A Method of Auditory Brainstem Response Testing of Infants Using Bone-Conducted Clicks

Méthode d'évaluation de la réponse évoquée du tronc cérébral d'enfants à l'aide de clics par conduction osseuse

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Résumé

La réponse évoquée du tronc cérébral aux stimuli par conduction osseuse semble pouvoir fournir de l'information sur la réserve cochléaire des nouveaux-nés. Elle peut contribuer à l'évaluation des potentiels évoqués auditifs (PEA) à l'aide de stimuli par conduction aérienne pour l'identification de la surdité de perception chez les enfants à risque. Cet article décrit une méthode d'évaluation des PEA d'enfants à l'aide de clics par conduction osseuse. Plus précisément, on présente le contrôle et le maintien de l'envoi de signaux par conduction osseuse. On a recueilli les PEA aux stimuli par conduction aérienne et par conduction osseuse chez un groupe contrôle d'enfants et chez des enfants à risque durant la période post-natale et à l'âge de quatre mois. On illustre des échantillons des ondes d'un enfant normal et de deux enfants à risque, l'un souffrant d'hypoacousie conductive et l'autre d'hypoacousie neurosensorielle. On pose comme principe que la méthode décrite pourrait avoir des conséquences pour la pratique clinique.

Abstract

The auditory brainstem response (ABR) to bone-conducted stimuli appears to be capable of providing information about the cochlear reserve in neonates. It may be used to assist ABR testing using air-conducted stimuli in the identification of sensorineural hearing loss in at-risk infants. This paper describes a method of ABR testing of infants using bone-conducted clicks. Specifically, the control and maintenance of the delivery of bone-conducted signals is presented. ABRs to air and bone-conducted stimuli were collected from normal control and at-risk infants during the postnatal period and at four months. Sample ABR waveforms from a normal infant and from two at-risk infants, one with a conductive deficit and one with a sensorineural hearing loss, are illustrated. It is postulated that the described method may have implications for clinical practice.

The auditory brainstem response (ABR) has been widely accepted as a clinical tool for testing infants, particularly in audiological screening of newborns at risk for hearing loss (Durieux-Smith, Picton, Edwards, Goodman, & MacMurray, 1985; Jacobson & Morehouse, 1984; Galambos, Hicks, & Wilson, 1984; Stein, Özdamar, Kraus, & Paton, 1983). ABR testing using air-conducted stimulation with at-risk infants, however, does not differentiate sensorineural hearing losses from conductive deficits (Stockard & Curran, 1990). ABR to bone-conducted stimuli appears to be capable of providing information about the cochlear reserve (Hall, Kripal, & Hepp, 1988; Hooks & Weber, 1984; Stapells, 1989; Stapells & Ruben, 1989; Yang, Rupert, & Moushegian, 1987) and hence may be used to identify sensorineural hearing losses in infants.

Concerns regarding the technical problems in obtaining ABR to bone-conducted stimuli in infants have been raised (Boezeman, Kapteyn, Visser, & Snel, 1983; Cornacchia, Martin, & Morra, 1983; Gorga & Thornton, 1989; Hall et al., 1988; Kavanagh & Beardsley, 1979; Schwartz, Larson, & De Chicchis, 1985; Stockard & Curran, 1990; Stuart, Yang, & Stenstrom, 1990; Yang, Stuart, Stenstrom, & Hollett, in press). These concerns include: (1) the lack of a standard procedure for the calibration of transient bone-conducted signals; (2) the relatively narrow dynamic range of transient bone-conducted stimuli; (3) the presence of stimulus artifact emanating from the bone vibrator during ABR recording; and (4) difficulties in controlling and maintaining the delivery of bone-conducted signals when testing infants.

The present paper is a preliminary report of an ongoing study investigating the use of ABR testing using bone-conducted clicks in the audiological screening of at-risk infants. The purpose of this paper is to describe the method which we currently employ for obtaining ABRs to bone-conducted clicks with infants. Herein, we specifically focus on the control and maintenance of the delivery of the bone-conducted signal.

Method

Subjects

One hundred normal full-term newborn infants served as the control group. Thirty-four of these subjects were followed at

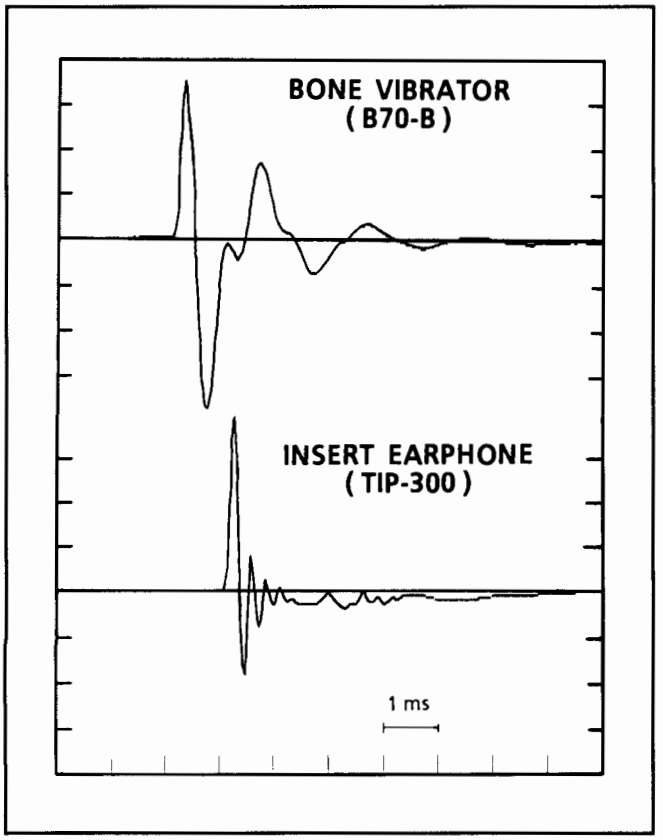
four (±two weeks) months of age. At present, 82 newborn infants at-risk for hearing loss (Joint Committee on Infant Hearing, 1982) have been tested using ABRs to air and bone-conducted clicks as part of the ongoing audiological screening study. All at-risk infants who have reached four months of age have been retested (n=48). In all cases, infants were tested in natural sleep, which usually followed a scheduled regular feeding.

Equipment and Procedures

I. Equipment and Signal Calibration

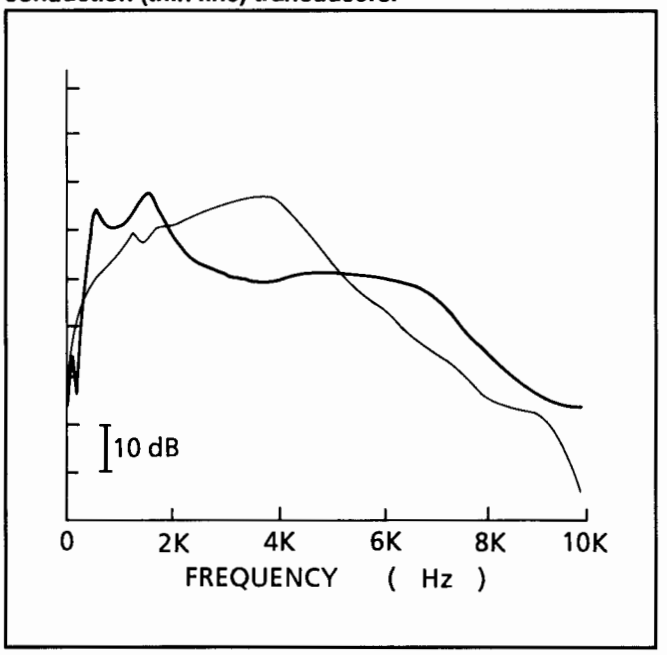
Each infant was tested using a Nicolet Compact Auditory Evoked Potential System. The click stimuli were generated by 100 μs rectangular voltage pulses and delivered through a bone vibrator (Radioear Model B-70B) and an insert earphone (Nicolet Model TIP-300). Click stimuli were presented at a rate of 57.7/s with alternating initial phase. The stimulus intensity levels for bone conduction were 15 and 30 dB nHL, and for air conduction were 30, 45, and 60 dB nHL.

Figure 1. Acoustic waveforms of clicks (100 μs rectangular voltage pulse) measured from the bone and air conduction transducers.



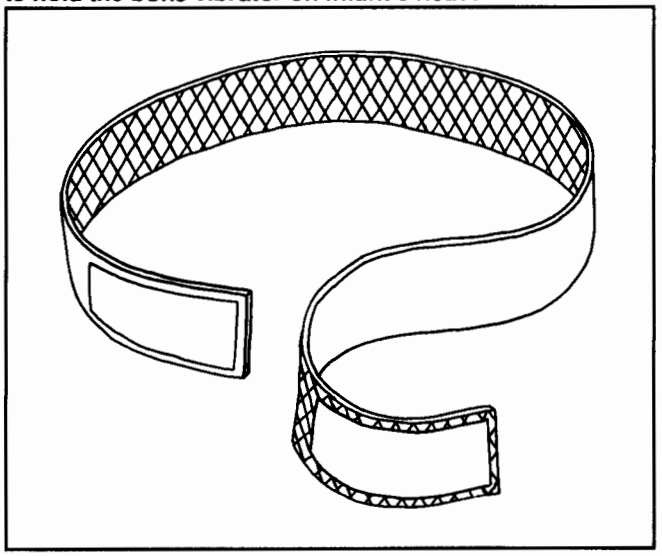
Stimulus intensities were calibrated relative to the averaged behavioral threshold of 10 normal hearing adults who were assessed by air conduction pure tone audiometry to have hearing thresholds no worse than 10 dB HL (American National Standards Institute, 1969) at octave steps from 250 to 8000 Hz. The reference level (0 dB nHL) for the bone vibrator was 20.0 dB pe (re: 20 V); the reference level for the insert earphone was 29.4 dB pe SPL using a 1000 Hz sinusoid as the reference tone.

Figure 2. Spectral analyses of clicks (100 μs rectangular voltage pulse) measured from the bone (bold line) and air conduction (thin line) transducers.



Signal analysis of the 100 μs rectangular voltage pulse was obtained from the bone vibrator while it was coupled to an artificial mastoid (Brüel & Kjær Model 4930). The electrical representation of the click signal was routed from the artificial mastoid to an analog and digital Input/Output board (Data Translation Inc. Model DT 2801) interfaced with an IBM compatible microcomputer. By using signal processing software (Signal Technology Inc. Interactive Laboratory System V6.1), a single click signal was digitized, stored, and analyzed. Spectral analysis of the click signal was performed utilizing fast Fourier transformation. Signal analysis of the 100 μs rectangular voltage pulse was obtained from the insert earphone while it was coupled to a 2 cm^3 coupler (Brüel & Kjær Model DB-0138) and a sound level meter (Brüel & Kjær Model 2209). The electrical representation of the acoustic waveform was routed from the sound level meter, similarly as for the bone-conducted signal, for digitizing, storing, and analysis. The acoustic waveforms of bone and air-con-

Figure 3. Fabric elastic band with velcro at each end used to hold the bone vibrator on infant's head.

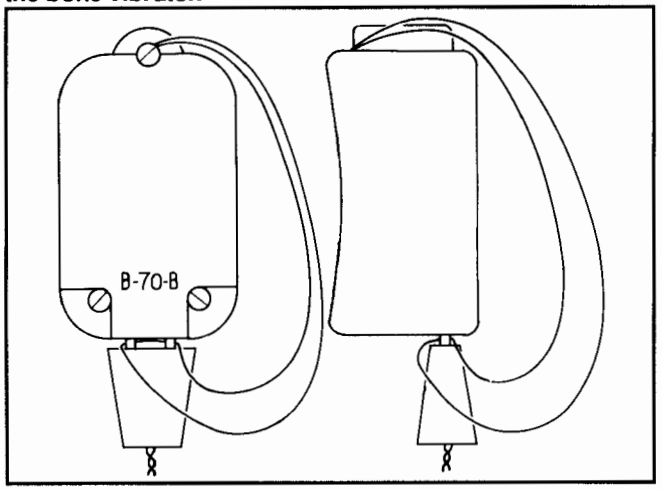


ducted clicks are displayed in Figure 1. The spectral contents of bone and air-conducted clicks are displayed in Figure 2.

II. Delivery of bone-conducted stimuli

A. Accessories for bone vibrator placement. A fabric elastic band of 2.5 cm in width with velcro attached on the opposite sides of the two ends was used to hold the bone vibrator on each baby's head. The elasticity of the fabric elastic band as expressed by Young's Modulus was: $E \approx 6 \times 10^5$ Pa (Halliday & Resnick, 1988). Two lengths of elastic bands were used to accommodate various head sizes of infants. They were 40 cm for the newborn infants (with 7 cm of velcro at each end) and 48 cm for the four month olds (with 8 cm of velcro at each end) (see Figure 3). Such a design allowed for the adjustment

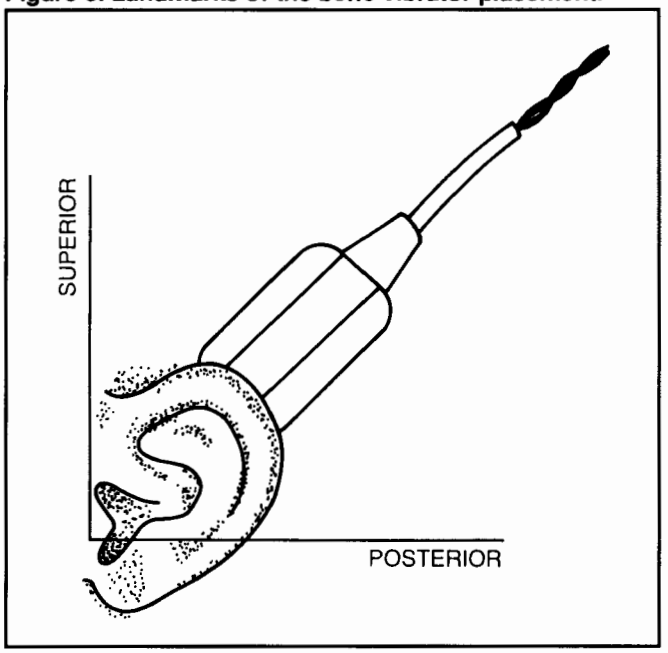
Figure 4. Arrangement of nylon monofilament attached to the bone vibrator.



of the elastic bands to obtain a specific vibrator-to-head coupling pressure.

B. Accessories for measurement of vibrator-to-head coupling force. The apparatus for measurement of vibrator-to-head coupling force was a palm size spring scale (Ohaus Model 8014) with a 2000 g limit. A fine nylon monofilament (fishing line) with a total length of 20 cm was used as a conjuncture between the bone vibrator and the hook of the spring scale. First, the nylon monofilament was tied into a loop. Then, the single casing screw at the distal end of the bone vibrator was loosened and the nylon monofilament attached under and around the casing screw while it was fastened. The other end of the nylon monofilament loop was placed around the transducer cord/plug attachment adjacent to the proximal end of the bone vibrator (see Figure 4). Such an arrangement was

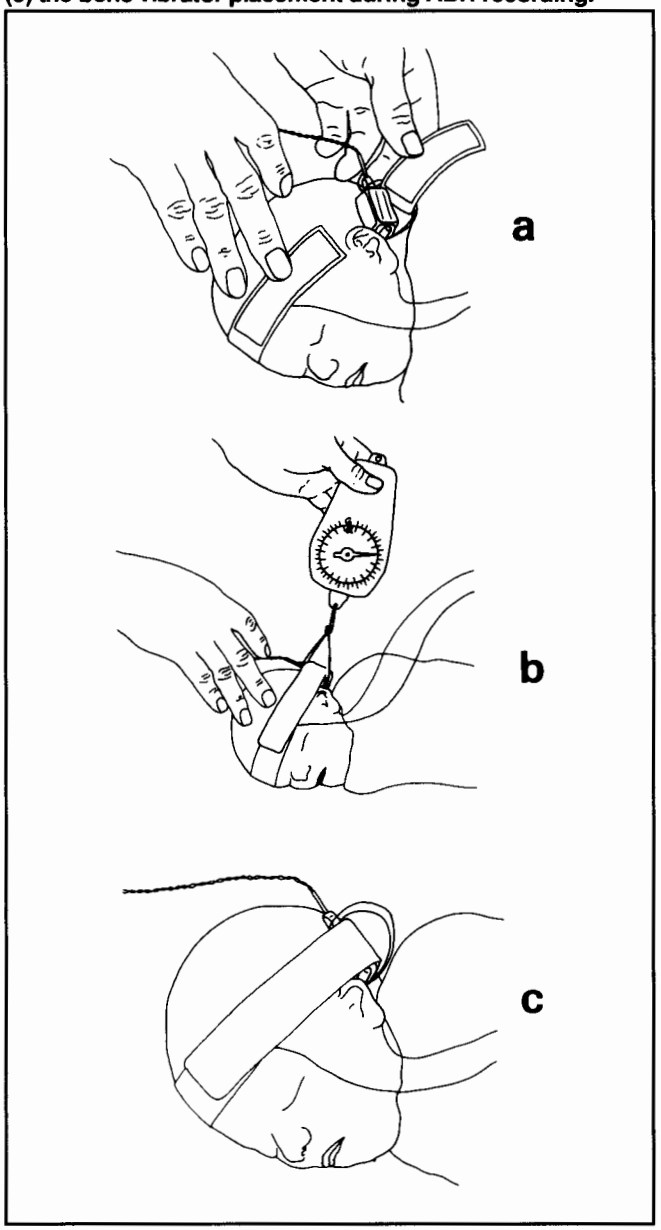
Figure 5. Landmarks of the bone vibrator placement.



designed to accommodate the lift of the bone vibrator against the tension of the elastic band for coupling force measurement.

C. Procedures for the delivery of bone-conducted stimuli. The bone vibrator was placed in a supero-posterior auricular position. The centre of the bone vibrator was dissected by a line drawn posteriorly at a 45° angle from the orifice of the external ear canal at the intersection of the frontal and sagittal planes (see Figure 5). The distal margin of the bone vibrator was positioned medial to the auricle adjacent to its supero-posterior attachment to the scalp.

Figure 6. Procedures for the bone vibrator placement: (a) placement of the bone vibrator and elastic band; (b) measurement of the vibrator-to-head coupling force; and (c) the bone vibrator placement during ABR recording.



The elastic band with velcro was placed around the head over the bone vibrator perpendicularly and under the nylon monofilament loop (see Figure 6a). Then the hook of the spring scale was connected to the loop of the nylon monofilament attached to the bone vibrator. The spring scale then was pulled manually against the tension of the elastic band so that the connected bone vibrator was lifted from the scalp. The vibrator-to-head coupling force was measured as soon as the bone vibrator cleared the scalp (see Figure 6b). The tension of the elastic band was adjusted, when necessary, by changing the contact position of the velcro. The coupling force was maintained between 400 to 450 g. The spring scale was removed from the measurement position during ABR recording (see Figure 6c). The coupling force measurement was repeated before and after the ABR recordings to ensure that it remained constant.

III. ABR Recording Procedures

Three gold-plated cup electrodes were attached to the high forehead (non-inverting), the ipsilateral inferior post-auricular area (inverting), and the contralateral inferior post-auricular area (common). Inter-electrode impedance for any pair of electrodes was maintained below 8000 ohms. The recorded electroencephalograph (EEG) was amplified 10^5 times and band pass filtered (30 - 3000 Hz). Sampling frequency for digitizing and averaging the response was 33,000 Hz. Recorded EEG samples exceeding 25 μV were rejected. Analysis time was 15 ms post-stimulus onset. A total of 2,048 samples were averaged and replicated for each stimulus condition. Replication was defined as two or more waveforms with identifiable ABR wave V peaks within 0.15 ms from one trial to the next.

All recordings were stored on flexible diskettes for later analysis. Wave V latencies were measured from ABRs to bone and air conduction conditions. An ABR wave V was judged as the first reproducible positive peak after 5.5 ms. If this component was trough-like, round, or bimodal, the last point before the rapid negative deflection was identified as the wave V peak (Durieux-Smith, Edwards, Picton, & MacMurray, 1985).

Results

Absolute ABR wave V latencies were measured from all recordings. For ABRs obtained from air conduction insert earphone stimulation, 0.90 ms was subtracted from the wave V latency measurement to take into account the signal travel time from the transducer to the external ear canal. Normative ABR wave V latencies were collected from 100 normal full-term newborn infants and 34 normal four month old infants. The means (±two standard deviations) of the ABR wave V latencies for each of the stimulus conditions were calculated from these two normal control groups. They are displayed in Figures 7 (for the newborns) and 8 (for the four month olds). The upper limits of ABR wave V latencies were defined as the mean plus two standard deviations for each given stimulus condition.

ABRs obtained from both ears for the at-risk infants were considered within normal limits (i.e., the infant passed the screening test) if the ABR wave V, elicited from either the bone or air-conducted stimulation at 30 dB nHL, was identifi-

able and its latency fell within plus two standard deviations from the mean of the age appropriate norm. Otherwise, the abnormal ABR findings were classified as sensorineural, conductive, and/or mixed losses. Degrees of hearing loss were estimated based on the presence or absence of ABR wave V and/or the extent of prolongation of wave V latency for a given stimulus condition.

An example of ABRs to air and bone-conducted clicks obtained from an ear of a normal infant during the newborn period and at four months of age is shown in Figure 9. An example of a transient conductive deficit, as revealed by ABRs to air and bone-conducted clicks obtained from an at-risk infant, is shown in Figure 10. As can be seen in Figure 10, the ABR wave V latency to air-conducted clicks during the newborn period was prolonged. The ABR to bone-conducted clicks, however, revealed a normal cochlear reserve during the initial test. A follow-up retest at four months of age indicated that ABR wave V latencies to air-conducted clicks were within normal limits. It was speculated that the abnormal ABR to air-conducted clicks during the newborn period reflected a conductive deficit that resolved prior to follow-up testing.

An example of ABRs from an ear with a suspected severe-to-profound hearing loss obtained from an at-risk infant is shown in Figure 11. The ABRs to air and bone-conducted clicks obtained during the newborn period and at four months of age indicated no observable response under all stimulus conditions. Unfortunately, one cannot rule out a conductive component as a contributing factor to the abnormal findings. This is due to the limitation of the dynamic range of bone-conducted clicks (i.e., ≈ 50 dB) as compared to air-conducted clicks (i.e., ≈ 100 dB).

Discussion

A method of delivery for bone-conducted stimulation in ABR testing with infants has been presented. Such an approach may provide a feasible means to differentiate sensorineural hearing losses from conductive deficits in at-risk infants who fail ABR audiological screening using air-conducted stimuli. Based on experience from our ongoing research, we postulate that the described method may have implications for clinical practice.

Although the aforementioned method's use for the audiological screening of at-risk infants is encouraging, its clinical application is hindered by limitations and unknown factors that occur with ABR testing using bone-conducted stimuli. First, it should be noted that the follow-up of infants who present with both normal and abnormal ABRs to air and/or bone-conducted clicks is necessary. This approach will help to assess the accuracy of interpretation and to determine the validity of test results obtained during early infancy. Behavioral testing, such as visual reinforcement audiometry, as early as six months corrected age may provide valuable information regarding the verification of hearing perception as well as frequency specific hearing sensitivity (Moore, Wilson, & Thompson, 1977; Primus, 1987; Thompson & Wilson, 1984). Otoscopic examination and acoustic immittance measures also may assist in the interpretation and validation of test results.

The problem of identifying the response ear for the ABR to bone-conducted stimuli still remains. It has been estimated that the interaural attenuation of a bone-conducted click is approximately 25 to 35 dB for the neonate and 15 to 25 dB for the one year old infant (Yang et al., 1987). In clinical testing of ABRs to bone-conducted clicks with one year olds, masking of the contralateral ear is recommended. When evaluating neonates, masking of the nontest ear may be required at higher stimulus levels, for example, at 35 dB nHL (Yang et al., 1987). There are cases where it is difficult or impossible to mask the ear contralateral to the bone vibrator placement (e.g., due to the position in which the infant may be sleeping and/or because of their light sleep state, or with those infants with bilateral conductive losses). The use of two channel ipsilateral and contralateral recordings may provide a possible solution to identify the response ear for ABR to bone-conducted stimuli (Stapells, 1989; Stapells & Ruben, 1989). Ipsilateral to contralateral latency and amplitude asymmetries present in ABRs from infants may help determine which cochlea is the primary contributor to the recorded ABR (Stapells & Ruben, 1989).

Another difficulty is the relative narrow dynamic range of the bone conduction transducer to the click stimulus which makes it difficult to differentiate severe-to-profound sensorineural from severe-to-profound mixed losses. The use of ABR to bone-conducted tones may provide a partial solution because the dynamic ranges of bone-conducted tones are higher (e.g., 500 Hz: 45 dB; 2000 Hz: 60 dB), "since most of the energy is concentrated in narrow band frequencies and because behavioral thresholds are lower for longer duration tones" (Stapells, 1989, p. 244).

The reliability of ABR testing using bone-conducted clicks as described in the present paper needs to be explored. Further investigation of the variability associated with repeated measures of ABR testing using bone-conducted stimuli with infants is warranted. Finally, it is essential that each clinic develop its own ABR norms for air and bone-conducted stimuli at different age levels, throughout infancy and beyond, for reliable testing.

Figure 7. Normative ABR wave V latencies (ms) to bone- and air-conducted clicks for newborn infants (n=100). Boundaries indicate 2 standard deviations. The mean latency to bone-conducted clicks is indicated by [●], while the mean latency to air-conducted clicks is indicated by [○].

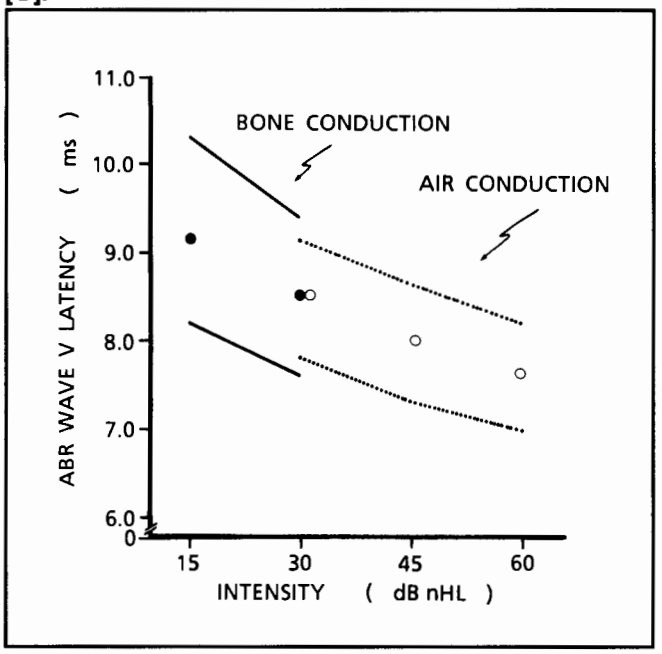


Figure 8. Normative ABR wave V latencies (ms) to bone- and air-conducted clicks for 4-month-old infants (n=34). Boundaries indicate 2 standard deviations. The mean latency to bone-conducted clicks is indicated by [●], while the mean latency to air-conducted clicks is indicated by [○].

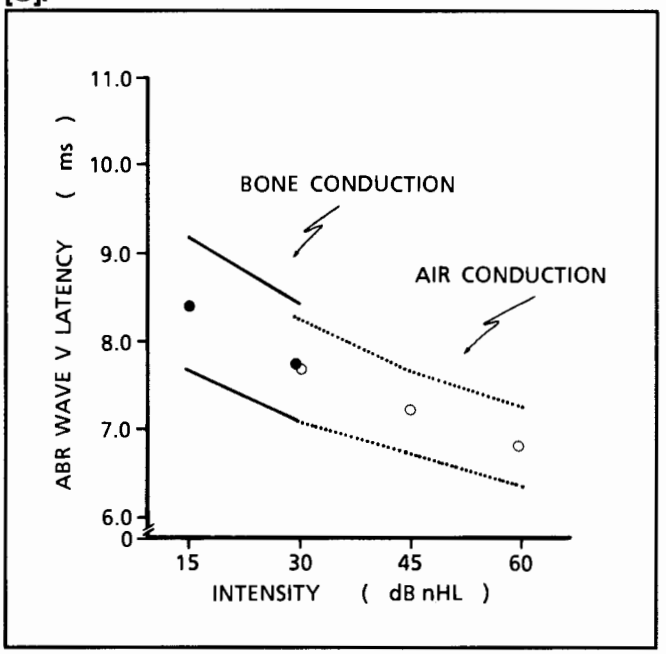


Figure 9. Example ABRs from an ear of a normal infant during the newborn period and at 4 months of age. Triangular labels indicate ABR wave V peaks.

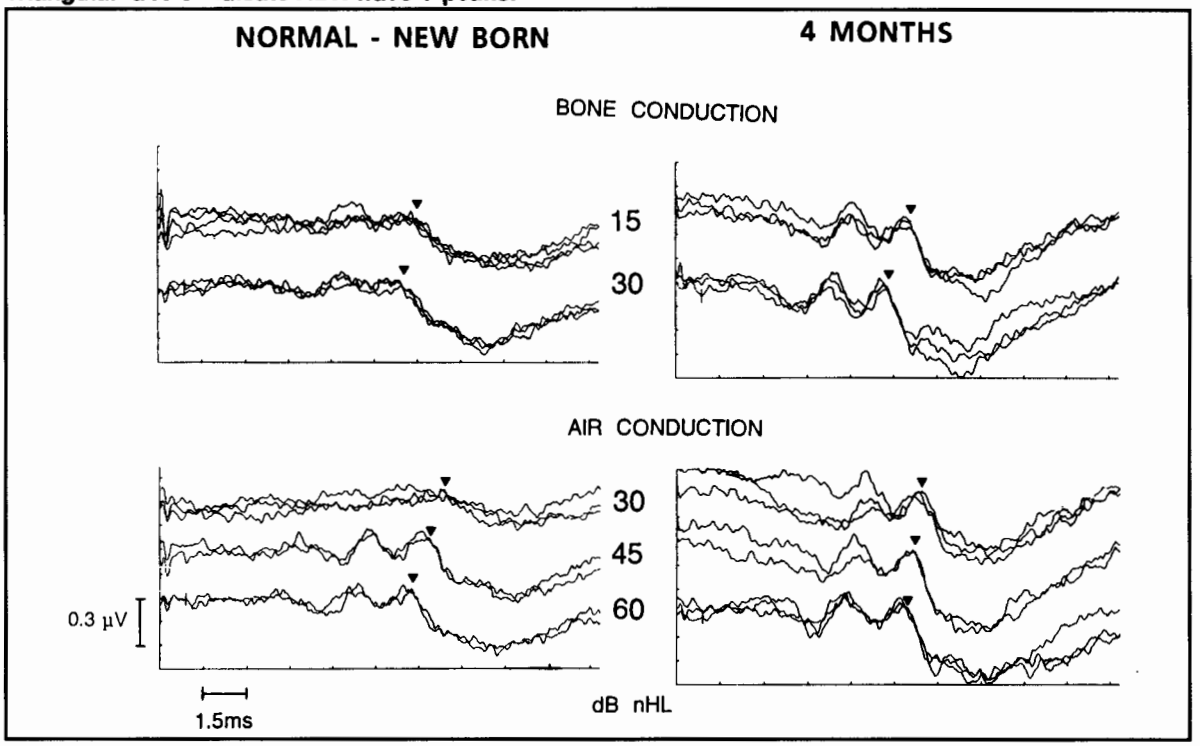


Figure 10. Example ABRs from an ear of an at-risk infant with a transient conductive deficit during the newborn period. Triangular labels indicate ABR wave V peaks.

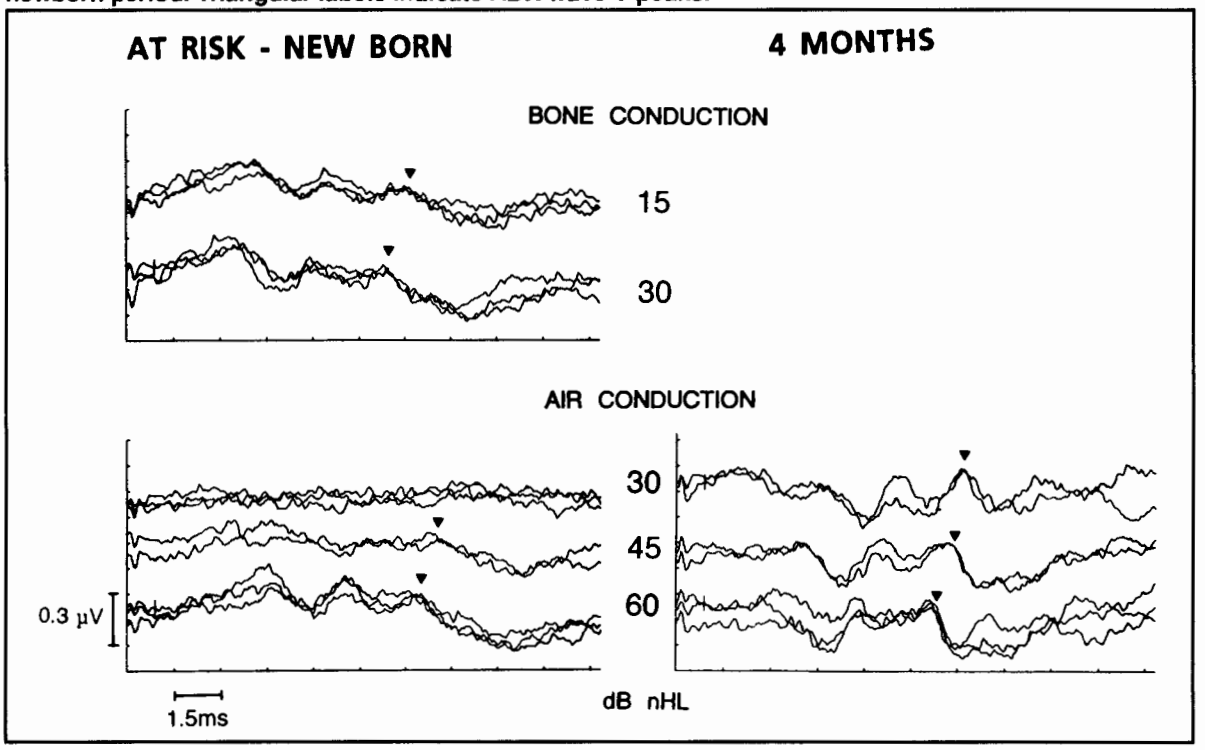
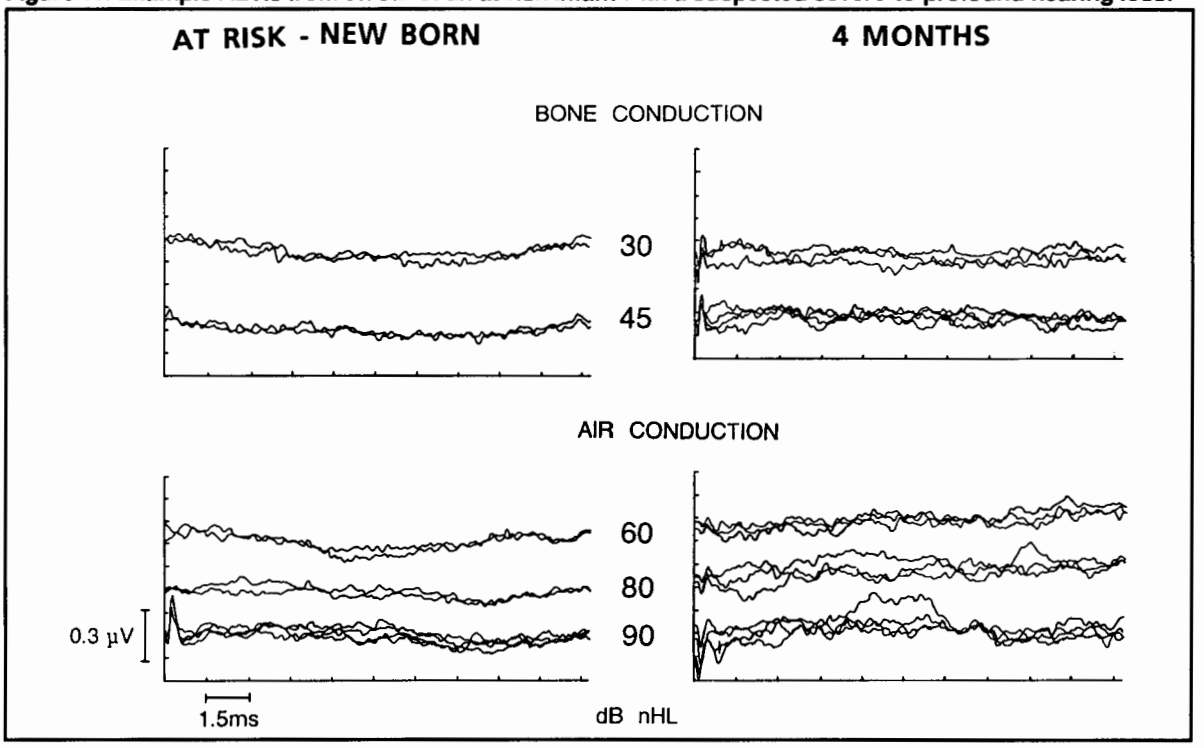


Figure 11. Example ABRs from an ear of an at-risk infant with a suspected severe-to-profound hearing loss.



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