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Otoacoustic emissions at compensated middle ear pressure in children

Emisiones otoacústicas con presión compensada del oído medio en niños

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Key Words

Otoacoustic emission
Middle ear
Pressure

Otoacoustic emissions at compensated middle ear pressure in children

Emisiones otoacústicas con presión compensada del oído medio en niños

Abstract

Middle ear pathology has a negative effect on the detectability of otoacoustic emissions.

In this study, we investigated the effect of compensating a deviant static middle ear pressure while measuring transient evoked otoacoustic emissions (TEOAEs). In 59 children (mean age 4 years, 5 months) TEOAEs were measured twice in one session: first at ambient pressure and then at compensated middle ear pressure.

On average, TEOAE amplitudes increased by 1.9 dB as a result of middle ear pressure compensation. The amplitude increase was largest in frequency bands centred at 1 and 2 kHz and a statistically significant correlation was found between the amount of compensated pressure and the TEOAE amplitude increase. In the higher frequency bands centred at 3 and 4 kHz, TEOAE amplitudes were almost insensitive to pressure compensation.

These results show that measuring OAEs at compensated middle ear pressure enhances the amplitude of TEOAEs, and thus improves the detectability.

Sumario

La patología del oído medio tiene un efecto negativo en la detectabilidad de las emisiones otoacústicas. En este estudio investigamos el efecto compensatorio de la presión estática desviada del oído medio, al medir emisiones otoacústicas evocadas por transitorios (TEOAE). Medimos dos veces en una sesión las TEOAE de 59 niños (edad promedio de 4 años, 5 meses): primero a la presión ambiental y después con una presión compensada del oído medio. En promedio, la amplitud de las TEOAE se incrementó en 1.9 dB como resultado de la compensación de la presión del oído medio. El incremento de la amplitud fue mayor en las bandas de frecuencia centradas en 1 y 2 kHz y se encontró una correlación estadísticamente significativa entre la cantidad de presión de compensación y el incremento de la amplitud de las TEOAE. En las bandas de frecuencia superiores centradas en 3 y 4 kHz, la amplitud de las TEOAE fue casi insensible a la compensación de la presión. Estos resultados muestran que la medición de las OAE con presión compensada del oído medio, incrementa la amplitud de las TEOAE con lo que mejora su detectabilidad.

Otoacoustic emissions (OAEs) can be influenced by the middle ear. The middle ear is not only important in the transmission of the evoking stimulus to the cochlea, but also for the delivery of the emission through the middle ear back into the ear canal.

OAEs are reduced when sound conduction through the middle ear is compromised (Zhao et al, 2000, Zhao et al, 2003). In ears with abnormal (negative) middle ear pressure, caused by Eustachian tube dysfunction, OAEs are attenuated (Plinkert et al, 1994). Other studies have shown that artificial higher air pressure in the external ear canal of normal ears, resulting in increased stiffness of the tympanic membrane, also caused a reduction of OAEs (Schloth and Zwicker 1983). The most rapid decrease of the emission amplitude occurred within the first 200 daPa's of pressure change (Hauser et al, 1993). In normal-hearing ears, even a small amount of negative middle ear pressure results in a reduced TEOAE amplitude and reproducibility (Owens et al, 1993). All these studies show that a deviation of the tympanic membrane from its normal position results in an attenuation of OAEs.

The effect of outer and middle ear pressure on OAEs is most pronounced at lower frequencies (Naeve et al, 1992; Trine et al, 1993; Marshall et al, 1997). The amplitude of frequencies above 2.5 kHz is relatively independent of pressure variations (Naeve

et al, 1992). These effects are consistent with a simple middle ear model (Avan et al, 2000). Not only are middle ear characteristics modified by static air pressure, but also the modification of the impedance of the labyrinthine windows affect OAEs in a compatible manner (Konradsson et al, 1999; Buki et al, 2000; de Kleine et al, 2001).

In this study, we investigated the effect of compensating middle ear pressure in ears with mild middle ear pathology. In our study group, a deviant pressure was present in the middle ear. This is expected to attenuate TEOAEs. As we will show, equilibrating pressure on both sides of the tympanic membrane increases the amplitude of TEOAEs, and thus improves their detectability. Our results are consistent with previous studies on the relation between middle ear pressure and OAE properties and may help to improve hearing screening.

Methods

Fifty-nine children with hearing complaints, aged between 0.5 and 9 years (mean 4 years and 5 months), were seen on the outpatient ward of the University Hospital Maastricht, the Netherlands. As part of the ENT diagnostic procedure, they were scheduled for audiometric assessment, including TEOAE

Figure 1. Scatter plots of amplitude increase versus compensated middle ear pressure. Each plot shows results for a particular analysis frequency band. (A) Total emission amplitude, (B) amplitude in the 1 kHz band, (C) 2 kHz band, (D) 3 kHz band, and (E) 4 kHz band. Solid curves are linear regression lines. For each panel, the Pearson correlation coefficient (R) and the corresponding significance (p) are denoted. The correlation between amplitude increase and compensated pressure was significant for the total emission amplitude, the 1 kHz band, and the 2 kHz band.

Table 1. Correlation between compensated middle ear pressure and TEOAE amplitude increase, for various TEOAE reproducibility criteria. Each column represents results for a particular reproducibility inclusion criterion. The highest correlations are found for the strictest criterion (85%). All criteria show the same trend: the correlation decreases with increasing frequency

	<i>Reproducibility 85%</i> <i>N = 18</i>	<i>Reproducibility 70%</i> <i>N = 31</i>	<i>Reproducibility 60%</i> <i>N = 35</i>	<i>Reproducibility 50%</i> <i>N = 40</i>
Overall increase				
Pearson corr. (<i>R</i>)	−0.821***	−0.671***	−0.665***	−0.588***
Increase at 1 kHz				
Pearson corr. (<i>R</i>)	−0.574*	−0.547**	−0.607***	−0.584***
Increase at 2 kHz				
Pearson corr. (<i>R</i>)	−0.506*	−0.440*	−0.389*	−0.348*
Increase at 3 kHz				
Pearson corr. (<i>R</i>)	−0.630**	−0.354	−0.238	−0.186
Increase at 4 kHz				
Pearson corr. (<i>R</i>)	−0.272	−0.043	0.013	0.012

***Sig. (*p*) < 0.001.

**Sig. (*p*) < 0.01.

*Sig. (*p*) < 0.05.

measurement and tympanometry. Children with sensorineural hearing loss or with perforated tympanic membranes were not included in the study.

The standard audiometric assessments were performed with the clinical audiometer (Camea, ADH Hoensbroek, the Netherlands). A pure-tone audiogram was included for the older children, and conditioned orientation reflex audiometry (CORA) for the younger children. All children underwent standard tympanometry using a clinical tympanometer (Camea, ADH Hoensbroek, the Netherlands). All included children had normal hearing, with thresholds better than 20 dB HL.

Additional emission and tympanometric measurements were conducted, in one ear of each child, with a purpose build OAE/tympanometry instrument (GN Otometrics). The airtight ear canal probe of this instrument contains a pressure tube for tympanometry, two miniature speakers and a sensitive microphone for TEOAE measurements. Thus, both TEOAE and tympanometry measurements could be performed with a single probe. A personal computer controlled tympanometry and TEOAE measurements.

The emissions were measured in the standard non-linear mode of the instrument. Stimuli were delivered in groups of four, with three pulses of polarity opposite to the fourth, the latter being three times greater in amplitude than the preceding three clicks. This scaled subtraction technique results in the elimination of linear components of the responses.

All measurements were performed with a broadband click between 77–84 dB pe SPL, with a repetition rate of 50 clicks per second. Otoacoustic emissions were analysed in the frequency range between 0.5–5 kHz. The artefact rejection threshold was 60 dB SPL. A total of 260 accepted sweeps was necessary to complete one test.

Tympanometry was performed, using a 226 Hz probe tone, and the ear canal pressure was varied from +200 daPa to −300 daPa. The sweep rate was around 40 daPa per second.

For each ear investigated, a sequence of measurements was performed. First, TEOAEs were measured at ambient ear canal pressure. Next, the tympanogram was obtained, from which the

pressure of maximum tympanic compliance was determined. Finally, the pressure in the outer ear was modified to match this pressure of maximum compliance. This pressure will be referred to as the peak pressure. Then, the TEOAE measurement was repeated while the static pressure in the ear canal was maintained at this compensating middle ear pressure (CMEP). The probe was not removed from the ear canal between these measurements. Peak stimulus level between the first and the second OAE measurements did not exceed 3 dB for any of the children. Measurements were performed in a soundproof chamber. The entire procedure lasted about 10–15 minutes, depending mainly on the (passive) co-operation of the child. SPSS (version 11.5) was used to analyse the effect of pressure compensation on the amplitude of OAEs.

Results

Gain in TEOAE amplitude

To evaluate the effect of compensating middle ear pressure on TEOAEs, we initially considered only ears for which the reproducibility of the OAE measurement was 70% or more for both before and after compensation. On average, the overall OAE amplitude increased from 20 dB at ambient pressure to 22 dB at CMEP. We also investigated the individual frequency bands. The amplitudes increased more at lower than at higher frequencies. The highest mean gain was reached in the 1 kHz frequency band, 4.7 dB (SD 5.1), followed by the 2 kHz band with 2.6 dB (SD 3.9). The highest two frequency bands at 3 and 4 kHz showed little rise in amplitude: 1.3 dB (SD 3.8) and 1.1 dB (SD 4.3), respectively.

Pressure and amplitude

The pressure at maximum compliance, as obtained from the tympanogram, ranged from −263 to +25 daPa (mean −85 daPa). The scatter plots in Figure 1 display the correlation between the peak pressure, (i.e. the amount of pressure which was compensated in the second TEOAE measurement) and the amplitude increase which resulted from pressure compensation. Only TEOAE data with 70% reproducibility are shown. A

statistically significant correlation (Pearson $R = -0.671$, $p < 0.001$) existed between the gain in the total TEOAE amplitude and the peak pressure (Figure 1A): the higher the compensation in pressure was, the larger the increase in OAE amplitude. The increase in total OEA amplitude could best be explained by the increase in the 1 and 2 kHz frequency bands. A statistically significant correlation was found for the TEOAE amplitude in these frequency bands ($p = 0.01$ for 1 kHz and $p = 0.013$ for 2 kHz), but was absent for the 3 and 4 kHz bands ($p = 0.50$ and $p = 0.819$ respectively) (Figure 1B-E and Table 1).

These figures also illustrate that for some ears compensation of middle ear pressure results in a lower amplitude of the emission. This happens in particular in the 4 kHz frequency band (Figure 1D): in 41.9% of the measurements, emission amplitude decreased as a result of pressure compensation. For the 1, 2, and 3 kHz bands, the percentages were 19.4%, 22.6%, and 22.6%, respectively.

The correlation between amplitude increase and peak pressure was also analysed for the reproducibility criteria $>85\%$, $>60\%$, and $>50\%$, respectively (see Table 1). Regardless of the reproducibility criterion set, the same pattern was seen. The correlation between TEOAE amplitude enhancement and peak pressure decreases with increasing centre frequency of the analysis band. These correlations were largest for the strictest reproducibility criterion (85%).

Discussion

A pressure difference between the middle ear cavity and the ear canal may attenuate the transmission of sound through the middle ear. Thus, it may compromise the measurement of otoacoustic emissions. The aim of this study was to investigate the effect of compensating for such a pressure difference on the amplitude of OAE.

We observed that middle ear pressure compensation might increase emission amplitudes. These results are in agreement with observations described in the literature. The introduction of a pressure difference across the tympanic membrane of normal middle ears results in an attenuation of emission amplitudes (Robinson and Haughton 1991; Naeve et al, 1992; Hauser et al, 1993; Trine et al, 1993; Marshall et al, 1997). We showed that the equilibration of middle ear pressure has the reverse effect: on average emission amplitude increases.

Middle ear modification by the introduction of static middle ear pressure (Naeve et al, 1992; Hauser et al, 1993; Plinkert et al, 1994; Marshall et al, 1997; Konradsson et al, 1999) or by manipulation of CSF-pressure (Avan et al, 2000; Buki et al, 2000; de Kleine et al, 2001), has the largest effect at lower frequencies (below about 2 kHz). Similarly, the compensation of a pre-existing middle ear pressure difference had the largest effect at the lowest frequencies (Figure 1). In the case of CSF-pressure manipulations, these effects can be described with a transmission model of the middle ear (Zwislocki 1962; Avan et al, 2000).

Conclusions

Our results indicate that equilibration of middle ear pressure by altering the pressure in the ear canal may increase TEOAE amplitudes. This may be important in diagnostic procedures. In some children, compensating middle ear pressure may facilitate the detection of otoacoustic emissions and quickly exclude a possible sensorineural hearing loss, thus making extensive additional auditory investigation unnecessary.

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