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Effects of Electrode Montage on the Spectral Composition of the Infant Auditory Brainstem Response

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Abstract

We evaluated the effect of electrode montage on the spectrum of the infant auditory brainstem response (ABR). Spectral profiles of ipsilateral, contralateral, noncephalic, and horizontal recordings obtained in response to slow and fast repetition rates and at low and high stimulus intensities were also evaluated. Findings indicate that the spectrum of the infant ABR is dominated by low-frequency energy, maximal below 200 Hz. The spectra of ipsilateral and noncephalic recordings are the strongest irrespective of stimulus intensity or repetition rate. Increase in stimulus intensity or repetition rate typically enhances the amount of energy below 200 Hz. These results reinforce the clinical utility of ipsilateral and noncephalic recordings for screening, threshold measurement, and neurodiagnostic purposes.

Key Words: Auditory brainstem response (ABR), electrode montage, infants, spectrum

Recent spectral analytic studies of the adult auditory brainstem response (ABR) reveal three major peaks of energy (Elberling, 1979; Kevanishvili and Aphonchenko, 1979; Boston and Ainslie, 1980; Doyle and Hyde, 1981; Laukli and Mair, 1981; Hoke et al, 1984; Urbach and Pratt, 1986; Spivak, 1993). The largest amount of energy occurs below 150 Hz, followed by two smaller but stable energy regions from 500 to 600 Hz and from 900 to 1100 Hz. This spectral composition is influenced by both subject- and measurement-related factors. Hall (1986) first reported spectral abnormalities in the ABRs of head-injured comatose subjects. Even though the ABRs obtained from these subjects appeared normal, the spectra showed reduced energy across all frequencies, especially high frequencies. These results indicate that spectral analysis, at least in the head-injured population, provides valuable prognostic information. Spivak and Malinoff (1990) reported significant differences in the ABR spectral profiles of young and old subjects. Spectra of older subjects showed large amounts of low-frequency energy compared to those obtained from young subjects. Based on spectral analysis of noise derived from ABR replications, they attributed these differences in spectra to the presence of low-frequency background noise associated with aging. The results of this study indicate that, when performing ABR on older subjects, recording parameters need to be modified so that the effects of high-frequency hearing loss and other factors associated with aging are minimized. In another study, Spivak (1993) showed that both infant and adult spectra are characterized by energy below 150 Hz; however, infant ABR spectra contained a greater percentage of low-frequency components than adult spectra. Thus, measurements in infants with a high-pass filter setting of 150 Hz or higher can greatly compromise the ABR, especially at low intensity levels. The possible influence of other subject factors (e.g., gender) has not been explored.

The effects of some measurement parameters on ABR spectrum have also been documented. As the intensity of the stimulus decreases, the overall amplitude of spectral energy decreases, especially in high-frequency regions of the spectrum (Kevanishvili and Aphonchenko, 1979; Laukli and Mair, 1981; Suzuki et al, 1982; Spivak and Malinoff, 1990;

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Spivak, 1993). Increasing the click rate increases the energy in the low-frequency portion (below 600 Hz) of the spectrum and use of rarefaction clicks (compared to condensation clicks) enhances the amplitudes of the high frequencies (Spivak and Malinoff, 1990). Spectral analyses of ABRs evoked with frequency-specific stimuli have shown that as stimulus frequency decreases, energy in the high-frequency region of the spectrum decreases (Suzuki et al, 1982). Information on effects of other measurement parameters such as sites of recording electrodes are not available. Such information should provide not only empirical evidence of the effects of measurement parameters on ABR, but also information on manipulating these parameters to optimize recordings. The present study evaluated the effects of electrode montage on the ABR spectrum of normal infants. Spectral profiles of ipsilateral, contralateral, noncephalic, and horizontal recordings obtained in response to slow and fast repetition rates, and at low and high stimulus intensities were evaluated.

METHOD

Subjects

Sixteen normal, full-term infants (39–42 weeks post conception), eight males and eight females, served as experimental subjects for this study. These infants were screened for (1) negative history of prenatal/perinatal complications; (2) no high-risk factors for hearing loss; and (3) repeatable ABRs with normal wave V latencies at 35 dB nHL measured on ipsilateral recording for each ear separately. The subjects were recruited from the normal newborn nursery at Fairview General Hospital, Cleveland, Ohio. Parental consent was obtained before recruiting the subjects.

Procedures

Electrophysiologic measurements were performed with a portable clinical averager. To facilitate the measurements, all recordings were performed in the nursery shortly after feeding. ABRs were elicited with 0.1-msec rarefaction clicks presented monaurally via tubephones at (1) 35 dB nHL and 11.1/sec repetition rate; (2) 70 dB nHL and 11.1/sec rate; and (3) 70 dB nHL and 61.1/sec rate. Four-channel recordings were obtained simultaneously, with the ipsilateral (Fz-Ai, noninverting-inverting), contralateral (Fz-Ac), horizontal (Ac-Ai), and noncephalic (Fz-nape of the neck) electrode montages, the ground electrode being placed at the Fpz site. Two to four thousand responses at the slow and fast repetiton rates were averaged in a time window of 15 msec, with a 2-msec prestimulus baseline and a bandpass filter of 30–3000 Hz (12 dB/octave slope). The artifact reject was set at 16 μvolts and the gain at 150,000. Each waveform was replicated to ensure reliability of responses. Each ear was tested separately, the order of test administration (right vs left) being counterbalanced between each gender group. All data were stored on standard diskettes for later analysis.

Analyses

Replications of waveforms obtained for each channel and test condition were digitally averaged across the two ears. A fast Fourier transform (FFT) was performed to obtain amplitude spectra of the averaged waveforms. The analysis had a 67-Hz frequency resolution (time window, 15 msec), with a maximum frequency of 4200 Hz. To minimize the contribution of broadband spectral energy associated with the stimulus artifact, the stimulus artifact was blocked from each record prior to FFT analysis. To reduce the frequency distortion associated with the gating functions, the spectra were not smoothened. Amplitude profiles were compiled by measuring the amplitude in microvolts of each frequency (67-Hz intervals) between 67 Hz and 1200 Hz. A four-factor, repeated-measure analysis of variance (ANOVA) was used to delineate significant differences between the spectra obtained from the male versus female subjects (grouping factor), the three measurement conditions (35 dB nHL-11.1/sec, 70 dB nHL-11.1/sec, and 70 dB nHL-61.1/sec-repeated factor 1), the four-channel recordings (ipsilateral, contralateral, noncephalic, and horizontal-repeated factor 2), and the 18 amplitude values representing the spectral profiles (repeated factor 3).

RESULTS

Figure 1 shows typical infant responses obtained with ipsilateral, contralateral, noncephalic, and horizontal electrode montages across the three measurement conditions.

Effect of Electrode Montage

Spectral profiles associated with the four electrode montages and averaged across the three measurement conditions are shown in Figure 2. Although the spectra of all four electrode montages show maximum energy below 200 Hz, there are differences in the amount and distribution of energy across the spectra. The

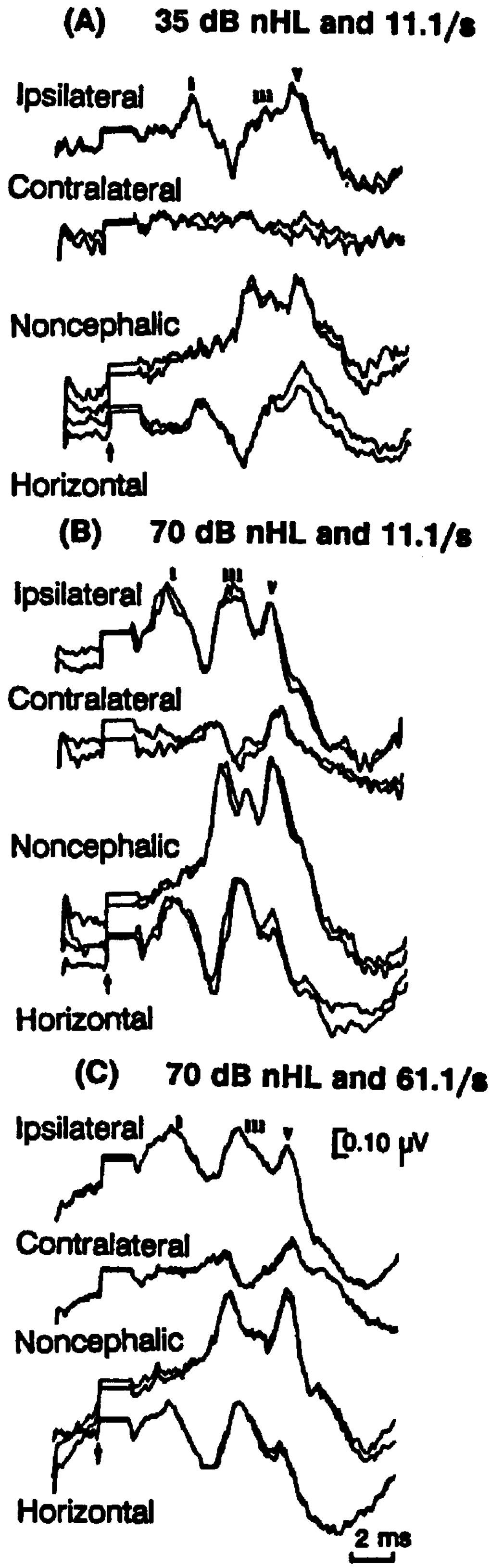

Figure 1 Illustrative multi-channel ABRs obtained from a 40-week-old infant for the stimulus parameters of (A) 35 dB nHL and 11.1/sec, (B) 70 dB nHL and 11.1/sec, and (C) 70 dB nHL and 61.1/sec.

spectrum of contralateral recording shows reduced energy across all frequencies when compared to the spectra of ipsilateral, noncephalic, and horizontal recordings. Variation in the location of the second spectral peak further differentiates the four electrode montages. The results of four-factor ANOVA (one between, three within design) performed on the FFT data substantiate these findings (Table 1). The significant interaction between montage and spectrum ($M \times S$) indicates that the spectrum changes as a function of electrode montage. Post-hoc Scheffe analysis defined amplitude disparities at (1) all frequencies except 333 Hz in the range of 67 Hz and 467 Hz when ipsilateral-contralateral comparisons were made; (2) 67 Hz and 133 Hz when noncephalic-contralateral recordings were compared; and (3) 67 Hz, 200 Hz, 267 Hz, and 333 Hz when horizontal-contralateral pairs were compared. Furthermore, variability of occurrence of the second spectral peak made horizontal-ipsilateral and horizontal-noncephalic spectral profile differences significant (critical difference = 0.02, df[1,2] = [3,42], $p < .05$).

Effects of Intensity and Click Rate

The effects of intensity and click rate on the spectral profiles were also significant (condition [C] $\times$ montage [M]) (see Table 1). Figure 3 shows average spectral profiles at (A) 35 dB nHL and 11.1/sec, (B) 70 dB nHL and 11.1/sec, and (C) 70 dB nHL and 61.1/sec. Regardless of the click rate, as intensity increased from 35 dB nHL to 70 dB nHL, the energy doubled, especially in the low-frequency portion of the spectrum. Post-hoc Scheffe tests located amplitude disparities at 67 Hz for both the click rates, and at 133 Hz and 467 Hz for the slow click rate,

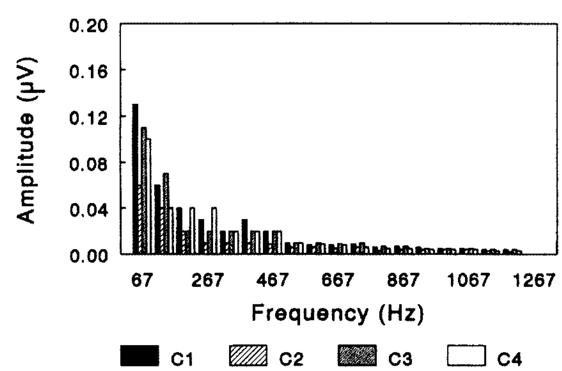

Figure 2 Mean spectral profiles showing the effects of electrode montage (C1: ipsilateral; C2: contralateral; C3: noncephalic; C4: horizontal) collapsed across the two gender groups and the three measurement conditions.

Table 1 Results of ANOVA For FFT Data

Source	Sum of Squares	df	Mean Square	F	Tail Probability
Mean	1.15	1	1.15		
Gender (G)	0.0003	1	0.0003	0.23	0.6370
Error	0.0155	14	0.0011		
Condition (C)	0.0382	2	0.0191	42.94	< 0.0001*
C × G	0.0011	2	0.0006	1.25	0.3021
Error	0.0125	28	0.0004		
Montage (M)	0.0474	3	0.0158	48.50	< 0.0001*
M × G	0.0018	3	0.0006	1.87	0.1492
Error	0.0137	42	0.0003		
C × M	0.0056	6	0.0009	7.83	< 0.0001*
C × M × G	0.0006	6	0.0001	0.81	0.5686
Error	0.0100	84	0.0001		
Spectrum (S)	1.86	17	0.1094	290.12	< 0.0001*
S × G	0.0080	17	0.0005	1.25	0.2249
Error	0.0897	238	0.0004		
C × S	0.2066	34	0.0061	36.21	< 0.0001*
C × S × G	0.0067	34	0.0002	1.18	0.2283
Error	0.0799	476	0.0002		
M × S	0.1520	51	0.0030	25.25	< 0.0001*
M × S × G	0.0104	51	0.0002	1.72	0.0017*
Error	0.0843	714	0.0001		
C × M × S	0.0505	102	0.0005	6.32	< 0.0001*
C × M × S × G	0.0055	102	0.0001	0.69	0.9917
Error	0.1119	1428	0.0001		

*indicates significant test results

when measurements obtained at 35 dB nHL were compared to those obtained at 70 dB nHL (critical difference = 0.02, df[1,2] = [2,28], $p < .05$). Increase in click rate from 11.1/sec to 61.1/sec increased the energy at 67 Hz (critical difference = 0.02, df[1,2] = [2,28], $p < .05$) and streamlined the energy in the remaining portion of the spectrum. Regardless of the measurement condition, the amplitude profiles of all recordings showed virtually no energy above 600 Hz (energy on the order of 0.002 μV to 0.008 μV).

Figure 3 also provides evidence for the significant interactions between condition (C) × spectrum (S), and condition (C) × montage (M) × spectrum (S), that is, the 18 amplitude values making up the spectral profiles differ not only as a function of condition, but also from montage to montage. We cannot explain the significant interactions among electrode montage (M), spectral profile (S), and gender (G).

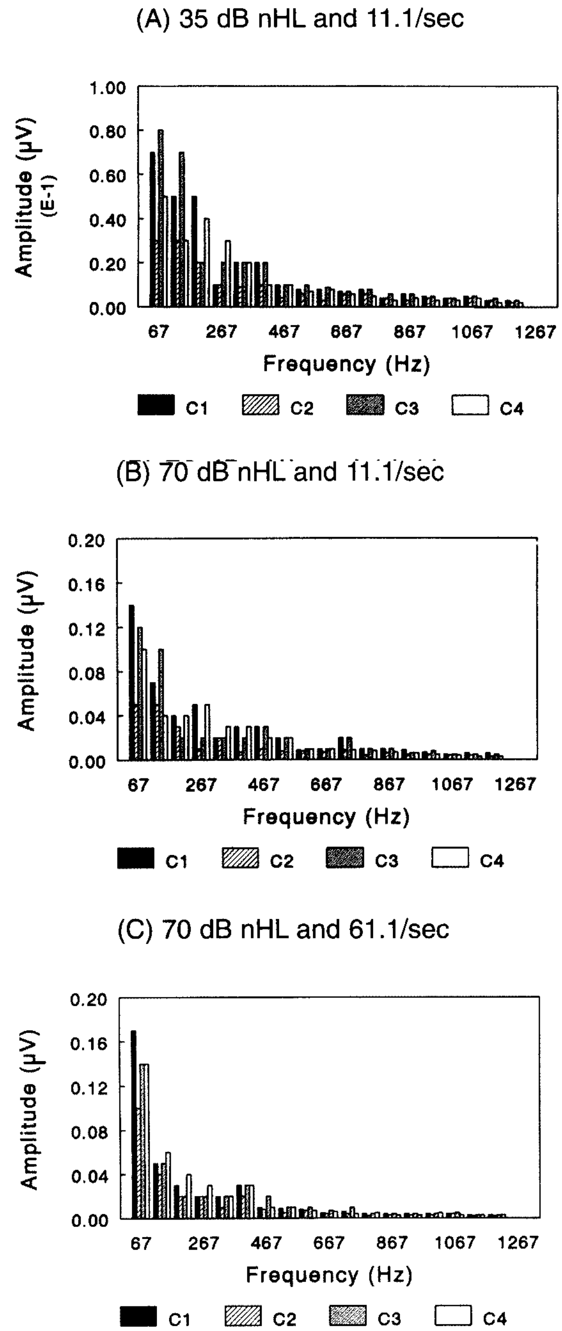

Figure 3 Mean spectral profiles collapsed across gender showing the effects of electrode montage (C1: ipsilateral; C2: contralateral; C3: noncephalic; C4: horizontal) for each measurement condition: (A) 35 dB nHL and 11.1/sec, (B) 70 dB nHL and 11.1/sec, and (C) 70 dB nHL and 61.1/sec.

DISCUSSION AND CONCLUSION

The findings of this study indicate that the infant ABR spectrum is dominated by low-frequency energy, extending only up to 600 Hz, regardless of the stimulus intensity or the electrode montage used. These results are somewhat different than those reported by Spivak (1993). She documented spectral peaks extending to 741 Hz (±158) and 753 Hz (±87) in the FFTs of ipsilateral (Fz-M1/M2) recordings obtained in response to clicks delivered at 35 dB nHL and 70 dB nHL, respectively. These differences may be related to the Hanning window used to generate FFTs of ABRs measured in a time frame of 15 msec. Windowing can introduce distortions particularly when a prestimulus delay is not built into the response time frame. The present study measured ABRs with a prestimulus baseline and the FFTs were not smoothed through a window.

Both the stimulus intensity and stimulus click rate changed the distribution of energy within the ABR spectrum. At the intensity of 35 dB nHL, used typically for screening and threshold estimation purposes, the spectra of ipsilateral, contralateral, noncephalic, and horizontal recordings generally showed variable energy distribution across the length of the spectrum to 600 Hz. However, the spectra of both ipsilateral and noncephalic recordings contained the largest amount of energy below 200 Hz, followed by horizontal recording and finally contralateral recording. This emphasizes not only the importance of using a high-pass filter setting of 30 Hz rather than 150 Hz or 300 Hz, as emphasized by Spivak (1993), but also the importance of disengaging the 60 Hz notch filter during ABR testing. Furthermore, since the majority of the spectral energy resides below 600 Hz, a low-pass filter setting of 1500 Hz is acceptable.

At the intensity of 70 dB nHL and click rate of 11.1/sec, the spectra below 200 Hz of both ipsilateral and noncephalic recordings were still the strongest compared to the other recordings. However, differences emerged in the energy distribution in the remaining portion of the spectrum. Ipsilateral and horizontal recordings showed smaller but stable peaks at 267 Hz and 400/467 Hz, whereas contralateral and noncephalic recordings showed only one peak at 333 Hz and 467 Hz, respectively. Increase in click rate from 11.1/sec to 61.1/sec at a constant intensity of 70 dB nHL not only increased the energy in the low-frequency portion of the spectrum, but also streamlined the energy in the remaining portion of the spectrum. Thus, the spectra of all recordings obtained at 61.1/sec showed two well-defined peaks, one at 67 Hz and a second at 400 Hz. These findings are directly related to changes in wave morphology imposed by a fast click rate. Unlike the adult ABR, the infant ABR becomes well defined at the fast repetition rate (see Fig. 1), facilitating wave identification required for neurodiagnostic purposes. This enhancement can be attributed to the shift in energy towards the lower frequencies of the spectrum, a region that best defines the infant spectrum. Furthermore, ipsilateral recordings contained the largest amount of energy and contralateral recording the lowest, suggesting the utility of ipsilateral recordings for neurodiagnosis.

In conclusion, ipsilateral and noncephalic recordings contain the largest amounts of energy regardless of the intensity or the click rate used to evoke ABR, indicating the clinical utility of these recordings for screening/threshold measurement, as well as neurodiagnostic purposes. Furthermore, use of a fast repetition rate facilitates wave identification due to enhancement of the low-frequency composition of the spectrum, a region defining the infant spectrum.

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