Auditory Brainstem Responses from Neonates: Special Considerations

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Numerous studies have reported on the use of Brainstem Electric Response Audiometry (BERA) in neonates and infants (1-6). These reports indicate that BERA is a reliable procedure for the assessment of peripheral and brainstem auditory function in this age group.

Using this technique, Galambos et al (6) found that approximately 10% of the graduates of a neonatal intensive care unit (NICU) have some degree of peripheral auditory dysfunction, with about 2% having bilateral sensorineural losses sufficient to warrant amplification.

This high incidence of auditory dysfunction, coupled with the importance of early identification of hearing loss, has prompted many centres to establish NICU hearing screening programs, with BERA as the recommended procedure (3-5).

BERA has gained widespread acceptance as a test of neonatal auditory function because the response which is measured is involuntary and quantifiable. The response, however, requires interpretation, which is based upon knowledge of the technical and physiological variables which influence the test results. Although the principle of BERA remains the same regardless of the age group tested, its application to NICU babies presents difficulties which require special attention.

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A neonatal hearing screening program using BERA has been in effect at the Children's Hospital of Eastern Ontario (in Ottawa) since 1981. Neonates admitted to our tertiary level NICU are tested just before discharge or, if not possible, shortly after. The details of our test protocol appear in *Table 1*. The purpose of this paper is to discuss those factors which, in our experience, deserve special consideration when applying BERA to an NICU population.

Table 1: *Details of our test protocol*

Recording Electrodes:	F_z - M_i
Averaging Sweep:	15 ms
Filters:	25 - 3000 Hz
Click nHL:	40 dB peak SPL
Click Polarity:	rarefaction
Replications:	1
Intensity and Presentation Rate:	70 dBnHL at 11/s 30 dBnHL at 61/s (increase in 10 dB steps if no-response)
Sum:	2000 at 11/s 4000 at 61/s

Factors Influencing the Interpretation of BERA Results from NICU Neonates

1. Selection of Test Parameters

We use a click stimulus to test neonates. The click stimulus does not provide frequency specific information because it contains energy over a broadband of frequencies. There are techniques available which attempt to assess auditory sensitivity at specific frequencies however we reserve these for follow-up testing and will discuss them later.

To pass the neonatal screening test, each ear must show an auditory brainstem response (ABR) to 30 dBnHL clicks presented at a rate of 61 per second, with no evidence of neurological dysfunction at 70 dBnHL when clicks are presented at 11 per

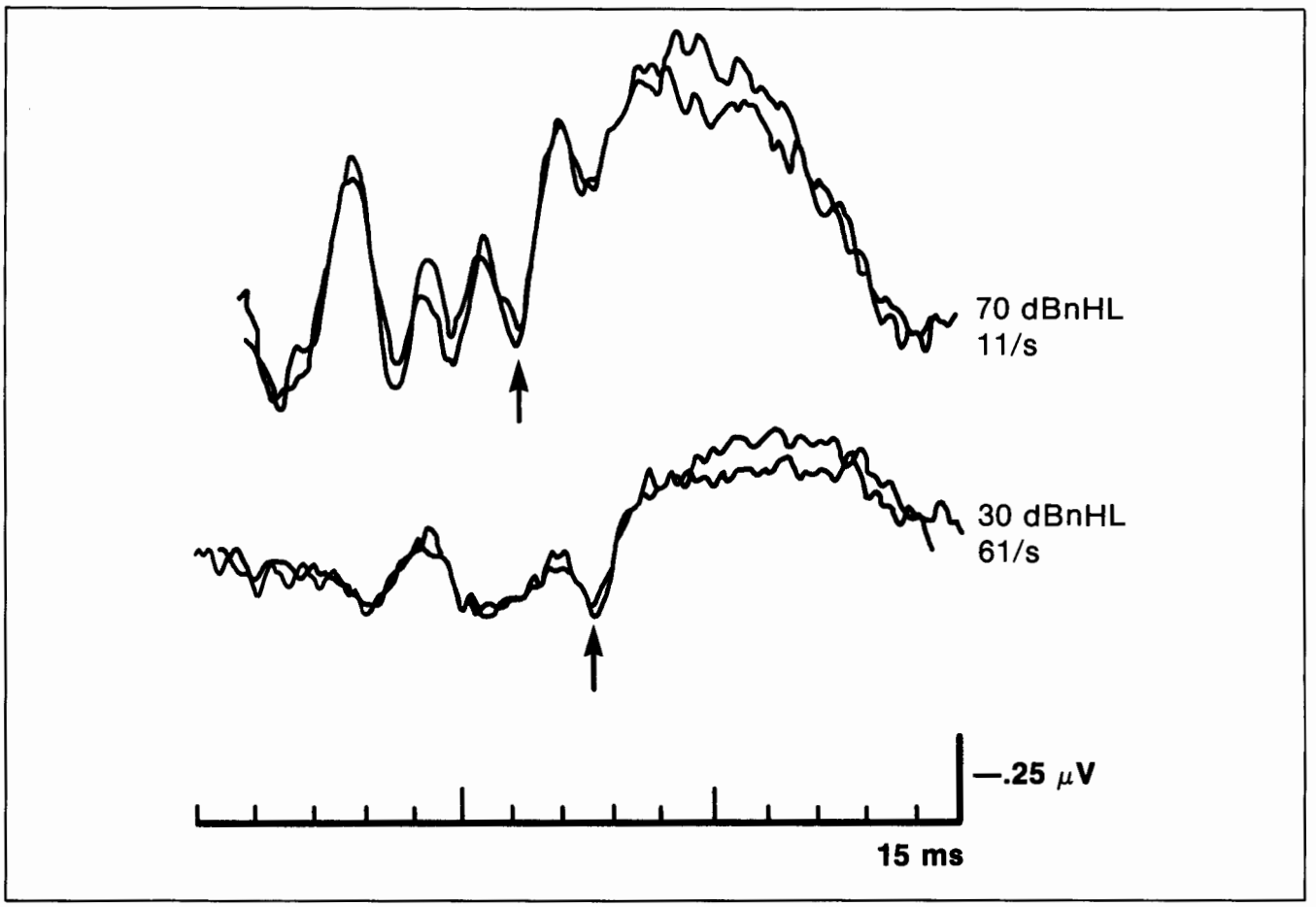

Figure 1: *Normal response from a 2 week old full term neonate. Positivity at the vertex is shown as a downward deflection in this and all succeeding figures. The arrow denotes wave V.*

second. Neurological function of the auditory pathways of the brainstem is assessed by measuring the wave V-I latency interval, calculating the wave V/I amplitude ratio and comparing these values to normative data. An example of a typical response from a neonate passing our screening test is shown in Figure 1. If there is no response at 30 dBnHL, we increase the intensity in 10 dB steps until threshold is reached. An elevated threshold or an abnormal response morphology suggestive of neurological involvement results in a follow-up test about 3 months later.

When assessing the auditory sensitivity, we present clicks at a rate of 61 per second and average over 4000 sweeps. It is advantageous to use a rapid presentation rate because it is possible to average many sweeps over a given time period without greatly affecting the amplitude of wave V, the principle ABR component at near threshold intensity. The newborn wave V amplitude at 70 dBnHL decreases only 20% as the rate increases from 11 to 61 per second. Any loss of amplitude at threshold is offset by the greater clarity of the recording, because the signal-to-noise ratio improves by the square root of the number of sweeps.

A rapid presentation rate will significantly reduce the amplitude of the other ABR components however, therefore when it is necessary to obtain good resolution of the ABR peaks for neurological assessment we present 70 dBnHL clicks at 11 per second and sum to 2000. This protocol gives rise to satisfactory peak resolution and does not disturb a sleeping baby.

The high pass setting of the EEG filter is another important factor. There is a considerable amount of low frequency energy in the spectrum of the ABR, particularly near threshold. The main power of the ABR lies below 250 Hz and shifts to increasingly lower frequencies as the intensity is decreased (7). Selecting a high pass filter setting below 250 Hz will increase the amplitude of the ABR. This is particularly important when testing neonates because their responses are smaller than older infants or children.

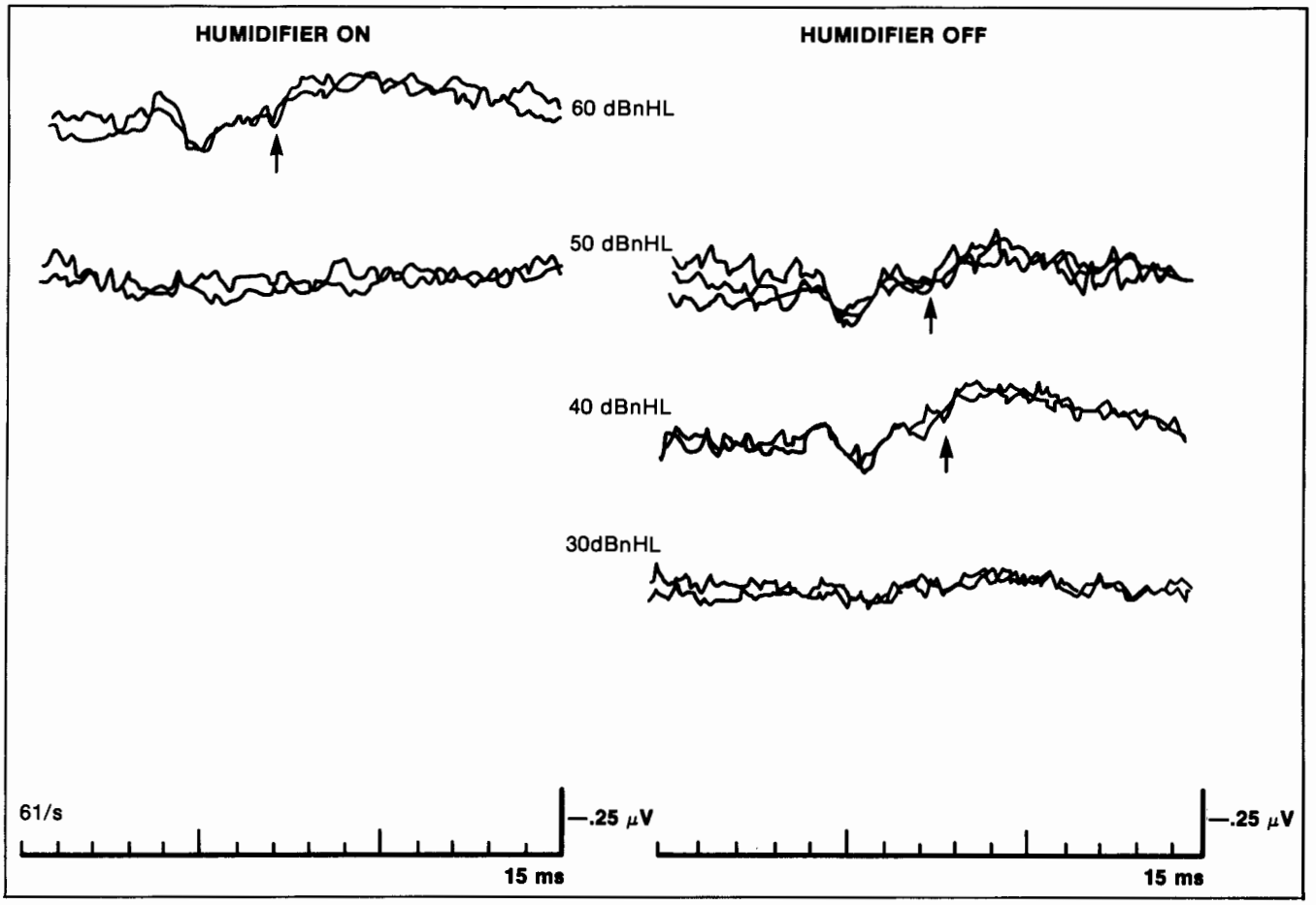

Figure 2: Effect of ambient noise on the auditory brainstem response. A 20 dB improvement in threshold was obtained when humidifier noise was eliminated.

2. Location of Test

Babies in an NICU are often tested as inpatients. Optimally the infants should be tested when stable and as close to discharge as possible. They can then be transported and testing can be conducted in a sound attenuated chamber.

When this is not possible and testing must be carried out in the NICU, one may encounter problems with electrical artifact and ambient noise levels. Low impedance contants can help reduce some electrical noise. We have found that low impedance contacts can be obtained as easily in neonates as in adults. Inter-electrode impedances of 3 kΩ or less, with no more than a 1 kΩ difference between pairs, have in our experience resulted in satisfactory recordings. Such impedance values can be easily obtained using only tape to attach gel-filled electrodes, and without leaving abrasions on the scalp.

Ambient noise levels are particularly difficult to control when testing neonates in an incubator. Noise levels in an incubator are reported to be about 60 dB(A), with the greatest concentration of energy below 500 Hz(5). One source of incubator noise that can often be temporarily eliminated is the humidifier. To illustrate the effect of ambient noise on the ABR, we obtained consecutive recordings from the same neonate with and without the humidifier (Figure 2). A 20 dB improvement in ABR threshold was seen in the no-humidifier condition. A spectral analysis showed that the humidifier was increasing the ambient noise level by about 20 dB above 1000 Hz.

Mild elevation of ABR threshold in noisy settings may therefore not always reflect a hearing loss. If tested under non-conventional conditions, some neonates may be inappropriately considered hearing impaired unless allowance is made for the test environment.

3. Earphone Placement

BERA testing is usually conducted by delivering sound stimuli through an earphone. Although of obvious importance in any test, the problem of ear-

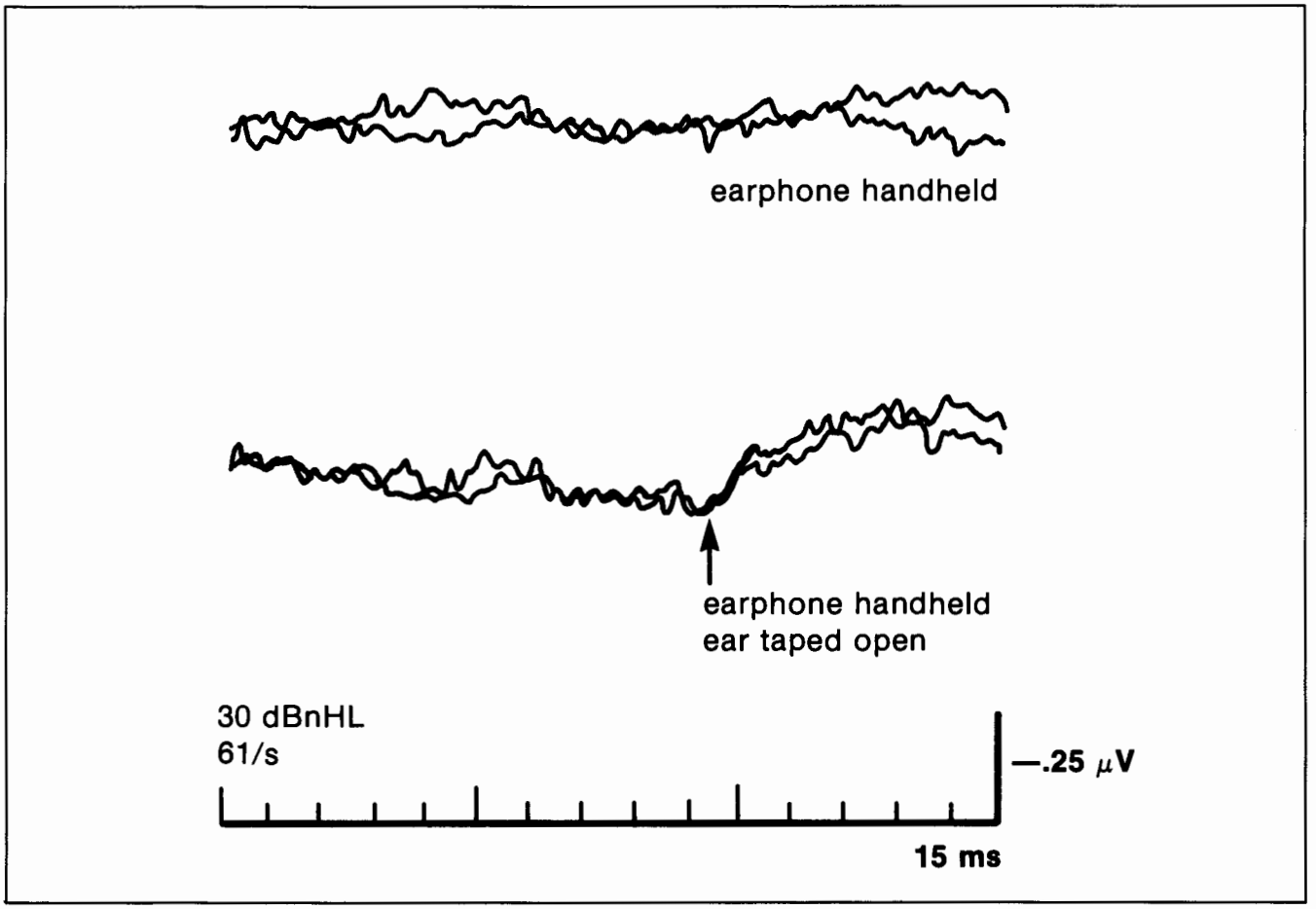

Figure 3: Effect of earphone placement. Consecutive recordings from the same sleeping neonate indicate that a response was recorded only after the ear was taped open.

phone placement becomes critical with neonates. Standard audiometric earphones are not designed for this age group. The earphone is much larger than the neonatal ear, and it is difficult to ensure proper placement. Only slight positive pressure should be applied to the earphone because the neonatal external canal is distensible and subject to collapse. In adults, collapsing ear canals can result in a hearing loss of up to 30 dB (8). It would seem reasonable to presume that a hearing loss of similar proportions could occur in the neonate. Elevated ABR thresholds in neonates due to collapsing ear canals have been reported (9).

To minimize the problem, earphones should be handheld and the position monitored periodically. A small mark on the cheek can aid in maintaining position. An unusual latency-intensity function (where latencies increase with increased intensity), or a different wave V latency upon replication are clues that earphone placement is a problem.

In cases where a collapsed canal is suspected, the tragus can be taped forward to help expose the external canal and restrict the degree of collapse. Some neonates pass our screening test only after the application of tape (figure 3). Alternately, one can simply apply less pressure to the earphone keeping in mind that lifting the earphone off the ear can attenuate the intensity of the stimulus and give rise to greater masking from ambient noise.

Small plastic tubes can be inserted into the canal if one is confident this procedure can be performed safely. Care must be taken not to push the tube deep into the canal when applying the earphone.

As a standard rule, whenever we record a no-response tracing, the earphone is re-positioned before obtaining a replication. On several occasions this has saved us from making an inaccurate diagnosis.

Bone conduction stimulation would eliminate concern about earphone position and collapsing canals. Unfortunately, calibration of the stimulus delivered through a bone oscillator is difficult and the frequency composition of the stimulus is altered. Bone conduction testing may, however, prove to be very useful in NICU screening programs using BERA (10), particularly in the detection of conductive hearing losses in infants prone to this disorder (cleft palate babies, Down's Syndrome babies etc.).

4. *Patient State*

The single most important factor to consider when obtaining ABRs is probably subject state. The most effective means of reducing noise artifact is to ensure patient relaxation (11). We do not attempt to test until the baby is asleep and movement artifact is at a minimum. The amplitude of the ABR from a neonate is smaller than that of an older child or adult and responses become difficult to identify when even slight movement is present. It does not usually take long for babies up to 6 months of age to fall asleep if they have been sleep deprived and if feeding is withheld until just before the test time. In no cases have we found that sedation is necessary; in fact, sedation is not part of our NICU screening or follow-up protocol.

5. *Electrode Montage*

Simultaneous ipsilateral and contralateral electrode montage recordings are frequently used when testing adults, usually to aid in peak identification. In the ipsilateral montage, the recording electrodes are placed on the vertex (or in the case of babies, the forehead, to avoid the fontanelle) and on the mastoid or earlobe on the same side as the stimulated ear. The contralateral montage records between the vertex and the mastoid or earlobe opposite the stimulated side. The differences between the two montages in adults are minor but predictable. In the contralateral recording, wave I is greatly reduced in amplitude, if not absent entirely, wave III is also smaller and waves IV and V show greater separation

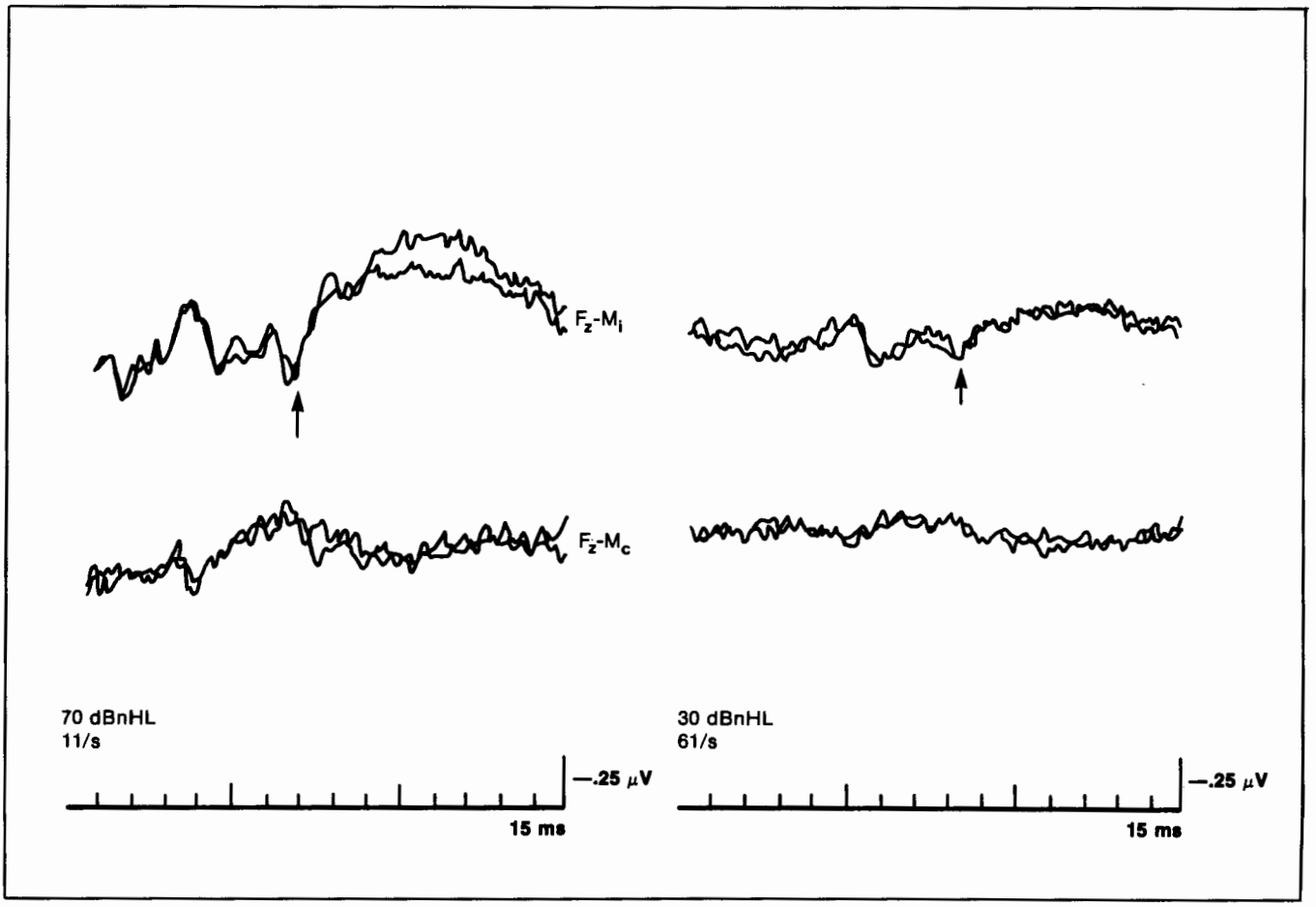

Figure 4: Simultaneously recorded ipsilateral (F_z-M_i) *and contralateral* (F_z-M_c) *responses from a neonate. On the left are shown the responses recorded upon stimulation with 70 dBnHL clicks presented at a rate of 11 per second. On the right are shown the responses recorded from 30 dBnHL clicks at 61 per second.*

and can usually be resolved independently. These changes can be used to help identify components in the ipsilateral recording. Because peak identification is important for neurological interpretation, the use of dual recordings is of clinical value.

In our experience, the contralateral recording obtained from neonates is considerably different than the ipsilateral. We find that the major component of the neonatal contralateral response is a positive peak occurring approximately .3 ms earlier than the ipsilateral wave III. Wave V appears to be opposite in polarity and considerably smaller in amplitude. A no-response tracing is frequently recorded at low intensities even when a definite response is present in the ipsilateral recording (figure 4).

Thus, the ipsilateral and contralateral recordings differ substantially in neonates. Contralateral recordings may confuse peak identification if the same differences seen with adults are expected. If the interpretation is based solely on the contralateral response, whether by design or accident, an inaccurate diagnosis of hearing loss, neurological abnormality or both may result. A more detailed report on ipsilateral and contralateral ABRs from neonates will be reported elsewhere (12).

6. *Maturation*

The ABR is first recordable at about 25 weeks from conception (2). Throughout the neonatal and infant period the latency and amplitude of the response change rapidly. An adult-like response is not reached until about 18 months of age.

The actual latency and amplitude values obtained depend not only on the age and auditory status of the baby tested, but also on technical factors such as the stimulus parameters (intensity, presentation rate, polarity and acoustic spectrum), electrode location and filter settings. Because these factors are not uniform across laboratories, the normative values reported in the literature should be used for comparative purposes but not as a substitute for developing one's own norms.

The maturational changes reported below refer to the time interval extending from 33 weeks from conception (7 weeks premature) to 52 weeks from conception (3 months after a full-term gestation).

a) Latency: Waves I, III and V all show a statistically significant decrease in latency with age, however the waves are affected differentially. The reduction in latency is less for wave I than for waves III and V. Consequently the V-I latency interval, a commonly used index of neurological dysfunction, also decreases with age (*Table 2*).

Table 2: The latency of the ABR components decreases as age increases. The values listed below were obtained from neonates who passed our screening protocol. A full term gestation lasts about 40 weeks.

		Latency (ms)		
AGE (weeks from conception)		I	V	V-I
33-34	X	2.16	7.48	5.32
	S.D.	.32	.50	.33
	n	34	34	34
41-42	X	1.88	6.86	4.96
	S.D.	.23	.33	.30
	n	151	151	151
51-52	X	1.77	6.42	4.65
	S.D.	.17	.28	.28
	n	50	50	50

Stim: Rarefaction click
Rate: 11/s
Int: 70 dBnHL
Filters: 25 - 3000 Hz
Sum: 2000 sweeps

Increasing the rate of stimulus presentation will result in an increase in the latency of the ABR components. It has been suggested that some neurological abnormalities of the auditory system will be manifested at high stimulus presentation rates (13). Our data indicate that there is a developmental interaction with the rate effect. Increasing the click rate will cause a greater increase in the wave V latency as age decreases. Values that may be considered pathological in 3 month old babies could be within normal limits for pre-term neonates.

Increasing the intensity of the stimulus will result in a decrease in the latency of all ABR components.

b) Amplitude: The amplitude of waves I, III and V will increase significantly over the first few months of life. The amplitude of these waves also increase as a function of increasing stimulus intensity and decreasing presentation rate. Amplitude values vary considerably among subjects and are affected by technical factors such as electrode placement and impedance, consequently it is difficult to establish criteria for abnormality. The wave V/I amplitude ratio, introduced by Starr and Achor (14), has been used clinically with some success, (15,

16). According to our data, the ratio remains approximately constant throughout the time frame mentioned, however this may depend to some extent on the filter settings and the scoring criteria (17).

Because maturation does have a major effect on the ABR, one must interpret neonatal recordings using age appropriate norms. This involves consideration of the gestational age of the child as well as the chronological age. Responses should be interpreted according to the conceptional age of the patient (gestational age at birth plus chronological age).

Responses from a 2 week old baby are shown in figure 5. For a full term baby, these results would suggest that a mild hearing loss was present as well as a neurological abnormality (based on the long V-I latency interval). The neonate was 11 weeks premature at birth however, and both the latency and the threshold of the response are within acceptable limits for his conceptional age, which is about 31 weeks. The mild elevation of threshold is attributed to the small amplitude response typically seen at this age and is not interpreted as a hearing loss, although such babies do receive follow-up testing.

7. Neurological Status

BERA assesses both the peripheral sensitivity and the function of the auditory pathways of the brainstem. Neurological problems may affect both the latency and the amplitude of the ABR components and in some cases may compromise its utility as a measure of peripheral auditory sensitivity.

Neurological function of the auditory brainstem is often assessed by measuring the interpeak latency of the ABR components and comparing these values to normative data. It was originally thought that the ABR waves resulted from the sequential activation of the nuclei of the auditory system, with each wave corresponding to a particular nucleus. Although the auditory nerve is widely accepted as the generator of wave I, the origin of the later components is less certain. A particular peak may represent activity from a variety of nuclei or fibre tracts, and each

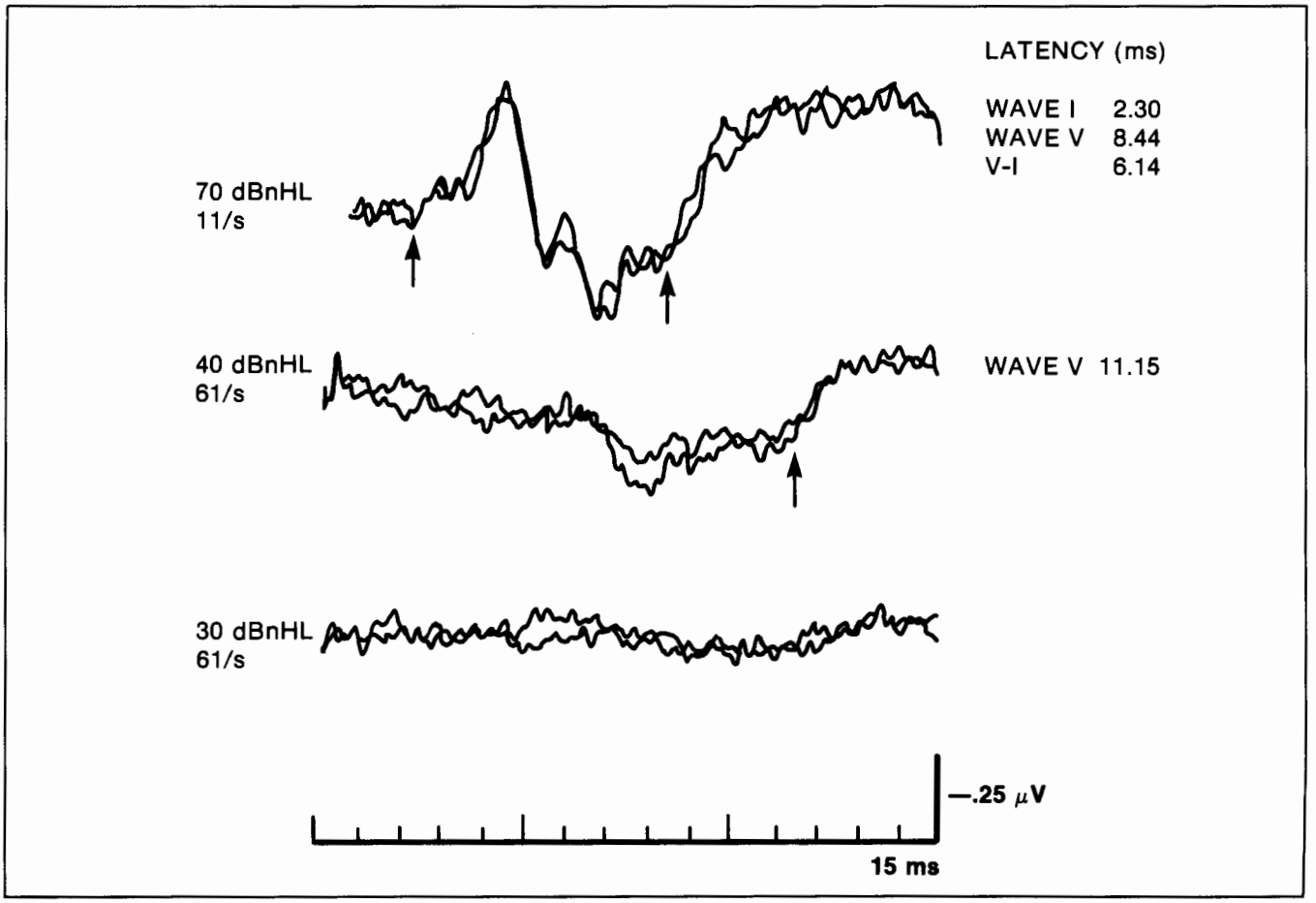

Figure 5: Responses from a premature neonate (about 31 weeks from conception at test time). Waves I and V are denoted by arrow in the 70 dBnHL tracings.

generator may contribute to more than one peak. There is evidence that wave II may also arise from the auditory nerve, and that the inferior colliculus is primarily responsible for the negativity following wave V (18, 19). Despite the uncertainty, the V-I latency is generally considered a measure of brainstem conduction time and is probably the most reliable measure of auditory brainstem function. Prolonged interpeak latencies are interpreted as indicating dysfunction.

Neurological problems can also affect the amplitude of the ABR components. The only amplitude measure which, to the authors' knowledge, has demonstrated clinical utility is the wave V/I ratio. An abnormally small or absent wave V in the presence of a normal wave I cannot be easily explained by a hearing loss, and is suggestive of neurological involvement.

Increased interpeak latency and a reduced V/I ratio has been associated with neonatal asphyxia. Hecox and Cone (15) tested 126 infants with acute asphyxia, with 15% showing prolonged interpeak latency and 17% an abnormal ratio. The latter measure was the best predictor of neurological function in term neonates and infants — 6 of the 21 babies with an abnormal ratio died before follow-up, with spastic quadriparesis present in all survivors.

Prolonged V-I latency intervals were also recorded in asphyxiated neonates by Kileny et al (20), with the III-I interval being the major contributor to the delay. Most of those who received follow-up testing 6-8 months later exhibited a normalization of the V-I interval.

Neurological problems that affect the latency of the ABR waves should not interfere with the assessment of peripheral sensitivity providing a sufficiently long averaging window is allowed. For neonates, responses should probably be averaged over a 15-20 ms interval.

Neurological problems which affect the amplitude of the ABR components can result in an elevated electrophysiological threshold, and therefore in a mistaken diagnosis of hearing loss. We have tested a series of neonates with hydrocephalus and have found that the majority of neonates with this disorder show responses which are significantly reduced in amplitude (16). The amplitude of wave V is reduced to a greater extent than that of wave I, thus the V:I amplitude ratio is also decreased. Wave V is the ABR component most resistant to decreases in intensity and is usually used to determine threshold. A small wave V amplitude may result in an elevated BERA threshold and may be interpreted as a hearing loss. The abnormal V:I ratio however, suggests that the elevated threshold reflects the neurological condition rather than a peripheral hearing loss. Many hydrocephalic neonates with such responses show normal peripheral sensitivity to click stimulation upon follow-up testing.

8. Incidence

As mentioned, pass for BERA screening in our program is defined as a response at 30 dBnHL in both ears with no evidence of neurological dsyfunction in the recordings. Most of our babies are tested while patients in the NICU, although some who cannot be tested then are assessed at 3 months of age.

Our results indicate that 27% of the babies tested while patients of the NICU fail initial BERA testing, with about half of these passing upon follow-up testing at 3 months of age. Other studies also report that many NICU babies who fail initial testing pass upon follow-up testing (5, 6). These neonates are sometimes referred to as false positives, however this is misleading because it implies that the threshold obtained initially does not reflect the auditory status at the time. It is more likely that the improvement noted upon retest is due to resolving conductive involvement.

As might be expected, the failure rate for babies initially tested as outpatients at 3 months of age is less than that of babies tested while patients of the NICU. Only 17% of the 3 month old babies tested as outpatients fail BERA screening.

It may therefore be more efficient to screen for hearing loss at 3 months of age rather than during the neonatal stage, when transient middle ear conditions may overburden follow-up resources. The chief advantage of NICU screening is the accessibility of the target population, which is an important consideration if parents are unwilling or unable to return.

Clearly, babies who fail BERA screening should not be considered hearing impaired until subsequent testing has confirmed the loss. The follow-up should include conventional audiometry if possible, impedance testing at 6 to 7 months of age, an E.N.T. examination and repeat BERA testing.

We attempt to obtain frequency specific information during our follow-up BERA if a hearing loss is still present. An elevated click threshold does imply a hearing loss (providing there are no technical or neurological problems) but doesn't establish the

audiometric contour. It has been our experience that the click threshold generally corresponds to the best threshold over a frequency range from 1000 to 4000 Hz.

Tonepips, stimuli with a more gradual onset and a less dispersed spectrum, have been used in an attempt to obtain discrete frequency thresholds. This technique is based on the questionable assumption that a restriction of the acoustic spectrum will always result in an ABR from a restricted frequency region of the cochlea. Ipsilateral masking techniques, where noise and stimulus are presented simultaneously, have also been used to obtain frequency specific data. Such techniques assume that the masking noise renders unrecordable the electrophysiological response from specific regions of the cochlea, thereby leaving the unmasked regions free to respond. A more detailed treatment of the frequency specific techniques devised for infant auditory assessment can be found elsewhere (21).

We know of no study which has systematically evaluated all possible frequency specific electrophysiological procedures in neonates or young infants. At present, our frequency specific testing during infancy is intended only to provide a global impression of the audiometric contour of the hearing loss, primarily to aid in hearing aid selection. A click threshold of 50 dBnHL in conjunction with a 4000 Hz tonepip threshold of 90 dBnHL would, for example, encourage us to select a hearing aid with high frequency emphasis capability.

Ultimately, the incidence of babies graduating from our NICU with bilateral sensorineural hearing losses requiring amplification is 2%. Another 5% have unilateral sensorineural or longstanding (3 to 6 months) conductive losses.

Summary and Recommendations

BERA is a reliable procedure for assessing the auditory capability of the neonate and young infant, however there are special factors to consider when interpreting responses from this age group.

We recommend that testing be conducted in a sound attenuated chamber whenever possible. This usually requires waiting at least until the baby is stable and as close to discharge as possible. Testing at 3 months of age will reduce the failure rate and is therefore recommended providing the baby can be retrieved following discharge. When testing, the earphone should be handheld and re-positioned whenever a no-response tracing is obtained or when inconsistencies appear in the recordings. Simultaneous multi-channel recordings may prove useful but only if developmental-montage interactions are known. All responses should be interpreted according to the conceptional age of the baby using normative data that has been developed by the clinic involved with the screening program. A diagnosis of sensorineural hearing loss should await follow-up testing, which should include repeat BERA, as many conventional tests as possible and otolaryngological examination. About 2% of the graduates from an NICU can be expected to have bilateral sensorineural hearing losses requiring amplification.

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