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AUDITORY BRAIN STEM POTENTIALS RECORDED AT DIFFERENT SCALP LOCATIONS IN NEONATES AND ADULTS

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The auditory evoked brain stem potential was recorded in 14 normal full-term infants and nine normal-hearing adults. Silver-silver chloride electrodes were placed at nasion, forehead, vertex, each mastoid over the bony prominence, and the seventh cervical vertebra (noncephalic reference) in order to study the scalp distribution of the auditory brain stem response. Large differences in the scalp distribution between the newborn and adult populations were observed. At the ipsilateral mastoid, an x wave occurring at approximately 2 ms and a y wave occurring at approximately 3.3 ms were identified in the adult; this contrasts to a y wave at approximately 3.7 ms in the neonate. It appears that there are either separate generators for some of the components in the adult versus the neonate, and/or as the nervous system matures, myelinization occurs with a concomitant change in the scalp distribution of the auditory brain stem potentials.

KEY WORDS — auditory evoked brain stem potential, auditory brain stem responses (ABR), neonates, scalp distribution of ABR.

INTRODUCTION

A sequence of potentials is recorded from the scalp in both humans and animals within the first 10 ms following an auditory stimulus. These potentials are the far-field reflection of activation of the brain stem auditory nuclei and pathways.[1-7] These auditory brain stem responses (ABR) are clinically useful in assessing cochlear function and in diagnosing neurological disorders affecting the brain stem.[1,2] Although the general anatomical origins of these potentials seem well established, their precise neural generators are not well understood. Detailed information on the topographical scalp distribution of the ABR could help to understand the generators of the ABR.

The waveform morphology of the ABR varies as a function of recording sites over the human scalp.[1,5,6,8] Amplitudes, latencies, and polarities of the peak responses vary according to elecrode placement. In addition, differences in the amplitudes and latencies of various peaks in the ABR have been identified and vary as a function of contralateral versus ipsilateral stimulus presentation.[8,9] Further latency disparities are observed and may be emphasized by the use of differential recordings.[1,10] The interpretation of the mechanism by which these shifts occur is complex since, in differential recordings of the ABR, both electrode sites are active, and positive (usually the vertex) and negative are a matter of definition.

One of the more interesting aspects is the development and maturation of the ABR potentials. Although many investigations describe the latency and amplitude changes in the maturing infant for standard electrode arrays, eg, Cz-Mi, Cz-Mc, etc,[11] there is neither a description nor a comparison of scalp distribution changes with maturation in the neonate. This investigation compares the scalp distribution of the ABR in the neonate and adult. In addition, we compared the referential with differential recordings to define the lateralization of the ABR generators.

METHODS

Fourteen normal full-term neonates with no history of prenatal or perinatal complications and nine normal-hearing adults were tested, one man and eight women ranging in age from 21 to 37 years. The neonates were studied during light sleep following a normal feeding period. The adults were tested during a quiet awake state in a supine position with eyes closed.

The acoustic stimulus used to evoke the ABR consisted of condensation clicks generated by a 0.1-ms pulse applied monaurally to a TDH-39 earphone in a MX41AR cushion. Presentations were made at 11.1 clicks/s at a 90-dB peak equivalent SPL.

The amplifier gain used to record the ABR was 80,000. The amplified response was filtered both from 5 to 3,000 Hz and from 150 to 3,000 Hz (3 dB down points, 6 dB/octave). Studies by Scherg' indicate that a high pass filter of 5 Hz for the ABR does not introduce distortion of the response. A set of duplicate averages were completed at each filter setting for 2,048 stimulus trials comprising each average. Sweep time was 20 ms, with a digitizing rate/address of 25 kHz. Four channels were averaged simultaneously and stored on a floppy disk.

Silver-silver chloride electrodes were placed at nasion (Na), forehead (Fz), vertex (Cz), each mastoid just over the bony prominence (ipsilateral mastoid designated as Mi and contralateral as Mc), and the seventh cervical vertebrae (CVII, noncephalic reference). The frontal electrode was used as a ground.

The ABR was recorded for Na, Cz, Mi, and Mc referenced to CVII using four simultaneous input channels to a minicomputer. This type of recording is described as referential. Recordings made between noncephalic electrode placements at CVII and on the sacrum demonstrated the electrode at CVII to contain no rec-

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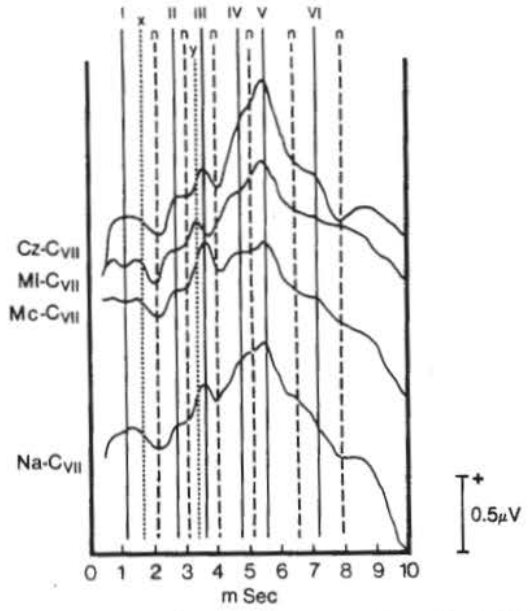

Fig 1. Recordings of grand average (18,532 trials) of ABR for four electrode sites (Cz, Mi, Mc, and Na referenced to CVII) for nine adult subjects.

ognizable ABR components in both infants and adults. The term differential recordings refers to the computer-derived potentials obtained by subtracting Cz with Mi, Cz with Mc, and Mi with Mc. Quantitative measures were made from cursor controls on the averaged waveforms. The measurements were taken either at the corresponding peak or at the center of the wave for broad waveforms in order to maintain consistency in measurements.

Paired t tests were used to evaluate latency differences among electrode locations. For the purposes of this paper a level of significance of $p < .02$ is used. This level was chosen as a more conservative approach due to the large number of t tests which were used. However, specific levels are given as a matter of form to provide the reader with additional information.

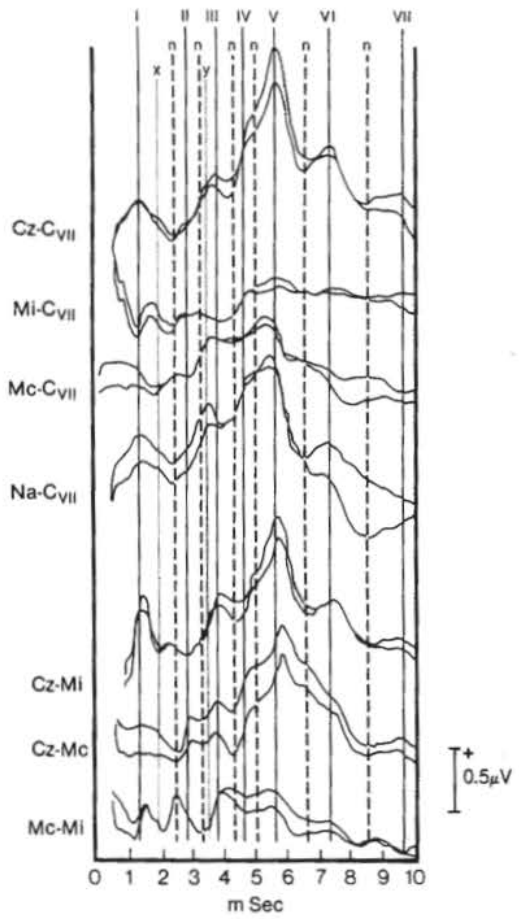

Fig 2. Recordings of individual averages of ABR for four electrode sites (Cz, Mi, Mc, and Na referenced to CVII) and derived differential recordings (Cz-Mi, Cz-Mc, and Mc-Mi) for one adult subject.

RESULTS

There are significant differences in the scalp distribution of the ABR between the newborn and adult populations.

It should be noted that in some instances there is an apparent discrepancy between mean latencies reported in the Tables and Figures of this study. The mean latencies in the Tables reflect equal weighting, eg, each individual latency, whereas, the mean latencies shown in the Figures may reflect an individual bias, eg, since the waveforms were digitally summed to obtain the grand average waveforms, unequal weighting occurs due to individual differences in waveform morphology.

ADULTS

The grand average of the ABR for the adults is illustrated in Fig 1, and a single case recording is illustrated in Fig 2.

Referential Recordings. Figure 1 shows the ABR components constructed from monopolar recordings made at Cz. These are labeled at the peaks by Roman numerals and by an n at the following troughs. The solid and dashed lines descend from the components identified at Cz. The definition of the components is affected by the filter settings. For instance, in Fig 3, waves IV and IVn are clearer in the 150 to 3,000-Hz setting than in the 5 to 3,000 Hz-filter settings. However, we chose the wide band pass (5-3,000 Hz) for all measures of amplitude and latency of the ABR to minimize phase shifts and waveform distortion provided by our analog high pass filters.

The noncephalic electrode at CVII is considered referential since recordings between that site and a second noncephalic electrode placed on the sacrum did not demonstrate replicable components in the latency domain of the auditory brain stem potentials.

The waveform morphology at Mi, particularly in the first few milliseconds, differs in polarity and form from the other recording sites (Figs 1 and 2). The first negative deflection at Mi corresponds to a positive deflection at Cz and Na in the grand average adult recording in Fig 1, and flat, or perhaps slightly negative, at Mc. The individual example from an adult subject (Fig 2) shows Cz, Mc, and Na having a positive deflection.

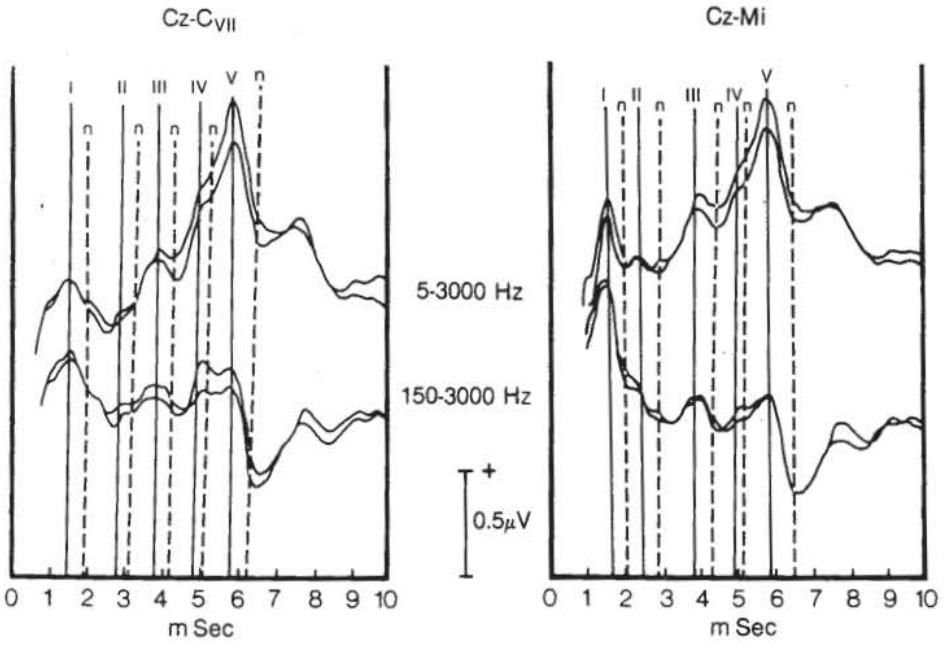

Fig 3. Recordings of Cz-CVII (left) and Cz-Mi (right) using filter settings of 5 to 3,000 (upper) and 150 to 3,000 Hz (lower) for one adult subject.

A large amplitude positive wave (x) between wave I and In is seen at Mi in Figs 1 and 2. For the individual recording, the x wave is not seen at Cz, Mc, or Na. However, in the grand average recording (Fig 1) it may be present at Mc. The second negative wave at Mi corresponds in latency to wave In at the other recording sites. Wave II is positive at all recording sites, as is wave IIn negative at all recording sites for the grand average (Fig 1). This is likewise generally true for the individual average (Fig 2). A positive peak, y, occurs between waves IIn and III at Mi and is not seen at other recording locations. Waves III and IIIn at Mi show both a polarity reversal and latency shift compared to the other electrode locations. The remaining waveforms (waves IV through Vn) are similar at all electrode locations.

Mean latencies of the ABR at the four recording sites are shown in Table 1. In evaluating the latency differences between the ABR components for the recording sites of Cz and Mi, waves II, III, and V are significantly different ($p < .01$) at the two sites (Table 2). Waves IIIn and IVn were not evaluated because of insufficient data.

Wave IVn was not defined in three of the nine adult subjects and is excluded from statistical analysis (Table 1). Significant latency differences ($p < .02$) exist for waves In, II, IIIn, V, and Vn (Table 2) between Mc and Cz recording sites.

The Na recording site was similar in waveform polarity to Mc and Cz (Figs 1 and 2). Except for wave II, the Na recording site tended to have more variability for each of the ABR components than did the other recording sites. Significant latency shifts ($p < .02$) for waves III and V were noted for Na as compared to Cz (Table 2).

Significant differences ($p < .01$) were noted for waves II and V for Mc versus Mi recordings (Table 2). A greater absolute time difference (0.41 ms) was observed for wave II between Mc and Mi than for wave V (0.19 ms), with longer latencies occurring at Mc for wave II and at Mi for wave V.

Differential Recordings. Differential recordings between Cz and Mi from one individual are illustrated in Fig 2. The major components of the ABR, except for wave IVn, are readily identifiable. Wave I is large in the Cz-Mi recording and this may account for its low variability of latency compared to the noncephalic referential recordings.

TABLE 1. MEANS AND STANDARD DEVIATIONS (MS) OF ABR COMPONENTS IN NINE ADULT SUBJECTS

Component		Cz	Mi	Mc	Na	Cz-Mi	Cz-Mc	Mc-Mi
I	$\bar{x}$	1.50	1.52	1.53	1.51	1.53	1.57	1.54
	SD	0.07	0.11	0.07	0.09	0.06	0.07	0.09
x	$\bar{x}$	NSD	1.92	NSD	NSD	3.69	3.61	3.69
	SD		0.11			0.12	0.19	0.13
In	$\bar{x}$	2.26	2.02	2.07	2.21	2.09	2.33	2.00
	SD	0.18	0.11	0.10	0.13	0.09	0.18	0.13
II	$\bar{x}$	2.79	2.34	2.66	2.76	2.56	NSD	2.46
	SD	0.13	0.12	0.14	0.09	0.13	NSD	0.14
IIn	$\bar{x}$	3.14	3.07	3.05	NSD	3.03	NSD	2.96
	SD	0.01	0.12	0.10		0.18		0.15
y	$\bar{x}$	NSD	3.34	NSD	NSD	4.17	4.11	4.56
	SD		0.12			0.11	0.14	0.19
III	$\bar{x}$	3.66	3.88	3.75	3.57	3.69	3.61	3.76
	SD	0.18	0.12	0.13	0.15	0.12	0.19	0.10
IIIn	$\bar{x}$	4.09	NSD	4.23	4.10	4.17	4.11	4.55
	SD	0.15		0.14	0.18	0.11	0.14	0.19
IV	$\bar{x}$	4.83	4.85	4.81	4.75	4.87	NSD	NSD
	SD	0.19	0.13	0.18	0.18	0.24		
IVn		NSD	NSD	NSD	NSD	NSD	NSD	NSD
V	$\bar{x}$	5.64	5.73	5.54	5.56	5.57	5.68	5.48
	SD	0.13	0.11	0.14	0.14	0.16	0.13	0.14
Vn	$\bar{x}$	6.46	6.36	6.21	6.37	6.28	6.26	6.05
	SD	0.23	0.18	0.13	0.27	0.19	0.22	0.14

NSD — not sufficient data.

TABLE 2. LATENCY DIFFERENCES (MS) OF ABR COMPONENTS AND LEVELS OF SIGNIFICANCE FOR PAIRED T TEST IN NINE ADULT SUBJECTS (DATA FOR EACH EAR COMBINED)

	I	*In*	*II*	*IIn*	*III*	*IIIn*	*IV*	*IVn*	*V*	*Vn*
Cz *v* Mi	−.17	−.08	.28*	.07	.22†	NSD	.07	NSD	.09†	.01
Cz *v* Mc	−.03	.22§	.13†	.10	−.09	−.10†	.01	NSD	.09†	.19§
Cz *v* Na	.01	NSD	.03	NSD	.08*	.00	.08	NSD	.08*	.09
Mc *v* Mi	.02	NSD	.41†	NSD	−.13	NSD	NSD	NSD	−.19*	NSD
Cz-Mi *v* Cz-Mc	NSD	NSD	NSD	NSD	.08	.06	NSD	NSD	−.11§	.02
Cz-Mi *v* Mc-Mi	.01	.09	.10*	.06	−.07	−.39	NSD	NSD	NSD	NSD

NSD — not sufficient data.
*p < .001.
†p < .01.
§p < .02.

The ABR components for the Cz-Mc differential recordings had inconsistent waveform identification for waves II, IIn, IV, and Vn. Wave I was observed as being small in amplitude. This is because the components at the two electrode sites (Cz and Mc) are of similar polarity, latency, and amplitude at this time domain. Consequently, by nature of differential recordings, the amplitudes are reduced.

The Mc-Mi differential derivation had significant latency shifts ($p < .001$, Table 2) compared to the Cz-Mi derivation for wave II. There is a considerable decrease in latency for waves V and Vn for Mc-Mi as compared to the other recording conditions (Table 1). In contrast, wave IIIn has a consistently longer latency for the Mc-Mi derivation than for the other recording sites.

NEONATES

The grand average ABR for the neonatal group is illustrated in Fig 4, and a single case recording is illustrated in Fig 5.

Referential Recordings. The ABR components in the neonatal subjects had longer latencies and greater variability than those in the adult subjects (compare Tables 1 and 3). Filtering between 150 to 3,000 Hz (Fig 6) enhances the peaks, especially for waves III and V, and the wave IV to V complex becomes narrowed.

In the neonate, waves In, IIn, IIIn, and Vn seen at Mi could not be easily identified compared to the adult potentials. Wave I at Mi was somewhat shorter in latency (0.095 ms) than wave I at Cz. Waves II, III, and V demonstrated significant latency differences between Cz and Mi (Table 4). The absolute differences in latencies between these two recording sites are greater in the infant than in the

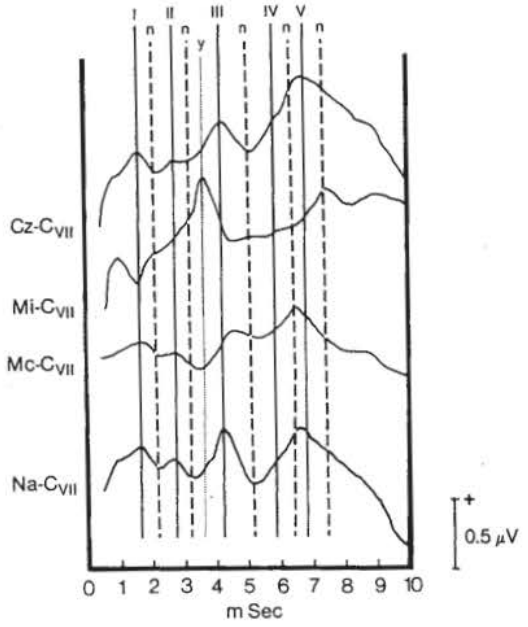

Fig 4. Recordings of grand average (28,672 trials) of ABR for four electrode sites (Cz, Mi, Mc, and Na referenced to CVII) for 14 neonatal subjects.

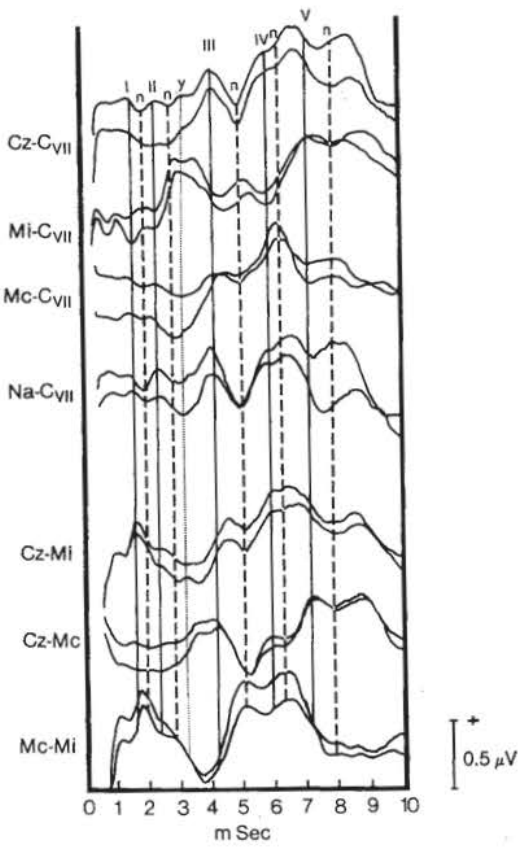

Fig 5. Recordings of individual averages of ABR for four electrode sites (Cz, Mi, Mc, and Na referenced to CVII) and derived differential recordings (Cz-Mi, Cz-Mc, and Mc-Mi) for one neonatal subject.

TABLE 3. MEANS AND STANDARD DEVIATIONS (MS) OF ABR COMPONENTS IN 14 TERM INFANTS

Component		Cz	Mi	Mc	Na	Cz-Mi	Cz-Mc	Mc-Mi
I	$\bar{x}$	1.69	1.60	1.67	1.66	1.59	NSD	1.61
	SD	0.11	0.10	0.12	0.12	0.15		0.13
In	$\bar{x}$	2.18	NSD	2.14	2.20	2.71		2.22
	SD	0.13		0.13	0.15	0.15		0.16
II	$\bar{x}$	2.72	2.71	2.65	2.65	2.69	NSD	2.72
	SD	0.22	0.15	0.14	0.16	0.15		0.15
IIn	$\bar{x}$	3.22	NSD	3.37	3.23	3.40	NSD	3.51
	SD	0.32		0.18	0.19	0.17		0.18
y	$\bar{x}$	NSD	3.70	NSD	NSD	5.15	5.07	4.39
	SD		0.16			0.25	0.28	1.26
III	$\bar{x}$	4.39	4.73	4.43	4.30	4.49	NSD	4.66
	SD	0.23	0.18	0.25	0.23	0.16		0.22
IIIn	$\bar{x}$	5.02	NSD	NSD	5.09	5.15	NSD	5.32
	SD	0.21			0.32	0.25		0.32
IV	$\bar{x}$	5.76	5.60	NSD	NSD	NSD	NSD	NSD
	SD	0.45	0.34					
IVn	$\bar{x}$	5.89	6.36	NSD	NSD	NSD	NSD	NSD
	SD	0.19	0.37					
V	$\bar{x}$	6.94	7.31	6.74	6.80	6.89	7.14	6.62
	SD	0.31	0.19	0.39	0.27	0.37	0.32	0.33
Vn	$\bar{x}$	7.92	NSD	7.70	7.58	7.65	7.83	7.47
	SD	0.45		0.39	0.24	0.31	0.32	0.30

NSD — not sufficient data.

adult. For instance, for wave V, the mean difference in the adult is 0.1 ms, whereas, in the infant it is 0.4 ms.

Waves III and V were the only consistently identifiable waves at Mc. Waves V and Vn at Mc demonstrated significant differences ($p < .01$) in latency from the Cz recordings.

The morphology of the Na recording is very similar to that seen for the Cz recording except for an increase in variability. Waves IV and IVn are generally not identifiable in the neonatal population from the Na recording site, whereas, in the adult population, only IVn could not be consistently identified at this recording site. Latency differences between Cz and Na recording sites were not significantly different. One of the more dramatic differences, other than the overall latency shift between the adult and neonate, is the amplitude and long duration of a positive potential shift (y) occurring between waves II and III defined at Mi (Figs 1 and 4 for the grand average and Fig 7 for the individual tracings). Since absolute amplitudes of ABR components are so variable, we utilized a relative measure of the ratio of the mean peak-to-peak amplitude at Mi of waves III and IIIn divided by the mean peak-to-peak amplitude of wave IIn-y. A significantly larger ($t = -3.43$, $p < 0.01$) mean amplitude ratio of 2.26 was observed in the adult compared to the mean ratio of 1.16 in the infant, confirming the impression that the y wave is especially prominent in newborns. To evaluate the scalp distribution of the y component, we placed in two newborns a vertical chain of four electrodes from Cz to below the mastoids at equidistant points, with electrodes on the vertex and mastoid. Each electrode was referenced to CVII. The electrode placed below the mastoid had no y component; the Mi electrode clearly showed a y component. However, the remaining electrodes did not show this potential, indicating the rather focally restricted field for the y component.

Differential Recordings. Wave I derived from Cz-Mi differential recordings in the neonates has the shortest latency compared to other recording sites. Wave I is quite easily distinguishable in this recording condition and, except for possibly the Mc-Mi condition, has the largest amplitude. This is due to the positivity of wave I in noncephalic referential recordings from Cz and its negativity on noncephalic referential recordings at Mi.

Waves I through IVn were not consistently observed for the Cz-Mc recording condition. There are significant latency shifts ($p < .01$) between the Cz-Mc recordings and the Cz-Mi recordings for waves V (0.245 ms) and Vn (0.179 ms) with Cz-Mi having shorter latencies (Tables 3 and 4).

Waves I, III, and V in the Mc-Mi derivations are of large amplitude and well defined. The wave IV and V peak complex is quite broad, with waves IV and IVn not consistently identified. Also, wave V occurs significantly earlier ($p < .001$) at Mc-Mi compared to Cz-Mc. There were insufficient data to evaluate the other components of the ABR for differences between Cz-Mc and Mc-Mi recordings.

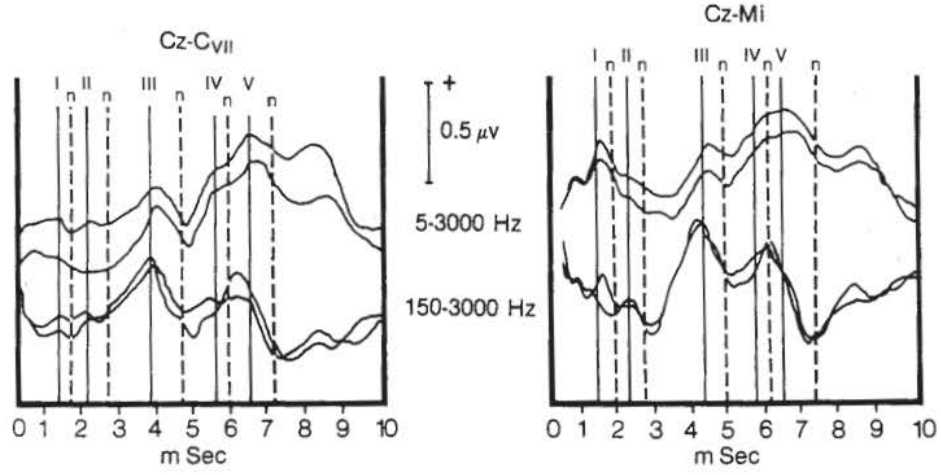

Fig 6. Recordings for Cz-CVII (left) and Cz-Mi (right) using filter settings of 5 to 3,000 (upper) and 150 to 3,000 Hz (lower) for one neonatal subject.

TABLE 4. LATENCY DIFFERENCES (MS) OF ABR COMPONENTS AND LEVELS OF SIGNIFICANCE FOR PAIRED *T* TEST IN 14 TERM INFANTS (DATA FOR EACH EAR COMBINED)

	I	*In*	*II*	*IIn*	*III*	*IIIn*	*IV*	*IVn*	*V*	*Vn*
Cz *v* Mi	.08	NSD	−.90*	NSD	−.38*	NSD	.14	NSD	.38†	NSD
Cz *v* Mc	.02	.01	.01	−.13	.06	NSD	NSD	NSD	.19†	.28†
Cz *v* Na	.05	NSD	NSD	NSD	.07	NSD	NSD	NSD	.12	NSD
Mc *v* Mi	.06	NSD	−.97*	NSD	−.34*	NSD	NSD	NSD	−.56†	NSD
Cz-Mi *v* Cz-Mc	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	−.29†	−.19†
Cz-Mi *v* Mc-Mi	.000	−.007	−.021	.13†	.18†	NSD	NSD	NSD	.27*	.18†
Cz-Mc *v* Mc-Mi	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	.58*	.39*

NSD — not sufficient data.
*$p < .001$
†$p < .01$.

However, differences that were observed were exceptionally large (0.579 ms for wave V and 0.386 ms for wave Vn).

DISCUSSION

We evaluated scalp distribution of the ABR in the neonate and compared scalp distribution between the adult and neonate brain stem.

Consistent with previous reports,[1,4,5] wave I has a positive polarity in both the adult and neonate over most of the scalp, with a negative polarity at Mi. Consequently, wave I may be more clearly defined by using a Cz-Mi or Mc-Mi derivation to emphasize the polarity reversal across the scalp. Clear identification of wave I is extremely important both when utilizing ABR for estimating cochlear function and for defining apparent central conduction times to assess brain stem function. As with the adult,[1] wave I in the neonate is positive at Mc and Na, and negative at Mi, and may be described as vectors oriented in both the horizontal and vertical planes originating close to the ipsilateral ear. Picton et al[5] and others [1,3,4,6,8,9,12] have suggested that wave I at the ipsilateral mastoid is identical to the whole eighth nerve action potential of N1 recorded at the round window.

Wave I generally has lower amplitudes for lateral-posterior electrode sites in referential recordings. Consequently, subject variability probably accounts for differences between the individual trac-

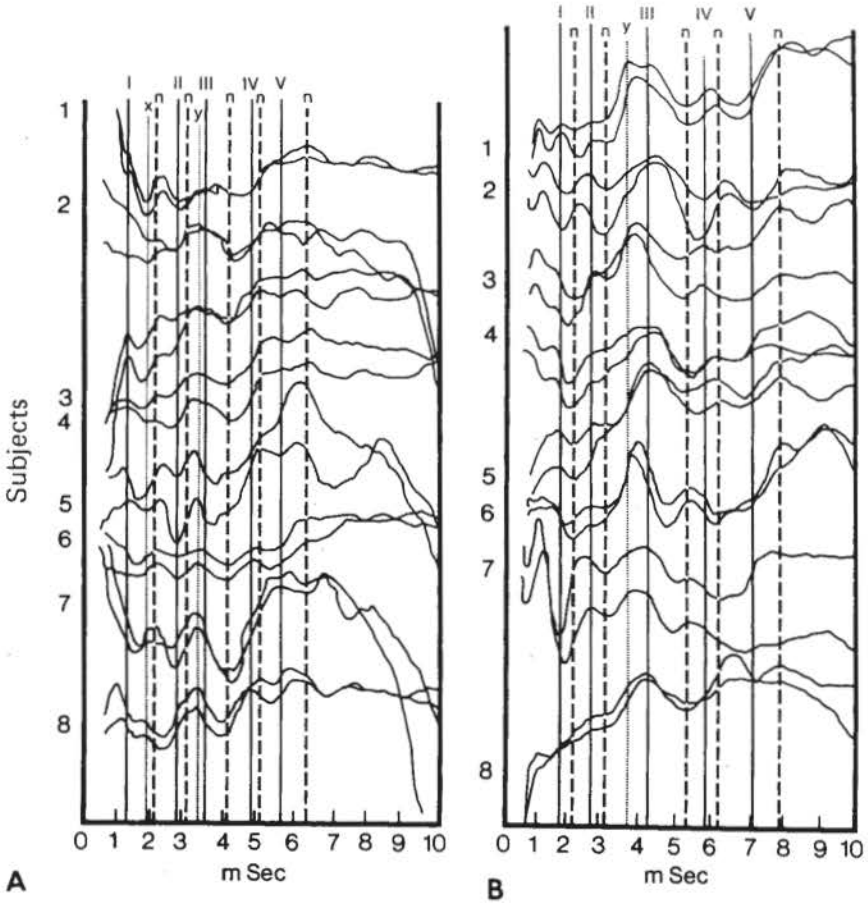

Fig 7. Recordings at Mi-CVII in 16 subjects. A) Adults (eight), B) neonatal (eight, identification referenced to Cz).

ings (Fig 2), grand average tracings of wave I (Fig 1), and perhaps wave x in the adult.

Hughes et al[9] identified wave In at Mi as being positive, and negative at Mc and Cz with the largest amplitude at Cz. Starr and Squires[1] were not able to consistently observe In at Mi, but similar to Hughes et al[9] found wave In to be greatest at Cz. The presence of a positive peak (x) at Mi in our data is similar to Hughes's[9] observations of a positive peak occurring after wave I at Mi. However, in our results this positive peak, x, is distinct from wave In which is negative at Mi. Hughes et al[9] also show a negative peak at Mi prior to wave II, which we identify as wave In.

Wave II is positive at all electrode locations in the adult[10] as in the neonate except at Mi where it is generally not observable. The adult tracings of wave II were much more stable for both amplitude and latency, whereas, the neonatal group showed greater variation. Starr and Squires[1] suggest that in the adult, wave II can be represented as a dipole oriented in the saggital plane. Because of the variability of wave II in the neonate, it is difficult to determine if the same generators are operational in both the adult and neonate.

Wave IIn is seen as a negative deflection at each electrode position in the adult, and in the neonate, the same is true except at Mi and Mc where either an extremely small amplitude for IIn is observed or it is absent altogether. In the adult, waves II and IIn are very similar in scalp distribution and may reflect the same generators.[1,4] In the neonate, wave II is more easily identified than wave IIn at Mi. Whether this is due to the features of the developing neonatal brain or to the separation of two different generators for wave II and IIn, cannot be ascertained; however, we favor the former postulate.

The definition of a high amplitude component at Mi occurring between waves IIn and III (labeled y in our recordings) may account for the difficulty, particularly in the neonate, in detecting wave II using the standard Cz-Mi recordings. In neonatal ABRs derived from Cz-Mi there is a large negative shift between waves I and III that obliterates wave II.[11] In contrast, in the adults the negative shift is slight and wave II is clear. The negative shift in the neonate is, in fact, the y positive component defined at Mi which in the differential recording, Cz-Mi, becomes negative. The amplitude of this shift is very large compared to wave II, thereby rendering the detection of wave II difficult.

Wave III occurs consistently as a negative deflection at Mi and a positive deflection at other electrode locations. This observation is in agreement with that of Picton et al[5] and Hughes et al,[9] but does not agree with Kevanishvili[8] who found wave III to be absent at Mi. There is more of a latency shift of wave III at Mi compared to Cz in the neonate (0.4 ms) than in the adult (0.2 ms). This shift is probably related to the absence of the x component at Mi and the reduced amplitude of the slow potential in the neonate. It has been suggested that wave III has both a vertical and horizontal dipole component[1] and is quite broad in its spatial extension. Our results agree with these findings. The neonate shows a positive polarity for wave III except at Mi where it is negative and peaks at an increased latency relative to the other recording sites. Wave II is longer in duration for both the adult and neonate in the Mc-Mi derivation supporting the concept that this wave has a spatial distribution as a horizontally oriented dipole. Wave IIIn is similar to wave III. Although wave IIIn was negative in the neonate, it had a much reduced amplitude at Mc and was generally not observed at Mi. The similarity in the behavior for waves III and IIIn may suggest that 1) a common generator(s) produces waves III and IIIn such that their dipoles are broad enough to produce a latency shift due to the spatial distribution of the two poles, or 2) two parallel, but separate, generators exist that are separated in space with similar orientations.

Wave IV had its longest mean latency at Mi and was not statistically different in latency from other electrode locations in either the adult or neonate. This was also observed for wave IVn. This finding is in contrast with that of Starr and Squires[1] and with the Kevanishvili[8] observation of increased latency at Mc, thereby suggesting a vertically oriented dipole. The morphology of waves IV and IVn with our wide filter setting are not consistently identifiable.

Wave V was positive at all scalp locations in both the adults and neonates. In addition, significant ($p < .02$) differences in latencies occurred between recording sites except for Cz versus Na in the neonate. Furthermore, there is a greater shift in latency differences between electrode sites in the neonate than in the adult. In both groups the shortest latency was observed at Mc. The amplitude of wave V is clearly largest at Cz, suggesting vertically oriented dipoles. Unlike Starr and Squires,[1] we did not observe an absence of wave V for the Mc-Mi derivation, but we did observe the latency disparities between the two sides of the brain stem (Mc versus Mi) at a significant level of difference ($p < .001$).

Wave Vn was negative at all scalp locations in both groups with the shortest latency at Mc. Wave Vn behaved quite similarly to wave V and may have similar origins.

It has been proposed by Robinson and Rudge[10] that, when there is a shift in the latency of a component of the ABR, one of three possibilities exists: 1) there is more than one active generator within a given pathway, 2) there is more than one pathway being activated in the generation of the waveform, or 3) that both of the above cases occur. Robinson and Rudge[10] confirmed earlier observations of Pic-

ton et al[5] relative to differences between vertex-ipsilateral mastoid recordings (Mc-Mi) and vertex-contralateral mastoid recordings (Cz-Mc). It was their contention that this could be accounted for by the presence of multiple generators, and they presented evidence for the existence of at least three sources contributing to the ABR. In addition to the above considerations, it may be that the latency shift is actually a partial phase shift in a dipole generating the component due to structural changes accompanying maturation, resulting in a reorientation of the dipole. Certainly, as the head size and shape change from infant to adult, boundary conditions for the current fields recorded at the scalp change. Since wave I is essentially the same in both the neonate and adult (except for a latency shift), it is unlikely, in our opinion, that differences in cochlear organization or timing would influence later waveforms without affecting wave I.

The results of our present investigation would likewise suggest the existence of multiple generators contributing to the many components of the ABR. The observations of statistically significant differences of latency across the head (Mi-CVII and Mc-CVII) in the two populations (adults versus neonates) could be due to 1) the effects of maturation on the neural generators of the ABR, 2) the existence of separate generators in the neonates and the adults, or 3) a combination of both. As the nervous system matures, myelinization occurs with a comparable decrease in both the absolute latencies of the ABR components and the scalp differences. As part of the maturing process the weighting of the neural components contributing to the various peaks may alter. Secondly, as the physical size of the brain and surrounding structures increase in size, the orientation of the generators might change, with alterations in their relative polarities, eg, orientation of the dipoles, relative to the scalp. One would expect then, by carefully following growing infants, to see gradual changes of the latency differences between various recording montages toward the adult type ABR.

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