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Tone burst evoked otoacoustic emissions in different age-groups of schoolchildren

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ABSTRACT

Introduction: Otoacoustic emissions (OAEs) are believed to be good predictors of hearing status, particularly in the 1–4 kHz range. However both click evoked OAEs (CEOAEs) and distortion product OAEs (DPOAEs) perform poorly at 0.5 kHz. The present study investigates OAEs in the lower frequency range of 0.5–1 kHz evoked by 0.5 kHz tone bursts (TBOAEs) in schoolchildren and compares them with emissions evoked by clicks.

Methods: Measurements were performed for two groups of normally hearing schoolchildren. Children from 1st grade (age 6–7 years) and children from 6th grade (age 11–12 years). Tympanometry, pure tone audiometry, and OAE measurements of CEAOEs, 0.5 kHz TBOAEs, and spontaneous OAEs (SOAEs) were performed. Additionally, analysis by the matching pursuit method was conducted on CEOAEs and TBOAEs to assess their time–frequency (TF) properties.

Results: For all subjects OAEs response levels and signal to noise ratios (SNRs) were calculated. As expected, CEOAE magnitudes were greatest over the range 1–4 kHz, with a substantial decrease below 1 kHz. Responses from the 0.5 kHz TBOAEs were complementary in that the main components occurred between 0.5 and 1.4 kHz. In younger children, TBOAEs had SNRs 4–8 dB smaller in the 0.5–1.4 kHz range. In addition, CEOAEs had lower SNRs in the 0.7–1.4 kHz range, by 3–5 dB. TBOAEs in younger children had maximum SNRs shifted toward 1–1.4 kHz, whereas in older children it was more clearly around 1 kHz. The differences in response levels were less evident. The presence of SOAEs appreciably influenced both CEOAEs and TBOAEs, and TF properties of both OAEs did not differ significantly between grades.

Conclusion: TBOAEs evoked at 0.5 kHz can provide additional information about frequencies below 1 kHz, a range over which CEOAEs usually have very low amplitudes. The main difference between the two age groups was that in older children CEOAEs and 0.5 kHz TBOAEs had higher SNRs at 0.5–1.4 kHz. Additionally, for ears with SOAEs, 0.5 kHz TBOAEs had higher response levels and SNRs similar to CEOAEs.

1. Introduction

Otoacoustic emissions (OAEs) [1] are believed to be good predictors of hearing status, particularly in the 1–4 kHz range. Click evoked OAEs (CEOAEs) are good indicators of cochlear function at 1 kHz, whereas distortion product OAEs (DPOAEs) perform better at higher frequencies. Both CEOAEs and DPOAEs perform poorly at 0.5 kHz [2–4] where there is still room for improvement.

There is still some debate on the value of testing the hearing of schoolchildren. Newborn hearing screening has been universally applied in many countries but doing the same for schoolchildren is not widely practiced. Some organizations recommend screening of preschool and school-age children, pointing out the risks associated with undetected hearing loss [5]. There is also some controversy on what screening method is the best. Some studies recommend OAEs [6,7], while others suggest pure tone audiometry [8]. If OAEs could be evoked over a broader frequency range then it

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is likely that their usefulness could be improved. A basic problem with measuring OAEs in children is that measurements at lower frequencies are often contaminated by noise [9].

This noise susceptibility problem might be overcome by using low frequency tone bursts as a stimulus. Some studies (e.g. [4,10,11]) have shown that OAEs evoked by tone bursts (TBOAEs) may provide a better estimate of hearing status than those evoked by clicks. In particular, the 0.5-kHz TBOAE seems to be a more reliable measure than CEOAE when probing cochlear responses at low frequencies (e.g. [12]). Indications are that TBOAEs can be effectively measured in children, and there are commercially available devices that offer this measurement [13].

Screening of schoolchildren can be organized in a way that schoolchildren are tested at the beginning of school (i.e. at 1st grade) and later at 6th grade, a scheme implemented in rural areas in Poland [14,15]. When considering OAE-based screening, it should be kept in mind that OAEs tend to change with age [16]. Their amplitude decreases with age and there are shifts in dominant frequencies [17]. OAEs stabilize at around age 18, and thereafter remain quite stable if there is no hearing loss. But for young subjects, a caveat is that the results and indications for one age group might not readily translate to another.

The least investigated type of OAEs are spontaneous OAEs (SOAEs) [18]. Because they are usually not detected in all ears [19], they are of little interest to clinicians. However, it is known that SOAEs generally coincide with minima in hearing thresholds [20], and several studies have shown that SOAEs tend to produce higher amplitude CEOAEs [17,21]. A similar effect has been detected in DPOAEs [22]. SOAEs are influenced by age: their presence is greatest in newborns and declines with age [17]. In terms of TBOAEs, the effect of SOAEs has so far only been seen as generating peaks in TBOAE spectra [4,23].

One analysis method that promises valuable insight into OAEs is time–frequency (TF) analysis. The method can reveal, for example, how the latency of CEOAEs depends on frequency, with high frequency components having shorter latency than low frequency components [24]. TF properties may be affected by some hearing deficits [25], although it is not clear if they change with age [26,27]. The TF properties of TBOAEs have already been the subject of a previous study [28] where it has been shown that sets of TBOAEs ranging in frequency from 1 to 4 kHz have the same main components as CEOAEs. However, the same work has also shown that the 0.5 kHz TBOAE may contain components not present in the CEOAE; in addition, the work also made clear that SOAEs show up in TF energy distributions of both CEOAEs and TBOAEs [28].

The present study investigates the usefulness of responses in the lower frequency range (0.5–1 kHz) evoked by 0.5 kHz tone bursts. Two age groups were tested, children from 1st grade and 6th grade of primary school, and the amplitude and SNR of 0.5 kHz TBOAEs recorded from them were compared with emissions evoked by clicks. The influence of SOAEs on evoked emissions was also investigated.

2. Material and methods

Measurements were performed on two groups of normally hearing schoolchildren: 32 children from 1st grade (64 ears) of age 6–7 years and 32 children from 6th grade (64 ears) of age 11–12 years. All children underwent visual inspection of the ear canal and tympanic membrane of both ears followed by tympanometry, pure tone audiometry, and OAE measurement. All had pure tone thresholds better than 25 dB HL at 0.5–8 kHz, type A tympanograms, and no known history of otologic disease. The parents gave written informed consent prior to participation of their children in the study. The research procedures were approved by the Ethics Committee of the Institute of Physiology and Pathology of Hearing, Poland.

OAEs were measured in low-noise ambient conditions using an ILO 292 system (Otodynamics Ltd). Standard click stimuli and 0.5 kHz tone bursts (average amplitude 80 ± 3 peak dB SPL, nonlinear averaging protocol) were used to evoke a total of 260 OAE responses. The tone bursts were two cycles long with equal rise/fall times and no plateau. The initial part of the response was windowed automatically by the system to minimize stimuli artifacts. Window onset was 2.5 ms for clicks and 5 ms for 0.5 kHz tone bursts, and all recordings used an acquisition window of 20 ms. Half-octave-band values of OAE response levels and signal-to-noise ratios (SNRs) were used for analysis. SOAEs were acquired using the in-built routine provided by the ILO 292 equipment, resulting in a measurement of so-called synchronized SOAEs (SSOAEs). An ear was classified as "with SOAEs" when at least one long-lasting peak was found in the SSOAE spectrum that exceeded the noise floor by 5 dB SPL [29].

For all parameters the statistical significance of the mean difference between groups was evaluated using the Wilcoxon rank sum test. As a criterion of significance, a 95% confidence level ($p < 0.05$) was chosen.

2.1. Time–frequency (TF) analysis

Time–frequency (TF) analysis of the recorded signals was done by decomposing the signals into their basic waveforms. The method of high-resolution adaptive approximation was used, a technique based on the matching pursuit (MP) algorithm [30]. A slight modification was used to account for the asymmetrical character of some components [31]. The modified MP method allowed the CEOAE and TBOAE signals to be decomposed into waveforms of defined frequency, latency, duration, and amplitude. The latency was taken to be the time taken from onset of the stimulus to the maximum point in the waveform envelope. Note that the presence of SOAEs can, when using some methods, cause a false shift in evoked OAE latency, whereas MP with an asymmetric dictionary provides estimates that are less prone to SOAEs [31].

3. Results

Global and half-octave band response levels and SNRs were calculated for OAEs from all subjects. Comparison of global parameters between grades revealed no significant differences in response level between CEOAEs (Fig. 1, left); a similar outcome can be seen for 0.5 kHz TBOAEs. However, Fig. 1 shows that in terms of SNRs, both CEOAEs and TBOAEs had significantly higher values in schoolchildren from the 6th grade. This probably relates to higher noise levels usually present in OAE measurements of younger children [32].

Fig. 2 shows average half-octave band values of OAE amplitudes evoked by clicks and 0.5 kHz tone bursts for children from the 1st grade. Fig. 3 shows comparable results for 6th grade children. As expected, CEOAE magnitudes were greatest over the range 1–4 kHz, decreasing substantially below 1 kHz. Responses from the 0.5-kHz TBOAEs were complementary in that the main components occurred between 0.5 and 1.4 kHz (top rows of Figs. 2 and 3). TBOAEs were larger than CEOAEs (on average more than 5 dB larger) at 0.5–1 kHz (the difference was significant at $p < 0.05$). At 1.4 kHz there was no statistically significant difference between CEAOEs and TBOAEs. As expected, at higher frequencies TBOAE response levels and SNRs declined, while CEOAEs were significantly higher. A notable feature is that the maximum level of the 0.5 kHz TBOAE occurs at 1 kHz, not at the center frequency of stimulation (0.5 kHz).

The subsequent rows of Figs. 2 and 3 show levels of TBOAEs and CEOAEs when the dataset was divided into ears with and without SOAEs. There were 27% of ears with SOAEs in the 1st grade dataset and 33% of ears in the 6th grade dataset. Generally, both CEOAEs