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The Effects of Body Position on Distortion-Product Otoacoustic Emission Testing

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Abstract

Otoacoustic emissions are frequently acquired from patients in a variety of body positions aside from the standard, seated orientation. Yet little knowledge is available regarding whether these deviations will produce nonpathological changes to the clinical results obtained. The present study aimed to describe the effects of body position on the distortion-product otoacoustic emissions of 60 normal-hearing adults. With particular attention given to common clinical practice, the Otodynamics ILO292, and the measurement parameters of amplitude, signal-to-noise ratio, and noise were utilized. Significant position-related effects and interactions were revealed for all parameters. Specifically, stronger emissions in the mid frequencies and higher noise levels at the extreme low and high frequencies were produced by testing subjects while lying on their side compared with the seated position. Further analysis of body position effects on emissions is warranted, in order to determine the need for clinical application of position-dependent normative data.

Key Words: Adult, body position, distortion-product otoacoustic emissions, hearing

Abbreviations: ABR = auditory brainstem response; DP-amp = distortion-product amplitude; DPOAEs = distortion-product otoacoustic emissions; NOISE = noise level; OAEs = otoacoustic emissions; SNR = signal-to-noise ratio; TEOAEs = transient evoked otoacoustic emissions

Sumario

Las emisiones otoacústicas se obtienen frecuentemente con los pacientes colocados en una variedad de posiciones, además de la posición convencional de sedestación. Sin embargo, existe poco conocimiento disponible sobre si estas desviaciones producen cambios no patológicos en los resultados clínicos obtenidos. El presente estudio buscó describir, en 60 adultos normo-oyentes, los efectos de la posición del cuerpo en las emisiones otoacústicas por productos de distorsión. Se utilizó un equipo Otodynamics ILO292, además de los parámetros de amplitud, tasa de señal-ruido y ruido, respetando los criterios comunes usados en la práctica clínica. Se revelaron efectos e interacciones significativas relacionadas con la posición para todos los parámetros. Específicamente, se produjeron emisiones más fuertes en las frecuencias medias y niveles más altos de ruido en las frecuencias graves y agudas, cuando se evaluó a los sujetos acostados en posición lateral, y los resultados se compararon con aquellos en posición sentada. Se necesita análisis adicional de los efectos de la posición del cuerpo sobre las emisiones, para determinar la necesidad de aplicaciones clínicas de los datos normativos dependientes de la posición.

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Palabras Clave: Adulto, posición corporal, emisiones otoacústicas por productos de distorsión, audición

Abreviaturas: ABR = respuesta auditiva del tallo cerebral; DP-amp = amplitud del producto de distorsión; DPOAE = emisiones otoacústicas por productos de distorsión; NOISE = nivel de ruido; OAE = emisiones otoacústicas; SNR = tasa señal-ruido; TEOAE = emisiones otoacústicas evocadas por transitorios

Since the first mention of otoacoustic emission (OAE) technology by Kemp in 1978, an exhaustive exploration of potential clinical applications has occurred. Additionally, researchers have successfully delineated many, but not all, of the pathological, nonpathological, instrumental, and environmental factors that may influence the clinician's interpretation of the OAE spectrum. Until the search for influencing factors has been concluded, it is not possible for the clinician to have unfailing confidence in the accuracy of all OAE applications. As noted by Hall (2000), one such factor that has not been extensively examined to date is that of body position. It is not uncommon for OAE testing to be conducted with the patient in a supine, or even one-sided, orientation. In fact, this is often the case in hospitals during bedside assessments and intra-operative monitoring. Ill clients may also be advised to recline during assessments conducted in community-based clinics, particularly if the test battery also includes auditory brainstem response (ABR) audiometry. Yet the clinician cannot currently be assured that such deviations from the traditional seated test position do not adversely, or otherwise, affect the OAE results obtained.

The effects of body position on hearing thresholds, sound localization, and middle ear measures have been well documented (Corso, 1962; Macrae, 1972; Lackner, 1974; Wilson, 1980; Daniel et al, 1985; Phillips and Marchbanks, 1989). The mechanisms associated with the body position effect, when the subject is in a supine position, are believed to be related to increased intracranial pressure. This, in turn, is reflected as increased perilymph pressure and venous blood pressure in the cochlea, and increased mucosal volume and stiffness of the middle ear (Wilson, 1980; Avan et al, 2000; Buki et al, 2000; Hall, 2000). Cumulatively, these studies suggest that auditory function is optimal with the subject in an upright position (Hall, 2000).

Less well documented have been studies concerning the effects of body position in relation to OAE testing, with most reports having only involved transient evoked otoacoustic emissions (TEOAEs) and small subject samples (Hall, 2000) and having only examined upright (standing/sitting) and recumbent head-down positions (varying from -10 to -40 degrees to the horizontal). Little attention has been given to distortion-product otoacoustic emissions (DPOAEs), another clinically utilized tool within the evoked class of OAEs. Also, prior investigations have not deliberated on how the body position effect alters the clinically obtained normative data of adults and children, using standard OAE measurement parameters. For example, Antonelli and Grandori (1986) and Phillips and Farrell (1992) were able to demonstrate body position-related changes in the TEOAEs of one and six subjects, respectively. In their investigations, TEOAE waveform amplitude and latency were measured, parameters that are rarely employed in a clinical (nonresearch) setting. Similarly, Buki et al (2000) displayed changes in TEOAE and DPOAE results due to the contributions of posture for groups of 5–12 subjects. These authors measured phase shifts in the emissions (a parameter not frequently utilized in routine clinical practice), as they were interested in the application of OAEs in the monitoring of intracranial pressure. Another of the limited number of studies previously undertaken (Froelich et al, 1994) failed to demonstrate any significant body position effects on TEOAE amplitude, based on five subjects. However, these researchers selected a stimulus intensity lower than normal clinical levels. Therefore, further investigation of the body position effect is warranted.

The primary aim of the present study was to describe the effects of body position on the DPOAE results of a large cohort of adults with normal hearing. Through enhancing the current literature on nonpathological factors affecting the DPOAE spectrum in a clinical context, the proposed investigation may contribute toward the development of efficacious analysis protocols.

MATERIAL AND METHODS

Subjects were recruited for participation from community sources in Brisbane, Queensland. All participation was voluntary, with written and verbal consent obtained prior to the commencement of data acquisition. Data collection was conducted by two final-year audiology students who operated under the direct supervision of a clinical/research audiologist. Subjects were tested individually, in a sound-treated room within the university's audiology clinic.

Subject selection was influenced by three restrictions. First, an age range of 21–40 years was applied, in order to reduce the likelihood of attracting participants with hearing impairment. The resulting mean age of subjects was 26.07 years (SD = 5.31). Second, it was expected that both genders would be represented in equal proportion. Therefore, the total group of 60 subjects (120 ears) included 30 males and 30 females. Third, all participants were required to pass otoscopic examination, pure-tone screening, and tympanometry testing, and have no significant history of otologic pathology.

Otoscopic results were considered to be "clear" in the absence of any pathologic indicators and cerumen occlusion. A pass status was awarded in pure-tone screening if a response was confirmed at 20 dB HL in both ears at all screening frequencies (0.5, 1.0, 2.0, 3.0, 4.0, 6.0 kHz). Participants were required to display type A tympanograms (determined using Jerger's [1970] classification system) in both ears in order to pass tympanometry testing. Otologic history was determined to be insignificant if the subject had never undergone ear, head, or neck surgery, had not experienced recurrent ear infections in childhood, and had not experienced any otologic infections that required medical treatment during the prior one-year period.

DPOAE testing and analysis was conducted utilizing the ILO292 Otodynamics Analyzer, connected to a desktop computer. The B-type adult probe with disposable foam tips was used for all subjects. DPOAE testing was completed three times for each ear, with the subject in three different body positions; seated upright, supine (with head pillow), and a one-sided orientation (with head pillow). The one-sided orientation involved the subject lying on his/her side rather than a simple head tilt; for example, when testing the left ear the subject would be lying on the right side of his/her body. The order of body positions was not randomized between subjects; that is, each subject was assessed in the above order of positions. Instead, the time delay between testing in each position was controlled (using a 30 sec interval) in an attempt to ensure stabilization of the emissions and to avoid any potential order effects upon the results. Such a method was selected in view of findings concerning the time course of postural changes to OAE phase shifts and amplitudes, with previous studies highlighting the adequacy of this delay duration (Antonelli and Grandori, 1986; Phillips and Farrell, 1992; Buki et al, 2000; de Kleine et al, 2001).

Further, the probe was not removed/refit between each test position. It was left in place as the subject was moved from a seated to supine to one-sided orientation. However, special care was taken to minimize probe movement, and the adequacy of probe fit was inspected prior to the commencement of data acquisition in each position. A series of simultaneous pure-tone pairs, of frequencies f_1 and f_2, at intensities of 65 dB SPL (L_1) and 55 dB SPL (L_2), respectively, were delivered to the test ear and produced a DP-gram. Optimal results in humans should be acquired using the chosen stimulus intensity levels, combined with a test frequency ratio (f_2/f_1) of 1.21 (Harris et al, 1989; Whitehead et al, 1995). Three points per octave were collected, and the distortion product emissions at $2f_1$-f_2 were measured.

Measurement parameters of interest included amplitude of the distortion product inclusive of the noise floor (DP-amp) and signal-to-noise ratio (SNR), defined as DP-amp minus noise floor (at +2 SD), at f_2 frequencies of 1.0, 1.2, 1.5, 2.0, 2.5, 3.1, 4.0, 5.0, and 6.3

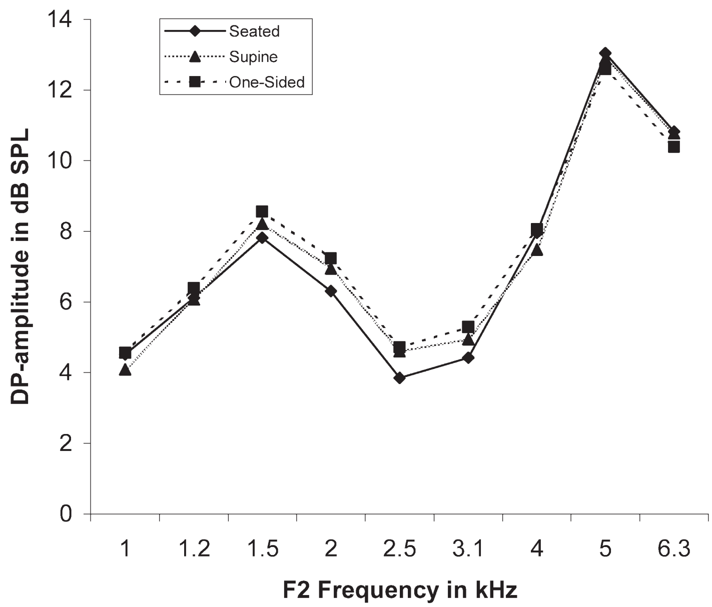

Figure 1. Distortion-product amplitude as a function of f_2 frequency for three body positions.

kHz. DP-amp is the parameter most regularly displayed in DPOAE systems and, therefore, in the research literature. SNR allows the researchers to view DPOAE generation without the inclusion of artifactual noise. The noise floor at +2 SD (NOISE) was included in the analyses as a third parameter of potential interest. To investigate the effects of body position on these measurement parameters at each of the f_2 frequencies, a multivariate analysis of variance (MANOVA), with one between-subjects factor (gender [male/female]) and repeated measures on three factors (ear [left/right], frequency, and body position [seated/supine/one-sided]), was performed on the data. The significance of any term was assessed using a 95% confidence level.

RESULTS

A significant body position effect was found for all DPOAE parameters: DP-amp [$F(2,120) = 4.104$, $p = 0.022$], SNR [$F(2,120) = 3.781$, $p = 0.026$], and NOISE [$F(1,120) = 8.494$, $p = 0.005$]. A significant frequency effect was also evident: [$F(1,120) = 37.211$,

Table 1. Effects of Body Position on Distortion-Product Amplitude (DP-amp) Values Obtained for 120 Ears

f_2 Test Frequency	Mean Seated	(SD)	Mean Supine	(SD)	Mean One-Sided	(SD)
1.0	4.52	(5.93)	4.09	(6.91)	4.56	(6.14)
1.2	6.11	(6.80)	6.07	(6.93)	6.40	(7.56)
1.5	7.82	(5.07)	8.22	(5.43)	8.56	(5.28)
2.0	6.31	(5.36)	6.95	(5.33)	7.23	(5.23)
2.5	3.85	(5.61)	4.61	(5.37)	4.72	(5.73)
3.1	4.42	(5.47)	4.95	(5.65)	5.29	(5.25)
4.0	7.95	(5.90)	7.49	(5.91)	8.06	(5.50)
5.0	13.04	(5.98)	12.88	(5.52)	12.59	(5.62)
6.3	10.82	(6.41)	10.78	(6.26)	10.39	(6.46)

Table 2. Effects of Body Position on Signal-to-Noise Ratio (SNR) Values Obtained for 120 Ears

f_2 Test Frequency	Mean Seated	(SD)	Mean Supine	(SD)	Mean One-Sided	(SD)
1.0	8.08	(7.16)	5.80	(8.23)	5.15	(7.91)
1.2	12.45	(7.87)	11.30	(8.13)	10.67	(8.41)
1.5	16.12	(5.80)	16.89	(6.12)	16.18	(6.26)
2.0	17.55	(6.07)	17.77	(6.00)	17.76	(6.20)
2.5	15.58	(5.84)	16.81	(5.63)	16.03	(6.94)
3.1	17.97	(5.86)	18.82	(6.01)	18.39	(6.19)
4.0	21.98	(6.36)	21.71	(6.32)	21.97	(6.12)
5.0	26.60	(5.98)	26.77	(5.53)	25.77	(6.11)
6.3	25.04	(7.12)	24.67	(6.61)	23.70	(7.18)

$p < 0.001$], [$F(1,120) = 149.323$, $p < 0.001$], and [$F(1,120) = 342.914$, $p < 0.001$], respectively. Further, a significant position x frequency interaction appeared for all parameters: [$F(9,120) = 2.986$, $p = 0.002$], [$F(1,120) = 5.540$, $p = 0.022$], and [$F(8,120) = 3.832$, $p < 0.001$], respectively. No significant gender or ear asymmetry effects were displayed.

Regarding the effect of body position, a significant difference was observed between mean DP-amp values obtained while seated and those obtained while in the one-sided orientation [$F(2,120) = 7.177$, $p = 0.008$]. In other words, DP-amp mean values were generally higher (by <1 dB) when subjects were tested in the one-sided position (see Figure 1). This effect was observed to be significant particularly for the f_2 test frequencies of 1.5, 2.0, 2.5, and 3.1 kHz. No significant difference was found between mean values obtained in the seated position and those from the supine position. The mean DP-amp values obtained for each body position appear in Table 1.

The SNR parameter behaved in a similar pattern to DP-amp. Again, a significant difference was observed between mean values obtained while seated and those obtained while in the one-sided orientation [$F(1,120) = 5.618$, $p = 0.019$]. Like DP-amp, mean SNR values were generally higher in the mid frequencies when subjects were tested in the one-sided position. However, the body position effect was only found to be significant for the f_2 test frequencies of 1.0, 1.2, 5.0, and 6.3 kHz, where mean values from the one-sided position were lower than those obtained from the seated position. Further body position comparisons were insignificant. The mean SNR values obtained for each body position are contained in Table 2.

For the NOISE parameter, a significant difference was again noted between mean values obtained while seated and those obtained while in the one-sided orientation [$F(1,120) = 14.317$, $p < 0.001$]. In particular, the significant effect was noted for the f_2 test frequencies of 1.0, 1.2, 2.0, and 6.3 kHz. However, a significant difference also existed between mean values obtained in the supine versus one-sided position [$F(1,120) = 6.345$, $p = 0.013$], for the 1.2 and 1.5 kHz f_2 test frequencies. In essence, mean NOISE values tended to be higher (by <3 dB) when subjects were tested in the one-sided position rather

Table 3. Effects of Body Position on Mean Noise Level (NOISE) Values Obtained for 120 Ears

f_2 Test Frequency	Mean Seated	(SD)	Mean Supine	(SD)	Mean One-Sided	(SD)
1.0	-3.55	(5.19)	-1.71	(5.53)	-0.59	(6.10)
1.2	-6.38	(4.63)	-5.20	(4.90)	-4.12	(5.21)
1.5	-8.31	(3.97)	-8.66	(3.89)	-7.62	(4.96)
2.0	-11.24	(3.72)	-10.82	(4.26)	-10.23	(4.92)
2.5	-11.74	(3.65)	-11.96	(4.19)	-11.31	(4.00)
3.1	-13.53	(3.32)	-13.65	(3.73)	-13.10	(3.22)
4.0	-14.03	(2.78)	-14.16	(2.26)	-13.67	(3.43)
5.0	-13.56	(2.41)	-13.50	(3.61)	-13.19	(2.18)
6.3	-14.21	(2.93)	-13.88	(2.74)	-13.30	(3.00)

Table 4. Summary of the Effects of Body Position on the Distortion-Product Amplitude (DP-amp), Signal-to-Noise Ratio (SNR), and Noise Level (NOISE) Values of 120 Ears

f_2 Test Frequency	DP-amplitude	SNR	NOISE
1.0		*	*
1.2		*	* †
1.5	*		†
2.0	*		*
2.5	*		
3.1	*		
4.0			
5.0		*	
6.3		*	*

*Denotes significance (at $p < 0.05$) between seated and one-sided positions
†Denotes significance (at $p < 0.05$) between supine and one-sided positions

than the seated and supine positions. The supine position was associated with lower values than the one-sided position. Refer to Table 3 for mean NOISE values recorded per body position. A summary of the significant body position effects found (per frequency) for the DPOAE test parameters, DP-amp, SNR, and NOISE, can be viewed in Table 4.

DISCUSSION

The current examination of DPOAEs in adult subjects with normal hearing sensitivity revealed that the nonpathological factor of body position does, in fact, exert a significant influence on results. The clinically measured test result parameters of DP-amp, SNR, and NOISE were all affected by the body position of the subject during testing. The effects of gender and ear asymmetry did not significantly impinge on the DPOAE data obtained, consistent with previous reports that suggest minimal or nil effects on DPOAE amplitude (Hall, 2000). Some researchers have proposed that the lack of such effects on DPOAEs, as opposed to TEOAEs, may be associated with the former's independence from the influence of spontaneous emissions (Hall, 2000).

The significant effect of body position revealed in the current study was not found to be uniform across the f_2 frequency range (refer to Table 4). For the DP-amp parameter, mean values were higher for those tested in one-sided orientation versus seated position for the mid frequencies: 1.5, 2.0, 2.5, and 3.1 kHz. For the SNR parameter, mean values were *lower* for those tested in one-sided orientation versus seated position for the low and high frequencies: 1.0, 1.2, 5.0, and 6.3 kHz. While for the NOISE parameter, mean values were higher for those tested in one-sided orientation versus seated position for a variety of frequencies; 1.0, 1.2, 2.0, and 6.3 kHz. Further, mean values were higher for those tested in the one-sided orientation versus supine position for 1.2 and 1.5 kHz.

From this varying position x frequency interaction across parameters, it can be proposed that for the DP-amp measure, subjects produced stronger emissions in the mid frequencies when they were in a one-sided orientation than when simply seated. That is, higher DP-amp values in the mid frequencies with the absence of higher NOISE levels could indicate that the DP-amp elevation was due to increased emission strength rather than increased noise contribution. The exception would be for 2.0 kHz, where higher DP-amp values coincided with higher NOISE values. However, even at this frequency, the presence of higher DP-amp values and higher NOISE values with increased rather than decreased SNR (although not significantly) could indicate that strengthening of the emission has occurred for subjects in the one-sided orientation.

For SNR, it is conceivable that the reduced values in the low and high frequencies obtained by subjects when in a one-sided orientation versus seated position was a result of higher noise levels in the low and high frequencies (with the exception of 5.0 kHz, which did not fit this pattern). Furthermore, although not statistically significant, SNR values were higher for subjects in the one-sided orientation versus seated position for the exact frequencies where significantly stronger emissions were detected for DP-amp.

Collectively, the findings of this examination support the notion that testing subjects while lying on their side will produce stronger emissions in the mid f_2 frequency range (1.5–3.1 kHz) and will also result in increased noise levels at the extreme low and high frequencies. With the current experimental design, it is not possible to provide any explanations regarding the underlying mechanisms responsible for such body position effects. It has yet to be clarified whether postural changes on OAE spectrums are primarily mediated by inner or middle ear alterations (de Kleine et al, 2001). It is assumed by many investigators that changes in body position (moving from a seated to head-down/supine orientation) will induce increases in intracochlear pressure, resulting in a bulging of the cochlear windows and, thus, an increase in stiffness (de Kleine et al, 2001). Further, it is thought that it is these particular alterations that provoke changes in OAE characteristics (Buki et al, 1996; de Kleine et al, 2001). Buki et al (2000), with the aid of a middle ear model, have also demonstrated that variations in the hydrostatic load of the stapes during postural changes may influence OAE features. Additionally, the role of intracochlear mechanisms beyond transmission issues requires further attention (de Kleine et al, 2001).

As previously noted, few studies are known to the authors with which to appropriately compare results of the present investigation. Most previous papers have referred to nonclinical OAE measurement parameters and have utilized TEOAEs rather than DPOAEs. In essence, past examinations of postural effects on DPOAEs have reported decreased amplitudes/levels subsequent to downward postural changes. The effect was often small in magnitude (e.g., 1–4 dB) and was most prevalent for frequency components below 2 kHz (Buki et al, 1996, 2000; de Kleine et al, 2001). In contrast, the current study found significant SNR decreases (seated versus one-sided orientation) for 1.0, 1.2, 5.0, and 6.3 kHz. The current effect was also small, being of the magnitude of <1–3 dB. To further compare and suggest explanations for the variance in outcomes between studies could be futile in view of much dissimilarity in methodology.

Regarding potential clinical applications arising from the present investigation, an awareness of body position, as a significant nonpathological effect, should occur during DPOAE testing of adults. Although position-related effects on DPOAE values appear to be small, the magnitude and direction of the effect, as well as the frequencies most likely to be affected, may differ depending on the clinician's measurement parameter of choice. In addition, in the event of using intrasubject differences (obtained from examining continuous DPOAE results) to make diagnostic decisions, due consideration should be given to the effects of body position. However, further analysis of these effects is warranted. Particularly, the effects of various body positions on test sensitivity and specificity should be examined in order to determine the need for clinical application of position-specific normative data.

Future investigations into the clinical effects of body position on DPOAEs should consider implementing methods to control middle ear pressure, as OAEs have been found to be affected by middle ear dynamic characteristics (Wada et al, 1995). For instance, it may be advisable to instruct subjects to swallow after postural changes, in order to promote stability (Buki et al, 2000). In fact, in view of the findings of these authors and those of the current study, clinicians should contemplate using such instructions as a matter of routine for all OAE testing. Replication of the present investigation, with a larger subject cohort, may also offer additional information regarding the noted positional effects.

In summary, this examination yielded the discovery of significant position-related effects on the clinical DPOAE data of adults. Specifically, stronger emissions were produced in the mid frequencies by testing subjects while lying on their side compared with the standard, seated position. Increased noise levels were also noted at the extreme low and high frequencies.

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