Positive Middle Ear Pressure versus Ear Canal Pressure Variations: A Preliminary Study with Wideband Power Absorbance in Humans

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Background: Recent studies demonstrated differences and similarities between negative middle ear pressure (nMEP) and positive and negative ear canal pressure (pECP and nECP) in effect on otoacoustic emissions (Sun, 2012, *Ear Hear*) and wideband power absorbance (PA) measured in the ear canal (Sun & Shaver, 2013, ARO). We postulate that there are difference and similarity between positive middle ear pressure (pMEP) and ECP in effect on wideband PA. Methods: Data were collected from 23 normal-hearing adults using a wideband tympanometry research system (Interacoustics). Wideband PA was measured from -0.223 to 8 kHz with two procedures: (1) at the ambient pressure (n=21); (2) with a tympanometry procedure, i.e., ECP swept from +200 to -300 daPa (n=11), under normal and pMEP conditions, respectively. Subjects produced pMEP by performing the Valsalva maneuver. MEP was estimated by a bandpass tympanogram peak pressure (BTPP). The effect of pMEP was defined as difference in PA between normal and pMEP conditions. Tympanometry data at BTPP under normal MEP was also subtracted from data with ECP manipulations under two MEP conditions to define three effects: compensation effect (PA at BTPP under pMEP) and pECP and nECP effects (PA at ECP = ± pMEP, respectively, under normal MEP). Results: Under pMEP (mean: 109.5 daPa), PA measured at the ambient pressure decreased for frequencies below 2 kHz (~0.33 at 1.1 kHz) and increased (up to 0.08) at 5 to 6 kHz. Similar PA changes by pMEP were shown when measured with the tympanometry procedure. The transition frequency for PA decrease and increase was at around 4 kHz. Difference in PA between the compensated and normal MEP conditions was small (<0.1). The PA changes by nECP and pMEP were similar for all frequencies. In contrast, pECP resulted in a larger reduction for low frequencies and larger enhancement for high frequencies (differences up to 0.1). Conclusions: Positive MEP substantially alters PA in a frequency-specific pattern. Compared with nMEP data previously reported, pMEP produces slightly less (~0.05) changes of PA for both low and high frequencies. Both pMEP and nMEP are common in individuals and their effects should be accounted for in establishing clinical PA norms. Compensation of pMEP with an equivalent ECP effectively rectifies the altered PA. This procedure may help achieve a more reliable diagnosis of middle ear diseases in ears with a concurrent MEP. The effects of nECP and pMEP are comparable, whereas the pECP effect is larger for both low and high frequencies.

Effects of Direction and Rate of Ear Canal Pressure Change on 1000 Hz Tympanograms

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The 1000 Hz tympanometry was suggested more reliable in testing infants. Absent research on procedural variables has resulted in difficulties in establishing clinical norms. Previous studies have demonstrated significant effects of several variables on 226 Hz tympanometry. The present study examined 1000 Hz tympanograms with four pressure sweep rates (12.5 to 600 daPa/s) in ascending and descending
directions in thirty adults. Tympanogram peak pressure and acoustic admittance measures ($Y_a$, $B_a$, and $G_a$) were analyzed for single-peak and notched tympanograms, respectively.

Negative Middle Ear Pressure versus Ear Canal Pressure Variations: Effects on Wideband Energy Absorbance Measurements in Humans

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Background: A recent study reported the effects of negative middle ear pressure (-MEP) and positive/negative ear canal pressure (±ECP) on the middle ear function using otoacoustic emissions (Sun, 2012). Wideband energy absorbance (EA) has been proposed to characterize the forward middle ear transfer function. It is determined by the ratio of absorbed to incident sound energy. This technique offers larger SNRs than otoacoustic emissions thus preventing underestimation by way of noise floor effects.

Methods: Data were collected from 34 adults with normal hearing using an Interacoustics wideband tympanometer. EA measurements were analyzed from 0.236 to 8 kHz with ECP swept from +200 to -300 daPa under normal and -MEP conditions. MEP was estimated by the bandpass tympanogram peak pressure (BTPP). Subjects produced -MEP by performing a Toynbee maneuver. Data were grouped into two MEP ranges: > -100 daPa (20 ears) and ≤ -100 daPa (23 ears). EA under normal MEP (at BTPP) was subtracted from EA with pressure manipulations to define four effects: (1) -MEP effect (EA under -MEP at the ambient pressure); (2) compensation effect (EA under -MEP at BTPP); and (3, 4) +ECP and -ECP effects (EA under normal MEP at ECP = ± (-MEP), respectively).

Results: Under normal MEP (mean = -15 daPa), mean ambient EA was ~0.07 and ~0.09 lower than EA at BTPP for the two groups. Under -MEP for Group 1, EA decreased for frequencies below 2 kHz (~0.38 at 1 kHz) and increased (up to ~0.13) above 2 kHz. For Group 2, the transition frequency for EA decrease and increase moved upward to 4 kHz with a maximal reduction of ~0.43 and enhancement of ~0.19. Difference in EA between compensated and normal MEP conditions was small (~0.05). The EA change by +ECP and -MEP was similar. In contrast, -ECP resulted in less reduction (~0.05) for low frequencies and less enhancement (~0.1) for high frequencies. Conclusions: Negative MEP substantially alters EA in a frequency-specific pattern. This effect is clinically important even in ears undergoing everyday MEP variations. These findings should be considered when establishing clinical norms. Application of an equivalent ECP in ears with -MEP effectively corrects the altered EA. This procedure may improve diagnosis of middle ear diseases with coexistent MEP. The effects of +ECP and -MEP are comparable while the -ECP effect is smaller. Positive ECP may be utilized to research -MEP effects on middle ear physiology.

Effects of Repetitive Measurements on Wideband Tympanometry and Energy Reflectance

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Wideband energy reflectance (ER) is a new procedure that assesses the middle ear function. Increase of the admittance in repetitive single-frequency tympanometry was reported, known as preconditioning effect. This study investigated this effect on ER with eight successive wideband tympanometry tests in
adults. Results revealed that repeated testing had frequency-specific changes in ER including significant increase and decrease. This effect should be accounted for to increase validity when repetitive wideband tympanometry is required in applications.

Effects of Repetitive Measurements on 1,000 Hz Tympanometry in Adults

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Previous studies reported that the admittance of low-frequency tympanometry varied with repeated testing, known as tympanometric preconditioning. This effect may place a methodological problem in research and clinical application. This study examined this effect on \( Y_a \), \( B_a \), and \( G_a \) in 1,000 Hz tympanometry with eight consecutive tests in thirty adults. Results show a trend that the magnitude of these measures increases in single-peaked tympanograms and decreases in notched tympanograms. Theoretical and clinical issues are discussed.

The sweep-frequency procedure for clinically estimating the middle-ear resonant frequency: data from ears with negative middle-ear pressure and implications

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A sweep-frequency procedure has been used for estimating the middle-ear resonant frequency (RF) in clinical tympanometry systems. It measures the acoustic susceptance for probe frequencies from 250 to 2000 Hz at a 200-daPa ear canal pressure and the tympanogram peak pressure and then calculates the difference (\( \Delta B \)). RF is defined as the frequency corresponding to the 0 crossing of the \( \Delta B \) vs. frequency function. A number of studies have suggested that RF has the potential of differentiating between stiffness- and mass-related middle-ear disorders. We tested the RF in 26 normal adult ears and in the same ears with a self-induced negative middle-ear pressure (MEP) between –50 and –245 daPa, using a modified test procedure. Results show that negative MEP causes an increase of RF by approximately 300 Hz on average. However, a correlation analysis displayed that the RF decreased as MEP became more negative, which is incongruent with the effect of increased stiffness on a system. Inspection of individual data exhibited unusual phenomena: (1) No RF was determined in eight ears (30%) because of no 0 crossing for the \( \Delta B \) frequency function, which may be projected to occur at a frequency above 2000 Hz; and (2) There were multiple crossings for the function in ten ears (38%) so that the crossing for the lowest frequency was always determined as the RF, which alludes to an underestimated RF. When data was grouped along with three MEP ranges, only the RF in ears of the low negative MEP group was significantly higher than that in normal ears. The RF in ears of the high negative MEP group tended to be lower than that of normal ears. The number of ears with unidentified RF increased with increasing negative MEP. These results denote limitations of the sweep-frequency procedure in estimating the RF of a stiffened middle ear. The present study also implies that acoustic resonance of the middle ear becomes broader with multiple RFs or RF ranges as the system is distorted by air pressure.
Effects of postural change on wideband energy reflectance measurements of middle ear function

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To advance the application of energy reflectance (ER) measurements, subject variables warrant investigations. Our study in adults revealed that postural change from upright to supine tended to alter the ER ratio in a frequency-specific pattern: increase for low-to-mid and decrease for high frequencies. This may be partially attributed to the verified significant but minor middle-ear pressure variation and predominately to intracranial pressure changes. Data was also repeatedly collected with certain manipulations at the two positions.

A study on noise-induced hearing loss in law enforcement officers

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Nose-induced hearing loss (NIHL) has not been well investigated in law enforcement officers. Our study demonstrated high prevalence of NIHL in this population. Ears with hearing loss displayed significantly elevated pure-tone thresholds for high frequencies, mostly with a notch audiogram at 4 kHz, and significantly decreased DPOAE amplitudes. Hearing sensitivity highly correlated with gun handedness. DPOAE amplitudes in ears with normal pure-tone thresholds also tended to be lower, indicating possible subclinical damage in the cochlea.

Immediate test-retest reliability of wideband energy reflectance in normal-hearing adults

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Immediate test-retest reliability quantifies reproducibility of a test from one measurement to another. This idealized retest reliability, with short inter-test time interval and no probe removal, should produce lower measurement error and higher correlations compared to measurements spanning days/weeks. Since probe removal/reinsertion is a common source of error in audiologic measures, the extent of this error needs to be identified. Wideband reflectance was measured in 48 normal-hearing adults—twice without removing the probe and once after reinserting the probe. A rationalized arcsine transformation was applied to all data due to non-normal distributions at select frequencies. Three components of retest reliability were determined at nine audiometric frequencies. Typical error at all frequencies was less when retest without probe removal was compared to retest with probe reinsertion. Significant differences were found at a few
frequencies in both test-retest conditions. While the reason for these changes is unclear, mean differences were typically smaller than random error suggesting that they are not clinically significant. Retest correlations were >0.95 for all frequencies without probe removal but ranged between 0.63 and 0.9 with probe reinsertion. These findings suggest that test-retest reliability in normal-hearing adults is good but that probe positioning contributes to the total error component.

**Tympanometric Preconditioning in Negative Middle-Ear Pressure**

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Tympanometric preconditioning, a phenomenon of increasing middle-ear admittance with repetitive trials of tympanometry, was studied in ears with normal and self-induced negative middle-ear pressures (MEP). The preconditioning effect on ambient $Y_{tm}$ is minimal under negative MEP, indicating an association with the initial admittance of ears. The effect on peak $Y_{tm}$ is significantly different between normal and negative MEPs, implying the effect is not only determined by the tympanic membrane. Theoretical and clinical issues are discussed.

**Resonant Frequency in Self-induced Negative Middle-Ear Pressure**

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Resonant frequency (RF) of the middle ear was evaluated by a sweep-frequency procedure in the same ears with normal and voluntarily produced negative middle-ear pressure (MEP). Results indicate that the conventional compensation process for estimating RF at peak tympanometric pressure is valid in eliminating the effect of negative MEP. Applying a modified procedure for testing at ambient pressure, the study also demonstrates that the actual RF in ears with sole negative MEP significantly shifts upward.

**A Preliminary Study on Simultaneous Testing of Auditory Brainstem Responses and Transient-Evoked Otoacoustic Emissions**

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Auditory brainstem responses (ABRs) and transient-evoked otoacoustic emissions (TEOAEs) have been clinically utilized for decades in evaluating functional status of the sensory and neural components of the auditory system. To counteract their shortcomings in diagnosing or screening hearing loss, the two techniques have been included in certain test batteries, thus they complement each other. Few previous
studies also proposed an alternative—simultaneous measurement of ABRs and TEOAEs, which should help reduce the testing time and cost. However, this new procedure has not been systematically investigated. The present study examined the simultaneous ABR/TEOAE procedure in 29 normal-hearing adults and compared it with the conventional procedure—individual measurement of ABRs and TEOAEs. For both procedures, clicks (75 µs, rarefaction in polarity) were presented at 75 dB SPL through an insert earphone. Preliminary data analysis shows that the difference between the simultaneous and individual tests in TEOAE amplitude is, on average, within 1 dB for all five frequencies from 1 to 4 kHz. The difference in TEOAE signal-noise ratio is within 1 dB for three frequencies, but around 2 dB for 2 kHz and 3 kHz. The difference in TEOAE reproducibility is within 0.03. Similar outcomes were revealed as well for these TEOAE measures in terms of test-retest difference of the simultaneous procedure. It is also displayed that, for ABR tests, the difference between the simultaneous and individual procedures is 0.2 ms or less in latency for ABR waves I, III, and V, and is 1 ms or less in the interwave latencies. The difference between the two procedures in amplitude is within 0.03 µV for all three ABR waves and 0.05 µV for the wave V/III ratio. Results of the present study demonstrate similar outcomes of the simultaneous ABR/TEOAE procedure and the individual procedures. This indicates that the simultaneous ABR/TEOAE test warrant further investigations for potential clinical applications.

Efforts of Negative Middle-Ear Pressure on Wideband Energy Reflectance

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Recent studies have demonstrated superior diagnostic performance using wideband energy reflectance (ER) compared to conventional tympanometry. Negative middle-ear pressure (MEP) is a highly prevalent, and often transient, form of middle-ear dysfunction. Ears with more substantial middle-ear dysfunction may present with concurrent negative MEP thus making ER test interpretation ambiguous. If negative MEP was compensated for by applying a negative ear-canal pressure, test performance could be preserved. The present study examined the effect of voluntarily-produced negative MEP on ER measurements from 226 to 8000 Hz in normal ears. Data for compensated MEP was derived from a sweep-pressure ER test. Thirty-five subjects were able to produce at least one negative MEP ranging from –40 to –220 daPa. Negative MEP significantly increased ER for frequencies from 500 to 1500 Hz while decreasing ER for 4000 or 6000 Hz, depending on the amount of MEP. Magnitude of changes and frequency at which maximum change occurred increased as MEP became more negative. Compensation of negative MEP restored ER to near baseline values. This study demonstrates that sole negative MEP alters ER in a frequency-specific pattern—transmission is impeded for low- to mid-frequencies and enhanced for high frequencies; the compensation procedure eliminates effects of negative MEP.