The Journal of Laryngology & Otology
February 2004, Vol. **118,** pp. 117–122

Bone conduction auditory brainstem responses in infants

P. E. Campbell, C. M. Harris, S. Hendricks*, T. Sirimanna*

Abstract

The contribution of air conduction auditory brainstem response (AC-ABR) testing in the paediatric population is widely accepted in clinical audiology. However, this does not allow for differentiation between conductive and sensorineural hearing loss. The purpose of this paper is to review the role of bone conduction auditory brainstem responses (BC-ABR). It is argued that despite such technical difficulties as a narrow dynamic range, masking dilemmas, stimulus artifact and low frequency underestimation of hearing loss, considerable evidence exists to suggest that BC-ABR testing provides an important contribution in the accurate assessment of hearing loss in infants. Modification of the BC-ABR protocol is discussed and the technical difficulties that may arise are addressed, permitting BC-ABR to be used as a tool in the differential diagnosis between conductive and sensorineural hearing. Two relevant case studies are presented to highlight the growing importance of appropriate management in early identification of hearing loss. It can be concluded that BC-ABR should be adopted as a routine clinical diagnostic tool.

Key words: Air Bone Conduction; Evoked Potentials, Auditory, Brain Stem; Child

Introduction

Detection of hearing impairment before the end of the critical language-learning period is considered crucial if a child is expected to acquire language.[1,2] For this reason, the newborn hearing screening programme (NHSP) has been implemented in 20 sites within the United Kingdom (UK), with more sites being included in the following years, with the expectation that every child born will be offered a hearing screen at birth by the year 2006.

Air conduction auditory brainstem response (AC-ABR) testing is currently the preferred technique alongside otoacoustic emission screening employed for such screening and diagnostic assessment within the UK. While the contribution of AC-ABR testing in the paediatric population is well recognized in clinical audiology,[3,4] it does not allow for accurate differentiation between conductive and sensorineural hearing loss.[5–8]

There are several reasons for accurately documenting the effect of conductive hearing loss on the auditory brainstem response (ABR). Conductive pathology can exist concurrently with sensory impairments producing an additional threshold elevation up to 40 dB in a child with significant sensorineural impairment that, if unrecognized, can hinder appropriate management.[9] Secondly, testing only with air-conducted stimuli can result in a large number of false positives of suspected sensorineural hearing loss due to transient middle-ear pathologies[10,11] compounding parental anxiety.[12] However, demonstration of good cochlear function using BC-ABR can be extremely reassuring to parents whose infant has failed a screen. Thirdly, unrecognized conductive pathology may complicate the detection of retrocochlear pathology. Finally, for infants with aural malformations or severe craniofacial defects, impedance measurements may be precluded; consequently, an alternative electrophysiological procedure to evaluate sensory reserve is necessary.[13,14]

ABR stimulation using a bone oscillator placed on the mastoid of the test ear has been recommended for clinical use with infants since the late 1970s.[6,15–17] However, it remains a technique that is vastly underutilized. The apparent reluctance of clinicians to adopt this approach to auditory assessment with ABR could be accounted for by the technical difficulties (outlined below) that are encountered while recording BC-ABRs. This paper highlights the usefulness of the BC-ABR. The two presented case studies illustrate the advantages of adopting both AC- and BC-ABR together allowing better identification of hearing loss in infants and neonates.

Technical difficulties

BC-ABR is still not routinely included in neonatal auditory assessment, possibly due to a number of identifiable technical problems: (1) narrow dynamic range; (2) masking problems; (3) stimulus artifact and (4) underestimation of low frequency hearing loss.

From the Plymouth Institute of Neuroscience, Plymouth University, Plymouth, and Great Ormond Street Hospital for Children*, London, UK.
Accepted for publication: 10 November 2003.

Narrow dynamic range

The maximim intensity level (approximately 55 dB nHL for bone-conduction stimulation) is a limiting factor. Intensity levels below 40–45 dB nHL for air-conduction stimuli generally shows only a distinct wave V component (not waves I and III). Therefore the minimal intensity level required to produce an air-conduction ABR (even the relatively large wave V), is 15–20 dB greater than the hearing threshold level (in the 1000–4000 Hz region).[18]

Difficulty generating a clear ABR waveform with normal adult subjects may have led some clinicians to assume that BC-ABR recordings would not be clinically feasible or useful for assessing sensorineural hearing sensitivity in infants and young children.[19] Normal hearing infants and young children, tend to have on average better sensorineural hearing sensitivity in the 1–4 kHz region (in comparison to adult standards, hence a greater dynamic range for bone conduction ABR stimuli).[20] Additionally, a distinct wave I component can often be consistently recorded with a bone conducted stimulus in these younger subjects.[11,21]

Stimulus artifact

Electromagnetic energy radiates from the bone vibrator that can cause a stimulus artifact in ABR recordings and can be intensified with mastoid placement if this is also used as a site for the inverting electrode, particularly if single polarity is used (rarefaction or condensation). Two simple technical modifications can reduce such stimulus artefact difficulties: an earlobe or ear canal electrode and the use of alternating polarity.

The transducer should be of sufficient quality to deliver a stimulus up to 60 dB nHL without distortion. A suitable bone conductor should be placed on the mastoid (avoiding the mastoid electrode) to ensure a higher stimulus level as there is also evidence of an inter-aural attenuation of approximately 20 dB in babies, which is taken advantage of by a mastoid location.[22]

Low frequency underestimation

Conductive hearing impairment is usually the greatest for frequencies in the region of 1 kHz and below, whereas the click-evoked ABR is dependent on stimulus energy mostly in the 1–4 kHz region. Such a discrepancy can lead to an underestimation of the predominantly lower frequency deficit, produced by some middle-ear pathologies such as otitis media or otosclerosis.[23] There is considerably less error in threshold estimation with other middle-ear pathologies, such as congenital aural atresia, which can cause a moderate-to-severe flat configuration hearing impairment throughtout the audiometric frequency region.

However, as with conventional behaviour audiometry, the addition of BC tonal stimuli to ABR threshold protocols provides clinicians with a more complete picture of the type (conductive, mixed, or sensorineural) and degree of hearing loss[24,25] Bone conduction tone-evoked ABR thresholds have been shown to demonstrate normal cochlear sensitivity in infants with a wide range of external and middle-ear pathologies including cleft palate, aural atresia and otitis media.[18,23,26]

Masking dilemma

Finally, the masking dilemma and the need for contralateral masking have been cited as a primary problem associated with bone conduction ABR measurement.[10] In moderate bilateral conductive hearing impairment, the intensity level of an air-conducted stimulus must sometimes be increased well above the 40–50 interaural attenuation level of the adult skull, leading to potential cross-over of the acoustic energy to the non-test ear. Yet the intensity level of the noise necessary to adequately mask the non-test ear, which has a mild-moderate conductive hearing impairment too, may also exceed the interaural attenuation of the head, and it may in fact cross back over through bone conduction to mask the test ear. The head offers little (10 dB or less) or no attenuation or bone-conduction stimulation with commercially available vibrators placed against the skin in adults.[18] Therefore, a stimulus presented with bone conduction to one mastoid may equally activate each cochlea.

Some authors have stated that the non-test ear must be routinely masked in ABR assessment by either air conduction or bone conduction, in order to rule out a contribution to the response from unintended stimulation of the better hearing non-test ear.[10] There is controversy about the intensity level at which an air conduction click stimulus will cross over to the non-test ear and evoke an ABR.[27] However, the presence or absence of the component, wave I, has been shown to provide reliable ear specific information.[28] A two-channel recording is preferable as it permits the recording of a contralateral response, to aid in the determination of which cochlea is being stimulated.[25]

Case reports

To demonstrate the usefulness of BC-ABR measurement in assessing abnormalities of the auditory pathway, two case studies are presented. The first case study highlights the problems of using AC-ABR as a hearing screening tool for infants in which there are a high percentage of failures associated with middle-ear problems at the time of ABR testing and the problems involved with the use of 226 Hz probe tone tympanometry in neonates and infants. The second case study can be considered representative of a group of patients identified with craniofacial abnormalities, in which impedance testing is difficult or impossible. Table I presents a list of salient patient characteristics.

Case 1

This male child was born by caesarean delivery to healthy non-consanguineous parents at 30 weeks gestation with mild physiological jaundice and a birth

https://doi.org/10.1258/002221504772784568 Published online by Cambridge University Press

TABLE I

SUMMARY OF THE CLINICAL CHARACTERISTICS OF THE TWO CASES

Case 1	
Neonatal problems	
	Premature
	Jaundice
	Low birth weight
Audiology	
	Abnormal ABR
Case 2	
Ophthalmology	
	Lt cryptophthalmos
	Rt lid coloboma
	Abnormal Rt fundus with hypoplastic optic disc
	VEPs – low amplitude responses on Rt
ENT and Audiology	
	Small ears with rudimentary canals
	Laryngeal web
	Tracheostomy
	ABR abnormal
Umbilical hernia	
Ambiguous genitalia	
	Small phallus/cliteromegaly
	Poorly formed labial swellings
	Perineal urethral opening
	No obvious vaginal opening
Imperforate anus	
	Small recto-perineal fistula requiring anoplatsy
Respiratory problems	
Cortisol insufficiency	
Cardiology	
	PDA
	Biventricular hypertrophy
	Hypertension
Renal	
	Absent Lt kidney
	Rt mega-ureter with reflux
Neurology	
	Abnormal cranial ultrasound
	Lt globe small on MRI
	Bilateral periventricular intracranial calcifications
	White matter abnormalities
	Cerebellar atrophy
G-positive septicaemia	

Rt = Right; Lt = left; MRI = Magnetic resonance imaging; VEP = visual evoked potentials; ABR = auditory brainstem response.

weight of 1.12 kg. There were no identifiable neurological problems or significant family history of hearing loss. Routine neonatal hearing assessment was performed at discharge (six weeks-corrected age). Otoacoustic emissions recorded from both ears were absent. AC-click stimuli presented by TDH-49 headphones at a rate of 31.1 clicks per second resulted in responses at intensities of 50 dB nHL bilaterally. Tympanograms measured with a 226 Hz probe tone were consistent with normal middle-ear function (Figure 1). Masked BC-ABR was present at 30 dB nHL on the right ear consistent with normal hearing.

The use of 226 Hz tympanometry in neonates and infants has been controversial due to the large number of false negative responses for middle-ear pathology.[29,30] This is thought to be due to the anatomical differences (smaller tympanic cavity and more fibrous tympanic membrane in neonates) that result in a mass-governed middle-ear transmission system that gradually changes to a more adult-like stiffness dominated system.[31]

ABR testing was repeated four weeks later, with the use of high probe tympanometry. The results showed a normal AC-ABR threshold at 30 dB nHL on the right but an elevated response on the left at 55 dB nHL. High probe tone tympanometry (1000 Hz) was normal for the right ear but showed low compliance for the left. Otoacoustic emissions were present for both ears but in the high frequency bands only. It was decided to monitor the hearing in this infant and review again at seven months with behavioural testing which later confirmed normal hearing thresholds.

Case 2

Fraser syndrome is a rare autosomal recessive disorder whose major manifestations are crypto-phthalmos, syndactyly and genital abnormalities. These patients also frequently have malformations of the ears, nose and/or larynx. This female child was born by caesarean delivery to healthy non-consanguineous parents at 41 weeks following an uneventful pregnancy. All antenatal scans were normal. Multiple congenital abnormalities were noted at birth including a left anophthalmos with a right malformed eyelid. She had small pinnae with rudimentary canals, an umbilical hernia with a wide base and low set umbilicus, ambiguous genitalia, and an anal atresia with a recto-perineal fistula. Soon after birth she required intubation because of respiratory distress (Table I). Audiological testing by ABR at age eight days showed no response to 102 dB nHL for either ear. Tympanometry could not be recorded.

Further audiological assessment was completed under general anaesthetic at age six weeks. AC-click stimuli presented by TDH-49 headphones at a rate of 31.1 clicks per second resulted in responses at intensities of 90 dB nHL for the right ear and 85 dB nHL for the left ear. Unmasked bone conduction responses were present at 40 dB nHL (Figure 2). These results were consistent with a severe mixed or conductive hearing loss, with unmasked bone conduction suggesting a mild sensorineural hearing loss in at least one ear.

It is important to note that when calibrating a bone conductor that the artificial mastoid mimics the adult skull, not the infant skull, so that clinicians may report extremely good BC thresholds in children, which could be due to calibration artefact. Correction values for infants are reported in Stevens *et al.*[14] Conversely, as illustrated in this case, a threshold of 40 dB nHL by BC-ABR may reflect a 20 dB HL threshold by behavioural audiometry when the child is old enough so that an apparent hearing loss may be associated with cochlear function at the lower limit of normal. Visual reinforcement audiometry (VRA) has enabled BC behavioural thresholds to be measured in children less than one year old so that each centre should undertake a comparative biological calibration.

The ABR (AC and BC) was repeated at age three months with similar results. She was fitted with a bone conductor hearing aid and her family report

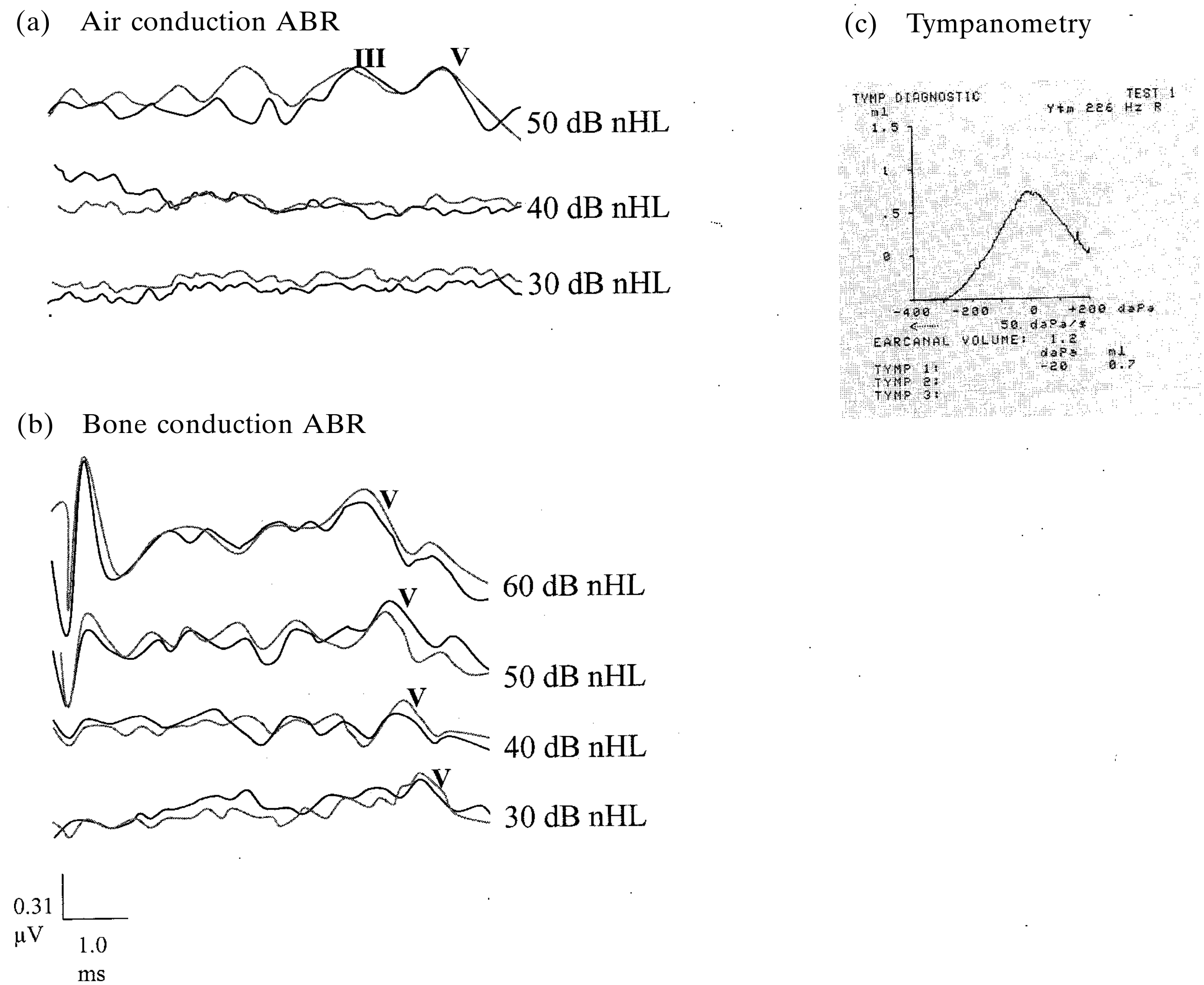

FIG. 1

(a) Auditory brainstem response (ABR) waveforms recorded in *Case 1*. The stimulus was an air conduction click presented at a rate of 31.1/sec, filter band-pass 150–1500 Hz. Each trace is the average of 1024 clicks, with two separate trials superimposed. Calibration marks are 0.31 μV and 1.0 msec. (b) Masked bone-conduction was normal in *Case 1* at age six weeks corrected. (c) Tympanograms indicated normal middle-ear function at 226 Hz for both ears (right ear shown). OAEs (not shown) were absent bilaterally.

that she is responding well to sound at minimal amplification levels. Behavioural assessments at age 12 months are shown in Figure 2.

- **This paper reviews the role of bone conduction brainstem responses in the diagnosis of childhood deafness**
- **The authors discuss modification of the protocol used to enable the technical difficulties encountered to be overcome**
- **Two case reports are included to illustrate the management of early investigation for hearing loss**

Discussion

When responses to air conduction (AC) clicks are present at normal levels, there is no need to obtain bone conduction (BC) responses. However, when the response is elevated, an ABR should be completed using BC clicks.[14] If a discrepancy does exist between air and bone conduction, this suggests the presence of a conductive or mixed loss in at least one ear.

In the past, BC-ABR was recorded essentially to assess cochlear reserve in subjects with congenital atresia or microtia of the external ear.[32] Later investigators suggested that the BC-ABR measurement should be included in the early identification of hearing loss in high risk infants who failed the AC-ABR procedure[33] enabling failures to be classified as being sensorineural, conductive or mixed. Yang and colleagues[16] have shown this when the absence of an ABR to a 30 dB nHL BC click is used as a criterion for a sensorineural deficit. Further they have shown that the inclusion of BC click testing of the AC click ABR screening failures enables them to classify 63 per cent of the initial failures as being purely conductive. However, most of the literature on BC-ABR is associated with normal hearing adults

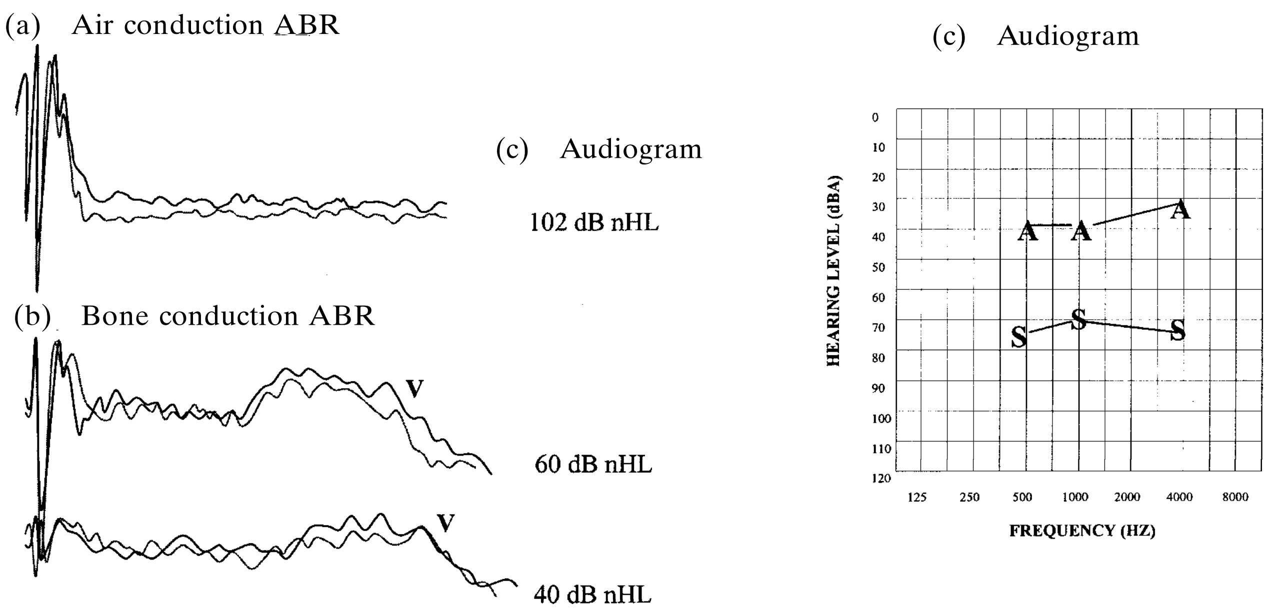

FIG. 2

(a) Air-conduction brainstem auditory evoked potentials of *Case 2* recorded at age eight days. (b) Unmasked BC-ABR thresholds were recorded down to 40 dB nHL in *Case 2* at age six weeks. Air-conduction responses were recorded at 85–90 dB nHL. Tympanometry and otoacoustic emissions were not able to be recorded. (c) Behavioural test results are shown following with a hearing aid fitting with a bone conduction hearing aid.
[A = aided hearing thresholds dB(A); S = unaided hearing levels in the soundfield dB(A)]

and infants, and only sporadic reports that discuss the BC-ABR in the presence of conductive HL in infants or adults are documented.[23,34]

Despite the aforementioned limitations, considerable evidence suggests that bone conduction ABR testing can make important contributions to the assessment of hearing in infants. Furthermore, modifications of test protocols can minimize some of these technical limitations allowing BC-ABR to be used as an additional tool in the differential diagnosis between conductive and sensorineural hearing.

References

1 Yoshinaga-Itano C. Benefits of early intervention for children with hearing loss. *Otolaryngol Clin North Am* 1999;**32**:1089–102
2 Moeller MP. Early intervention and language development in children who are deaf and hard of hearing. *Pediatrics* 2000;**106**:E43
3 Galambos R, Hicks GE, Wilson MJ. The auditory brain stem response reliably predicts hearing loss in graduates of a tertiary intensive care nursery. *Ear Hear* 1984;**5**:254–60
4 Jacobson JT, Morehouse CR. A comparison of auditory brain stem response and behavioral screening in high risk and normal newborn infants. *Ear Hear* 1984;**5**:247–53
5 Coats AC. Human auditory nerve action potentials and brian stem evoked responses. *Arch Otolaryngol* 1978;**104**:709–17
6 Jerger J, Maudlin L. Prediction of sensorineural hearing level from the brain stem evoked response. *Arch Otolaryngol* 1978;**104**:456–61
7 Sohmer H, Kinarti R, Gafni M. The latency of auditory nerve-brainstem responses in sensorineural hearing loss. *Arch Otorhinolaryngol* 1981;**230**:189–99
8 Johnson KC. Audiologic assessment of children with suspected hearing loss. *Otolaryngol Clin North Am* 2002;**35**:711–32
9 Ruben R, Fishman G. Otological care of the hearing impaired child. In: Mencher G, Gerber S. eds. *Early Management of Hearing Loss.* New York: Grune & Stratton, 1981;105–20
10 Weber B. Masking and bone conduction testing in brainstem response audiometry. *Semin Hear* 1983;**4**:343–52
11 Cone-Wesson B, Ramirez GM. Hearing sensitivity in newborns estimated from ABRs to bone conducted sounds. *J Am Acad Audiol* 1997;**8**:299–307
12 Watkin PM, Beckman A, Baldwin M. The views of parents of hearing impaired children on the need for neonatal hearing screening. *Br J Audiol* 1995;**29**:259–62
13 Ysunza A, Cone-Wesson B. Bone conduction masking for brainstem auditory evoked potentials (BAEP) in pediatric audiological evaluations. Validation of the test. *Int J Pediatr Otorhinolaryngol* 1987;**12**:291–302
14 Stevens J. State of the art neonatal hearing screening with auditory brainstem response. *Scand Audiol Suppl* 2001;**52**:10–12
15 Hooks R, Weber B. Auditory brainstem responses to bone conduction stimuli in premature neonates: A feasibility study. *Ear Hear* 1994;**5**:42–6
16 Yang EY, Stuart A, Mencher GT, Mencher LS, Vincer MJ. Auditory brainstem responses to air- and bone-conducted clicks in the audiological assessment of at-risk infants. *Ear Hear* 1993;**14**:175–82
17 Yang EY, Stuart A, Stenstrom R, Green WB. Test-retest variability of the auditory brainstem response to bone-conducted clicks in newborn infants. *Audiology* 1993;**32**:89–94
18 Finitzo-Hieber T, Friel-Patti S. Conductive hearing loss and the ABR. In: Jacobson JT, ed. *The Auditory Brainstem Response.* San Diego: College Hill Press California; 1985;113–31
19 Kavanaugh K, Beardsley J. Brainstem auditory evoked response III. Clinical uses of bone conduction in the evaluation of otologic disease. *Ann Otol Rhino Laryngol* 1979;**88**:22
20 Stuart A, Yang EY, Stenstrom R, Reindorp AG. Auditory brainstem response thresholds to air and bone conducted clicks in neonates and adults. *Am J Otol* 1993;**14**:176–82

https://doi.org/10.1258/002221504772784568 Published online by Cambridge University Press

21 Gorga MP, Kaminski JR, Beauchaine KL, Bergman BM. A comparison of auditory brainstem response thresholds and latencies elicited by air- and bone-conducted stimuli. *Ear Hear* 1993;**14**:85–94

22 Hall III JW. *Handbook of Auditory Evoked Responses.* Needham, MA; Allyn Bacon, 1992

23 Stapells DR, Ruben RJ. Auditory brainstem responses to bone-conducted tones in infants. *Ann Otol Rhinol Laryngol* 1989;**98**:941–9

24 Stapells DR, Oates P. Estimation of the pure tone audiogram by the auditory brainstem response: a review. *Audiol Neuro-Otol* 1997;**2**:257–80

25 Stevens J, Baldwin M, Elliott C, Lightfoot G, Mason S, Parker D, *et al.* Bone conduction auditory brainstem response testing in babies. *Neonatal Hearing Screening and Assessment. Revised UK Protocols for Screening Well and NICU Babies in Hospital.* http://www.unhs.org.uk

26 Picton TW, Durieux-Smith A, Moran LM. Recording auditory brainstem responses from infants. *Int J Pediatr Otorhinolaryngol* 1994;**28**:93–110

27 Finitzo-Hieber T, Hecox K, Cone B. Brain stem auditory evoked potentials in patients with congenital atresia. *Laryngoscope* 1979;**89**:1151–8

28 Tucci DL, Ruth RA, Lambert PR. Use of the bone conduction ABR wave I response in determination of cochlear reserve. *Am J Otol* 1990;**11**:119–24

29 Paradise JL, Smith CG, Bluestone CD. Tympanometric detection of middle ear effusion in infants and children. *Pediatrics* 1976;**58**:198–210

30 Sutton G, Baldwin M, Brooks D, Gravel J, Thornton R. Tympanometry in neonates and infants under 4 months: a recommended test protocol. *Neonatal Hearing Screening and Assessment. Revised UK Protocols for Screening Well and NICU Babies in Hospital.* http://www.unhs.org.uk

31 Sanders JC, Kaltenbach JA, Relkin EM. The anatomical and functional development of the outer and middle ear. In: Romand R, ed. *Development of Auditory and Vestibular Systems.* New York: Academic Press, 1983;3–25

32 Muchnik C, Neeman RK, Hildesheimer M. Auditory brainstem response to bone-conducted clicks in adults and infants with normal hearing and conductive hearing loss. *Scand Audiol* 1995;**24**:185–91

33 Stuart A, Yang EY, Stenstrom R. Effect of temporal area bone vibrator placement on auditory brainstem response in newborn infants. *Ear Hear* 1990;**11**(5):363–9

34 Mauldin L, Jerger J. Auditory brainstem evoked responses to bone-conducted signals. *Arch Otolaryngol* 1979;**105**:656–61

Address for correspondence:
Pauline Campbell,
Plymouth Institute of Neuroscience,
Plymouth University,
Plymouth PL4 8AA, UK

Ms P. Campbell takes responsibility for the integrity of the content of the paper.
Competing interests: None declared