Stapells and Oates (1997), refers to how autonomous a threshold is at one frequency from contributions by surrounding frequencies. When estimating hearing thresholds using the ABR, it is important that responses be as frequency specific and as close to the behavioral pure-tone hearing thresholds as possible. For example, when fitting a child with hearing aids, over amplification at specific frequencies must be avoided; therefore, frequency specific hearing thresholds, however obtained, are crucial.

There are several ways to estimate the pure-tone audiogram using ABR measures. Air conduction clicks and brief tones as well as bone conduction clicks and brief tones are four stimuli used to estimate hearing sensitivity via the ABR. When selecting among the available stimuli, the general goal is to obtain the most frequency specific information that will estimate the pure-tone audiogram best. This is a legitimate concern that several researchers have addressed (Abdala & Folsom, 1995; Beattie & Kennedy, 1992; Davis, Hirsh, Turpin, & Peacock, 1985; Gorga, Kaminski, Beachaine, & Bergman, 1993; Gorga & Thornton, 1989; Oates & Purdy, 2001; Stapells & Oates, 1997; Stapells, Picton, Durieux-Smith, Edwards, & Moran, 1990).

The air conduction click is currently the most widely used stimulus for estimating the pure tone audiogram (Stapells & Oates, 1997). However, the click may not be the best choice for frequency specificity due to its broad spectral content and rapid onset. Because of these characteristics, a large area of the basilar membrane is activated representing a broad range of frequencies. (Stapells & Oates, 1997), and estimation of hearing thresholds at specific frequencies is difficult, particularly in cases with high frequency hearing loss. Stapells, Picton, and Durieux-Smith (1994) found that similar click ABR thresholds could be obtained for listeners with a wide range of pure-tone audiograms. Thus, the use of unmasked clicks alone when estimating the pure-tone audiogram is not recommended (Stapells & Oates, 1997).

Perhaps an alternative is to use short duration tone burst stimuli. According to Stapells and Oates (1997) a short duration tone burst stimulus provides more frequency specificity and allows for reasonably accurate estimation of the pure-tone audiogram. The tone burst has primary energy at a single characteristic frequency and ideally contains no energy at other frequencies; therefore, one may assume that a 500 Hz tone burst is only stimulating the neurons tuned to 500 Hz in the cochlea (Hall, 1992). This stimulus would seem to be ideal for obtaining thresholds representative of the pure-tone audiogram; however, the tone burst has a brief stimulus onset, which may produce spectral splatter, or acoustic energy at unwanted frequencies (Hall, 1992). The splatter occurs when using high intensity stimuli (80 dB SPL and higher) and/or low frequency stimuli which spreads into the higher frequency regions of the cochlea. When splatter occurs it can generate a response that is not representative of the nominal frequency being tested (Hall, 1992). Several studies have addressed the issue of the spectral splatter that occurs when higher intensities are used (Picton, Ouellette, Hamel, & Smith, 1979; Stapells, Gravel, & Martin, 1995; Stapells & Picton, 1981; Stapells et al., 1994). The spectral

splatter is due to the spread of energy to frequencies higher or lower than the characteristic frequency and the upward spread of cochlear stimulation that occurs when using high intensities (Rose, Hind, Anderson, & Brugge, 1971). In cases of spectral splatter, there will likely be contributions from frequencies other than the characteristic frequency stimulated and the frequency specificity of the ABR will be reduced.

Spectral splatter is a particular problem when assessing patients with steeply sloping hearing loss because contributions may arise from the frequency regions where the hearing is better (Picton et al., 1979; Purdy & Abbas, 1989; Stapells et al., 1994; Stapells, Picton, Perez-Abalo, Read, & Smith 1985). In these cases, it is necessary to introduce some form of masking that will restrict inappropriate areas of the basilar membrane from responding. There are several different masking noises that can be used when assessing the ABR, including high pass noise, notched noise, and derived band masking. Only notched noise will be discussed here.

Notched noise is defined as a broadband of noise that has been band rejected (“notched”); a specific range of frequencies has been removed from the noise (Hall, 1992). When obtaining a tone burst ABR with notched noise masking, both the stimulus and the masking noise are introduced at the same time and only the frequencies within the notch are involved in generating the ABR (Hall, 1992). Thus, using notched noise masking improves the frequency specificity of the tone burst ABR (Stapells & Oates, 1997). It does not require more acquisition time to record the notched noise tone burst ABR than it does to record the standard tone burst ABR because both the masker and the stimulus are presented simultaneously (Hall, 1992). However, there are disadvantages to this method (Hall, 1992).

First, low frequency masking noise spreads into the notch. Second, the morphology of the waveform is compromised when using notched noise masking. Wave V has a more broad

shape and smaller amplitude and may sometimes be unidentifiable. When using tones presented at low to moderate intensity levels, the early waves (I, II, III and IV) are not typically present from 500 to 4000 Hz. These early waves may appear at higher intensity levels but only around 500-1000 Hz (Stapells & Oates, 1997). Third, extra peaks may appear in the waveform and be misinterpreted as wave V. It is important to remember that responses to tones usually occur at later latencies, which could lead to misinterpretation of earlier peaks as wave V. Lastly, using notched noise-masking overestimates the auditory threshold levels. Despite these disadvantages, several studies have shown that using this masking paradigm does give reliable threshold estimates (within 10-20 dB) from 500 to 4000 Hz in most individuals with hearing loss (Munnerley, Greville, Purdy, & Keith, 1991; Picton et al., 1979; Stapells, 1984; Stapells et al., 1985; Stapells et al., 1990; Stapells et al., 1994; Stapells et al., 1995).

There is limited research on whether the notched noise masking is more effective than the standard unmasked tone burst ABR and, if so, in what ways. Therefore, the present study was designed to investigate the differences in latency between the notched noise tone burst ABR and the standard unmasked tone burst ABR. It was hypothesized that there will be no difference between the ABR tone burst latencies without notched noise and those with notched noise masking.

Methods

Participants

A total of 41 participants, 25 participants with normal hearing in at least one ear and 16 participants with bilateral sensorineural hearing loss (SNHL) participated in this study. The mean age for the participants with normal hearing was 27.42 (SD = 8.40) and 54.38 (SD = 14.38) for the participants with SNHL. Participants were recruited from the University of South Florida

Communication Disorders Center. The participants with normal hearing had audiometric thresholds at or better than 25 dB HTL from 500 to 8000 Hz in the test ear. Table 1 displays the average (± 1 SD) HTLs for the normal hearing group. The participants with sensorineural hearing loss (SNHL) had audiometric thresholds in the mild to moderate range (30–55 dB HTL) from 500 to 8000 Hz. The ideal configuration was sloping with 10-15 dB decrease per frequency; however other configurations were accepted due to limited number of participants. Table 2 displays the average (± 1 SD) HTLs for the SNHL group.

TABLE 1. Hearing threshold data for the normal hearing subjects.

Auditory Thresholds (dB HL)						
Frequency	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Mean	7.50	7.04	7.04	7.27	5.91	10.95
SD	4.30	3.98	5.04	6.50	6.84	7.84

TABLE 2. Hearing threshold data for the hearing impaired subjects.

Auditory Thresholds (dB HL)						
Frequency	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Mean	27.64	37.06	40.88	50.59	59.41	66.18
SD	13.80	12.12	15.62	15.93	14.78	14.31

All participants had normal middle ear function, defined as the following: peak pressure within +50 to -100 daPa, static immittance from 0.37 to 1.66 ml, and an ear canal volume between 0.65 and 2.5 ml (Gelfand, 1997). Contralateral acoustic reflexes were within normal limits as determined by published guidelines (Silman & Gelfand, 1981). All participants passed a click ABR screening, indicating normal neurosynchrony.

Instrumentation

Tympanometry was conducted using the GSI Tymptstar Middle Ear Analyzer and pure tone testing was conducted using the Interacoustics AC40 diagnostic audiometer. Air conduction thresholds were obtained using EAR-insert earphones. All of the testing was conducted in a sound-treated booth that meets ANSI and ISO specifications for maximum ambient noise. All of the audiograms considered for this study were deemed reliable by the audiologist completing the behavioral audiogram.

Acquisition of the ABR measurements was obtained using the Nicolet *Spirit* evoked potential system with all stimuli delivered through an ER-3A tubeophone. All of the ABR measurements were conducted in a sound treated booth that meets ANSI and ISO specifications for maximum ambient noise conditions. The participants were seated in a reclining chair for the acquisition of the ABR measurements.

The stimulus used for the click ABR screening was a 100 μ sec click with intensity of 75 dB nHL or higher if needed based on the amount of hearing loss. The clicks were presented at a rate of 17.7 per second with a 12 msec time window and a filter bandwidth of 100 to 3000 Hz. A two-channel recording was obtained using gold-plated cup electrodes placed at the vertex (non-inverting), earlobe (inverting) and nape of the neck (inverting) ipsilateral to the stimulated ear (i.e. C_Z-A₁ or C_Z-A₂ and C_Z-C₇) electrode montage. The forehead (F_{pz}) served as

the ground and inter-electrode impedance was less than 2000 ohms. Two replications of 1500 sweeps were obtained, one with condensation polarity and one with rarefaction polarity.

Tone burst ABR recordings were one channel ipsilateral recordings obtained using the C_Z-A₁ or C_Z-A₂ and C_Z-C₇ electrode montage with F_{pZ} serving as ground. Inter-electrode impedance was less than 2000 ohms and two replications of 1500 sweeps were obtained for each recording. The pre-amplifier filter was set to a band pass of 30–1500 Hz (12 dB/octave slope) and averaged using a post stimulus time window of 15 msec.

Stimuli for the standard tone burst ABR testing were 500, 2000 and 4000 Hz short duration tones. A Blackman gating function with no plateau and the following rise/fall times was used for the tone bursts: 4 msec rise/fall time for 500Hz; 2 msec rise/fall time for 2000Hz; and 1.0 msec rise/fall time for 4000Hz. All the monaural tone burst ABR thresholds were obtained at a presentation rate of 17.7 using the modified Hughson-Westlake technique with a 5 dB step size.

Stimuli parameters for the notched noise tone burst ABR testing were the same as for the standard tone burst ABR with the addition of the masking noise. The notched noise was produced by passing broadband noise through a band-reject filter resulting in a one octave-wide notch centered on the nominal frequency of the tone with high-pass and low-pass rejection slopes of 48 dB per octave. The masking noise intensity was set at 10 dB below the peSPL of the tone and was kept constant for all tone intensities. All of the equipment used undergoes yearly calibration checks as well as daily biological listening checks to insure that it meets ANSI specifications. The latest calibration date was March 11, 2003.

Procedure

Each participant was given the same test battery in three stages, starting with the basic hearing test, which included the tympanogram, acoustic reflex testing, and the pure-tone audiogram. This first stage took approximately 30 minutes. In the second stage, the click ABR screening was measured using the test parameters detailed above. Preparation and acquisition of the click ABR took approximately 30 minutes. Once normal neurosynchrony was determined, the third stage began with the tone burst ABR measured in quiet followed by notched noise. The tone burst ABRs were measured in the chosen ear. There was no particular method for choosing the ear of stimulation for the participants with normal hearing. A total of 14 right ears and 11 left ears were used in the participants with normal hearing group. The ear that was stimulated for the participants with SNHL depended on the audiogram. For example, if a participant with SNHL had an asymmetry, the better ear was chosen so that there would not be contributions from the better ear contributing to the response of the poorer ear. A total of 8 right ears and 8 left ears were used for the participants with SNHL. The stimuli were presented and then lowered in 10 dB intensity increments until two no-response recordings at two successive intensities were obtained. The order of frequency presentation was 2000 Hz, 4000 Hz and 500 Hz. At least two replications of 1500 trials each were obtained at each intensity/frequency condition. Acquisitions of the tone burst waveforms, or stage three, took approximately two hours, for a total data collection time of approximately three hours. The experimenter's committee chair, an experienced ABR reader, who was blind to each participant's pure-tone audiogram, judged the latencies of the resulting ABR waveforms.

Latency results were analyzed using descriptive statistics as well as inferential statistics such as the analysis of variance (ANOVA). The recorded latencies of wave V were analyzed for

each frequency at a high and low intensity level with the results analyzed using an ANOVA. Results were considered significant at the $p = < 0.05$ level.

Results

In order to determine if there was an intensity/latency effect, the ABR data were analyzed at two intensity levels which were designated as “high” and “low” intensity, respectively. For the normal hearing participants, high intensity was 65 dBnHL and low intensity was 35 dBnHL while for the SNHL participants, the high and low intensity designations were based on the sensation levels analogous to the two fixed intensity levels for the normal hearing participants. To assure that the two high and low intensity designations were equivalent, these data were subjected to a mixed ANOVA which indicated that there were no significant latency differences ($F [1,15] = 0.98, p > 0.05$) between the two participant groups at either tone burst condition, or tone burst frequency for the “low” intensity designation. Further, there was no significant latency difference ($F [1,15] = .54, p > 0.05$) between the two participant groups at either tone burst condition, or tone burst frequency for the “high” intensity designation. Thus, the designation of high and low intensity for the two groups was equivalent.

ABRs thresholds, behavioral thresholds, and wave V latencies obtained for both participant groups were averaged across the masking and frequency conditions. For the participants with normal hearing, the main effects of frequency ($F [2, 28] = 287.53, p < 0.001$) and level ($F [1,24] = 906.64, p < 0.001$) were statistically significant as was the interaction between frequency and level ($F [2, 48] = 27.82, p < 0.001$). Neither the main effect of noise condition nor any of the other potential interactions were statistically significant ($p < 0.05$). A Tukey HSD post- hoc analysis of the significant interaction between frequency and level revealed that wave V latencies differed significantly across all meaningful pairings ($p < 0.05$).

For the participants with hearing loss, the main effects of frequency ($F [2, 30] = 116.46$, $p < 0.001$) and level ($F [1, 15] = 380.77$, $p < 0.001$) were statistically significant as was the interaction between frequency and level ($F [2, 30] = 12.45$, $p < 0.001$). Neither the main effect of noise condition nor any of the other potential interactions were statistically significant ($p < 0.05$). A Tukey HSD post-hoc analysis of the significant interaction between frequency and level revealed that wave V latencies differed significantly across all meaningful frequency and level combinations ($p < 0.05$).

Figures 1 and 2 display the comparison of the tone burst ABRs and the notch noise tone burst ABRs. The above mentioned analysis demonstrates that there were no significant latency differences between the two ABR tone burst procedures at any of the three frequencies or at either of the two intensity levels. Further, the results of the above ANOVA were the same for both participant groups.

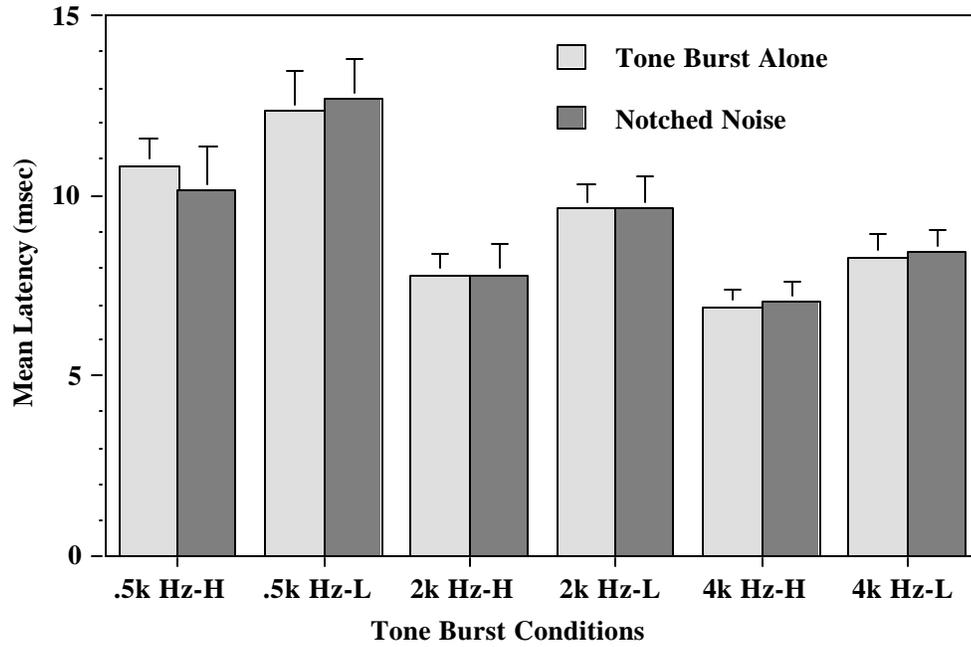


Figure 1. Mean (± 1 SD) latencies for the 500, 2000 and 4000 Hz tone burst and tone burst in notched noise conditions at the high (H) and low (L) presentation levels for the normal hearing subjects.

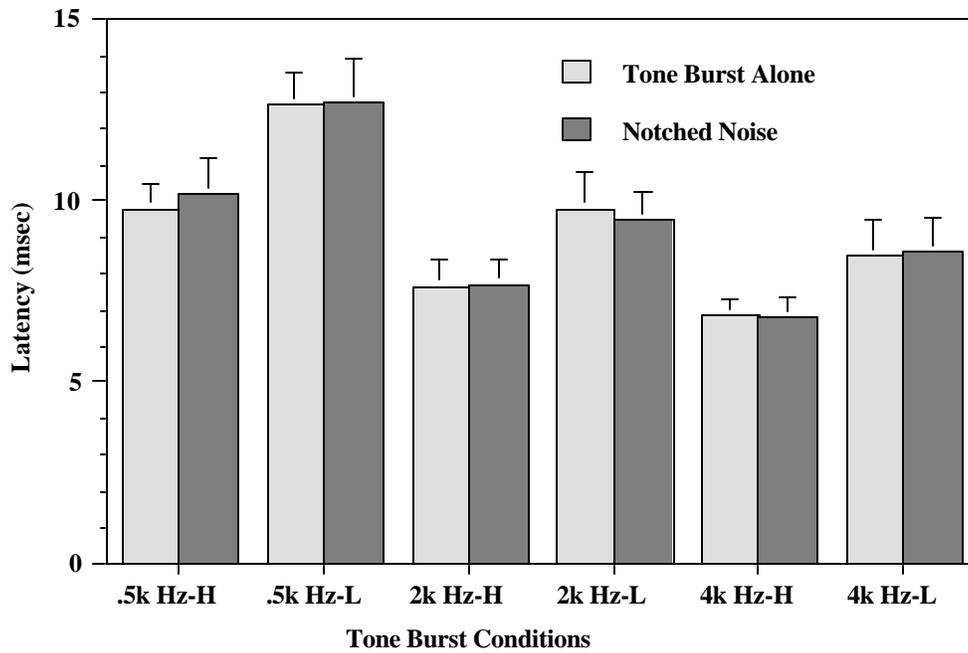


Figure 2. Mean ($\pm 1SD$) latencies for the 500, 2000 and 4000 Hz tone burst and tone burst in notched noise conditions at the high (H) and low (L) presentation levels for the sensorineural hearing loss subjects.

Discussion

It was hypothesized that wave V latencies obtained in notched noise would not be significantly shorter than those obtained without notched noise. This hypothesis was supported by the data analysis. Based on some previous results (Stapells & Picton, 1981), the expected results of the present study would indicate greater frequency specificity for ABRs in notched noise masking, especially for hearing impaired individuals; however those results were not seen in this study. Contrary to previous results (Stapells et al., 1990) the effect of notched noise masking was not seen more in participants with SNHL. This study showed no significant difference in the frequency specificity for ABRs in notched noise masking for the participants with SNHL. Further, the results of this study did not indicate that there is a significant difference between the frequency specificity of the tone burst in quiet and noise for participants with normal hearing. In summary, the results of this study indicate that there is no significant difference in frequency specificity when obtaining a tone burst ABR in notched noise versus obtaining a standard tone burst ABR for both individuals with normal hearing and those with sensorineural hearing loss. Thus, the null hypothesis was upheld.

There are a few discussion points that should be mentioned. First, the morphology of the waveform is compromised when using notched noise masking. Wave V has a broad shape and smaller amplitude, which makes it difficult to identify (Hall, 1992). This was evident with the data collected for the present study. A suggestion for further studies would be to run a third replication to help identify the waves. Second, the present study used a rate of 17.1/sec. and collected 1500 sweeps. Stapells et al. (1990) used a rate of 39.1/sec. According to that study,

using a rate of 39.1/sec records both the ABR and a steady-state response, making it difficult to determine how much of the response is derived from each component; therefore, they recommend using a rate of 27.1/sec so that the steady state response is not recorded. Perhaps, using a faster rate such as 27.1/sec would allow for more sweeps to be collected in the allotted time, which in turn will improve the signal to noise ratio of the response. Stapells et al. (1990) recommends using at least 2000 sweeps so that the resulting waveform has minimal residual noise. The present study collected 1500 sweeps so perhaps collecting 2000 sweeps would have made the resulting waveforms easier to identify wave V. Thirdly, previous studies by Stapells et al. (1990) utilized a linear gating function and this study utilized a non-linear gating function (Blackman). According to Gorga and Thornton (1980), the Blackman gated tone burst, with its reduction of energy at the side lobes, is more frequency specific than the linear gated tone burst. Lastly, the ideal configuration of hearing loss for this study is a sloping SNHL with more loss in the high frequencies than the low frequencies; however, to increase the number of participants, other configurations were used in this study. The above listed points of discussion could be contributing reasons as to why the results of this study differ from previous findings by Stapells et al. (1990).

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