Distortion-product otoacoustic emissions: body position effects with simultaneous presentation of tone pairs

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Abstract

This study examined the effect of three different body positions on distortion-product otoacoustic emission (DPOAE) amplitude and noise levels with multiple primary tone pairs simultaneously-presented to 36 normal-hearing female human adults. Other studies have demonstrated that the simultaneously presented tone pairs method shows clinical promise as a screener, but the sequential method remains in widespread clinical use. Postural changes have been suggested to have an effect not only on DPOAEs, but also transient-evoked OAEs and stimulus-frequency OAEs. DPOAE amplitude and noise levels were recorded in seated, supine, and side-lying positions to the following order of simultaneously-presented tone pairs relative to the f2 frequencies: 1187, 2375, and 4812 Hz; 1500, 3000, and 6062 Hz; and 1875, 3812, and 7625 Hz. No DPOAE could be detected reliably at 7625 Hz as result of poor signal-to-noise ratio. For remaining DPOAEs, statistical analyses revealed that amplitudes were not significantly different among the three body positions. However, at 1500 Hz and below, body position did have a statistically significant effect on noise levels though they are likely clinically negligible. Except at 7625 Hz, results suggest that DPOAEs recorded using a simultaneously presented tone pairs appear to be comparably recorded regardless of an individual's body position.

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Introduction

The utility of distortion-product otoacoustic emissions (DPOAEs) as a non-invasive, objective assessment of cochlear function has come a long way since it was first described by Kemp in 1979.[1] Despite the widespread clinical use of DPOAEs and its long list of published investigations, clinicians continue to have to judge the validity and reliability of their results in the face of numerous non-pathological factors including age, gender, ear differences, diurnal effects, race, and body position to name a few.[2] Within the last decade, another non-pathological factor was introduced as a change in instrumentation method involving sequential (single) versus simultaneous (multiple) presentation of paired primary tones.[3-7] The simultaneous method purportedly offers a one-third to one-half time-savings advantage compared to the sequential method. For example, Kim *et al.*[5] reported that it took between 40 and 80s to obtain DPOAEs to six tone pairs (1500, 2000, 3000, 4000, 5000, 6000, and 8000 Hz), whereas it only took 11 to 25s when two sets of three-tone pairs simultaneously (e.g., 1500, 3000, and 6000 Hz and 2000, 4000, and 8000 Hz). Beattie[3] also demonstrated the time-savings advantage in a different, but related study by evaluating DPOAE amplitude as a function of decreasing intensity levels in the sequential and simultaneous methods. The intensity levels began at L1 = 65 and L2 = 55 dB SPL and decreased in 5 dB steps together until they reached L1 = 40 and L2 = 30 dB SPL. Though Beattie only examined f2 frequencies of 1000, 2000, and 4000 Hz, the sequential method took an average of 313s, whereas the simultaneous method of all three-tone pairs took an average of 141s (again, about half the recording time). Lastly, Kumar *et al.*[7] compared sequential and simultaneous methods with eight tone pairs (500, 750, 1000, 1500, 2000, 2500, 4000, and 4500 Hz) in normal and hearing-impaired listeners. The average time administration time for the normal hearing subjects was 37 and 25s for sequential and simultaneous methods, respectfully. For hearing-impaired subjects, the average administration time was 160 and 51s, respectively. Again, the time-savings advantage of the simultaneous method is about half. Taken together, the time-saving advantage would be potentially useful for screening difficult-to-test patients before they become uncooperative (such as newborns) and for critically ill patients who are unable to complete audiometric testing or screening. Other potential advantages include affordability due to shortened test duration and allowing a professional to test more patients in a short amount of time.[3] Exactly how test time is shortened and the results are influenced is dependent on the methodology implemented. The simultaneous method is a generally well-known feature available on the GSI 60 Distortion Product Otoacoustic Emission system, but it is no longer being manufactured.

Though there are some methodological differences between previous sequential and simultaneous studies, the general consensus is that the measured DPOAE amplitudes are comparable between the two

methods. Additionally, it has been reported that DPOAE results are comparable between ears for both methods that the simultaneous method could be used to screen patients with hearing loss, and that noise levels tended to be higher using the simultaneous method. The benefits of the simultaneous DPOAE method are indeed promising; however, the effect of body position on DPOAEs and associated noise levels using a simultaneous presentation of multiple tone pairs is currently unresolved.

A seminal paper by Wilson[8] demonstrated that hydrostatically induced changes in middle ear pressure by changing body position significantly influenced auditory microstructure as measured using Békésy audiometry. Specifically, the configuration of the audiogram thresholds varied as much as 12 and 14 dB across test frequencies below 1000 Hz in upright and upside-down positions compared to the much flatter audiogram configuration in the horizontal position. Because of Wilson's findings, later investigators wondered if differences in body position would affect tests of cochlear hair cell function. Using an Otodynamics ILO292 system, de Kleine *et al*.[9] indicated that body position changes were most pronounced below 2000 Hz for both click-evoked and stimulus frequency OAEs. Using an ILO88, Fukai *et al*.[10] reported significant positional effects on click-evoked OAE measurement parameters including A-B difference, whole wave reproducibility, noise levels, and response amplitudes. At least one study has been conducted on the effect of body position on DPOAEs using the sequential method.[11] Using the Otodynamics ILO292 system, Driscoll *et al*.[11] found significant posture-related effects on DPOAE amplitude, signal-to-noise ratio, and noise levels. However, across these three studies, mean differences are only on the order of several dB across body positions. This suggests that the reported body position effects seen are not likely to be clinically significant and would not warrant changing the test protocol at this time. Where such minute changes in DPOAE amplitudes might be critical and relevant is in the application of neurosurgery where intracranial pressures can be non-invasively measured.[12,13] Unfortunately, due to stimulus and instrumentation differences, the effects of body position between DPOAEs and other OAE types cannot be directly compared, particularly with the simultaneous presentation method in mind.

Patients who would likely benefit from a shortened DPOAE test time are quite likely to be in positions other than sitting upright, such as reclining, supine, or side-lying. It seems instructive that if patients are not going to be in the same body position during DPOAE recordings, then any normative data associated with it must reflect that variability. Thus, the primary aim of this study was to describe the effects of body position on DPOAE amplitudes and noise levels in a cohort of young, adult females. It was hypothesized that there would be no clinically significant difference in DPOAE amplitudes among the three body positions. Moreover, it was anticipated that this study would be a useful contribution to the existing literature on another non-pathological factors with clinical promise.

Materials and Methods

Participants

Forty-three young adult females, between the ages of 18 to 35 years, were recruited voluntarily without compensation. Three subjects were initially excluded due a failed hearing screening or exhibited abnormal middle-ear function. Another four subjects completed the study, but their data were removed due to significant DPOAE test-retest reliability concerns. Ethical approval to conduct the study was obtained by the University of South Dakota human subjects review board. Each recruited subject was informed of the experiment's goals and procedures and signed a written consent form prior to determination of eligibility for the study. Subjects were excluded if they reported a history of chronic ear infections, significant head trauma, neurophysiologic pathology, and/or any major illnesses that resulted in treatment with ototoxic medications. For determination of eligibility, subjects were required to have otoscopically-clear ear canals, normal tympanic membrane landmarks, no external ear pathologies, normal middle-ear function defined as static admittance between 0.30 to 1.60 mL and tympanometric peak pressure between -100 and +25 daPa using a 226 Hz probe tone, and hearing at or better than 15 dB HL for audiometric frequencies 500 to 8000 Hz.

Procedure

DPOAE and noise measurements were obtained for the right ear only in three body positions: Seated upright (SE), supine (SU), and side lying (SL). In the SL position, subjects were placed on their left sides with their right ear toward the ceiling. Their head was cradled and supported by their left arm. To simulate clinical conditions, all measurements were obtained i) at least twice for each of the three body positions and ii) in a quiet room outside of a sound booth. The order of body positions was counterbalanced across subjects in order to control for possible habituation of DPOAE responses. A time interval of 30s was used before testing in each position in an attempt to stabilize the emission and reduce any possible effects related to postural changes. Subjects were instructed to swallow prior to each test run after postural changes to equalize middle-ear pressure. The probe tip was not removed between each test position, and was held in place manually by the investigator during postural changes to minimize movement. Administration time was not evaluated in this study given previous reports by others that the simultaneous method offers about a one-third to one–half time savings advantage.[3,5,7]

Equipment and stimuli

The GSI 60 Distortion Product Otoacoustic Emissions System was used for all DPOAE measurements. Responses were collected and processed by the GSI 60 application software Version 4.5 on a PC laptop with Windows 95 operating system. A probe assembly, consisting of two transducers and one microphone (standard Knowles Electronics EK3024 microphone), was inserted deeply in each participant's ear to reduce movement of the probe tip during positional changes. The microphone was used to measure the DPOAE with the ear canal. The probe was sealed in the ear canal with a removable soft-rubber eartip.

In order to extract the DPOAE response from background noise, the signal recorded from the ear canal was spectrally analyzed using the following frame parameters: a 16 ms sampling time window was divided into 512 Fast Fourier Transform (FFT) bins with a sampling rate of 32,000 Hz, and a bandwidth of 62.50 Hz. The minimum and maximum number of frames necessary per average was set between 200 and 1500. The maximum number of frames, number of sampling points, sampling rate, and bin width used were comparable to Kim *et al*.[5] and Schairer *et al*.[6] The highest sampling rate of 32,000 Hz available on the GSI 60 was selected to maximize frequency resolution. In addition, data acquisition criteria were set to match the following parameters: Testing at a given frequency was terminated when a signal-to-noise ratio of 10 dB was attained within the minimum and maximum number of averaged frames. Frames were rejected if they ever exceeded 30 dB SPL or if L1 and L2 ever differed by ±2 dB. Thus, testing was completed in a minimum of 3.2s if all criteria were met or a maximum of 24s even if all criteria were not met. In terms of noise measurements, there is a distinct difference between sequential and simultaneous methods. The noise floor is calculated as a root-mean-squared (RMS) average of the measured noise in the two bins (four total) on both sides of the DPOAE bin and is used largely to determine whether frames are

accepted or rejected. In other words, they are not true absolute noise level measurements. Whereas the noise floor is an averaged, independent measure for each of the sequentially-measured DPOAEs, the GSI 60 simultaneous method only gives noise floor measurements for the DPOAE of the lowest tone pair in the three tone-pair set. Thus, noise floor measurements are to be interpreted only as they relate to accepted frames, and when comparing the sequential and simultaneous method.

Nine tone pairs in groups of three were presented at 3 points per octave between 1000 and 8000 Hz using the *DP Stimulus* option within the GSI 60 Application software. The three tone pair sets were: 1187, 2375, and 4812 Hz, 1500, 3000, and 6062 Hz, and 1875, 3812, and 7625 Hz. All 2f1-f2 DPOAE data were examined relative to the f2 frequency. All tone pairs were selected to be presented at an f2/f1 ratio of 1.20 with L1 = 65 dB SPL and L2 = 55 dB SPL. It should be noted that in our decision to collect DPOAEs with nine tone pairs within our specified frequency range, we were cognizant of the fact that the some of the f2 frequencies were not presented at the typical test frequencies, but close approximations (e.g., 1187 Hz rather than 1000 Hz; see Technical Note).

Data analyses

The DPOAE amplitude and noise level values (all in dB SPL) for each f2 frequency in each body position were recorded in a database for statistical analysis. All analyses were completed using SPSS Version 14.0 (SPSS Inc., 2005) statistical analysis software package. Pearson product-moment correlation coefficients were calculated to compare the DPOAE amplitudes for runs 1 and 2 for each body position (SE, SU, and SL) at each f2 frequency. A second correlation analysis was also conducted to compare the averaged runs between body positions (SE *vs* SU, SE *vs* SL, and SU *vs* SL) at each f2 frequency. For comparison, a total of 9 pairs were accounted for resulting in 7 degrees of freedom (df) for significance testing. A two-way repeated measures analysis of variance (RM-ANOVA) was completed with DPOAE amplitude as the dependent variable and f2 frequency and body position as the two independent variables. A second two-way RM-ANOVA also was completed using the noise level as the dependent variable and the above-mentioned independent variables. DPOAE amplitudes and noise levels for run 1 and run 2 were averaged. This averaged value was used for all analyses. It should be noted that except for the 7625 Hz f2 frequency, runs 1 and 2 did not exceed 5 dB.

For the RM-ANOVAs, if Mauchley's test of sphericity was significant for a factor, the Greenhouse-Geisser epsilon was used to correct the *df* for the test of within-subject effects. Tukey (Q) pairwise post-hoc tests were completed for any significant main effects, and critical values were taken from the Studentized range distribution with the appropriate *df* and number of factor levels. If sphericity was not met, the Greenhouse-Geiser mean square error (*MSerror*) term was used in the Tukey analyses. In the case of a two-way interaction, tests of simple main effects were completed using one-way RM-ANOVAs, with F ratios and means comparisons calculated using the mean square error from the interaction. An alpha level of < 0.05 was used as the level of rejection for all tests.

Results

The means and standard deviations for each body position and f2 frequency are shown in Figure 1. The results for the two-way RM-ANOVAs for f2 frequency, body position, and f2 frequency-by-body position are displayed in Table 1 for both DPOAE amplitude and noise level. A Tukey post hoc analysis for frequency revealed that the DPOAE response amplitudes for 7625 Hz were significantly lower (essentially absent) than all other test frequencies except for 6062 Hz in all three body positions. No other significant differences in DPOAE response amplitude were found.

Pearson product-moment correlation coefficients were calculated separately for the different body positions to compare DPOAE response amplitudes for run one versus run two for each f2 frequency. Correlations were significant across all frequencies in each body positions except for 7625 Hz in the SE and SL positions. This indicated that measures in all three-body positions were stable at least across two runs except at 7625 Hz. The correlations for DPOAE response amplitude for run 1 versus run 2 for each body position are listed in Table 2. Pearson product-moment correlation coefficients also were calculated for the averaged runs for SE versus SU, SE versus SL, and SU versus SL. Correlations were significant for all averaged runs between SE and SU, SE and SL, and SU and SL except for 7625 Hz for SU versus SL. The correlations for DPOAE response amplitude for the averaged runs for SE versus SU, SE versus SL, and SU versus SL are listed in Table 3.

Table 1. Results of the two-way RM-ANOVA for F2 frequency, body position, and F2 frequency-by-body position.

	DPOAE amplitude		Noise level	
Factor	df	F	df	F
F2frequency	4.879, 170.772	55.920 ***	2.918, 102.132	99.334 ***
Body position	2, 70	1.361	2, 70	7.424 **
Freq-by-BP	6.486, 226.993	1.927	7.981, 279.318	1.235

**P<.01; ***P<.001; DPOAE, distortion-product otoacoustic emission.

Table 2. Correlations of DPOAE amplitudes for Run 1 versus Run 2 for each body position.

f2 Frequency (Hz)	SE	SU	SL
1187	.973*	.976*	.910*
1500	.983*	.979*	.979*
1875	.960*	.975*	.976*
2375	.987*	.909*	.985*
3000	.987*	.981*	.983*
3812	.982*	.990*	.981*
4812	.963*	.954*	.979*
6062	.940*	.964*	.931*
7625	.633	.685*	.558

*P<.05; DPOAE, distortion-product otoacoustic emission.

Table 3. Correlations of DPOAE Amplitudes for averaged Runs for SE versus SU, SE versus SL, and SU versus SL.

f2 Frequency (Hz)	SE-SU	SE-SL	SU-SL
1187	.923*	.959*	.947*
1500	.924*	.942*	.959*
1875	.949*	.958*	.964*
2375	.887*	.934*	.893*
3000	.937*	.934*	.933*
3812	.956*	.912*	.906*
4812	.950*	.943*	.920*
6062	.958*	.897*	.916*
7625	.745*	.753*	.663
7625	.633	.685*	.558

*P<.05; DPOAE, distortion-product otoacoustic emission.

The results for the two-way RM-ANOVA for f2 frequency, body position, and f2 frequency-by-body position for DPOAE noise levels were displayed previously in Table 1. The two-way RM-ANOVA revealed a significant main effect for frequency [F (2.918, 102.132) = 99.334, P<.001]. A Tukey post hoc analysis for frequency revealed that the DPOAE noise levels at 1500 Hz were significantly different (P<.001) from 2375, 3000, 3812, and 4812 Hz in all three body positions. Noise levels at 2375, 3000, 3812, and 4812 Hz were significantly different from 6062 and 7625 Hz in all body positions. Noise levels at 1187 Hz were significantly different from 7625 Hz in the SE and SL positions. Noise levels at 1875 Hz were significantly different from 3000 Hz in the SE and SU and 4812 Hz in the SU and SL positions. Noise levels at 1187 Hz were significantly different from 3000, 3812, and 4812 Hz, and 1875 Hz were significantly different from 7625 Hz only in the SU position. Noise levels at 1875 Hz were significantly different from 3812 Hz in the SL position.The two-way RMANOVA also revealed a significant main effect for body position (F (2, 70) = 7.424, P<.01). A Tukey post hoc analysis revealed that DPOAE noise levels were significantly different between the SE and SU positions at 1187 Hz. The frequency and body position interaction also was statistically different between the SE and SU and SE and SL positions at 1500 Hz. The interaction between frequency and body position was not significant (F (7.981, 279.318) = 1.235, P>.05). No other significant differences in DPOAE noise levels were found.

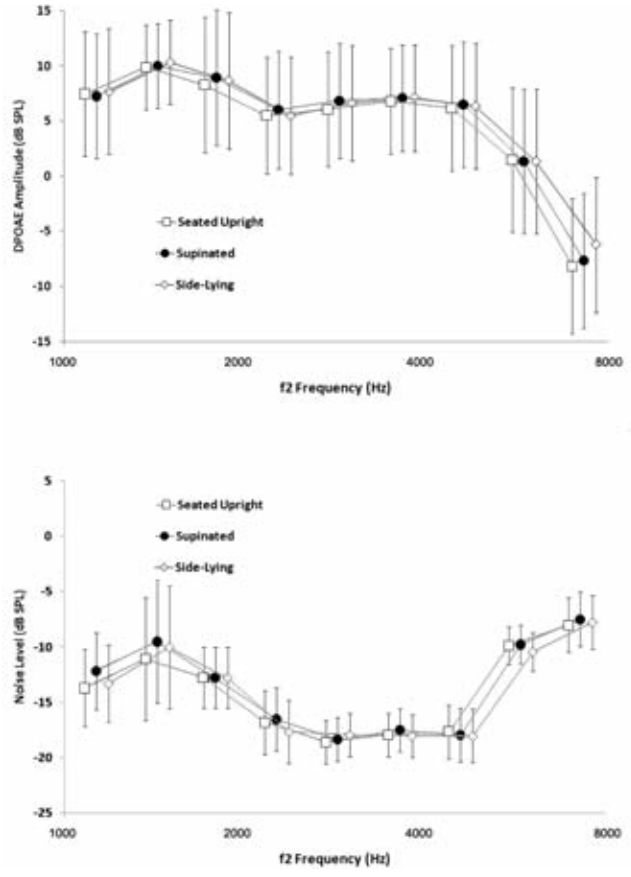

Figure 1. Mean DPOAE amplitudes and noise levels with ± 1standard deviations in dB SPL for seated (SE), supine (SU), and side-lying (SL) positions.

Discussion

Distortion-product otoacoustic emissions (DPOAEs) were evoked by three sets of three primary tone pairs that were simultaneously-presented in three body positions: seated upright, supine, and side-lying. DPOAE amplitudes were similar among the different body positions and at expected levels for all f2 frequencies except at 7625 Hz, which were essentially absent. The results suggest that body position may have no clinically significant effect on DPOAE amplitudes. Additionally, although administration time was not calculated in the presented study, it should be noted that the DP Stimulus option likely saved some additional test time by eliminating the need to load different protocols to present the three different sets of simultaneous tone pairs. In other words, once Go was clicked to begin the measurements, the computer recorded data for all three sets of simultaneous tone pairs in a sequential fashion (refer to Technical Note).

However, three major observations bear relevance for clinicians interested in using a simultaneous DPOAE protocol: The first observation is that the pattern of mean DPOAE amplitude across f2 frequency appears show a one maxima between 1000 and 1500 Hz and a second maxima around 4000 Hz (or 3812 Hz in the present study). This pattern has also been reported by Kim *et al*.,[5] Schairer *et al*.,[6] Kastanioudakis *et al*.,[4] and Kumar *et al*.[7] It is currently unknown why there are these two consistent maxima with simultaneous versus sequential methods; however, the complex cochlear interactions of multiple 2f1-f2 distortion products with other distortion products such as f2-f1 might be contributory.

The second observation is that noise levels were highest not only for the lowest three tone pairs, but also for the highest two tone pairs. The increased noise levels in the lower frequencies are not a new finding, as it is often seen in the sequential tone pair method. This low frequency noise is largely attributable to both biologic and environmental noise.[14] However, the increased noise levels for the higher frequency tone pairs has also been reported by both Schairer *et al.*[6] and Beattie,[3] but not by Kim *et al*.[5] or Kastanioudakis *et al.*[4] Some of the methodological differences among studies may partially explain the differences. For example, Kim *et al*.[5] and Schairer *et al*.[6] used the same intensity levels of L1=65 dB and L2=50 dB, but they differed in the stimulus/microphone probe assembly used (i.e., Etymotic Research ER-10B versus the standard probe assembly provided with the GSI 60). The present study, as well as Beattie[3] and Kastanioudakis *et al.*[4] all also used the standard GSI 60 probe; however, the intensity levels used were L1 = 65 dB and L2 = 55 dB. Except for Beattie,[3] all studies including the present study included stimuli at 6000 Hz and above and noise levels were notably higher than expected for sequential method.

The final observation is that the noise levels appear to be higher in the supine and side-lying positions at certain frequencies. These findings are similar to those reported by Driscoll *et al*.[11] and Fukai *et al*.[10] Driscoll *et al*.[11] reported < 3 dB between the highest noise level in the side-lying position and the lowest noise level in the seated upright position. Fukai *et al*.[10] reported <1 dB between the same positions. In the present study, the greatest noise level difference was only 1.8 dB between the SU and SE positions. It is believed the higher noise levels in the supine and seated positions may result from vibrations the test subject lying on a hard table.

Conclusions

While research has shown that different body positions can affect audiometric test results including DPOAEs, this study suggests that the

differences in DPOAE response amplitudes and noise levels may not be clinically significant between body positions. This demonstrates that multiple-tone-pair DPOAEs are a valuable clinical tool that provides comparable information to single-tone-pair DPOAEs regardless of an individual's body position during testing. In addition, this demonstrates that multiple-tone-pair DPOAEs continue to show great promise as a fast and reliable screening tool that is not influenced by different body positions likely to be encountered. However, further research is still needed using different stimulus protocols, using the GSI 60 software or comparable technical setup, in order to verify the reliability of results from this study with other stimulus protocols while in the supine, seated or side-lying position.

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