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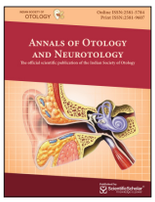

Original Article

Test-Retest Reliability of Distortion Product Otoacoustic Emissions Input-Output Function in Younger Adults

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ABSTRACT

Objectives: Distortion product Oto Acoustic Emission (DPOAE) is an objective test to identify the cochlear functions. Previous studies have reported various factors such as probe insertion and reinsertion, frequencies and levels of primary tones, and the mode of presentation, either single-frequency or multi-frequency mode. These results indicated there might be redundant factors that are confounding in nature during the test, and hence, there is a need to study those factors to assure reliability. The current study aimed to determine the test-retest reliability of DPOAE input-output functions.

Material and Methods: Sixty young female college-going students aged 18–25 years were taken for the study. The subjects underwent DPOAE input-output function in the Intelligent Hearing Systems Duet instrument on the following frequencies: 703 Hz, 1060 Hz, 1416 Hz, 2114 Hz, 2827 Hz, 4243 Hz, and 5645 Hz. To measure intra- and inter-test reliability, the DPOAE test was conducted within and between days. The area and slope of the DPOAE input-output were calculated.

Results: The analysis of the study shows good test-retest reliability for the slope and area of the DPOAE input-output function based on Cronbach's alpha values and repeated measures analysis of variance (ANOVA).

Conclusion: This indicates that the slope and area of DPOAE are stable measures that can be clinically used for evaluation and can be used for research studies. The DPOAE input-output function is an efficient tool for assessing cochlear functioning and understanding cochlear nonlinearity.

Keywords: Area, Distortion product otoacoustic emission, Input-output, Reliability, Slope.

INTRODUCTION

Otoacoustic emissions (OAE) is a commonly used test in audiological test batteries to evaluate the integrity of hair cells in the cochlea, specifically the OHCs (outer hair cells). Kemp first reported it has more sensitivity in identifying cochlear hearing loss.[1] Otoacoustic emission originates from the cochlea and transfers through the middle ear, the external auditory canal. It can be recorded through a probe placed inside the ear.[2] The OAEs can be spontaneous, which means the emission of sound from the cochlea without any external stimulus. Another type of OAE is evoked OAE, which is produced as a response to any auditory stimuli. Distortion Product Otoacoustic Emission (DPOAE) is an evoked OAE that depends on two stimuli at different frequencies and tone levels combined to give the input and output function of the cochlea, which the microphone can pick up. The slope of the input and output functions of the OAE varies based on the tone levels, which indirectly represent the current status of the cochlea in terms of its functioning. Hence, the input-output (I/O) function of DPOAE serves as an essential and reliable test in identifying sensorineural hearing loss, specifically cochlear hearing loss. Since OAE has been found to be sensitive in identifying cochlear health, it is vital to establish the reliability of the test without any discrepancies across the time of testing to use it in clinical populations.[3] Previous studies have reported more significant test and re-test reliability within the same subjects.[4,5]

Many factors can influence the test and re-test reliability of the DPOAE, specifically the noise floor during the test time. These noises can be subjective or environmental,

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affecting the lower frequencies predominantly.[5] Studies have reported that ecological noises primarily affect low frequencies compared to high frequencies.[6] This factor was supported by a Roede et al.[7] survey in which they measured OAE in different frequencies ranging from 800 Hz to 8000 Hz. The test results showed more variations in frequencies lower than 1000 Hz and above 6000 Hz. These changes are attributed primarily to instrumental and environmental noises.[7] Another factor influencing the test outcomes is the probe fitting due to the resonance change between the stimuli and the external auditory canal, which can more possibly affect the low-frequency regions. The stimulus intensity level is another factor that influences the OAE results, as reported in previous studies. One study that supported this finding was done by Roede et al.,[7] where they reported more variability in the results found in lower stimulus levels, and the reason attributed was the clinical change in the cochlea.[7] Since there are many variabilities due to the various influencing factors, it is crucial to determine how many variations are acceptable to report a test as reliable. It was found that a 7 dB difference across different repeated recordings was considered statistically significant with a 95% confidence interval.[6] DPOAEs must be repeatable if they are to be helpful. The dependability of DPOAEs can be evaluated by comparing the level of the primary tones (L1 and L2) of distortion-product (Ld) set to moderate intensities [i.e., 50–75 dB sound pressure level (SPL)]. In the clinic, these particular primary levels are frequently applied. DPOAEs obtained by moderate-level primaries can be measured with reliability, according to a number of studies.[6–9] The fact that every participant in these studies had hearing thresholds within normal limits may be significant to note. Data on the accuracy of DPOAE measurements in subjects with hearing impairment are limited. This can be attributed to the fact that the subjects with normal hearing produce large responses that are significantly above the noise floor. Smaller responses from hearing-impaired subjects lead to a reduced signal-to-noise ratio, thus compromising the accuracy of these measurements.

Previous studies have been done on human and non-human primates to check the reliability of DPOAE functions. One such study was on the common marmoset. The results showed reliability is high when there are high primary tones.[10] Previous studies compared the test and re-test reliability of DPOAE to the behavioral thresholds in humans.[11] and reliability across various frequencies precisely between 1 kHz and 8 kHz. The results showed the frequency range from 6.5 kHz to 7 kHz is reliable in measuring cochlear damage.[12] Studies have been done on younger children and the pediatric population because of their less exposure to noise, which is one of the confounding variables in OAE.[13] Studies are showing good test-retest reliability of OAE. But to date, there is a shortfall in studies showing the test and re-test reliability of DPOAE input-output (I/O). Test-retest reliability of DPOAE was also reported in children with normal hearing,[13,] and the results showed variability in the DPAOE thresholds, especially in the high frequencies, which can be attributed to the interferences in the ear canal due to the standing waves. A study done by Franklin et al. (1992) with 12 healthy adults with normal hearing showed that reliability was high for higher primary levels (L2 > 55 dB SPL) and vice versa.[8] Since there is a shortage of studies in generalizing the result outcomes, there is a need to study the young adult participants to correlate the findings with those of children. Previous studies have reported various factors such as probe insertion and reinsertion, levels and frequencies of primary tones, and the mode of presentation, single-frequency or multi-frequency modes.[9] These results indicated there might be redundant factors that are confounding during the test, so there is a need to study those factors to assure reliability. The present study aims to evaluate the test-retest reliability of DPOAE input-output functions. The objectives are to measure the intra-test reliability by administering the test within a day. In addition, to measure the inter-test reliability by administering the test between the days.

MATERIAL AND METHODS

Participants

A total of sixty college-going young female adults aged between 18 and 25 years (mean age: 19.6 years) participated in the present study. The inclusion criteria were individuals with no significant history of any relevant external middle ear disorders, neurological symptoms, intake of ototoxic drugs, exposure to loud sounds, and family history of hearing loss.

Procedure

Screening Procedures

All the participants were screened for normal hearing using a standard diagnostic test battery. To estimate the air conduction thresholds, bone conduction thresholds, speech recognition thresholds, and speech identification scores using a calibrated clinical audiometer (Inventis Padova, Italy) with Telephonics Dynamic Headphones 39 earphones enclosed in MX-41/AR supra-aural ear cushions and Radio Ear B-71 bone vibrator transducers. Immittance evaluation was carried out using a calibrated Inventis Clarinet (Inventis Padova, Italy) middle ear analyzer. Transient evoked otoacoustic emissions measurements were recorded for both ears using the Intelligent Hearing Systems Duet (IHS, Miami, FL)

equipment. An inclusion criterion for a normal peripheral auditory system is as follows: All the participants had hearing sensitivity thresholds within normal limits (≤15 dB HL) for the air conduction at the octave frequencies from 250 Hz to 8000 Hz and bone conduction at the octave frequencies from 250 Hz to 4000 Hz using the modified Hughson-Westlake procedure in both ears.[14] In tympanometry, a bilateral "A" type tympanogram with an acoustic reflex threshold is present in both ears.[15–17] In addition, the presence of transient otoacoustic emissions in both ears.[18,19] All the participants met the inclusion criteria and underwent further evaluation. All the tests were conducted in an acoustically treated room. The permissible noise level of the room was as per American National Standards Institute (ANSI)/American Standards Association (ASA) S3.1-1999 standards.[20]

DPOAE Input Output Function

The subjects underwent DPOAE input-output function in the Intelligent Hearing Systems Duet (IHS, Miami, FL) instrument on the following frequencies: 703 Hz, 1060 Hz, 1416 Hz, 2114 Hz, 2827 Hz, 4243 Hz, and 5645 Hz. To measure intra- and inter-test reliability, the DPOAE test was conducted within and between days. The within-day procedure is done by performing the DPOAE I/O function testing three times, including a baseline, at 30 minutes and 60 minutes. The between-day tests were conducted on the 1st, 7th, and 14th days. An average of three responses was determined for each individual response. Using the linear trend model, the slope was estimated. The DPOAE I/O data were fitted with linear functions for the stimulus range from 55 to 37 dB SPL. Once a linear fit was obtained, the slope was calculated at 2 points of the x coordinate equal with x2 = 55 dB SPL and x1 = 37 dB SPL. Given the corresponding points of the DPOAE amplitude as y2 and y1, the slope of the fitted linear function was defined as $b = (y2–y1)/(x2–x1)$.[21,22,23] The area under the curve was to be determined as the difference between the noise floor and the DP amplitude at all the 5 dB stimulus level steps from 55 dB SPL to 37 dB SPL. The additive amplitude of the DP responses higher than the noise floor was multiplied by five and expressed in $dBSPL^2$ ($area^2$). The square root of $area^2$ (i.e., area) was used for the analyses. This procedure for calculating the area was proposed by Gates et al.[24]

Ethical Consideration

All of the testing procedures were accomplished using a non-invasive technique in the current study and adhered to the conditions of the institutional ethical approval committee.

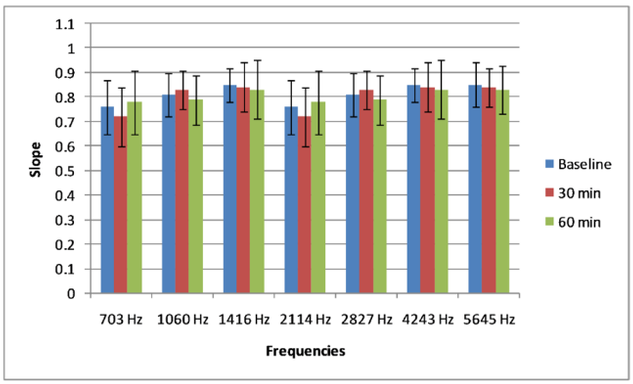

Figure 1: Mean and SD of intra-session DPOAE input-output slope at different frequencies. SD: Standard deviation, DPOAE: Distortion product otoacoustic emissions.

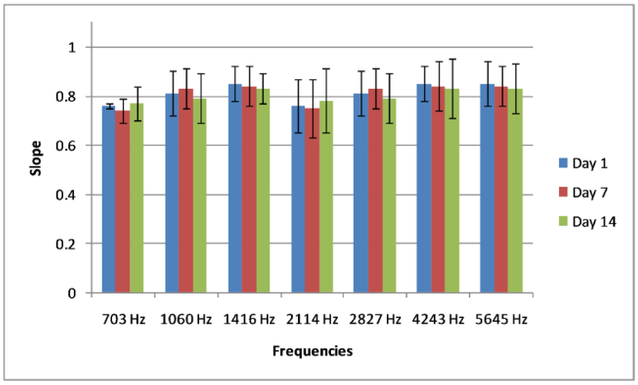

Figure 2: Mean and SD of inter-session DPOAE input-output slope at different frequencies. SD: Standard deviation, DPOAE: Distortion product otoacoustic emissions.

The test procedures were clearly explained to the participants before testing.

Statistical Analyses

The statistical analysis of the data was done using the Statistical Package for Social Sciences (SPSS). The Cronbach alpha test was conducted to measure the reliability within and across days. A repeated measures ANOVA was also conducted to determine the test-retest reliability.

RESULTS

The mean and standard deviation of the DPOAE slope and area for intrasession and intersession recordings were noted. The same results are shown in Figures 1 and 2, respectively.

The mean and standard deviation (SD) of the area of the DPOAE input-output function at different frequencies for

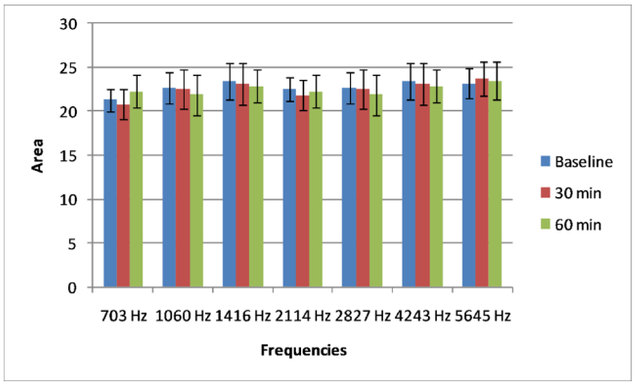

Figure 3: Mean and SD of intra-session DPOAE input-output area at different frequencies. SD: Standard deviation, DPOAE: Distortion product otoacoustic emissions.

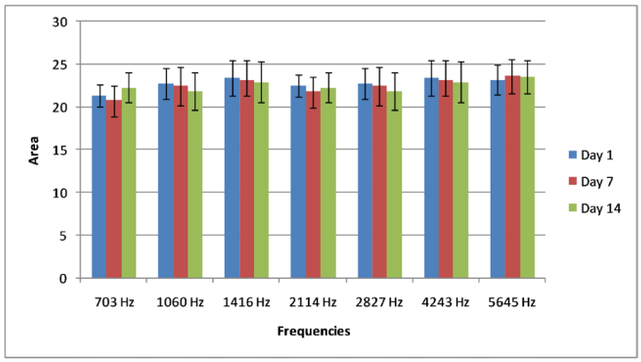

Figure 4: Mean and SD of inter-session DPOAE input-output area at different frequencies. SD - Standard deviation, DPOAE - Distortion product otoacoustic emissions.

intra-session and inter-session are shown in Figures 3 and 4, respectively.

The test-retest reliability was determined using Cronbach's alpha test. The results demonstrated that the alpha values for the slope and area of the DPOAE input-output function were in the range of 0.75–0.89 and 0.77–0.84, respectively. The results of Cronbach's alpha are shown in Table 1.

The Shapiro-Wilk test of normality demonstrated that the distribution of the data was normal ($p > 0.05$). Hence, repeated measures ANOVAs were done for slope and area at all frequencies separately. Repeated measures ANOVAs showed a non-significant difference ($p > 0.05$) between the trials for both slope and area for intra-session and inter-session.

DISCUSSION

The current study was carried out to measure the test and re-test reliability of the DPOAE input-output function within and across days within the same subjects. DPOAE input-output functions are more reliable in assessing the effect of earlier signs of ototoxicity when compared to other measures, such as DPOAE levels.[25] Comparing various I/O function parameters can also be used to evaluate the accuracy of DPOAE measurements. When attempting to forecast the hearing threshold from the measurements of DPOAE, descriptions of the reliability of the entire I/O function of the DPOAE (including low-level conditions) are pertinent.[26–28] DPOAE I/O functions exhibit nonlinear, compressive growth in individuals with normal hearing, but they linearise with hearing loss.[29,30] When hearing loss is present, the DPOAE I/O functions exhibit a change in response growth consistent with a loss of compressive nonlinearity, which may be the mechanism underlying loudness recruitment.

Table 1: Cronbach alpha values at different frequencies for slope and area.

Frequency	Slope	Area
703 Hz	0.78	0.78
1060 Hz	0.75	0.77
1416 Hz	0.83	0.81
2114 Hz	0.79	0.83
2827 Hz	0.82	0.80
4243 Hz	0.85	0.82
5645 Hz	0.89	0.84

The current study results reported no variability observed across different repeated measures. The results of Cronbach's alpha showed that the alpha values were between 0.75 and 0.89 for the slope of the DPOAE input-output function. These results were similar to the previous study by Franklin et al.,[8] which estimated the DPOAE input/output (I/O) functions over short- and long-term re-test intervals. DPOAE repeatability decreased (r = 0.30–0.90) with lower primary levels (L2 45 dB SPL), which is a result of the fact that Ld depends on levels of the primary tones, but noise levels are not directly related to primary levels. DPOAE reliability was high (r = 0.90–0.97) with moderate and high primary levels (L2 > 55 dB SPL). The signal-to-noise ratio (SNR) consequently declines as the primary level does.[8] A similar study was done by Thorson et al.[31] in individuals with normal hearing and hearing loss; the accuracy of DPOAE measurements and their relationship to loudness measurements were evaluated. Two sessions of comparing the distortion product level (Ld) produced correlations that were higher than 0.90. When parameters from nonlinear fits to the input/output (I/O) functions were compared across visits, the reliability of DPOAEs decreased.[31] Studies have reported more excellent test and re-test reliability of DPOAE across weeks (about 1–35 days) without any significant variability, which indicates that the repeatability is

independent of the time intervals across testing.[9] Contrastive results from previous studies also reported that there is significant variability in the levels of DPOAE, specifically in children. The possible reasons attributed to these changes were probe placements, internal or physiological noises, and middle ear status across different times and days.[13] Since previous studies have reported either intra-session (within a day) or inter-session (between days) test-retest reliability, this study has reported the findings of both reliability measures.

CONCLUSION

The present study attempted to evaluate the test-retest reliability of the DPOAE input-output function by measuring the slope and area. The results of the study suggested good test-retest reliability for both the slope and area of the DPOAE input-output function. The reliability was seen in both intra-session and inter-session recordings. The result of the study indicates that the DPOAE input-output function can be used reliably for clinical analysis and research studies. However, further studies on a larger population are essential for better generalization of the results.

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Ethical approval: The research/study approved by the Institutional Ethics Committee at Holy Cross College number HCC/ERB/EC/PB-06/2023-2024, dated 12th March 2023.
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