Selected Publications on middle ear pressure and otoacoustic emission testing

(Pressurized OAEs)

This collection consists of 14 selected papers discussing middle ear pressure and otoacoustic emissions written over a period of 11 years. The papers describe the difficulties surrounding obtaining otoacoustic emissions in the presence of abnormal middle ear pressure and suggested improvements using pressurization techniques in otoacoustic emission testing.

The abstract[1] for each paper follows the reference providing an overview of the research conducted and the conclusions found.

Hauser, R., Probst, R., & Harris, F.P. (1993). Effects of atmospheric pressure variation on spontaneous, transiently evoked, and distortion product otoacoustic emissions in normal human ears. *Hearing Research, 69*(1), 133-145.

Abstract

The effects of atmospheric pressure changes on the frequency and amplitude of spontaneous (SOAEs), transiently evoked (TEOAEs) and distortion product (DPOAEs) otoacoustic emissions in normally hearing humans were compared. The purpose was to determine if the transmission of each form of OAE was influenced differently by the middle ear. Sixty-one subjects were tested in a pressure chamber. Twenty-seven SOAEs with a frequency range between 535 to 4729 Hz from 21 subjects were examined. Transiently evoked OAEs were studied in 20 subjects using clicks and tone-bursts at 0.5, 1, 2, 3, and 4 kHz. Distortion-product OAEs were generated at seven geometric mean frequencies between 1 and 8 kHz in another 20 subjects. Spontaneous OAEs were examined by applying atmospheric pressure up to 9 kPa and down to -2.5 kPa, for the measurement of TEOAEs and DPOAEs the pressure was varied from 0 kPa up to 8 kPa. In spite of large inter-individual differences, results suggest that the influence of pressure on the three OAEs is frequency specific. The frequency and amplitude change of SOAEs, the modification of the amplitude and spectra of TEOAEs, and the amplitude change of DPOAEs are more influenced by changes in middle ear pressure below 4 kHz than are OAEs in the range at 4 kHz and above.

Hof J.R., van Dijk, P., Chenault, M.N., & Anteunis, L.J.C. (2003). Otoacoustic emissions at compensated middle ear pressure: preliminary results. *International Congress Series, 1254,* 159–163.

Abstract

OBJECTIVE: *Otoacoustic emissions (OAEs) are widely used for assessing congenital and early-acquired sensorineural hearing loss in young children. Middle ear pathology has a negative effect on the presence of OAEs. In this study we investigated whether measuring OAEs at compensated middle ear pressure (CMEP) resulted in a higher pass rate than at ambient pressure. Secondly, we analyzed the influence of 12 different pass definitions on the pass rates.*
METHODS: *One hundred and eleven children (age 1-7 years, mean 4 years and 5 months) were measured twice in one session: first at ambient pressure and then at CMEP.*
RESULTS: *The study showed a higher pass rate of OAEs at CMEP than at ambient pressure. A two-step scenario reduced the number of fails by 18-26%, depending on the pass/fail definition used.*
CONCLUSION: *Measuring OAEs at CMEP results in higher pass rates. Secondly, pass/fail definitions have a large influence on pass rates and this issue deserves further attention. Further studies must be done, before this method is readily applicable to universal neonatal screening.*

[1] http://www.ncbi.nlm.nih.gov/pubmed/

Hof, J.R., Anteunis, L. J. C., Chenault, M. N., & van Dijk, P. (2005). Otoacoustic emissions at compensated middle ear pressure in children. ***Int J of Audiol, 44***(6), 317-320.

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.

Hof, J.R., de Kleine, E., Avan, P., Anteunis, L.J., Koopmans, P.J., & van Dijk, P. (2012). Compensating for deviant middle ear pressure in otoacoustic emission measurements, data, and comparison to a middle ear model. ***Otol Neurotol, 33***(4), 504-511.

Abstract

OBJECTIVE: *Deviant middle ear pressure has a negative effect on the forward and backward transmission of stimulus and emissions through the middle ear. Resolving this deviant middle ear pressure is expected to lead to better middle ear transmission and, as a result of this, stronger otoacoustic emissions, which are better detectable. We investigated the effect of compensation o a deviant tympanic peak pressure on click-evoked otoacoustic emissions (CEOAEs). Second, we compared patient data to model predictions made by Zwislocki's middle ear model.*
SETTING: *University Medical Center.*
PATIENTS: *Fifty-nine children aged between 0.5 and 9 years (mean, 4.4 yr).*
INTERVENTION: *Hearing investigations including CEOAE measurements at ambient and at compensated tympanic peak pressure (TPP).*
MAIN OUTCOME MEASURE: *CEOAEs at ambient and compensated TPP.*
RESULTS: *Compensation of TPP resulted in higher emission amplitudes below 2 kHz (increase of 8-11 dB). In addition, the compensated measurement showed an increased phase lag (up to one-fourth cycle). For ears with mild deviations of TPP, Zwislocki's model could describe these changes. Pressure compensation was well described by a compliance increase of the tympanic membrane, the malleus, and the incus.*
CONCLUSION: *Compensating the ear canal pressure for negative tympanic peak pressure increased CEOAE amplitudes below 2 kHz and increased the phase lag. These changes can be predicted from an increase of the compliance of the tympanic membrane, incus, and malleus, as a consequence of the pressure compensation.*

Marshall, L., Heller, L.M., & Westhusin, L.J. (1997). Effect of negative middle-ear pressure on transient-evoked otoacoustic emissions. ***Ear & Hearing, 18***(3), 281-226.

Abstract

OBJECTIVE: *The purpose of the study was to illustrate the effect of negative middle-ear pressure (MEP) on both the stimulus and response of transient-evoked otoacoustic emissions (TEOAEs) and the effect of compensating for negative pressure in the middle ear by pneumatically introducing pressure into the ear canal. Simulation of negative MEP by introducing positive pressure into the ear canal also was examined.*
DESIGN: *TEOAEs were measured over 6 mo in a subject who frequently had negative MEP out to -150 daPa. Compensation was done for MEPs of -105, -135, and -165 daPa. Simulation of negative pressure was done for these same pressures. The effect of a pressure differential across the eardrum on the stimulus spectrum was measured at 100, 200, and 300 daPa. All measurements were made on the same subject.*
RESULTS: *Small amounts of negative MEP significantly affected both stimulus and response spectra. The simulated negative MEP approximated actual MEP at MEPs of -105 and -135 daPa. At -165 daPa, a divergence between the two spectra occurred below 2.0 kHz. Compensation for negative MEP by pneumatically introducing pressure into the ear canal essentially returned both spectra to that seen when the MEP was close to ambient pressure, at least for frequencies above 1.5 to 2.0 kHz. At lower frequencies, compensation resulted in increased TEOAE amplitude relative to the amplitude at ambient pressure.*

CONCLUSIONS: *Small amounts of negative MEP may affect TEOAE spectra and potentially influence the reliability of the test. For long-term monitoring of TEOAEs, MEPs either should be near ambient pressure or should be compensated for by an equivalent pressure in the ear canal.*

Naeve, S.L., Margolis, R.H., Levine, S.C., & Fournier, E.M. (1992). Effect of ear-canal airpressure on evoked otoacoustic emissions. *J Acoust Soc Am, 91*(4), 2091-2095.

Abstract

The effect of ear-canal air pressure on click-evoked otoacoustic emissions was measured for pressures ranging from 200 to -200 daPa and stimulus levels ranging from 60-90 dB PeSPL. Positive and negative ear-canal pressures (relative to ambient pressure) reduced the emission amplitude by 3-6 dB. A spectral analysis of the emissions revealed that the effect of ear-canal air pressure is that of a high-pass filter with a cutoff frequency of 2600 Hz and a slope of 4 dB/oct. The spectral changes are the expected effect of an increase in stiffness of the middle ear and were independent of pressure polarity and click level. Ear-canal air pressure substantially reduced the reproducibility of the emission waveform, in many cases rendering the emission indistinguishable from background noise. The implication of these findings for hearing screening applications is that a high false alarm rate may occur in normal-hearing patients with intratympanic air pressures that are significantly different from ambient pressure.

Perez, M., Delgado, R.E., & Ozdamar, O. (2011). Design of a clinically viable pneumatic system for the acquisition of pressure compensated otoacoustic emissions. *Conf Proc IEEE Eng Med Biol Soc, 2011*, 7699-7702.

Abstract

Otoacoustic emission (OAE) screening is perhaps one of the most common diagnostic tools used on both adults and children alike to clinically asses hearing health. However small to moderate middle ear pressures (both positive and negative), which are quite prevalent among the general population, are known to significantly reduce the OAE response specifically among frequencies below 2 kHz. This study focuses on the design and development of a software controlled syringe pump which will be used for the automatic compensation of middle ear pressure. This study reports validating test results which confirm the feasibility of using this system for future clinical trials.

Plinkert, P.K., Bootz, F., & Vossieck, T. (1994). Influence of static middle-ear pressure on transiently evoked otoacoustic emissions and distortion products. *Eur Arch Otorhinolaryngol, 251*(2), 95-99.

Abstract

Otoacoustic emissions (OAE) are influenced in their amplitude and frequency spectra by the middle ear. The effects of changes in the middle ear transmission mechanisms on transiently evoked OAE (TEOAE) and distortion product emissions (DPOAE) were investigated as a function of static ear canal pressure in 25 normal-hearing test persons aged 18-35 years. The ear canal pressure was varied stepwise between positive and negative values of 200 daPa. TEOAE and DPOAE amplitudes were attenuated significantly with changes of the static ear canal pressure, with greatest changes at low frequencies (< 2 kHz). The alterations of OAE amplitude were slightly dependent on the polarity of the pressure, with positive pressure producing a greater attenuation (0.6 dB). The results demonstrate that changes in middle ear impedance can cause a misinterpretation of OAE. To avoid this problem, tympanometry should always precede OAE measurements. Alternatively, both methods can be combined using one acoustic probe, so that the emissions can be evoked at the peak of middle ear compliance.

Prieve B.A., Calandrucccio L., Fitsgerald T., Mazevski A., Georgantas L.M. (2008). Changes in transitent-evoked otoacoustic emission levels with negative tympanometric peak pressure in infants and toddlers. *Ear & Hearing, 29(4),* 533-542.

Abstract

OBJECTIVES: *Otoacoustic emission (OAE) testing is now a standard component of the diagnostic audiology protocol for infants and toddlers and is an excellent tool for detecting moderate-to-profound cochlear hearing loss. Detection of hearing loss is especially important in infants and toddlers. Unfortunately, middle-ear dysfunction has a high incidence in this age range and can confound interpretation of OAEs. The goal of the study was to determine how transient-evoked otoacoustic emission (TEOAE) and noise levels were different when tympanometric peak pressures (TPP) measured from tympanograms were normal versus negative in the same individual. Another goal was to determine how TEOAE screening pass rates using a priori pass criteria were affected on days when TPP was negative.*
DESIGN: *TEOAE and noise levels were collected in 18 cases under 2 conditions: on a day when the tympanogram TPP was normal and on a day when the tympanogram TPP was negative. Data were collected from 11 children aged 3 to 39 mo, some of whom were tested more than once. Paired t tests were performed to determine whether there were changes in overall TEOAE and noise levels and TEOAE and noise levels analyzed into half-octave bands. A one-way ANOVA was performed on differences across half-octave bands to determine whether TPP affected TEOAE levels for some frequency bands more than others. Equality-of-proportion Z tests were run to determine whether there were significant differences in the percentage of "passes" on days when TPP was negative and TPP was normal.*
RESULTS: *Mean TEOAE level was lower when TPP was negative, but noise levels did not change between the 2 conditions. Mean TEOAE levels were lower for all frequency bands from 1000 to 4000 Hz and no significant differences were found among the mean reduction across frequency bands. There were no significant differences in the percentage of passes between TEOAEs collected on days when TPP was normal and when TPP was negative.*
CONCLUSIONS: *Mean data indicated that when tympanograms had negative TPP, TEOAE level was lower by approximately 4 dB across all frequency bands. However, this affected the pass rate in only 5% to 6% of cases. Although the number of participants in the current study was small, the data suggest that it is possible to measure TEOAEs in children with negative TPP. If emission-to-noise ratio is used to identify hearing loss in mid-to-high frequency bands, the majority of children will still have TEOAEs that meet clinical criteria, this providing the clinician with important information about cochlear status.*

Sun, X.M. (2012). Ear canal pressure variations versus negative middle ear pressure: comparison using distortion product otoacoustic emission measurement in humans. *Ear & Hearing, 33*(1), 69-78.

Abstract

OBJECTIVE: *For more than a century, positive and/or negative ear canal air pressure (ECP) has often been employed to simulate negative middle ear pressure (MEP) in exploring the latter's effect on hearing sensitivity and outcomes of various physiological assessments of the auditory system. However, systematic investigation is lacking on validation of these practices. This study was aimed at comparing these air pressure variations in humans in terms of effect on distortion product otoacoustic emissions (DPOAEs) and discussing certain issues pertaining to the middle ear transfer function.*
DESIGN: *The 2f1 – f2 DPOAE was measured for nine f2 frequencies from 600 to 8000 Hz in 27 adult ears under four air pressure conditions: normal MEP, negative MEP, and positive and negative ECPs. The subjects voluntarily induced negative MEPs with magnitudes ranging from -40 to -420 daPa, as estimated by the tympanometric peak pressure. For each negative MEP, positive and negative ECPs were applied, respectively, at the same magnitude in absolute value as the negative MEP after it was equalized. Negative MEP and ECP variations were compared in terms of change in DPOAE level.*
RESULTS: *Positive ECP resembled negative MEP, showing a distinct frequency-specific model of effect on DPOAE level: (1) DPOAEs were attenuated the greatest for frequencies at and below 1000 Hz, which increased from 4-6 to 10-12 dB with increasing the pressure for the tested range; (2) DPOAE attenuation decreased with increasing frequency and was minimal at 2000 Hz; and (3) DPOAE level significantly declined for the frequencies between 2000 and 6000 Hz and tended to increase for high frequencies. Compared with a negative MEP, an equivalent negative ECP yielded a smaller reduction of DPOAE levels for frequencies below 2000 Hz, as well as 3000 Hz, but greater reduction for frequencies above 4000 Hz. One phenomenon that occurred under all three air pressures was a minimal change of the DPOAE level at 2000 Hz. This resulted in a peak at 2000 Hz in the DPOAE level change versus frequency function.*

CONCLUSIONS: *Effects of negative MEP and ECP variations on DPOAEs in human ears are comparable, to a great extent, to findings from previous studies on hearing sensitivity in humans and tympanic membrane vibration at the umbo in human temporal bones. The present study demonstrates that positive ECP can be used to simulate negative MEP in research on the middle ear function in live humans. Results also suggest that long-lasting beliefs regarding the ECP effect on the middle ear conduction should be amended: (1) only positive ECP, not negative ECP, attenuates sound transmission more for low frequencies than for high frequencies, and (2) positive ECP has a greater effect than negative ECP only for low frequencies and not for high frequencies. Discussion of the present results together with those from previous studies sheds light on the middle ear dynamics under diverse pressure changes across the tympanic membrane and proposes that distorted configuration of the tympanic membrane and ossicular chain is the key factor in the effect of MEP or ECP on the middle ear sound transmission for low frequencies.*

Sun, X., & Shaver, M.D. (2009). Effects of negative middle ear pressure on distortion product otoacoustic emissions and applications of a compensation procedure in humans. *Ear & Hearing, 30*(2), 191-202.

Abstract

OBJECTIVE: *This study was intended to systematically examine the effect of negative middle ear pressure (MEP) on distortion product otoacoustic emissions (DPOAEs) and to validate a compensation procedure to account for negative MEP encountered in DPOAE measurement.*
DESIGN: *In experiment 1, the 2f1 – f2 DPOAE was measured for nine f2 frequencies from 600 to 8000 Hz in 16 adults under three MEP conditions: normal MEP, negative MEP, and compensated MEP. The subjects' voluntarily induced negative MEPs, with magnitudes ranging from -40 to -420 daPa, were measured tympanometrically with the tympanometric peak pressure. Each negative MEP was then compensated for by applying an equivalent amount of negative air pressure into the ear canal. The three MEP conditions were compared in terms of difference in DPOAE level. Experiment 2 was conducted to measure the DPOAE under normal and negative MEP conditions by using a different system with a higher frequency resolution in 19 subjects.*
RESULTS: *Negative MEP generally attenuated DPOAEs more for low frequencies than for high frequencies. For the frequencies of 1000 Hz and below, the mean DPOAE level was reduced by at least 4 to 6 dB for negative MEPs lower than -100 daPa (i.e., less negative). Reduction of the DPOAE level increased with increasing negative MEP (e.g., 10 to 12 dB for -160 daPa and higher, i.e., more negative). For f2 = 2000, 4000, and 6000 Hz, the effect of negative MEP was not significant. For 3000 Hz, DPOAE-level reduction was significant (e.g., 5 dB for MEP = -70 to -95 daPa and up to 12 dB for -290 to -420 daPa). As a result, a peak at 2000 Hz and a notch at 3000 Hz appeared in the DPOAE change versus frequency function. For 8000 Hz, DPOAE levels tended to increase in high negative MEPs, although the changes were not significant. Intersubject variability in the effect of negative MEP on DPOAEs was large. As the negative MEPs were compensated for, the decreased DPOAE levels were significantly corrected. DPOAEs measured with higher resolution in experiment 2 verified the frequency-specific effects of negative MEPs. Results revealed that the peak and notch in the DPOAE change versus frequency function shifted toward higher frequencies when negative MEP was increased, and a second peak emerged at a higher frequency.*
CONCLUSIONS: *Negative MEP substantially decreases DPOAE level for low frequencies and some mid-frequencies but tends to increase DPOAE level for high frequencies. Results suggest that any degree of negative MEP should be corrected to obtain an accurate outcome of DPOAE measurement. The MEP compensation procedure is effective in restoring normal DPOAEs in ears with negative MEPs. Examining changes in DPOAE level under negative MEP allows for further study of the transmission of acoustic signals through an altered middle ear system. A minimal change of DPOAE level at 2000 Hz indicates that the primary resonant frequency of the middle ear is lower than 2000 Hz. The variation in DPOAE change in the middle to high frequency range implies multiple resonances of the middle ear system.*

Trine, M.B., Hirsch, J.E., & Margolis, R.H. (1993). The effect of middle ear pressure on transient evoked otoacoustic emissions. *Ear & Hearing, 14*(6), 401-407.

Abstract

To determine the effect of middle ear pressure on transient evoked otoacoustic emissions (TEOAEs), emissions were recorded in ears with tympanometric peak pressures < or = -100 daPa and audiometric thresholds < or = 30 dB HL at 500 through 2000 Hz. TEOAEs were alternately recorded at ambient pressure and at the tympanometric peak pressure. As demonstrated for the 14 ears tested, equalization of the middle ear pressure increased TEOAE amplitude. Reproducibility was similarly improved in 12 of 14 ears. Unequalized middle ear pressure attenuated low frequency emissions more than high frequency emissions. These amplitude and *spectrum differences were consistent with previously reported observations of the effects of ear canal pressure on otoacoustic emissions. Results suggest that unequalized middle ear pressure may increase the occurrence of false positive failures, if otoacoustic emission testing is used for hearing screenings without consideration of middle ear pressure.*

Veuillet, E., Collet, L., & Morgon, A. (1992). Differential effects of ear-canal pressure and contralateral acoustic stimulation on evoked otoacoustic emissions in humans. *Hearing Research, 61*(1), 47-55.

Abstract

The effect of ear canal pressure variation (ECPV) on click evoked otoacoustic emissions (EOAEs) was compared to the suppressive effect observed with contralateral acoustic stimulation (CAS) in 11 healthy subjects. Both total EOAE amplitude and amplitude of 200 Hz frequency bands (22) were analyzed. Our results revealed that the ECPV as the CAS induced a decrease of the total EOAE amplitude; these two factors showed an additive effect when they are conjoint. The study of the EOAE frequency bands showed that the majority of them decreased under CAS and ECPV; however, a few bands are not affected. Moreover, it appeared that amplitude of the EOAE frequency bands were not modified in a similar way between the two factors: indeed some bands around 4.1 kHz did not decrease either by CAS or ECPV. These results suggest that these applied factors exert different actions on EOAEs. Moreover, the lack of a decrease effect for the same bands, both with CAS and ECPV, may explain the vulnerability of some cochlear locations.

Zebian, M., Schirkonyer, V., Hensel, J., Vollbort, S., Fedtke, T., & Janssen, T. (2013). Distortion product otoacoustic emissions upon ear canal pressurization. *J Acoust Soc Am, 133*(4), EL331-337.

Abstract

The purpose of this study was to quantify the change in distortion product otoacoustic emission (DPOAE) level upon ear canal pressurization. DPOAEs were measured on 12 normal-hearing human subjects for ear canal static pressures between -200 and +200 daPa in (50 ± 5) daPa steps. A clear dependence of DPOAE levels on the pressure was observed, with levels being highest at the maximum compliance of the middle ear, and decreasing on average by 2.3 dB per 50 daPa for lower and higher pressures. Ear canal pressurization can serve as a tool for improving the detectability of DPOAEs in the case of middle-ear dysfunction.