Audiology *20:* 41–52 (1981)

Audiometric Study of the Neonate: Impedance Audiometry. Behavioural Responses and Brain Stem Audiometry[1]

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Key Words. Brain stem audiometry · Infant auditory evaluation

Abstract. The following clinical measurements of acoustic impedance were carried out successfully on 25 neonates. Average compliance was 0.48 cm^3, with a range from 0.28 to 0.81 cm^3. Tympanometry showed a high percentage of maximum compliance curves with positive pressures. In a notably high percentage, the stapedial reflex was combined with generalized body movements and was therefore considered a behavioural response. Behavioural responses of the child were also observed separately. Ipsilateral stimulation did not evoke a measurable stapedius reflex in any of the cases, but with contralateral stimulation some babies did show this reflex. The most intense behavioural responses occurred when white noise was used as the stimulus.

Of the 25 children studied with impedance audiometry, 10 were evaluated audiologically by brain stem electric potentials. The latency of wave V was within the normal range in all the cases. Electric response audiometry could be a promising method for audiological evaluation of the neonate.

Introduction

Impedance has shown itself to be an excellent diagnostic tool in audiometry. Considerable work dealing with impedance audiometric determination has been done in normal children and adults. *Brooks* [1971] studied children between 4 and 11 years of age; *Jerger* [1970] studied children over 2 years of age; *Lidén et al.* [1970] studied adults; *Robertson et al.* [1968]

[1] Paper presented at the 14th International Congress of Audiology in Acapulco, Mexico, on November 13, 1978.

[2] The authors wish to thank Prof. *Robert W. Keith* for his valuable comments and suggestions in reviewing this article.

evaluated the audiometric impedance in children between 12 and 36 months. Several studies related to audiometric impedance in neonates have been carried out more recently by *Keith* [1973, 1975] and *Keith and Bench* [1978]. Their findings are important reference points for this work.

The latency of one of the principal components of the brain stem electric response, wave V, is highly valuable as an objective indicator of peripheral hearing in children and adults. *Hecox and Galambos* [1974] established that brain stem electric responses are present at birth and *Schulman-Galambos and Galambos* [1975] established their existence in the premature infant. *Salamy et al.* [1975] and *Salamy and McKean* [1976] studied the brain stem electric responses of newborns, young infants and adults.

In this article, we are concerned with the correlation between ipsilateral and contralateral acoustic reflexes, and the brain stem electric responses in the newborn child.

Material and Methods

Impedance and Behavioural Audiometry

26 ears from 25 neonates were studied at the Maternity Hospital Santa Cristina, Madrid; the subjects, ages ranged from 24 to 144 h. The infants were selected according to the following criteria: (1) absence of a history of hearing loss in the parents; (2) full-term pregnancy; (3) pregnancy and birth without complications; (4) Apgar score over 8 at 5 min; (5) more than 2 600 g birth weight, and (6) good health and normal otoscopy at the time of testing.

All the neonates had a previous otoscopic examination and the study was carried out only when the tympanic membrane was clearly visible. Some ears presented meconium in the external auditory canal which was left *in situ*, impedance was not performed in these cases. The average weight of the 25 babies (11 boys and 14 girls) was about 3 000 g.

A Grason-Stadler 1721 otoadmittancemeter, with a 220-Hz probe tone frequency, was used. This instrument has an audiometric section (maximum output 110 dB HL) for examining the stapedius reflex contralaterally by means of an acoustic stimulus through a TDH-39 earphone. A 1722 Grason-Stadler otoadmittancemeter (with a maximum output of 95 dB HL) was used for ipsilateral stimulation. Small probes were used, and there was no need for special additions to procede with these measurements. All measurements were taken at the Maternity Hospital, in a quiet room, immediately after the neonate had been fed.

The neonate was laid in a crib with his ear on the earphone. The hermetic seal of the external auditory canal was verified and determinations were made of: (1) compliance, (2) tympanometry and (3) the stapedius reflex, in every case. The tympanogram was performed by recording the compliance at pressure intervals of 50 mm H_2O, between +200 and –200 mm. At this time, the point of maximum compliance was noted.

The stapedius reflex was obtained in the following way: one person determined the

activity level of the neonate before receiving the acoustic stimulus. Any movement or change in behaviour after the stimulus was carefully observed. The pre-stimulus status was established following *Bench's* [1976] criteria. Status I, no activity, regular respiration, no limb or facial movements; status II, associated with slight activity, somewhat irregular respiration and movement of fingers but not limbs, occasional facial movements; status III, movement of one or more limbs including movement of the head and some facial movements. Observations were always made when the new-born was in status I of pre-stimulation. One person devoted himself exclusively to the interpretation of behavioural responses in relation to acoustic stimuli and rated them according to the following grading: 0 no response; + slight movement of head, ocular, or a limb; + + movement of various limbs; + + + generalized body movements. Behavioural responses were studied as the stapedius reflexes were elicited. The following guidelines were followed: no response, stapedius reflex present, or atypical stapedius reflex. When the stapedius reflex occurred simulataneously with generalized body movements this was interpreted as a behavioural response, not as a stapedius reflex.

The stimulation frequencies used were 1 kHz with white noise, presented at 5-dB intervals between 95 and 110 dB HL. Stimulation was repeated a maximum of 5 times. The time interval between stimuli was several seconds and the neonate was always in status I of pre-stimulation.

Electric Response Audiometry

Evaluation by means of audiometry through electrical responses was done separately at the Clinica del Trabajo in Madrid. 10 ears of the 26 studied by impedance audiometry were examined by means of brain stem potentials. Recordings of electric responses were always carried out when the babies were sleeping. The same ear was stimulated as that studied by impedance audiometry. 3 of the ears elicited an acoustical reflex with white noise or with a 1-kHz tone at one or more intensities between 95 and 110 dB. No stapedius reflex could be elicited in 7 ears, either with white noise or with pure tones.

The exploration was done following the technique described by *Barajas and Olaizola* [1978] using a Madsen ERA 74 system composed of an ERA audiometer, a computer pre-amplifier with a filter between 0.15 and 4.5 kHz, oscilloscope and monitor. The computer part included a buffer memory section for the rejection of artifacts.

The acoustic stimuli were single cycles gated abruptly, in constant phase, from a 1 000-Hz (electric) tone and applied unfiltered directly through a TDH-39 earphone. The resulting acoustic click had a maximum acoustic energy near 1 kHz. The repetition rate was 20 stimuli per second. Sweep time was fixed at 10 ms. A 1.5-ms delay was set between the stimulus and the computer to reduce artefacts in the first part of the response. The electrodes used were attached with a chlorided silver disc. Each was used only once. One input electode was placed on the vertex, the other input electrode on the homolateral mastoid and the ground electrode on the contralateral mastoid. Each plotting was the sum of 2 000 responses accepted by the computer. A minimum of two and a maximum of four plottings were recorded for each intensity before attributing a response to the auditory pathway. The intensity of the signals was calibrated in decibels of hearing level (dB nHL) referred to the mean threshold hearing level of 10 normally hearing adults tested under noise-free conditions. Stimuli were presented initially at 60 dB nHL and this was gradually reduced until the hearing threshold was found. The time required to test each baby was about 1½ h, although this depended on how well the baby slept.

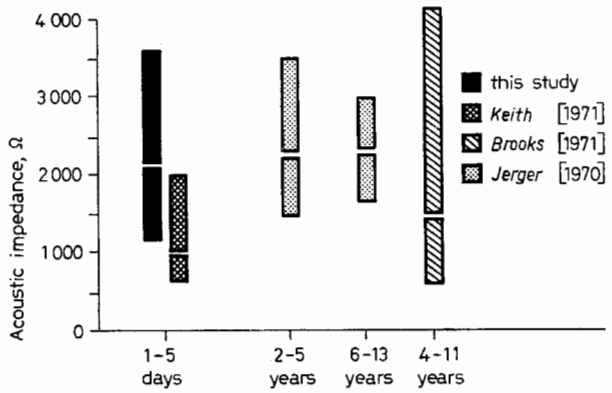


Fig. 1. Comparison of impedance between different studies with respect to age. The breaks in the vertical bars indicate the average values.

Results and Comparisons

Impedance Audiometry

Testing was impeded in only 7 cases due to lack of cooperation by the newborn baby. Cooperation was more frequent if the test followed a feeding. The majority of the babies slept during the impedance audiometric measurement.

Compliance-Impedance

Compliance measurements using the Grason-Stadler 1721 otoadmittancemeter indicated an average of 0.48 cm^3. The values ranged from 0.28 to 0.81 cm^3. In impedance terms, this is equivalent to an average value of 2083 Ω, and ranges between 1234 and 3571 Ω. Figure 1 compared our results with those of other studies on older children: *Brooks* [1971] reported average impedance audiometric values of 1 500 Ω in children from 4 to 11 years and *Jerger et al.* [1972] shows average values of 2 050 Ω in children from 2 to 5 years. Of greater interest are differences between our results and those of *Keith* [1973] since both studies were carried out on new-borns. His results were on the order of 935 Ω, that is, much lower than the 2 083 Ω established as our average impedance. Figure 2 compares the results of these two studies showing a greater frequency of maximum compliance between 0.5 and 1 cm^3 in our study, while *Keith's* results ranged between 1.10

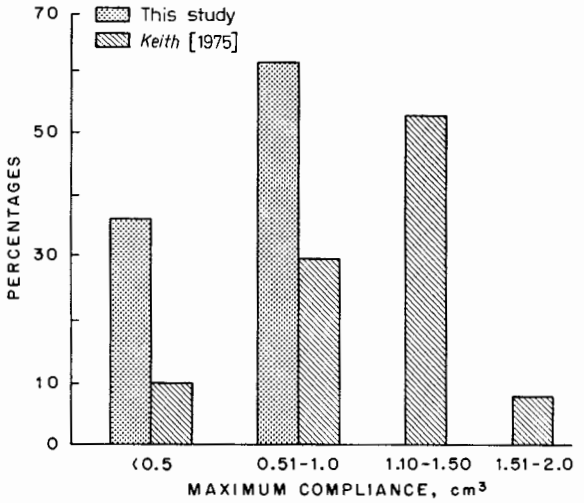


Fig. 2. Comparison of maximum compliance between our results and those obtained by *Keith* [1975].

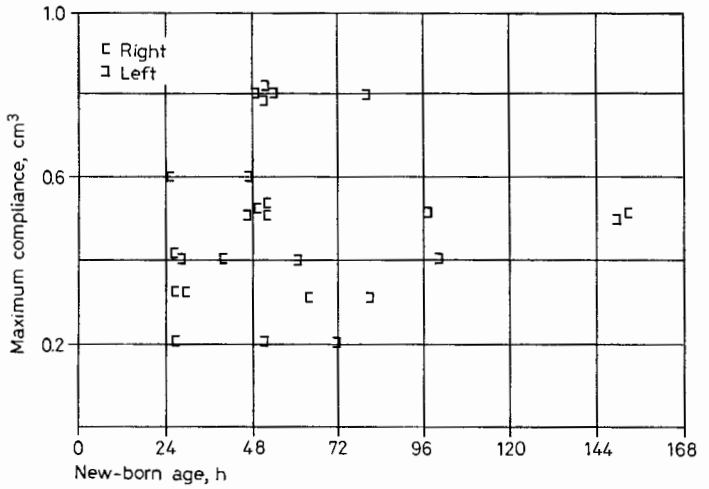


Fig. 3. Correlation between maximum compliance and age of the new-born child.

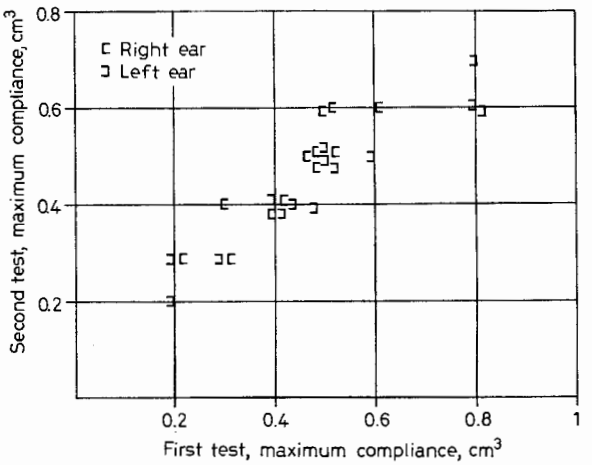


Fig. 4. Correlation of compliance between a first and a second measurement.

and 1.50 cm^3. Figure 3 shows the maximum compliance values of the right and left ear plotted against age expressed in hours. The scattered nature of these measurements leads to the conclusion that a calculation of the correlation coefficient would not be applicable, as it appears that there is no correlation between the compliance and the age of new-born babies.

Having assessed the compliance in a first measurement, an attempt was made to establish the accuracy of this measurement by repeating the test (fig. 4). The Pearson product-moment correlation coefficients computed for all the right and left ear data points shown in figure 4 are 0.91 and 0.95, respectively. These correlation coefficients indicate that the retest measurements for the experiment are highly reliable.

Tympanometry: Pressure-Compliance, Function

The results of this study were compared to those reported by *Keith* in his tympanometric study in neonatal life. The most significant finding was that 12 ears showed tympanograms with maximum compliance shifted towards positive pressures (+ 100 mm H_2O). This displacement of the maximum compliance towards positive pressures is the most important difference between our results and those obtained by *Keith*. On the other hand, 11

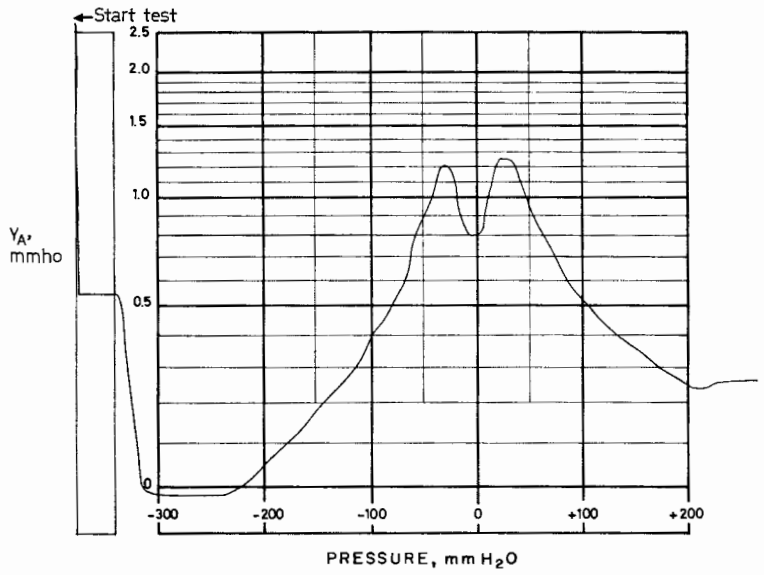


Fig. 5. M tympanogram found in 5 cases.

ears presented maximum compliance at an atmospheric pressure of 0 mm H_2O. To these data we should add 2 tympanograms with maximum compliance at +50 mm H_2O and 1 with maximum compliance at –100 mm H_2O. The most pronounced maximum compliances (0.8 cm^3) systematically occurred at atmospheric pressure. The average middle ear pressure was established at 51.7 mm H_2O. The M tympanogram described by *Keith* was recorded by us in 5 cases (fig. 5).

Stapedius Reflex and Behavioural Responses

Table I establishes the number of 0, +, ++ and +++ states with a 1 000-Hz tone and white noise at 95–110 dB HL intensities. There is no apparent difference in response relative to intensity and the results do not show reduced but rather increased behavioural response to successive stimulations. White noise evoked better behavioural responses although we observed a certain tendency towards habituation as the number of stimulations was increased. With white noise and 1 kHz as stimuli, the behavioural responses were evoked at the + level in 21 and 45% of the stimulations, respectively. With white noise the +++ type of responses was detected in 27% of the stimulations while no response at that level was detected at 1 kHz.

Table I. Distribution of behavioural responses with 1-kHz pure tones and white noise as stimuli

Stimuli	Responses, %			
	0	+	++	+++
White noise	14	21	38	27
1-kHz tone	23	45	32	

0 = No response; + = mild response; ++ = movements of several limbs; +++ = generalized body movement.

Table II. Percentage of babies showing stapedius reflex, behavioural response with stapedius reflex obscured or absent, or no response, with white noise and 1-kHz pure tones as stimuli

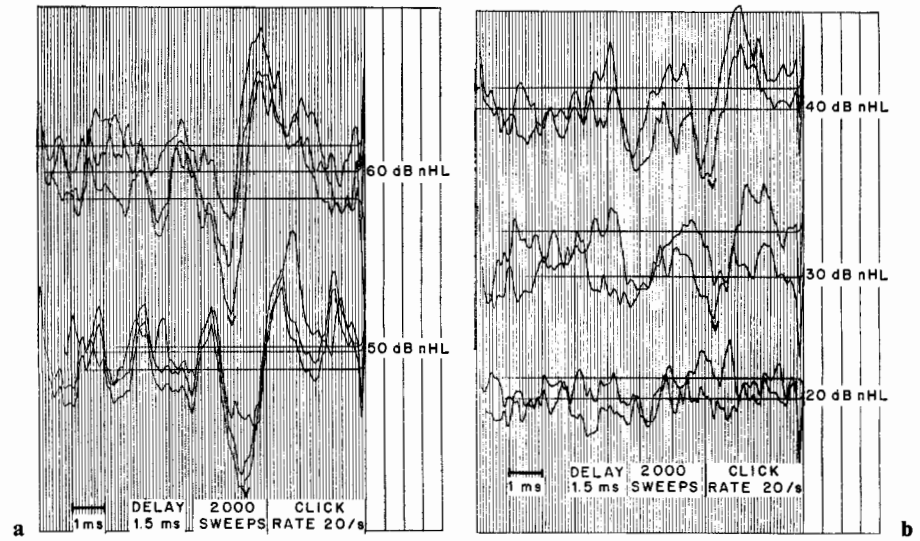
Stimuli	Stapedius reflex alone, %	Behavioural response (stapedius reflex possibly obscured), %	No response %
White noise	7.7	87.9	4.4
1-kHz tone	4.4	75	20.6

The results of stapedius reflex testing by contralateral stimulation and simultaneous evaluation of behaviour responses are shown in table II. Again stimuli white noise evoked better stapedius reflexes and behavioural responses.

Ipsilateral stimulation at 95 dB HL did not elicit the stapedius reflex in any of the cases.

Audiometry through Evoked Brain Stem Potentials

This study was done following the same principles as our previous paper [*Barajas and Olaizola,* 1978]: wave V latency was selected as the preferred parameter. 10 ears were studied in which only 3 (cases 8, 14 and 15) yielded a stapedius reflex at 110 dB both with white noise and 1 kHz tone. The other ears studied yielded no reflex. Behavioural reactions, although of different



a b

Fig. 6. Typical response with brain stem audiometry (2–10 ms) at 60 and 50 dB nHL (a) and at 40, 30 and 20 dB nHL intensities (b). Wave V is discernible down to 30 dB nHL, which is consistent with an intact peripheral auditory system.

types, were evident in all the cases. Whether or not the reflex was present, we were able to obtain wave V in all cases down to 30 dB nHL. The latency of wave V was 8.8 ms at 30 dB nHL, 8.4 ms at 40 dB nHL, 7.9 ms at 50 dB nHL and 7.5 ms at 60 dB nHL.

A typical example of the brain stem response in neonatal life is shown in figure 6a, b.

Discussion

The results of this study confirm *Keith's* [1973] report, that it is possible to perform impedance audiometric studies on the new-born baby. It should, however, be emphasized that it is important that the child be as quiet as possible and it is therefore advisable to test after feeding. We found markedly lower compliances than *Keith* [1973]. Our results are closer to those obtained in older subjects by *Jerger et al.* [1972] and *Brooks* [1971].

An interesting finding is the large number of tympanograms in our study with maximum compliance displaced to positive pressures (+100 mm

H_2O). This has been associated with the initial stage of acute otitis, although similar results have also been reported in normal ears [*Paradise et al.,* 1976]. This has been confirmed in our work, since we found that 12 of the 26 normal ears studied showed displacement of maximum compliance to positive pressures. The elicitation of M tympanograms in our neonates does not support *Holt and McIntosh's* [1961] view that the middle ear of the neonate is full of fluid. A similar conclusion was reached by *Keith* [1973, 1975]. The M tympanograms found in the new-borns with a probe frequency of 220 Hz may indicate changes in the middle ear resonant frequency.

The behavioural responses (not coinciding with the stapedius reflex study) did not show marked adaptation, although we observed a tendency towards adaptation with white noise. Behavioural responses often interfered with observation of the stapedius reflex reducing the percentage of recorded reflex manifestations. Our 7.6% with white noise and 4.1% with 1 kHz, are lower than those of *Keith* [1973], who recorded 30%. However, in a recent study, *Keith and Bench* [1978] obtained less than 5% positive response for the stapedius reflex using as stimuil a 1 000-Hz tone, a 2 600-Hz low-pass noise and a broad-band noise presented at levels between 95 and 110 dB HL. The reason for the low detectability of the stapedius reflex in the newborn is not clear. It has been established by the development of the auditory pathway that the changes occurring in the human ear after birth take place only in the external ear, antral and mastoid ear cells. The inner ear structures have reached full adult proportions by the 23rd week of fetal life [*Anson and Donaldson,* 1973; *Paparella and Shumrick,* 1973]. These changes in the new-born may interfere with the measurement of the reflex threshold. However, we cannot conclude from this study that obliteration of the response is due to these changes exclusively. An important possible explanation for the low incidence of the reflex in neonates has recently been presented by *Weatherby and Bennett* [1979]. These authors attribute the high resistance and low reactance relationship in the acoustic impedance component to the difficulty of obtaining reflexes at 220-Hz probe frequency. Furthermore *Weatherby and Bennett* established that the acoustic reflex was present 100% of the times, using a 800-Hz probe frequency.

Brain stem audiometry was especially effective in demonstrating an intact hearing route, and wave V could be identified with intensities as low as 30 dB nHL. Its latencies corresponded well with those reported by *Hecox and Galambos* [1974] in the new-born, although our stimuli were not identical to theirs. No correlation could be established between the presence of the stapedius reflex and wave V latency.

From this study the following conclusions can be drawn:

(1) Stapedial reflex testing at a 220-Hz probe frequency is not a good method for screening hearing in neonatal life.

(2) The function of the middle ear can be evaluated by impedance in the new-born child.

(3) Electric response audiometry, specifically for responses that take place between 2 and 10 ms (brain stem potentials), is a promising method for hearing evaluation from the very first moment of life.

Résumé

Chez 25 nouveau-nés (26 oreilles) âgés de 24 à 144 h et sélectionnés de manière à constituer un groupe homogène «normal», nous avons procédé aux examens suivants avec un appareillage Grason-Stadler 1721: d'une part, un tympanogramme et d'autre part, une audiométrie par comportement réflexe en même temps qu'un test du réflexe stapédien. Par ailleurs, pour quelques-uns de ces nouveau-nés (10 oreilles), nous avons effectué par la suite une audiométrie des potentiels évoqués du tronc cérébral (BER) avec un équipement Madsen ERA 74. La moyenne des compliances enregistrées a été de 0,48 cm^3. Le tympanogramme a fait apparaître: 1) un pic en pression positive pour 12 oreilles et en pression nulle pour 11 oreilles; (2) une forme en M pour 5 oreilles. Le réflexe contro-latéral fut obtenu dans 7,7% des cas (bruit blanc) et dans 4,4% des cas (1 kHz). Le réflexe ipsilatéral ne fut jamais obtenu. Une réponse de comportement réflexe fut observée dans 87,9% des cas (bruit blanc) et dans 75% des cas (1 kHz); dans 4,4% des cas (bruit blanc) et dans 20,6% des cas (1 kHz), aucune réponse ne put être notée. L'onde V fut enregistrée jusqu'à 30 dB nHL pour chacune des 10 oreilles examinées en audiométrie BER alors que pour 7 d'entre elles le réflexe stapédien n'avait pu être obtenu.

En conclusion, nous estimons que la recherche du réflexe stapédien ne permet pas d'évaluer l'audition du nouveau-né de manière satisfaisante; elle permet toutefois d'apprécier correctement la fonction de l'oreille moyenne. Comme beaucoup d'autres ont déjà pu le constater, l'audiométrie BER est un examen nettement plus sûr.

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