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Chirp-evoked otoacoustic emissions in children

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ABSTRACT

Objective: The purpose of the study was to investigate the properties of otoacoustic emissions (OAEs) evoked by chirp stimuli and compare them with standard click-evoked OAEs. Differences between evoked OAEs in children with and without spontaneous otoacoustic emissions (SOAEs) were also assessed.

Methods: OAEs were first recorded from 54 children (age 4–10 years) in a screening setup. In each ear five OAE measurements were made using two types of chirps (7.5 ms and 10.5 ms) at around 70 dB pSPL; clicks at 70 and 80 dB pSPL; and a standard synchronized SOAE stimulation protocol. Tympanometry was also conducted. Pass/refer criteria based on signal to noise ratios (SNRs) were applied to all OAEs. Pass/refer rates from all methods (OAEs evoked by chirps and clicks, and tympanometry) were compared. Additionally, half-octave-band values of OAE SNRs and response levels were used to assess statistical differences.

Results: Chirp-evoked OAEs generated a similar number of passes to click-evoked OAEs when the same level of stimulus was used. When using lower stimulus levels, both chirp- and click-evoked OAEs diagnosed nearly all ears that failed tympanometry. The response levels and SNRs of OAEs evoked by clicks and chirps were very similar. The highest response levels were in the 1.4 kHz half-octave band. The SNRs for ears with SOAEs were highest at 1.4 kHz, whereas they were at 4 kHz for ears without SOAEs. Both response levels and SNRs were higher by about 5 dB for ears with SOAEs than ears without SOAEs. Also all ears with SOAEs generated a pass result in screening, while ears without SOAEs gave a pass less frequently (at least 30% fewer cases).

Conclusions: The results suggest that performance of chirp-evoked OAEs for screening purposes is similar to click-evoked OAEs when the same stimulus level is applied. OAEs evoked with lower stimulus levels (70 vs. 80 dB pSPL) are more sensitive to middle ear pathology. The presence of SOAEs significantly influences the pass rates of OAEs evoked by chirps and clicks.

1. Introduction

Otoacoustic emissions (OAEs) – acoustic signals from the cochlea [1] – are now one of the most useful objective tests of hearing [2]. One of their main applications is for hearing screening, especially in newborns [3]. Recently the ENT and audiological science community has turned attention to screening older children [4,5] because of an interest in documenting the impact of sensorineural hearing loss (even if mild) on child development. The incidence of minimal or mild hearing loss appears to increase as children age, and the prevalence in school-age children (6–19 years) is estimated to be between 11% and 15% [6,7] with unilateral sensorineural hearing loss being the most prevalent form [7]. These findings mean there is a significant difference in incidence between the newborn period and school age. For children as young as 4 years old, screening based on pure tone audiometry may be used [8,9]. However, fast objective methods such as OAEs are valuable, and recent studies have shown the usefulness of OAE testing in screening preschool/school-age children [10,11].

The most popular method of measuring transiently evoked otoacoustic emissions (TEOAEs) uses a click stimulus. This stimulus has advantages of short duration and broadband range (usually 500–4500 Hz for OAEs) and is used in most commercial equipment; therefore most clinical research on TEOAEs is based on it [12].

OAE levels tend to decrease with age [13], and the biggest change is between 0 and 4 years [14]. It is also associated with a change in the dominant frequencies recorded: in newborns the response is highest in the 2–4 kHz range; in preschool/school age children the response is roughly uniform across 1–4 kHz; and in adults the dominant frequencies are 1–2 kHz. When using an 80 dB

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pSPL click with children, the amplitude of the response in the 1–4 kHz range is around 0–5 dB SPL on average and the SNR is around 10 dB [10,15,16]. Additionally, all types of evoked OAEs are affected by the presence of spontaneous OAEs (SOAEs), and the prevalence of SOAEs decreases with age [14].

OAEs evoked by click stimuli sometimes have quite low SNRs at low frequencies [17]. To overcome this problem, some researchers recommend use of additional measurement with tone burst stimuli [18–20]. The advantage is a possible reduction in referral rates, but the cost is a somewhat prolonged measurement time.

Alternatively, a broadband TEOAE response can be evoked by a so-called chirp stimulus, which is a very short sweep tone of rapidly increasing frequency. The main advantage of a chirp is that it is broadband, similar to a click, but it has some of the frequency specificity of a tone burst. The application of chirps to OAEs was introduced by Neumann et al. [21]. They showed that a chirp contains more energy than a click stimulus of the same maximum amplitude, yielding a better SNR. These workers therefore recommend this method for clinical use. However, chirp-evoked OAEs (ChEOAEs) have so far only been used in research studies (e.g. [22]), so it seems important to check the suitability of ChEOAEs in audiological applications such as screening.

Chirp stimuli are also of interest in auditory brainstem evoked responses (ABRs) which are often done concurrently with OAE screening. Wave V of an ABR is the main indicator of correct auditory function, and it has been shown [23] that chirps evoke signals of higher amplitude than the conventionally used click. In recent years other workers have also looked at designing chirp stimuli for ABRs [24]. Chirp-evoked ABRs have already been successfully used in a hearing screening program for newborns [25].

The purpose of this study was to investigate the properties of OAEs evoked by chirp stimuli in a child hearing screening program. OAEs evoked by two types of chirps were compared with standard click-evoked OAEs. Differences between TEOAEs recorded with and without spontaneous otoacoustic emissions (SOAEs) were also assessed.

2. Methods

2.1. Participants

Measurements were conducted in two schools connected with kindergartens in a rural area of Poland. Data were obtained from both ears of 54 participants, 17 boys and 37 girls, giving 80 ear recordings in total (37 left, 43 right). The children were 4–10 years old, and none had reports of any otolaryngological problems. For each subject the parents were asked to sign a statement of consent, and an audiological questionnaire was filled in by the parents and by an audiologist. The parents of children that did not pass the screening were instructed to visit an audiology specialist. The research procedures were approved by the Ethics Committee of the Institute of Physiology and Pathology of Hearing, Poland.

It should be mentioned that preschool/school children are not easy subjects for prolonged (more than 1 min) OAE testing. Even though each single measurement usually lasts less than a minute, it can take 5 min to record one ear. For some children from this age group it can be hard for them to keep still long enough to record quiet OAEs. For this reason, in some children only one ear was fully tested.

2.2. Procedures

OAEs were measured in a quiet school room using a HearID system (Mimosa Acoustics, Inc., USA, software version 3.3) [26] equipped with an ER-10C probe microphone (Etymotic, USA). Factory preset measurement protocols were applied. Chirps were elicited at approximately 70 dB pSPL level. Clicks at 70 and 80 dB pSPL were used for comparison. In total, four types of evoked OAEs were measured:

D-ChEOAE – called 'DauChirp47' in the system. Chirp of 7.5 ms designed by Dau et al. [27], non-linear mode, 67 $\pm$ 2 dB pSPL, rms level 47 dB, recording window 14 ms.
S-ChEOAE – called 'SheraChirp47' in the system. Chirp of 10.5 ms designed by Shera et al. [28], non-linear mode, 66 $\pm$ 1 dB pSPL, rms level 47 dB, recording window 14 ms.
CEOAE – called 'Click47' in the system. Click, non-linear mode, 69 $\pm$ 1 dB pSPL, rms level 47 dB, recording window 14 ms.
CEOAE80 – called 'default' in the system. Click, non-linear mode, 80 $\pm$ 2 dB pSPL, rms level 57 dB, recording window 18 ms.

Other default settings were stimulus spectrum approximately flat from 1 to 5 kHz, 0.7–5 kHz bandpass filter, measurement ends when 4 out of 5 frequency bands produce 3 dB SNR (or 400 good responses or rejects are obtained for clicks of 80 dB pSPL, and 500 for all other stimuli). The levels of chirps were calibrated in rms dB in order to provide similar energy to a click. Other details of chirp stimuli and recording protocols are described in Appendix A.

Each subject was tested for the presence of SOAEs using the synchronized SOAE technique provided by the HearID equipment. Each ear was deemed to contain SOAE components when there was at least one peak in the spectrum that exceeded the noise by 5 dB. Exactly 36 ears presented at least one SOAE whereas 44 did not.

To assess middle ear function an additional screening tympanometry test was performed. Tympanograms were obtained using a Madsen Zodiac 901 tympanometer (GN Otometrics, Denmark). The probe tone frequency was 220 Hz. Pure tone audiometry was not included in the study as such comparisons already exist [9] (in any case, only screening audiometry would have been possible because the study was done in a school, not a clinic, and the extra time required would have tired the children). Any child with uncertain/poor results was directed to see a specialist.

Analyses were made in a Matlab environment (The MathWorks, Inc., USA). This was straightforward as HearID has an option to export all data directly to Matlab. For all parameters the statistical significance of the mean difference between groups was evaluated using the Wilcoxon rank sum test. This is equivalent to Student's *t*-test when the analyzed populations do not have normal distributions. As a criterion of significance, a 95% confidence level ($p < 0.05$) was chosen.

3. Results

This study attempted to compare ChEOAEs with CEOAEs at the same stimulus level (i.e. approximately 70 dB pSPL). In addition, these measurements were compared with CEOAEs at 80 dB SPL (marked CEOAE80), which is the default setting of many systems and is described in most reports. There were no statistical differences in response levels and SNRs between left and right ears and so all data were pooled together. Usually pass/refer results relate to a subject, not a single ear, and a refer result could be generated in cases where a subject has one ear that passed. Here, all analysis and results refer to ears, not subjects (and so the results may differ slightly to studies in which percentages are calculated in relation to number of subjects).

In the present study, pass/refer rates were based on criterion of SNR > 3 dB. Fig. 1 shows the percent of responses that fulfill this criterion in each separate frequency band. This initial analysis shows how each frequency band contributes to the pass criterion based on a '3 out of 5 band rule' used later in the study. S-ChEOAEs,