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Transient evoked otoacoustic emissions (TEOAEs) in new-borns: normative data

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Abstract

Objective: Early diagnosis and rehabilitation of congenital hearing loss are mandatory in order to achieve a satisfactory linguistic and cognitive development. A universal hearing screening in order to identify congenital hearing losses before 3 months of age is required. *Methods*: TEOAEs are an easy to perform, short lasting, not invasive and low-cost test with a high sensitivity. 320 at term new-borns (640 ears) without any risk factor for hearing loss underwent TEOAEs. The new-borns were screened 3 days after birth. Those who failed the first test were retested when possible before the discharge from the hospital. ABR was performed 3 months later in cases who failed TEOAE. *Results*: The median TEOAE sampling time was 98 s, the median test duration was 14 min. The mean stimulus amplitude was 80 dB peSPL in the left ear and 81 dB peSPL in the right ear, noise levels within the external meatus during sampling were 44 dB SPL on the right ear and 43 dB SPL on the left one, noise contained within the response (A–B difference) was 8.65 dB SPL in the left ear and 8.74 dB SPL in the right ear, mean TEOAEs amplitudes were 21.49 dB SPL and 21.78 dB SPL in the right and left ear respectively, the mean lower and upper limit of the spectrum being 678 and 5720 Hz. According to these criteria 494/640 ears (77.2%) passed the test at the first recording, while TEOAEs resulted to be absent in 146/640 ears (22.8%). A retest was performed successfully before the discharge from the Hospital in 30/640 ears (4.7%). An ABR recording within the third month of life was scheduled as out-patient in the 58 new-borns (116 ears, 18.2%) who failed the test. 18 of them (36 ears, 5.6%) did not complete the program, 19 new-borns (38 ears, 11.8%) showed a normal ABR, while two new-borns (four ears, 0.6%) failed ABR after 3 months. A second ABR performed after 6 months was normal. *Conclusions*: TEOAEs recording seems at now the test of choice for a universal hearing screening. However, a greater standardization of criteria both in performing the test and in evaluating the results is needed.

Keywords: New-borns; Screening; Transient evoked otoacoustic emissions

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1. Introduction

A successful neonatal hearing screening program should detect hearing losses that will interfere with a satisfactory linguistic and cognitive development. Because normal hearing is critical for speech and oral language development during the first 6 months of life, it is desirable to identify hearing loss before 3 months and to begin treatment by 6 months of age.

In 1994 the Joint Committee on Infant Hearing [1] emphasized the importance of a universal hearing screening in order to identify congenital hearing losses because a risk factor screening identifies only 50% of new-borns with significant hearing loss. A hearing loss greater than 30 dB HL in the frequency range important for speech recognition (approximately 500–4000 Hz) will interfere with the normal development of speech and language [2–5].

Since 1978, when Kemp [6] was able to record within the external auditory canal a sound pressure variation 5 ms after the stimulus delivery by means of a miniaturized microphone, the universal neonatal hearing screening has become the main field of interest of the 'otoacoustic emissions' [7,8].

It is now well known that otoacoustic emissions represent a part of the energy produced within the inner ear and more specifically by the outer hair cells. Such energy can be recorded within the external ear canal following a retrograde pathway through the ossicular chain and the tympanic membrane. Their presence seems to demonstrate a normal function of the outer hair cells and they are absent in ears with hearing loss greater than 40 dB [2,9,10].

Otoacoustic emissions can be spontaneous (SOAEs), evoked by transient stimuli such as clicks or tone bursts (TEOAEs) and distortion products (DPOAEs). TEOAEs are not invasive and easy to perform, the time needed to their recording is short, the cost is low and their sensitivity is high. For these reasons they are at present considered the test of choice for the first level neonatal screening, while ABR represents the second level and should be employed in cases who fail TEOAEs. Aim of the present study was to relate the results obtained by means of TEOAEs in an at-term new-born population and to discuss the criteria used both for stimulation and for response analysis comparing them with those reported in the literature.

2. Materials and methods

During 1997, after a period of training in 1996, we have carried out TEOAE measurements on 320 at term new-borns ($N = 640$ ears) without any risk for hearing loss as defined by the 'Committee on Infant Hearing' in the Nursery of the Catholic University of the Sacred Heart of Rome. All of them were bilaterally tested ($N = 640$ ears).

The new-borns were screened 3 days following birth after a clinical evaluation including otoscopy, in order to determine the presence of 'vernix caseosa' occluding the external meatus or a middle ear effusion.

The ILO88 Otodynamic Analyzer introduced by Kemp and Bray was used for testing.

A probe fitting into new-born ears was placed into the external ear canal. Stimuli were 75–85 dB peSPL 80 μs duration clicks, with a flat acoustic spectrum between 0.6 and 5 kHz, presented at a rate of 50 stim/s.

Stimulus stability reflecting changes of the stimulus intensity occurring during the test, was calculated every 3 s and was never lower than 75% of the initial stimulus.

The differential non-linear test paradigm was used. The stimulus was characterized by a train of four clicks, three with the same amplitude and polarity, followed by a fourth one with a 3-fold greater amplitude and an opposite polarity. Responses were represented by an average of a maximum of 260 click stimuli trains (1040) stored into two different buffers (A and B) for a total of 2080 clicks.

In order to establish numerical pass criteria for TEOAEs, the following parameters were used in combination:

1. Response amplitude.
2. The cross-correlation of the two waveforms (wholerepro).
3. OAEs spectrum.

The frequency-domain analysis was determined by performing the fast Fourier transformation of the two buffers. During the registration the noise rejection thresholds were adjusted by the examiner to obtain the cleanest signal.

The TEOAE test was considered passed when the whole response reproducibility was equal or greater than 50% and the amplitude of the response exceeded significantly the background noise in at least three of the five frequency bands.

The new-borns were examined in a quiet room in the nursery during spontaneous sleep about 30 min after meal.

TEOAEs probe was placed delicately to seal the wall of the external meatus. When the probe was correctly inserted, the stimulus waveform was biphasic and decayed rapidly.

Increased oscillations ('ringing') were due to a poor probe fit, to debris occluding the ear canal, or to excessive stimulus intensity levels.

When the probe was occluded by vernix caseosa, it was removed, cleaned and replaced.

Sometimes the external canal was collapsed because of the soft tissues and a repeated placement of the probe improved coupling between the ear canal and the probe.

The stimulus intensity gain never exceeded 3 dB.

The following parameters were considered:

1. TEOAEs sampling.
2. TEOAEs recording time.
3. Stimulus amplitude.
4. Noise levels within the external meatus during sampling.
5. Noise within the response (A–B difference).
6. Mean TEOAEs amplitude.
7. TEOAEs spectrum.
8. percent reproducibility (cross-correlation between A and B waveforms).

The results of the investigation in terms of pass–fail, sensitivity and specificity were evaluated following these criteria.

3. Results

The mean sampling time resulted 110 ± 59.4 s, (median 98 s, range 41–390 s). The mean test duration for both ears was 13.9 ± 2.3 min, (median 14 min, range 6–20 min) (Table 1). In 13% of cases it reached 20 min while in 7% the time needed for the check fit exceeded 20 min and the test was delayed at the end of the session. The increased duration of the test was due to the spontaneous motor activity, to the rewakening during the probe fit, to the environmental and biological noise levels and more frequently to the time needed to clean the external auditory meatus with a small ear swab or with repeated placements of the probe.

The mean peak stimulus level was 80 dB peSPL in the left ear and 81 dB peSPL in the right ear (Table 1). The mean noise levels in the right and left ear canals were 44 and 43 dB SPL, respectively (Table 1). The A–B difference (noise contained within the response) was 8.65 dB SPL in the left ear and 8.74 dB SPL in the right ear (Table 1).

The mean amplitude of TEOAEs was 21.49 and 21.78 dB SPL in the right and left ear, respectively, and their distribution is showed in Fig. 1. Mean response reproducibility resulted to be 84% for the right ear and 88% for the left ear (Table 1). Concerning the spectral content of TEOAEs, the mean lower limit was 678 Hz, while the upper limit was 5720 Hz.

Table 1
Mean, (S.D.) and median for some of the TEOAE characteristics in new-borns who passed the screening

	Right ear (mean and S.D.)	Left ear (mean and S.D.)
Sampling time (s)	115 (59.5) 98[a]	110 (54.4) 97[a]
Recording time (min)	13.98 (2.3) 14[a]	14.3(2.82) 14[a]
Stimulus level (dB peSPL)	81.13 (3.18)	80 (6.55)
Noise (average) (dBSPL)	44.27 (4.65)	43.21 (4.53)
A–B diff. (response noise) (dBSPL)	8.74 (2.0)	8.5 (2.5)
Amplitude of the response (dBSPL)	21.49 (5.05)	21.78 (5.75)
Reproducibility (%)	84.6 (22.8)	88.8 (5.5)

[a] Median.

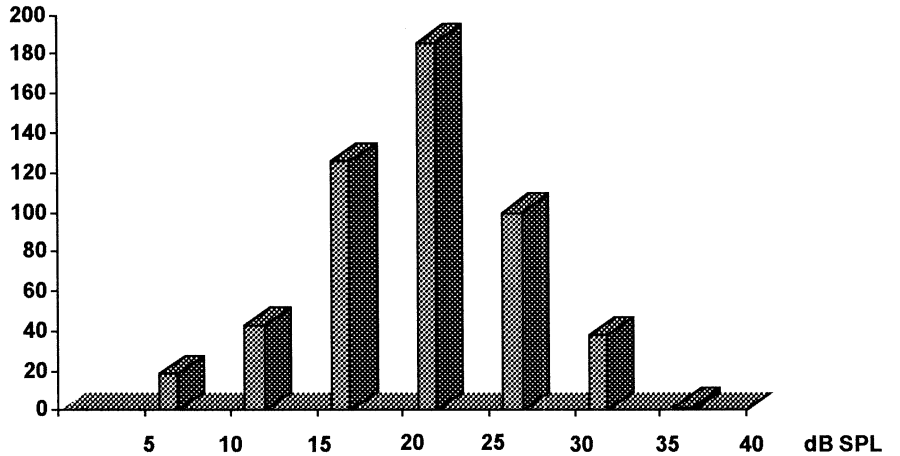

Fig. 1. TEOAEs amplitude distribution in 640 ears. The amplitude ranged between 8.5 and 40.2 dB SPL. The mean amplitude of TEOAE response was 21.49 dB SPL (S.D. = 5.05) in the right ear and 21.78 (S.D. = 5.75) in the left ear.

494 out of 640 ears (77.2%) passed the test at the first recording, while TEOAEs were absent in 146/640 ears, with a false alarm rate of 22.8%. In 30 out of 640 ears (4.7%) a retest was performed before hospital discharge and all passed the test. An ABR recording within the third month of life was scheduled as out-patient in the 58 new-borns (116 ears, 18.2%) who failed the test, because they were discharged from the hospital immediately after the first TEOAEs recording. 18 of them (36 ears, 5.6%) did not complete the program, 19 new-borns (38 ears, 11.8%) showed a normal ABR, while two new-borns (four ears, 0.6%) failed ABR after 3 months. A second ABR performed after 6 months was normal.

In the present series TEOAEs sensitivity reached 100% with a specificity of 77.2%.

4. Discussion

Most authors agree that a universal hearing screening has to be performed and that TEOAEs seem to be at present the test of choice, but the test parameters and evaluation criteria have not yet been clearly defined.

Differential non linear (DNLR) stimulation reduces stimulus artifacts and is at now the best way to determine the response within a neonatal hearing screening program [11,12].

Clicks are the most suitable stimuli as their whole frequency range and the response analysis by means of the FFT makes them almost as frequency specific as tone bursts [13,9].

The stimulus intensity used in the present study is similar to that used by other authors [14–18]. The stimulus stability, measured as percent pressure variation every 3 s and compared to the initial one, should be greater than 75% [15,19].

Biological and environmental noise exceeding 30 dBA SPL is able to mask TEOAEs [20] and Kemp [9] emphasizes that noise should not exceed 45 dB SPL. In the present study we were able to keep the noise level below 43 dB SPL. This was achieved by recording the otoemissions during the new-borns spontaneous sleep and performing the test in a separate room. The lower is the noise level and the shorter is the test duration.

One of the reasons of success of TEOAEs as a new-born auditory screening test is the response amplitude. In the present study the mean response amplitude was 21 dB SPL and anyway in 97% of cases it was greater than 10 dB SPL. Such high amplitudes could be explained by the summation of spontaneous and evoked otoacoustic emissions [21,22]. On the other hand Bonfils [23], who recorded spontaneous emissions in 70% of normal new-borns, believes that low amplitudes of TEOAEs could indicate a cochlear damage.

Table 2
A review of the literature with comparison of new-born age, stimulus level, reproducibility and pass rate

Authors	No. ears	New-born age (TEOAE recording)	Stimulus level (dB-SPL)	Reproducibility (%)	Pass rate (%)
Bonfils et al. [13]	100	2 h–4 days	?	?	98
Kok et al. [27]	20	36–108 h	<96	>100	75
Lafreniere et al. [18]	44	2–4 days	82 ± 4	>70	100
Thornton et al. [35]	121	1–3 days	70	>50	70
Chang et al. [15]	82	43 ± 21 h	80	>75	76
Jacobson [17]	119	33–41 weeks p.c.	80	>50	52.2
White et al. [19]	1850	24–48 h	71–83	>50	73.1
Kok et al. [31]	127	43–53–66 weeks	>72.5	>40–50	83
Aidan et al. [21]	508	2–3 days	78 ± 4	>60	?
Salamy et al. [33]	267	At nursery	87	>50	63.5
Doyle et al. [40]	400	5–48 h	85–95	>50	79
Aidan et al. [14]	1164	>48 h	79.4	>60	98.9
Lutman et al. [44]	1738	>48 h	70	?	83.8
Molini et al. [29]	2656	4 days	80–85	>70	86.9
McNellis and Klein [32]	100	4–40 h	80–85	?	61
Present study	640	4 days	78–85	>50	77.2

The pass–fail criteria described in the literature are quite variable and can be visual or numerical. The visual one is based upon the evaluation of the FFT of the response: the test is passed if the response is detectable in at least half of the extension of every frequential band of the whole spectrum. The most recent screening programs adopt as the most reliable criterion the reproducibility of the response within the frequency bands between 1000 and 4000 Hz [24]. The National Consortium on New-born Hearing Screening [25] suggested the option Quickscreen with reproducibility of 50% at 1600 Hz and of 70% or more at 2400, 3200 and 4000 Hz.

The correlation index of 50% was adopted by several authors [26,17,27,19], while others prefer correlations of 85% [28], 70% [18,29] and 60% [14].

We believe that the number of false alarms can be reduced both using higher correlation indexes or using a correlation index of 50% added to a spectral representation between 1000 and 5000 Hz and a response amplitude greater than 10 dB SPL. In the present paper we showed that the reproducibility of the response is high (88 ± 4%) if the test is correctly performed (stimulation, noise etc.).

A review of the literature shows that the pass rate is quite variable ranging from 52% [17] to 98–99% [14,30] (Table 2). The pass rate of 77% at the first test obtained in the present study agrees with that obtained by most authors [31–33].

The single most important factor influencing the pass-rate of the test is the day of test performance as it's pass rate increases more than 50% between the first and the third day of life [34,35]. In fact during the first 4 days of life the external meatus cleans up spontaneously from the vernix caseosa. Maturation of cochlear mechanics [36,37], ending between the 29th and the 32nd gestational week [23,38] may also be involved in the improvement of the response.

The technical factors able to significantly influence the results of the test are the coupling between the probe and the external meatus [9], the noise [17] and less frequently, a middle ear effusion [15,39] that was present in 9% of cases without significant differences within the first days of life [40]. These authors observed that the prevalence of occlusion of the external meatus due to vernix caseosa was 14.3% within the first 24 h, decreasing to 11.7% between the 25th and the 48th h, while only 45% of new-borns showed a clean meatus during the first day of life. When the

external meatus contained vernix caseosa the success rate of the test decreased to 38%.

A universal hearing screening by means of TEOAEs poses several problems, concerning the standardization of the method and of the response evaluation. Moreover the activity of the Audiology Services is highly affected by screening and follow-up programs. In fact, if a universal screening is really performed, the rate of false alarms requiring an ABR is still too high with whatever screening test we choose. Moreover, the cost reductions cause an overall tendency to an earlier discharge of babies from the nursery (second–third day of life) thus reducing the possibilities of performing the test in the best conditions.

On the other hand a late diagnosis of congenital hearing loss is really not acceptable as hearing loss shows a higher incidence (1–2/1000) than phenylketonuria (1/12000) and hypothyroidism (1/3500) [41–43].

In conclusion, TEOAEs recording seems at now to be the test of choice for a universal hearing screening. A greater standardization of criteria both in performing the test and in evaluating the results is needed.

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