Original Article

Effect of Head Position on Distortion Product Otoacoustic Emissions

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Abstract

Objectives The study aimed to explore the impact of various head positions on the distortion product otoacoustic emissions (DPOAE) amplitudes, identifying the specific DPOAE frequencies showing the effect was also of interest.

Materials and Methods DPOAEs were recorded from the right ears of 50 normal-hearing individuals in six head positions, supine, and five sitting positions (head erect, roll left, roll right, pitch backward, and pitch forward). DPOAEs were averaged and measured for their overall and frequency-specific amplitudes at 1 kHz, 1.5 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, and 8 kHz.

Statistical Analysis To investigate the statistical significance of the observed mean differences, the data was tested using repeated measures of analysis of variance (ANOVA) following the Shapiro–Wilk normality test. The pair-wise comparison was tested using the Bonferroni post-hoc test and one-sided Bayesian paired sample t-test.

Results The results of ANOVA revealed a significant main effect of head posture only at 1 kHz. The Bonferroni post-hoc test and one-sided Bayesian paired sample t-test results showed significantly higher DPOAE amplitude in the head erect compared to the supine position. There were no significant differences between other pairs of head postures.

Conclusion Head posture is a trivial influencing factor of DPOAEs and hence, does not require consideration in interpreting DPOAEs.

Keywords
- intracranial pressure
- DPOAEs
- head posture
- middle ear stiffness

Introduction

Distortion product otoacoustic emissions (DPOAEs) are evoked OAEs generated when the cochlea is stimulated by two pure tones with frequency ratios between 1.1 and 1.3.[1] Since the inception of DPOAEs, it has been a prominent tool for detecting outer hair cell dysfunction, differential diagnosis among various sensorineural pathologies, and characterization of cochlear physiology. Body posture during the assessment is one of the many procedure-related factors affecting DPOAEs.

Postural change is known to induce changes in transient evoked otoacoustic emission (TEOAE) amplitude, latency,[2] and response phase and has been attributed to the differences in intracranial pressure (ICP).[3] The effect of body posture on the amplitudes of DPOAEs is reported to be maximum in the supine position compared to erect posture and predominantly at low frequencies, below 2 kHz.[4] The mechanism underlying the influence of posture change-induced cochlear changes is less understood. The widely accepted view is that postural changes induce intracranial hydrostatic pressure (ICP) gradient variations. Since the

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cranial cavity has an incompressible volume, the pressure change gets transferred to the cochlear fluids through the cochlear aqueduct. This tiny tube runs through the otic capsule of the temporal bone, connecting the posterior cranial base to the basal turn of the cochlea.[5,6] The rise in intracochlear pressure leads to increased stiffness of the middle-ear system, thereby reducing DPOAE amplitudes.[6] The influence of ICP changes is relatively better reflected on DPOAEs due to the stiffness-induced reduction in the forward transduction of stimulus and the reverse transduction of the generated distortion products.[6]

Typically, the clinical recordings of DPOAEs are done in a sitting posture, except in infants and very young children. Hence, DPOAE decrement associated with reclined posture (as in supine) shall not be present. However, the effect of different head positions within sitting posture on DPOAEs is not explored. Depending on the seating arrangement and the habitual influences, the position of the head is likely to vary within the sitting posture. Further, in addition to the body position (supine vs. erect), changes in the position of the head are also known to cause changes in ICP.[7] Though studies in the past have explored the effect of body positions on DPOAEs, there is a dearth of explorations on the impact of head positions on DPOAE parameters. If head position affects DPOAEs, it could act as a procedural variable in both clinical and research domains. Further, DPOAEs have been proposed as a noninvasive method for monitoring ICP for research as well as medical conditions such as hydrocephalus, brain tumors, and other brain injuries.[8] Along similar lines, recently, Kemp et al proposed DPOAEs as a measure of space-flight-induced ICP change, which is crucial in abating space flight-associated neuro-ocular syndrome.[9] This study would throw light on the intricacies of the ICP pressure influence on cochlear functioning and aid in developing and advancing DPOAEs as a tool for ICP monitoring. Hence, this study was taken up to investigate the effect of different head positions on the DPOAE amplitudes.

Method

Ethical Consideration

Prior to the execution of the study, ethical committee approval was obtained from the institutional ethical committee, and informed consent was obtained from each participant in accordance with the World Medical Association Declaration of Helsinki.[10]

Participants

This study employed a repeated measures research design, and 50 normal-hearing adults (25 females) were recruited through volunteer sampling from students of the parent university through open social media invitation. Their age ranged from 18 to 25 years (mean age: 21.4 years ± 2.72). Any subject with significant otologic history or history of noise exposure was excluded from the study. As part of the subject selection criterion, all the participants had to undergo a routine audiological evaluation to rule out auditory dysfunction.

Test Environment and Instrumentation

All the audiological tests were administered in a sound-treated audiometric room with noise levels within the permissible limits.[11] A pure-tone audiometer, Inventis Piano (Inventis, Italy), connected to a Sennheiser HDA 200 transducer and Radioear B-71 bone vibrator, was used for pure-tone audiometry. The audiometer was calibrated in compliance with the American National Standards Institute/Acoustical Society of America.[12] Inventis Clarinet (Inventis, Italy) middle ear analyzer was used for immittance evaluation. DPOAEs were recorded using ILO-V6 (Otodynamics Ltd, 36-38, Beaconsfield Road, Hatfield, Herts, AL-10 United Kingdom) otoacoustic emission equipment. An indigenous protractor was used to determine the angle of the head position.

Procedure

Audiological Evaluation

As part of the routine audiological evaluation, all participants had to undergo immittance evaluation and pure tone audiometry to estimate air conduction and bone conduction thresholds. For the immittance evaluation, a probe tone of 226 Hz was used, and acoustic reflexes were elicited at 0.5 kHz, 1 kHz, 2 kHz, and 4kHz, for the ipsilateral and contralateral presentation of tones. Pure-tone audiometric thresholds were tested at regular audiometric octave frequencies of 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz, 4,000 Hz, and 8,000Hz using modified Hughson-Westlake procedure. The average of air conduction thresholds at 500 Hz, 1,000 Hz, 2,000 Hz, and 4,000Hz was used to classify the audiogram based on classification proposed by Goodman and adapted by Clark.[13,14] Only the participants who had normal audiograms with "A" type tympanogram and acoustic reflex present ipsilaterally and contralaterally participated in this study.

DPOAE Measurements

DPOAEs from the right ear of all participants were recorded in five head positions in a sitting posture (head erect, roll left, roll right, yaw backward, and yaw forward) and in the supine position. The participants were seated on a cushioned chair with a low backrest. For the yaw forward and yaw backward head tilts, the angle was ensured to be more than 45 degrees with reference to an imaginary line dissecting the auricle in the vertical. For the roll left and roll right head tilts, the angle was ensured to be more than 45 degrees, measured with the vertical plane of the nasal bridge as a reference.

A series of simultaneous pure-tone pairs of frequencies f1 and f2 ($f1 > f2$), with the ratio between f1 and f2 fixed at 1.22, was presented through the equipment probe. DPOAEs were recorded at seven f2 frequencies (1 kHz, 1.5 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, and 8 kHz). The intensity levels of the primaries were L1 (65 decibel sound pressure level [dB SPL]) and L2 (55 dB SPL). The stimulus was swept from 1 to 8 kHz sequentially. DPOAEs were averaged over 600 sweeps of stimuli. Noise rejection threshold of 6mPa was maintained to reduce noise interference during the DPOAE measurements.

The order of body/head positions was randomized to eliminate the order effect. Participants were instructed to swallow after each posture change to stabilize the middle ear pressure. A time interval of 60 seconds was given after each posture change, prior to the recording, for the ICP to stabilize. This time interval was based on the evidence provided in previous studies.[2,3,15] The probe placement was the same in all the head positions and was unaltered during the posture change, as ensured by plasticine filling around the probe. A stabilized ear canal SPL and relatively flat spectrum ensured a good probe fit.

DPOAE Analysis

DPOAEs were deemed present if the recorded response was 6 dB SPL above the noise floor at three adjacent test frequencies.[16] The overall DPOAE amplitudes (OADP) and DPOAE amplitudes at each test frequency and across head positions were noted and compared using further statistical analysis. The OADP was considered for analysis in this study as an indicator of the cumulative cochlear distortion production activity.[17]

Statistical Analysis

The group data across head positions were statistically analyzed using JASP 0.16.1[18] to determine the effect of head position on DPOAEs. The data was analyzed for descriptives followed by normal distribution using the Shapiro–Wilk test. Repeated measures ANOVA (RM ANOVA) and post-hoc test with Bonferroni correction were employed to test the effect of head positions. Further, a one-sided Bayesian paired sample t-test was used to find the probability of the occurrence of the findings from the post-hoc test.

Results

This study focused on testing the effect of different head positions on the DPOAE amplitudes. ►**Fig. 1** shows the OADP and standard DPOAE amplitudes at 1 kHz, 1.5 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, and 8 kHz in different head positions. A comparison across frequencies shows that the DPOAE amplitudes at all test positions were comparatively less at 1 and 8 kHz. On the other hand, comparison across head positions showed mean differences in the DPOAE amplitude, although there was no consistent trend across frequencies in how head position influenced DPOAEs.

The results of the Shapiro–Wilk test revealed a normal distribution of data ($p < 0.05$); hence, to investigate the statistical significance of the observed mean differences, the data was tested using RM ANOVA. The results of RM ANOVA revealed a significant main effect of head posture at 1 kHz (F [5, 245] = 2.782, $p = 0.02$). There was no significant main effect of head posture on OADP (F[5, 245] = 1.896, $p = 0.10$), and at individual frequencies; 1.5 kHz (F [5, 245] = 0.796, $p = 0.55$), 2 kHz (F [5, 245] = 1.784, $p = 0.11$), 3 kHz (F[5, 245] = 0.338, $p = 0.89$), 4 kHz (F[5, 245] = 0.877, $p = 0.49$), 6 kHz (F[5, 245] = 0.661, $p = 0.63$), and 8 kHz (F[5, 245] = 1.692, $p = 0.13$).

As there was a significant main effect at 1 kHz, a pair-wise comparison was tested using post-hoc test with Bonferroni correction applied. The post-hoc test results showed a significant difference ($p < 0.01$) only between supine and head erect posture.

Further, the DPOAE amplitudes at 1 kHz between supine and erect positions were subjected to a one-sided Bayesian paired sample t-test. The Bayesian test compares the probability of compliance of data with the hypothesis. The hypothesis that the DPOAE amplitude at 1 kHz was higher in the erect position was tested against an alternative that the DPOAE amplitude at 1 kHz was higher in the supine position (►**Fig. 2**). The results revealed a Bayesian factor (BF_{+0}), suggesting that the data was 65.12 (error~3.773e-5) times more aligned with the alternative hypothesis than the null with a median effect size () of 0.48 indicating moderate

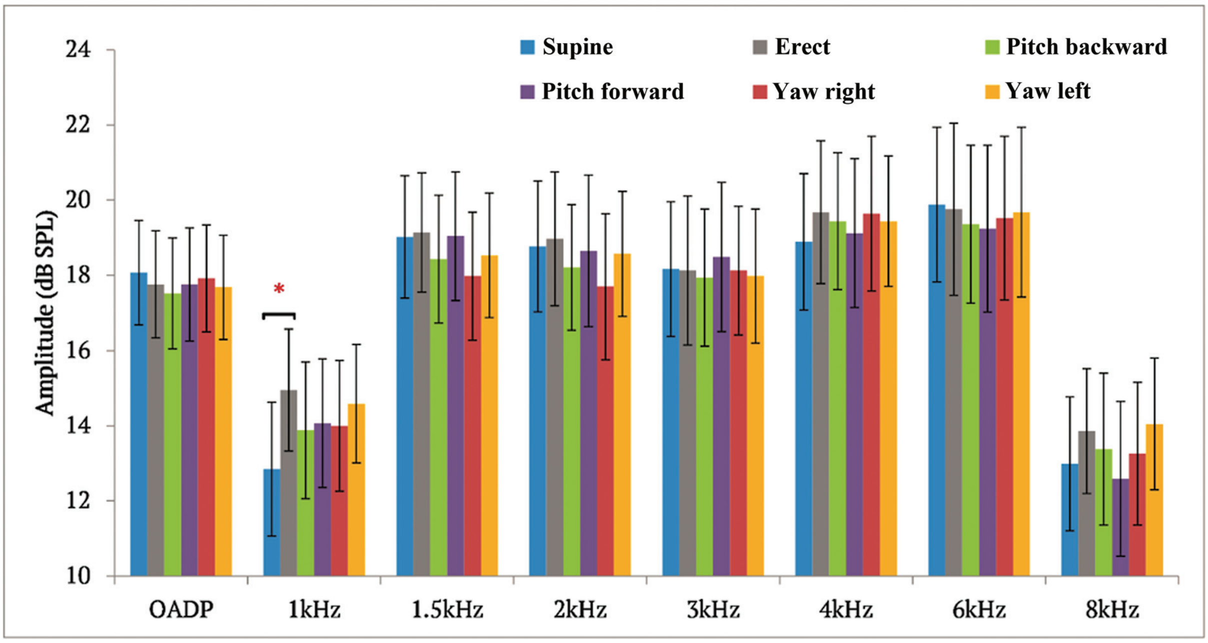

Fig. 1 Mean (and ± two standard deviation) of OADP and distortion product otoacoustic emission amplitudes. The asterisk symbol "*" denotes statistical significance. dB SPL, decibel sound pressure level.

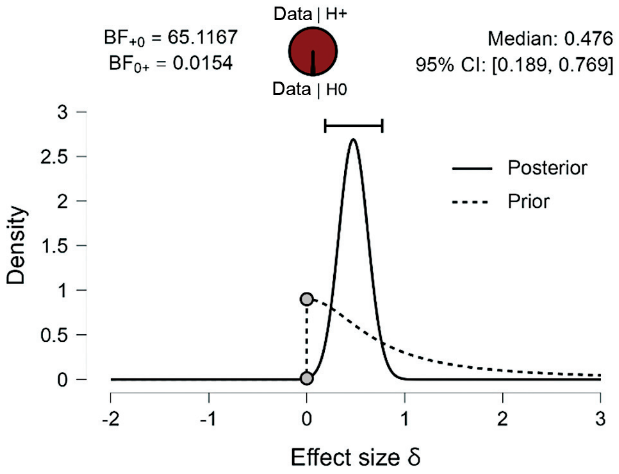

Fig. 2 The output posterior and prior plot for the one-sided Bayesian paired *t*-test. CI, confidence interval.

evidence for higher DPOAE amplitude in the erect position compared to supine position.

Discussion

This study investigated whether head position as a variable influences the DPOAE amplitudes across frequencies. The results showed a significant effect of the variable on DPOAEs at 1 kHz. In the supine position, DPOAEs are reduced in amplitude compared to the erect head position. The findings agree with earlier studies.[3,4,6,19] One can justify the results with two theoretical explanations.

Anatomically, the cochlear aqueduct connects subarachnoid space with the scala tympani.[20] Hence, any change in the cerebrospinal fluid (CSF) pressure will be reflected in the perilymphatic fluid pressure in the cochlea.[6] In the erect position, the CSF pressure and the blood flow to the cochlea will be lower than in the supine position or other head positions.[17] This might be due to the effect of gravity and the difference in the pathway of CSF and blood circulation.[21] Due to the comparatively lower pressure of the perilymphatic fluid in the erect position, the acoustic emissions generated by outer hair cells in the cochlea are transmitted with comparatively less loss. Reciprocal circumstances happen while a person is supine. Perhaps because of this, the amplitude in the erect posture has a relatively higher value.

The second explanation for the reduction in low-frequency OAEs is the increase in middle ear stiffness secondary to increased ICP.[6] The increased ICP gets transmitted to intralabyrinthine spaces and modifies the hydrostatic load on the stapes, thereby influencing the reverse transduction of DPOAEs.

In this study, significant decrement was seen only at 1 kHz. This is also in agreement with earlier findings,[3,4,6,19] which indicate the significant effect is expected below 2 kHz. Considering that the changes seen in OAEs are due to increased stiffness in the middle ear, a more significant effect on low frequencies can be justified considering the principles of impedance. The principles of impedance state that stiffness reactance (Xs) and frequency (f) are inversely related ($Xs = S/2\pi f$).[22] Hence, in increased ICP, which leads to an increase in middle ear stiffness, the backward transduction of the low-frequency OAEs will be more affected. Due to equipment limitations and clinically used protocol in this study, DPOAEs could not be measured below 1 kHz. Considering this theoretical reasoning, it is logical to assume that if one could measure low-frequency DPOAEs, the effect would have been more evident.

Also, it is interesting to note that ►**Fig. 1** shows that all the head positions except the head erect showed lower DPOAEs similar to the supine position. Although not statistically significant, the trend in the data contributes a unique piece of information. Change in the head position of greater than 45 degrees within the erect posture leads to a decrease in DPOAE amplitudes, but not to the extent of the supine position. The bed side evaluation of cochlear functioning, especially in the intensive care units, is administered with the patient in a supine or reclining posture. These findings, in tandem with the earlier reports, suggest that head posture-induced ICP changes might influence the findings in such a scenario and might need consideration in the interpretation. However, this needs to be further evaluated on a larger sample size, and the findings could be consequential to the clinical and research applications of DPAOEs.

Conclusions

This study explored the effect of head positions on DPOAE amplitude. The findings revealed that head posture has little bearing on the amplitude of DPOAEs. Hence, monitoring static head posture across trials or participants during the research applications and clinical evaluation using DPOAEs is trivial. However, future trends in research might extend the measurement of DPOAEs to frequencies lesser than 1 kHz. Maintenance of a static head posture might be essential in that case.

Ethical Disclosure

The authors hereby declare that the research article titled "Effect of Head Position on Distortion Product Otoacoustic Emissions" has been conducted following clauses of the Declaration of Helsinki (2013).

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Conflict of Interest

None declared.

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