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Normative Behavioral Thresholds for Short Tone-Bursts

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Abstract

Although tone-bursts have been commonly used in auditory brainstem response (ABR) evaluations for many years, national standards describing normal calibration values have not been established. This study was designed to gather normative threshold data to establish a physical reference for tone-burst stimuli that can be reproduced across clinics and laboratories. More specifically, we obtained norms for 3-msec tone-bursts presented at two repetition rates (9.3/sec and 39/sec), two gating functions (Trapezoid and Blackman), and four frequencies (500, 1000, 2000, and 4000 Hz). Our results are specified using three physical references: dB peak sound pressure level, dB peak-to-peak equivalent sound pressure level, and dB SPL (fast meter response, rate = 50 stimuli/sec). These data are offered for consideration when calibrating ABR equipment. The 39/sec stimulus rate yielded tone-burst thresholds that were approximately 3 dB lower than the 9.3/sec rate. The improvement in threshold with increasing stimulus rate may reflect the ability of the auditory system to integrate energy that occurs within a time interval of 200 to 500 msec (temporal integration). The Trapezoid gating function yielded thresholds that averaged 1.4 dB lower than the Blackman function. Although these differences are small and of little clinical importance, the cumulative effects of several instrument and/or procedural variables may yield clinically important differences.

Key Words: Auditory brainstem response, behavioral tone-burst thresholds, Blackman gating function, repetition rate, Trapezoid gating function

Abbreviations: ANSI = American National Standards Institute, IHS = Intelligent Hearing Systems, peSPL = peak equivalent sound pressure level, ppeSPL = peak-to-peak equivalent sound pressure level, pSPL = peak sound pressure level

The auditory brainstem response (ABR) is a useful electrophysiologic technique for assessing hearing sensitivity in patients whose age or handicaps rule out the use of conventional behavioral audiometric techniques (Jacobson and Hyde, 1985; Hood and Berlin, 1986; Kileny and Magathan, 1987; Hall, 1992; Weber, 1994; Oates and Stapells, 1998; Gorga, 1999). Because wave V is typically the most prominent component of the ABR waveform, particularly at low intensities, threshold is usually defined as the lowest level at which wave V is identifiable. Several investigators have suggested that ABR audiometry should include at least one low-frequency stimulus (500 or 1000 Hz) and one high-frequency stimulus (click, 2000 Hz, or 4000 Hz) for estimating auditory sensitivity (Davis and Hirsh, 1979; Hood and Berlin, 1986; Kileny and Magathan, 1987; Fjermedal and Laukli, 1989; Conijn et al, 1993). This enables the clinician to construct a two-point audiogram that can serve as a basis for making rehabilitative decisions (Kileny, 1981; Eggermont, 1982; Fjermedal and Laukli, 1989; Conijn et al, 1993; Stapells and Oates, 1997; Gorga, 1999). Clinical studies using tone-bursts have demonstrated that behavioral pure-tone thresholds can be estimated within 10 to 20 dB in 90 percent of measurements (Coats and Martin, 1977; Hayes and Jerger, 1982; Fjermedal and Laukli, 1989; Beattie et al, 1996a). These data are judged sufficiently accurate to allow initiation of a habilitation program (Stapells and Oates, 1997; Gorga, 1999).

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The ABR is an onset response in which only the earliest portions of the stimulus are most important in eliciting a response (Debruyne and Forrez, 1982; Gorga et al, 1984). Stimuli with rapid onsets, however, are characterized by spectra having a relatively wide main lobe and relatively intense side lobes outside of the nominal frequency (spectral splatter). The amplitude spectrum narrows as rise-plateau-fall times increase in duration, improving the acoustic frequency specificity of these stimuli. Therefore, when selecting the test stimulus, clinicians compromise between choosing a sufficiently long stimulus to achieve frequency specificity and sufficiently short stimulus to elicit a maximal response. Investigators have typically selected stimuli ranging from approximately 2 to 10 msec for frequencies from 500 to 4000 Hz (Stapells et al, 1985). We have used 1-msec rise-plateau-fall times (total duration = 3 msec) in recent studies because these durations were considered to represent a reasonable compromise between good frequency specificity and response identifiability (Beattie et al, 1996a, b; Beattie and Torre, 1997). Linear envelopes (also called gating functions or windows) were used in these studies. The amplitude spectra had center frequency bandwidths that were about 800 Hz wide at the 20-dB down-points, and the side lobes were approximately 25 dB below the peak energy of the main lobe. Nonlinear windowing (e.g., Blackman windows) uses higher-order trigonometric functions to shape the rise and fall of a tonal stimulus. Although the envelopes are similar for the linear and Blackman windows, the side lobes are approximately 65 dB down from the main lobe for Blackman windows. Gorga and Thornton (1989) advocate using nonlinear windowing functions because the reductions in side lobe energy minimize the spread of energy to surrounding portions of the cochlea and may excite a more narrowly defined cochlear region (place specificity) . However, other authors have concluded that Blackman windows may not provide greater place specificity than conventional linear windows (Purdy and Abbas, 1989; Robier et al, 1992; Oates and Stapells, 1998). Without masking noise, the responses generated by tone-bursts may arise from regions other than those suggested by the nominal frequency (Stapells et al, 1985). The specificity of the ABR response depends on how precisely the stimulus activates a specific place on the basilar membrane (place specificity). It is important to recognize, however, that the acoustic spectrum of the test stimulus may not reflect those frequencies that actually elicit the ABR (Stapells and Oates, 1997). Place specificity is dependent on several factors. First, the onset of the tone-burst is the effective stimulus for the ABR (Debruyne and Forrez, 1982; Gorga et al, 1984). Second, the frequency response of the transducer shapes the spectrum that is delivered to the ear canal. Third, the outer ear and middle ear alter the spectrum that reaches the inner ear (Durrant and Lovrinic, 1995). Fourth, because of the hydrodynamics of the cochlea (Békésy, 1960), low-frequency stimuli presented at moderate to high intensity levels activate basal and apical regions of the cochlea. Fifth, the effective stimulus is dependent on the audiometric configuration (i.e., flat versus steeply sloping audiograms). It is evident from the above comments that generating frequency-specific stimuli (acoustic frequency specificity as measured in a coupler) does not ensure that specific regions of the cochlea are stimulated (place specificity).

There is general agreement among investigators that stimulus rates of less than 10 to 20/sec have little effect on the latencies or amplitudes of ABR waves I, III, or V (Don et al, 1977; Yagi and Kaga, 1979; Beattie, 1988). Repetition rates greater than about 20/sec tend to increase latencies (Fowler and Noffsinger, 1983; Campbell and Abbas, 1987) and reduce amplitudes, particularly for the earlier waves (waves I and III); these increased rates have less effect on the amplitude of wave V and little effect on the threshold of wave V (Sininger and Don, 1989; Beattie and Torre, 1997; Oates and Stapells, 1998). When using ABR measurements for site-of-lesion testing, clinicians often use a relatively slow rate of about 10/sec because interwave latency measurements require identification of waves I and III as well as wave V (Glattke, 1983; Silman and Silverman, 1991). For threshold measurements, however, clinicians often select a faster rate of 30 to 40/sec (Silman and Silverman, 1991; Oates and Stapells, 1998). These faster rates allow the tester to present more stimuli within a given time, which tends to improve the signal-to-noise ratio and threshold (Jacobson and Hyde, 1985; Beattie et al, 1992). Although even faster rates have been suggested (Picton et al, 1981), stimulus rate is limited by the analysis time. When using tone-bursts, it is common to select an analysis time of approximately 25 msec to ensure identification of low-level, low-frequency wave V thresholds in hearing-impaired subjects. A 25-msec analysis time limits the maximum rate to 40/sec (1000 msec/25 msec = 40). In view of the above, we selected rates of 9.3/sec and 39/sec as representative of the range of stimulus rates that are typically employed by clinicians when using tone-bursts. Increasing the stimulus rate from 9.3/sec to 39/sec is expected to decrease the behavioral (psychoacoustic) threshold because the auditory system integrates or sums energy that occurs within a time interval of about 500 msec (Wright, 1978). This improvement in threshold as the duration of the stimulus is increased to about 500 msec is referred to as temporal integration (Garner and Miller, 1947) or temporal summation (Zwislocki, 1960). For example, Wright (1978) reported that tone thresholds for normal-hearing subjects improved about 10 dB as duration increased from 10 to 100 msec. The improvement in threshold was only about 2 dB as duration increased from 100 to 200 msec, and another 2-dB improvement was observed as duration increased from 200 to 500 msec. Compared to normal-hearing listeners, investigators reported smaller temporal integration effects for subjects with sensorineural hearing loss (Wright, 1978; Gorga et al, 1984). Because more stimuli (approximately four times as many) would be contained within a given time interval for the 39/sec rate than for the 9.3/sec rate, lower psychoacoustic thresholds are expected for the faster rate. Based on click results (Stapells et al, 1982), the behavioral threshold is expected to decrease about 3 dB as stimulus duration is increased from 9.3/sec to 39/sec.

Although tone-bursts have been commonly used in ABR evaluations for many years, national standards describing normal calibration values have not been established. Four stimulus intensity references are frequently reported in the literature: (1) dB hearing level for a small group of normal-hearing subjects (dB nHL), (2) dB peak sound pressure level (pSPL), (3) dB peak equivalent sound pressure level (dB peSPL) or peak-to-peak equivalent sound pressure level (dB ppeSPL), and (4) dB sound pressure level (dB SPL) for a stimulus having a fast repetition rate (e.g., 50 tone-bursts/sec). One common clinical practice for specifying stimulus intensity for an ABR system is to obtain behavioral thresholds on a group of 6 to 12 normal-hearing young adults in response to a specific stimulus (e.g., the rise-plateau-fall times, stimulus rate, and earphone should be specified). The average behavioral threshold is designated as 0 dB nHL for that specific stimulus (Picton et al, 1977). This reference implies that a relatively small group of normal listeners was tested at a specific clinic and/or that rigorous controls were not employed for subject selection, ambient noise, or psychophysical method. Thus, there is no assurance that equivalent dial readings among clinics (e.g., 80 dB nHL) will produce equivalent sound pressure levels as measured on a sound level meter. Moreover, periodic recalibrations are time consuming because 6 to 12 listeners must be tested to confirm threshold. Although this procedure may be required if there are no normative data available that have used identical or similar stimulus conditions, one of the physical intensity measurements should also be obtained so that stimulus conditions can be replicated as closely as possible across laboratories (Gorga and Thornton, 1989). Measuring the pSPL is one of the most accurate and consistent measures of stimulus intensity (Hall, 1992). This measurement requires a 2-cc (insert earphones) or 6-cc coupler (supra-aural earphones) with an associated microphone and a sound level meter that is capable of recording very brief signals (time constant = 50 μsec) with a peak-hold feature to enable reading of the pSPL. Peak-to-peak equivalent sound pressure level is the root-mean-square sound pressure level of a continuous pure tone having the same amplitude as the transient (Stapells et al, 1982). These measurements are made by directing the output of the earphone to an appropriate coupler (2 or 6 cc) with an associated microphone and sound level meter and then connecting the output of the sound level meter to an oscilloscope (Glattke, 1983). First, the peak-to-peak voltage of the test tone-burst (Zerlin and Naunton, 1975) is measured on the oscilloscope at a specified intensity (e.g., 80 dB nHL). Second, a continuous tone having the same frequency as the tone-burst is directed through the earphone, coupler, and sound level meter to the oscilloscope. The intensity of the continuous tone is adjusted to provide a peak-to-peak voltage that is equivalent to the peak-to-peak voltage of the tone-burst. Third, the sound pressure level of this continuous tone is read from a sound level meter. This reading is referred to as the ppeSPL; it may be called the peSPL. However, sometimes base-to-peak voltages are measured for both the test stimulus and the substituted continuous tone; this measurement is also referred to as the peSPL. When measurements are reported in peSPLs, care should be taken to specify whether the values are based on base-to-peak or peak-to-peak voltages. Base-to-peak SPLs for clicks may be about 3.5 dB higher than peak-to-peak SPLs (Burkhard, 1984). These differences may be explained by the asymmetry that is typically observed between the initial positive and negative deflections of a click stimulus (Glattke, 1983) and for tone-bursts that are only a few cycles in duration (Beattie et al, 1984). Although peSPL or ppeSPL measurements are more time consuming than pSPL measurements, the former may be required if the sound level meter does not allow pSPL measurements. Another calibration method that uses a conventional sound level meter is to measure the sound pressure level of a stimulus having a repetition rate that is sufficiently fast so that a constant sound level meter reading can be obtained. For example, Intelligent Hearing Systems (IHS) suggests calibration values for tone-bursts in which 10-msec stimuli (rise–fall times = 1 msec) are presented at a rate of 50/sec. IHS recommends that the sound level meter be set to a fast meter response (125-msec time constant) and that the linear weighting mode (unfiltered) be selected.

In view of the foregoing, this study was designed to gather normative threshold data that specify a physical reference for tone-burst stimuli that can be reproduced across clinics and laboratories. More specifically, we gathered normative data for 3-msec tone-bursts presented at two repetition rates (9/sec and 39/sec), two gating functions (Trapezoid and Blackman), and four frequencies (500, 1000, 2000, and 4000 Hz). Our results are specified using three physical references: dB pSPL, dB ppeSPL, and dB SPL (fast meter response, rate = 50/sec).

METHOD

Subjects

Twenty-five normal-hearing adults (18–26 years) participated in the study. The subjects passed a 10 dB HL (ANSI, 1996) pure-tone screening test at 500, 1000, 2000, and 4000 Hz. The subjects had tympanometric peaks within ±50 daPa and compensated static admittances ranging from 0.3 to 1.75 mL. One ear from each subject was randomly selected for testing.

Instrumentation

The test stimuli consisted of 500-, 1000-, 2000-, and 4000-Hz rarefaction tone-bursts with linear (Trapezoid) and Blackman gating functions. Because rarefaction and condensation stimuli have identical spectra, we would expect no behavioral threshold differences among condensation, rarefaction, or alternating stimuli. Thus, any polarity could have been selected for testing. However, when the ABR is elicited with a low-frequency tone-burst (e.g., 500 Hz), a single polarity may yield larger wave V responses than when using alternating polarities (Beattie et al, 1994a). The total durations used in the present study were 3 msec for both gating functions; the linear tone-bursts had rise, plateau, and fall times of 1 msec each. The tone-bursts were presented at repetition rates of 9.3/sec and 39/sec. A commercially available system (IHS) was used to present the test stimuli. The stimuli were generated by the Digital Signal Processor board and directed to insert earphones (E-A-RTONE 3A, 300 ohms) connected to foam eartips (E-A-RLINK, size 3A or 3B). Sound pressure levels were measured with a sound level meter (Quest, Model 155), microphone (Bruel & Kjaer, Model 4144), and 2-cc (HA-2) coupler (Bruel & Kjaer, Model DB-0138). The SPLs corresponding to 0 dB nHL were 31 dB for 500 Hz, 24 dB for 1000 Hz, 21 dB for 2000 Hz, and 15 dB for 4000 Hz. The tone-burst spectra were consistent with previous research for the linear (Beattie and Torre, 1997) and Blackman windows (Gorga and Thornton, 1989). That is, the main energy peaks corresponded to the nominal center frequency. The adjacent side lobes were about 25 dB below the main lobe for the linear stimuli and about 65 dB below the main lobe for the stimuli with the Blackman gating function. The linear stimuli had bandwidths of ~550 Hz at the 6 dB down-points and ~840 Hz at the 20 dB down-points. The Blackman stimuli had bandwidths ~750 Hz wide at the 6-dB down-points and ~1200 Hz at the 20-dB down-points.

Procedures

The subjects were tested in a sound-treated booth (Industrial Acoustics Company, Series 400). They were instructed that the tones would be presented very softly on purpose and that they were to respond even if the tones were very soft and difficult to detect. The 3-msec Trapezoid and Blackman tone-bursts were presented at rates of 9.3/sec and 39/sec. The total duration for each presentation of the stimuli varied from approximately 1 to 3 seconds. A response was judged present if the subject responded appropriately to both the onset and offset of the tones. The vicinity of threshold was ascertained by presenting the tone-bursts at 20 dB below the expected threshold and then increasing the tones in 10-dB steps until a response was obtained. The intensity was then decreased 16 dB, and the search for threshold began in ascending 2-dB

Table 1 Means, Medians, SDs, and Ranges in dB pSPL for Behavioral Tone-Burst Thresholds at Four Frequencies, Two Gating Functions, and Two Repetition Rates

	500 Hz				*1000 Hz*				*2000 Hz*				*4000 Hz*			
	Trapezoid		*Blackman*		*Trapezoid*		*Blackman*		*Trapezoid*		*Blackman*		*Trapezoid*		*Blackman*	
	9.3/sec	*39/sec*	*9.3/sec*	*39/sec*	*9.3/sec*	*39/sec*	*9.3/sec*	*39/sec*	*9.3/sec*	*39/sec*	*9.3/sec*	*39/sec*	*9.3/sec*	*39/sec*	*9.3/sec*	*39/sec*
Mean	33.4	30.4	35.4	33.4	25.6	23.0	26.2	24.7	24.2	21.2	25.5	21.8	17.2	14.4	18.9	15.7
Median	32.0	30.0	36.0	32.0	26.0	22.0	26.0	24.0	24.0	20.0	26.0	22.0	16.0	14.0	18.0	16.0
SD	5.0	5.5	5.2	4.9	3.6	4.4	2.7	3.4	5.7	4.8	5.2	6.2	5.0	4.4	3.7	4.3
Range	18.0	22.0	20.0	20.0	14.0	16.0	10.0	18.0	26.0	18.0	24.0	27.0	16.0	16.0	17.0	20.0

steps over a 20-dB range. A total of five ascending trials were used, and threshold was defined as the softest level at which at least three of the five stimulus presentations were detected. Sixteen thresholds were obtained in random order for each subject. That is, thresholds were obtained at four frequencies (500, 1000, 2000, and 4000 Hz), at two stimulus rates (9.3/sec and 39/sec), and for two gating functions (Trapezoid and Blackman). The total testing time was approximately 90 minutes, including rest periods.

RESULTS

Table 1 presents means, medians, standard deviations, and ranges for thresholds in dB pSPL at 500, 1000, 2000, and 4000 Hz for each gating function (Trapezoid and Blackman) and repetition rate (9.3/sec and 39/sec). The table shows that the means and medians agree within 1.5 dB, suggesting that either statistic is a representative measure of central tendency. Standard deviations range from 2.7 to 6.2 dB, with a median value of 4.9 dB. A three-way analysis of variance (ANOVA) for repeated measures was used to identify statistically significant differences among the two repetition rates, two gating functions, and four frequencies. Because the ANOVA revealed no statistically significant three-way or two-way interactions ($p > .01$), the three main effects are reported. Table 1 shows that the 39/sec rate yielded lower thresholds than the 9.3/rate; when averaged across gating functions, differences ranged from 2.1 dB at 1000 Hz to 3.3 dB at 2000 Hz, with an average of 2.73 dB ($F = 67.0$, $df = 1, 24$, $p < .01$). The table also shows that threshold systematically decreased as frequency increased from 500 to 4000 Hz ($F = 62.2$, $df = 3, 72$, $p < .01$). When the data were averaged across rates and gating functions, thresholds in pSPL were approximately 33 dB at 500 Hz, 25 dB at 1000 Hz, 23 dB at 2000 Hz, and 17 dB at 4000 Hz. Finally, Table 1 reveals that the Trapezoid gating function yielded thresholds that were approximately 1.4 dB lower than the Blackman function ($F = 6.8$, $df = 1, 24$, $p = .015$). When the data were averaged for both repetition rates, the differences were 2.5 dB at 500 Hz, 1.2 dB at 1000 Hz, 1.0 dB at 2000 Hz, and 1.4 dB at 4000 Hz.

To facilitate comparisons among studies and to allow calibration of auditory evoked response systems when a sound level meter with peak-hold capability is not available, the mean pSPL data in Table 1 (rounded to the nearest dB) are presented in Table 2 along with ppeSPLs and SPLs using a stimulus rate of 50/sec with 1-msec rise–fall times and an 8-msec plateau and with the sound level meter set to "fast" meter mode. This latter procedure is suggested by the manufacturer of our ABR system (IHS); this procedure does not require an oscilloscope and allows calibration of ABR stimuli with a sound level meter that does not have the peak-hold SPL measurement option. With reference to pSPLs, ppeSPLs are –3 dB at 500 Hz, –3 dB at 1000 Hz, –1 dB at 2000 Hz, and 0 dB at 4000 Hz. With reference to pSPLs, SPLs (fast mode, 50/sec stimulus rate, 1-msec rise–fall and 8-msec plateau) are –6 dB at 500 Hz, –6 dB at 1000 Hz, –6 dB at 2000 Hz, and –4 dB at 4000 Hz.

DISCUSSION

The 39/sec stimulus rate yielded tone-burst thresholds that were approximately 3 dB lower than the 9.3/sec rate. These data are consistent with previous studies (Zerlin and Naunton, 1975; Yost and Klein, 1979; Stapells et al, 1982). For example, Stapells et al (1982) observed a 3.3-dB improvement as click rate increased from 10/sec to 40/sec. The improvement in

Table 2 Mean Intensities for Normal-Hearing Behavioral Tone-Burst Thresholds in pSPL, SPL (Fast Meter Averaging, 50 Stimuli/Sec), and ppeSPL at Four Frequencies, Two Gating Functions, and Two Repetition Rates

	500 Hz				*1000 Hz*				*2000 Hz*				*4000 Hz*			
	Trapezoid		*Blackman*		*Trapezoid*		*Blackman*		*Trapezoid*		*Blackman*		*Trapezoid*		*Blackman*	
	9.3/sec	*39/sec*	*9.3/sec*	*39/sec*	*9.3/sec*	*39/sec*	*9.3/sec*	*39/sec*	*9.3/sec*	*39/sec*	*9.3/sec*	*39/sec*	*9.3/sec*	*39/sec*	*9.3/sec*	*39/sec*
pSPL	33	30	35	33	26	23	26	25	24	21	26	22	17	14	19	16
ppeSPL	30	27	32	30	23	20	23	22	23	20	25	21	17	14	19	16
SPL	27	24	29	27	20	17	20	19	18	15	20	16	13	10	15	12

threshold with increasing stimulus rate may reflect the ability of the auditory system to integrate energy that occurs within a time interval of 200 to 500 msec (Garner and Miller, 1947; Wright, 1978; Stapells et al, 1982). The theory of temporal auditory summation (Zwislocki, 1960) postulates that the neural response of the auditory system does not end abruptly when the tone is terminated but systematically decreases over time. For pure-tone durations less than 200 msec, the improvement for tones is approximately 8 to 10 dB for a 10-fold increase in duration (e.g., 10 to 100 msec). Wright (1978), for example, observed that thresholds for 125 to 8000 Hz tones improved approximately 11 dB as stimulus duration increased from 10 to 200 msec; thresholds decreased another 1.5 dB as the tones were lengthened to 500 msec. However, short-duration stimuli such as clicks and tone-bursts yield a decrease in threshold of only about 5 dB per 10-fold change in rate (Zerlin and Naunton, 1975; Yost and Klein, 1979; Stapells et al, 1982). Threshold is expected to decrease as the on-time of the stimulus increases within a 200- to 500-msec time window. Thus, as stimulus rate and duration increase to lengthen the total on-time of the signal within a 200-msec window, threshold is expected to decrease. The 9.3/sec rate has an interstimulus interval of approximately 100 msec, whereas the 39/sec rate has an interstimulus interval of approximately 25 msec. Therefore, within any 200-msec time period, the energy from approximately two stimuli for the 9.3/sec rate and eight stimuli for the 39/sec rate will be integrated by the auditory system. That is, 3-msec stimuli that are presented at a 9.3/sec rate will stimulate the auditory system for a total of 6 msec (2 stimuli × 3 msec = 6 msec total stimulus duration) during any 200-msec time interval, and the 39/sec rate will stimulate the auditory system for approximately 24 msec (8 stimuli × 3 msec = 24 msec total stimulus duration). Thus, the improvement in tone-burst thresholds with increasing stimulus rate from 9.3/sec to 39/sec is consistent with previous research and was expected based on the theory of temporal integration.

As noted above, the 39/sec rate yielded lower thresholds than the 9.3/rate. These differences averaged 2.73 dB (combined across gating functions) and were 2.5 dB at 500 Hz, 2.1 dB at 1000 Hz, 3.3 dB at 2000 Hz, and 3.0 dB at 4000 Hz. These results reveal no systematic frequency effect and are consistent with those of Wright (1978), who reported no systematic differences in the magnitude of temporal integration for pure tones from 125 to 8000 Hz. In contrast, some studies have observed less temporal integration at the higher frequencies with pure tones (Watson and Gengel, 1969) and with ⅓-octave clicks (Zerlin and Naunton, 1975). Because of many differences in experimental designs, however, it is difficult to ascertain the reasons for the different findings.

The Trapezoid gating function yielded thresholds that averaged 1.4 dB lower than the Blackman function ($p = .015$); these differences were 2.5 dB at 500 Hz, 1.2 dB at 1000 Hz, 1.0 dB at 2000 Hz, and 1.4 dB at 4000 Hz. Although these differences are small and of little clinical importance, the cumulative effects of several instrument and/or procedural variables may yield clinically important differences. That is, differences in earphones (e.g., insert versus supra-aural), repetition rate, frequency, stimulus duration, gating function, and SPL measurement (pSPL, ppeSPL, fast-mode SPL) may combine to yield differences that are clinically important. The data for both the Trapezoid and Blackman gating functions are reported in Table 2. These data are offered for consideration when calibrating ABR equipment. Clinicians are

Table 3 Intensities in pSPL, SPL (Fast Meter Averaging, 50 Stimuli/Sec), and ppeSPL Corresponding to Normal Hearing for Several Studies

	Frequency (Hz)									
Intensity	*500*	*1000*	*2000*	*4000*	*Authors*	*N*	*Earphones*	*Stimulus Rate/Sec*	*Rise–Fall*	*Plateau*
pSPL	31	24	21	15	Current study	25	Insert	39	1 msec	1 msec
		21		16	Beattie et al (1994b)	10	Supra-aural	26	1 msec	1 msec
	26		20		Beattie et al (1994a)	10	Supra-aural	26	1 msec	1 msec
SPL (50/sec)	25	18	15	11	Current study	25	Insert	39	1 msec	1 msec
	21	17	20	20	IHS (1994)		Insert		1 msec	8 msec
ppeSPL	28	21	20	15	Current study	25	Insert	39	1 msec	1 msec
	18	17	20	23	Davis et al (1984)	16	Supra-aural	~40	2 cyc	1 cyc
	25	20			Beattie et al (1984)	20	Supra-aural	31	~2 msec	1 msec
	25	20	20		Beattie and Boyd (1985)	20	Supra-aural	31	4 msec	1 msec
	28	22	24	21	Purdy et al (1989)	20	Supra-aural	42	~2 cyc	~1 cyc
	25	23	26	29	Stapells et al (1990)	10	Supra-aural	10	2 cyc	1 cyc
	23	17			Beattie and Torre (1997)	10	Supra-aural	26	1 msec	1 msec
	22		20		Stapells and Oates (1997)		Insert	39	2 cyc	1 cyc
	25	23	26	29	Oates and Stapells (1998)		Supra-aural	39	2 cyc	1 cyc

The sample size, type of earphones (insert or supra-aural), stimulus rate in stimuli per second, and rise-fall-plateau times in msec or the number of cycles (cyc) are indicated for each study if known. If rise-fall-plateau times varied across frequency, the approximate symbol is used (~). Values from the current study represent an average of the means for the Trapezoid and Blackman gating functions for the 39/sec stimulus rate.

cautioned to use these values only if their equipment, methods, and calibration procedures are similar to those used in the present study.

Table 3 presents intensities in pSPL, SPL (fast meter averaging, 50 stimuli/sec, 1-msec rise–fall and 8-msec plateau), and ppeSPL corresponding to normal hearing for several studies (Beattie et al, 1984; Davis et al, 1984; Beattie and Boyd, 1985; Purdy et al, 1989; Beattie et al, 1994a, b; Intelligent Hearing Systems, 1994; Beattie and Torre, 1997; Stapells and Oates, 1997; Oates and Stapells, 1998). The sample size, earphone type (insert or supra-aural), stimulus rate in stimuli per second, and rise-fall-plateau times in msec or number of cycles are indicated for each study if known. If rise-fall-plateau times varied across frequency, the approximate symbol is used. Values from the current study represent an average of the means for the Trapezoid and Blackman gating functions for the 39/sec stimulus rate. Examination of Table 3 shows that, despite differences in methods, the pSPL values are very similar (within 3 dB) for all three cited studies at 1000, 2000, and 4000 Hz; a difference of 5 dB is evident at 500 Hz. Table 3 shows that our SPL values (fast meter averaging, 50/sec rate, 1-msec rise–fall and 8-msec plateau) are in good agreement (within 5 dB) with the norms recommended by IHS for insert earphones at 500, 1000, and 2000 Hz. However, the 4000-Hz values differ by 9 dB; these data suggest that additional study is warranted at this frequency in which the pertinent variables are systematically manipulated. The ppeSPLs shown in Table 3 show good agreement across studies at 1000 (17–23 dB) and 2000 Hz (20–26 dB), despite differences in methods. Although most of the studies show values between 25 and 28 dB at 500 Hz, one study (Davis et al, 1984) yielded an SPL of 18 dB. An even larger difference of 14 dB was observed at 4000 Hz. As noted above, however, comparisons among studies should be made cautiously because of differences in experimental designs, including earphone types, psychophysical procedure, stimulus durations, and stimulus rate. Direct comparisons in which only one variable is manipulated at a time are required to ascertain the extent to which these variables contributed to the results.

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