International Journal of Pediatric Otorhinolaryngology 75 (2011) 1502–1509

Contents lists available at SciVerse ScienceDirect

International Journal of Pediatric Otorhinolaryngology

journal homepage: www.elsevier.com/locate/ijporl

Is behavioral audiometry achievable in infants younger than 6 months of age?

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ARTICLE INFO

Article history:
Received 23 May 2011
Received in revised form 16 August 2011
Accepted 19 August 2011
Available online 19 September 2011

Keywords:
Auditory brainstem responses
Behavioral audiometry
Psychomotor development
Bone and air-conducted sounds
Cognitive status
Reinforcement

ABSTRACT

Background and goal: When carried out in addition to objective tests, behavioral audiometry performed in children with the so-called "Delaroche protocol" [IJORL 68 (2004) 1233-1243] enables to determine hearing thresholds by air and bone conduction over the whole auditory frequency range. In the present report, seventy-three hearing-impaired infants with different levels of motor and cognitive development were tested behaviorally before 6 months of age. Reliability of these early determined behavioral thresholds was then after analyzed using: (a) cross-sectional study, and (b) longitudinal study.
Methods: Cross-sectional study compared click-evoked ABR thresholds in the better ear with binaural high-frequency hearing thresholds. In longitudinal study, early measured binaural hearing thresholds from 500 through 4000 Hz were reassessed at 18 months.
Results: In 13% of babies behavioral testing was not fully completed by 6 months of age. Nevertheless, both cross-sectional and longitudinal studies yielded intraclass correlation coefficients above 0.80, suggesting that behavioral testing is applicable to this very young population.
Conclusions: Assessment of hearing after newborn screening should not be restricted to objective tests before 5 months. It should also include bone- and air-conduction behavioral tests adjusted to developmental stage and performed in presence of parents.

1. Introduction

Much evidence suggests that, early in life, auditory input and communication are essential for the normal development of language, cognition, and behavior [1]. Newborn hearing screening is aimed at identifying hearing-impaired children as early as possible. Powerfulness of objective tests in measuring auditory thresholds over the first months is well documented. Otoacoustic emissions (OAE) and auditory brainstem response (ABR) tests are extensively used at this age.

When performed in addition to these objective tests, behavioral audiometry (BA) enables to determine hearing thresholds by air and bone conduction over the whole auditory frequency range [2]. This information is essential to know as far as speech development is concerned. Second, by assessing "the response of the entire auditory system from the outer ear through the cortex" [3,4] BA enables to analyze how babies react to acoustic stimuli and, consequently, provides further information on their cognitive and relational aptitudes [5]. In the follow-up of infants who failed newborn screening test, a behavioral measure of hearing [6] should be the gold standard against which results of objective diagnostic tests are compared.

Even though above-mentioned capacities of BA are recognized from 5 to 6 months onwards [4,7–10], this method of exploring hearing is often considered to be unfeasible or unreliable below this age [11–13].

In contradiction to these restrictive assertions, researchers have evidenced astonishing precocity of babies' sensory and mnemonic capacities, starting already in utero [14]. Given these early skills, audiometric assessment procedure known as "*the Delaroche Protocol*" [2] has been adapted to infants of less than 6 months. This protocol differs from the Observer-based Psychoacoustic Procedure (OPP) described by Olsho et al. [15]. It also varies from the classic procedures of Behavioral Observation Audiometry (BOA) wherein robust unilateral head-turns towards lateral loudspeakers are reinforced by attractive visual stimuli in infants as young as 5 months [4,16–18]. Characteristically, in the present study, modalities of observation, stimulation and reinforcement are adapted to individual stage of development. Babies are turned into "active partners" with customized reinforcement.

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doi:10.1016/j.ijporl.2011.08.016

Behavioral assessment of pure-tone sensitivity in normal-hearing infants aroused interest in providing reference values to findings in hearing-impaired babies. According to Olsho et al. [19] thresholds of 3 month-old infants are 15–30 dB higher than those of adults and thresholds of 6–12 month-old infants are 10–15 dB higher than those of adults, with the difference being greater at lower frequencies. In a follow-up of babies screened at birth, Widen et al. [6] reported that normal-hearing infants tested between 8 and 12 months corrected age demonstrate "minimum response level" of 20 dB HL at 1, 2 and 4 kHz, this value of 20 dB HL being thus a plausible fence to characterize normal hearing sensitivity by 12 months.

The study here described was undertaken to determine whether subjective measurement of hearing is achievable below 6 months of age. We report on audiometric threshold findings in babies with sensorineural hearing loss (SNHL) whose age was less than 6 months at first audiometric tests, henceforth called early tests. We also analyze reliability of early test results by comparing them with more widely accepted test results around these ages: (a) ABR thresholds in the framework of a cross-sectional study performed by 6 months of age, and (b) hearing thresholds measured behaviorally at 18 months along a longitudinal assessment.

2. Methods

2.1. Procedures for auditory measurements

2.1.1. ABR tests

Electrophysiological investigations were approved by Ethics Committee of our University and tests were conducted after parents gave informed consent. Babies were tested while asleep (natural sleep in most cases). Using a vertex-ipsilateral mastoid montage, ABR signals were amplified, band-filtered (100 Hz–3 kHz) and averaged 2000 times. Alternated broad-band clicks (100 μs of duration) were delivered through a TDH39 headphone, at 21/s, from 80 to 90 dBnHL to threshold at 10 dB steps in a descending order. Contralateral ear was masked systematically. For the precise determination of ear-separated auditory thresholds, increments of 5 dB were used when signals were not any more identifiable and recordings were repeated three times. When no replicable response was observed at 90 dBnHL, two series of measurement were undertaken at 100 dBnHL (maximum output of equipment). Early audiometric data to which ABR thresholds were confronted in the cross-sectional study will be described in a section apart (see Section 2 for assessing validity).

2.1.2. Other objective tests

Tympanometry was performed systematically at the end of each behavioral test. A single probe tone of 226 Hz was used, even though higher frequencies (≥660 Hz) are advocated in the first months [20]. OAE test results were not taken into account as not performed systematically. The same reasoning was applied to auditory steady-state response (ASSR) tests.

2.1.3. Behavioral audiometry (BA): the "Delaroche protocol"

Adaptation of the protocol to the specific age category (less than 6 months) is described in the following sections addressing installation of the baby, nature of observable reactions, and stimulation strategy, successively (see also Appendix derived from Brunet-Lézine's scale) [21]. For a behavioral threshold to be considered as valid at a given frequency–intensity sound condition, the rule here is that two definite responses need to be substantiated.

2.1.3.1. Installation of the baby assessed behaviorally. The technical installation promoted in the protocol enables recourse to a single examiner, located in front of the audiometer and in the lateral field

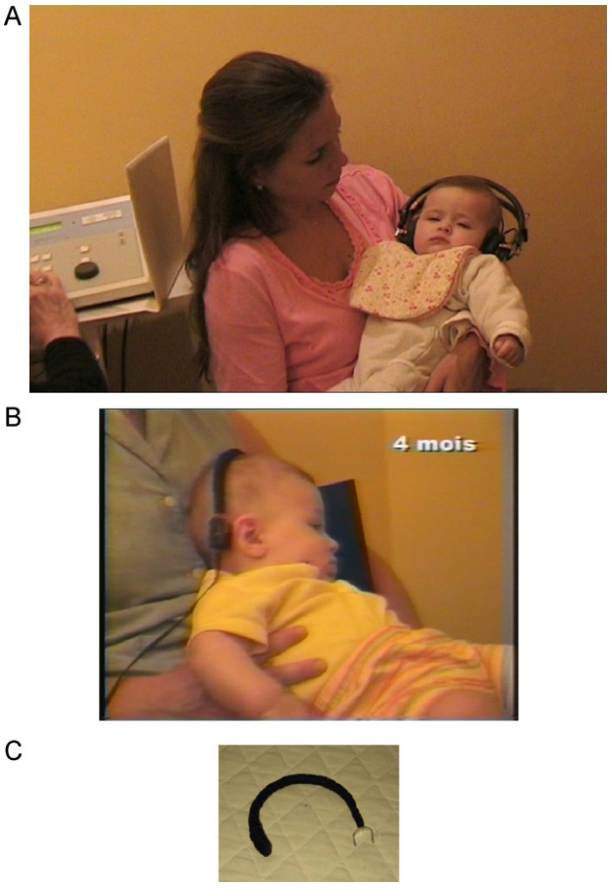

Fig. 1. (A) Measurement of air conduction sensitivity in a 2-month-old baby who is about to sleep (see Section 2 for criteria of valid sound-related responses). The left part of the figure displays the audiometer and the hand of the examiner, both separated from baby's visual field by a small screen. (B) Measurement of bone conduction sensitivity in a 4-month-old baby who is awake. The examiner is on the left, as in (A). (C) Bone vibrator adapted to less than 6-month-old babies.

of the baby (Fig. 1A). In this setting, the examiner is able to control in permanence a series of influential variables: (a) proper positioning of the baby and her parents; (b) state of vigilance of the baby, muscular relaxation, rhythm of sucking, breathing or gaze when awake; (c) adequate timing of stimulation, often performed in apnea to decrypt a minimal reaction; (d) shortness of delay in accordance to sound delivery, an important parameter to substantiate observed reactions; (e) synchronization of reinforcement to baby's reaction; and (f) readjustment of installation or vigilance. The baby may be held in the arms of her parent or, alternatively, placed in a lounger or laid on a small mattress. Timing of examination is determined by baby's rhythm of life, e.g. profound sleep or pangs of hunger are unsuitable circumstances to perform the test.

2.1.3.2. Nature of detectable reactions during BA test. Stimulus-related reactions that can be detected with this protocol extend well beyond the changes in sucking reported e.g. by Madell [4]. They are described according to three distinguishable states of alertness:

a) The baby is tested in *drowsiness* (Fig. 1A): eyelids are still fluttering between opening and closure, suggesting that brain is still susceptible to process auditory signals. The so-called "*alert*" phase is ideal to observe a wide range of most often combined reactions as described in literature [22,23]: generalized cochlear-muscular reflex, cochleo-palpebral reflex, Moro reflex,