Reliability of Contralateral Suppression in Evoked Distortion Product Otoacoustic Emissions

Ana Carolina dos Santos[1] Ludimila Labanca[1] Larissa Resende Assumpção[1] Patricia Cotta Mancini[1] Sirley Alves da Silva Carvalho[1] Luciana Macedo de Resende[1]

[1] Department of Speech-Language Pathology and Audiology, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil

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Address for correspondence Luciana Macedo de Resende, PhD, Departamento de Fonoaudiologia, Universidade Federal de Minas Gerais, Avenida Alfredo Balena, 190, sala 249 - Santa Efigênia, Belo Horizonte, MG – Brazil (e-mail: lmacedo.luciana@gmail.com; lucianamr@ufmg.br).

Abstract

Introduction Distortion product otoacoustic emissions (DPOAE) and their suppression may be considered useful in monitoring cochlear function and the efferent auditory pathway inhibitory effect. Nonetheless, the establishment of reliable parameters of response variations is of great importance.

Objectives To verify the replicability of test and retest in the research of the inhibitory effect of the efferent pathway using contralateral suppressing stimulus during DPOAE recording for clinical applicability.

Methods Cross-sectional study with 48 volunteers, aged 18 to 30 years, with normal audiometric thresholds. The procedures included were audiometric and immittance measures to overrule any conductive or sensorineural conditions and DPOAE recordings without and with contralateral suppression with a 60 dBHL white noise. Distortion product otoacoustic emissions amplitudes were analyzed and compared in both conditions with Wilcoxon test, and the Spearman correlation test was used to assess test-retest reliability.

Results The comparative analysis showed differences between amplitudes in test and retest conditions only in 1,500 Hz for DPOAE measures with all other tested frequencies showing no differences ,and no difference was observed in all recorded frequencies in the test and retest comparison for DPOAE suppression. The degree of correlation between test and retest of DPOAE amplitude was good at 6,000 Hz and strong ($r > 0.880$) at the other frequencies. For DPOAE with suppression, all frequencies presented strong correlation between test and retest: 1,500 Hz ($r = 0.880$), 2,000 Hz ($r = 0.882$), 3,000 Hz ($r = 0.940$), and 6,000 Hz ($r = 0.957$).

Conclusions The study found good replicability in contralateral suppression of DPOAE with potential clinical applicability, and we recommend conducting the test from 2000Hz to higher frequencies for more reliable results.

Keywords

- cochlear hair cells
- auditory efferent pathway
- reproducibility of results
- hearing loss
- young adult
- noise effects

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Introduction

The pure-tone threshold audiometry is a universally adopted method to monitor the auditory function.[1,2] However, the audiometry has subjective results and is not flawless, as it depends on both the examiner's attention and the examinee's responses. Moreover, it has low sensitivity to identify subtle cochlear changes that occur before hearing loss is detected in the audiogram.[1,2]

Recording evoked otoacoustic emissions (OAEs) is a reliable, precise, noninvasive method to analyze the cochlear mechanisms. Otoacoustic emissions are sounds originated in the inner ear and picked up in the external acoustic meatus, resulting specifically from the activity of the outer hair cells.[1,3,4] The OAEs can be spontaneous or evoked—generated by an acoustic stimulus.[4] The transiently evoked otoacoustic emissions (TEOAEs) are triggered by a short acoustic broad frequency band click in the cochlea, revealing the performance of the whole organ.[2,4] The distortion-product otoacoustic emissions (DPOAEs) are acoustic energy of cochlear origin resulting from the interaction between two pure tones with different stimulation intensities presented simultaneously (L1 and L2) in neighboring frequencies (f1 and f2). It results in nonlinear responses in the cochlea, which enables specific frequencies of the cochlear activity to be analyzed.[4,5]

Evoked OAEs have higher sensitivity and specificity to monitor the auditory function than the pure-tone threshold audiometry.[1] Ever since they were discovered, they have been widely used in neonatal hearing screening to help diagnose cases of neural changes and to follow up cochlear function in treatments with ototoxic medications or in exposure to cochlear-damaging agents.[6] The record of the DPOAE has been used for the differential diagnosis of hearing losses of cochlear origin, as they are sensitive to the first stages of cochlear changes.[1,2,7,8]

The auditory system comprises the integrated afferent and efferent pathways.[9] The afferent innervation sends information to the brain about the condition of the outer hair cells regarding their tension, length, and stiffness.[10] Most of the large myelinated efferent fibers start at the superior olivary complex and are projected toward the contralateral cochlea, ending in the outer hair cells, whereas a smaller number of fibers are projected to the ipsilateral cochlea.[10,11] The efferent innervation, or medial olivocochlear bundle, is responsible for regulating the slow contractions of the outer hair cells, attenuating the quick contractions, and increasing the system's impedance, which promotes the damping and amplitude of the otoacoustic emissions.[10]

The inhibitory effect, or suppression of the OAE, is the action of the fibers of the medial olivocochlear bundle attenuating the cochlear amplification gain and consequently reducing the movement of the cochlear membrane. It takes place when a simultaneous stimulus is used as these emissions are recorded, applied either ipsi- or contralaterally to the tested ear.[9,11] With this technique, it is possible to assess the medial olivocochlear bundle that participates in the modulation of the otoacoustic emissions, besides the auditory sensitivity, the localization of the sound source, the better detection of the signal when in noise, the selectivity of frequencies, and the cochlear protection function when there is an exaggerated acoustic stimulation.[5,11–14]

Studies[5,12,14–17] indicate that it is important to investigate the DPOAE amplitude test-retest repeatability, as it is a noninvasive technique that makes it possible to identify differences between the measurement of deviations and true changes, either physiological or pathological, in the auditory monitoring over time.[5,12] The record of the DPOAE with suppression effect has proved to have great applicability in clinical practice to detect cochlear changes in people exposed to noise or those who suffered some sort of acoustic trauma,[2,18] and whose auditory thresholds found in the pure-tone threshold audiometry (gold standard examination to detect hearing loss) are within normality standards.

Though there are some peer-reviewed studies already published with DPOAE suppression, there is also a great variability in recording protocols, and no consensus to what would be more feasible to implement in the clinical setting.

To monitor hearing, it is necessary to establish reliable parameters of response variations in normal individuals to use them in patients exposed to harmful ototoxic agents, chemicals, and loud noises[6]; the latter particularly when searching for retrocochlear dysfunctions, such as hidden hearing loss or acquired synaptopathy. Hence, the present study aimed to verify the replicability of the test and retest in the research of the inhibitory effect of the efferent pathway using contralateral suppressing stimulus when picking up the DPOAE for clinical applicability.

Methods

Study Design and Ethical Aspects

The present cross-sectional study compared the amplitude records of DPOAEs performed twice without changing the position of the probe, and also twice with contralateral suppression with white noise in the same condition.

The study, as well as the informed consent form, was approved by the Institutional Review Board of the academic institution under evaluation report number 2693169.

Sample

A total of 48 volunteers—young adults enrolled in various higher education programs—participated in the research. They were 29 females and 19 males, aged 18 to 30 years, with no otologic complaints. The inclusion criteria were having audiometric thresholds up to 25 dBHL, bilaterally, at the frequencies from 500 to 8,000 Hz, and having no tympanometric changes, besides signing the informed consent form.

Procedures

The individuals answered a standardized questionnaire about their hearing condition (auditory complaints, history

of otitis and traumas, tinnitus, dizziness, etc.), and whether they had undergone otologic surgeries and presented with metabolic diseases.

Then, the acoustic immittance measures were conducted to ensure that there were no conductive auditory problems. The acceptable tympanometry results were those with a type A curve. The air-conduction audiometry was performed at the frequencies of 500, 1,000, 2,000, 3,000, 4,000, 6,000, and 8,000 Hz.

The acoustic immittance was performed with a Madsen Otoflex 100 device, model 1,012 (Natus Hearing & Balance [formerly Otometrics], Taastrus, Denmark), with a 226 Hz probe; and the audiometry, with a Madsen Astera audiometer (Natus Hearing & Balance [formerly Otometrics]).

The DPOAE tests were performed with response record protocol f1/f2 ratio = 1.22 and intensity of L1 = 65 and L2 = 55 dBSPL. The frequencies (f2) assessed were 1,500, 2,000, 3,000, and 6,000 Hz.

The records were taken twice without changing the position of either the probe or the participants, who were instructed to remain still. Following the noiseless test, another two records of the DPOAE were taken with contralateral suppression. The testing with suppression was performed with white noise at the intensity of 60 dBSPL[6] transmitted via TDH39 (Huntington, NY, USA) supra-aural earphones, connected to the audiometer, and taking all the necessary caution to not trigger crossover responses. The probe remained in the same position in both tests.

The DPOAEs were considered present when the signal-to-noise ratio (distortion product-noise floor - DP-NF) was equal to 6 dBSPL or higher, and the minimum amplitudes per frequency were also observed (►**Table 1**). The record of the DPOAE was taken with the AuDX device (Bio-Logic Systems Corp., Mundelein, IL, USA), and the analysis was performed with the Scout OAE software.

Table 1 Pass/fail criteria for the minimum amplitudes per frequency of the distortion product otoacoustic emissions established by the manufacturer (Biologic Co)

Pass/Fail Criteria				
f2 Frequency (Hz)	DP	And/Or	DP-NF	Noisy Message
8,000	−13	And	6	−5
7,000	−10	And	6	−5
6,000	−7	And	6	−5
5,000	−6	And	6	−5
4,000	−5	And	6	−5
3,000	−8	And	6	−5
2,000	−7	And	6	−5
1,500	−3	And	6	−5

Abbreviations: DP, distortion product; IEEP, inhibitory effect of the efferent pathway; NF, noise floor.

The inhibitory effect was calculated by subtracting the response obtained in the '*without noise* condition from the response obtained in the *with noise* condition.

Statistical Data Analysis

The descriptive results were presented through measures of dispersion and variability for the continuous variables and frequency analysis for the categorical variables. Continuous variables of interest were tested for normality with Kolmogorov-Smirnov test and showed a non-normal distribution. The nonparametric Wilcoxon test was used to compare the values of the DPOAE measures of both the right and left ears, with and without noise, besides the DPOAE test and retest with and without noise. The values of $p < 0.05$ were considered significant. The reliability of the test was assessed by the intraclass correlation coefficient (ICC). The interpretation of the magnitude of the concordance estimators ICC was 0 to 0.50 poor; 0.51 to 0.75 moderate; 0.76 to 0.90 good, and > 0.90 excellent reliability.

Results

A total of 48 young students—29 (60%) female and 19 (40%) male—were included in the study; the mean age was 22 years (standard deviation 2.5 years), with the minimum being 18 and maximum 30 years. All the individuals included in the study had hearing thresholds better than 25 dBHL in all tested frequencies in the audiometric examination.

There was no statistical difference ($p > 0.05$) when comparing the results of the otoacoustic emissions of the right and left ears (**Appendices 1** and **2**) according to the Wilcoxon test. Given such results, the DPOAE test and retest results were analyzed, regardless of the ear. Hence, 96 ears were included in the analysis of the results.

The comparative analysis for test and retest of the DPOAE amplitudes indicated a difference only at the 1,500 Hz frequency. There was no difference ($p > 0.05$) at the other tested frequencies (2,000 Hz, 3,000 Hz, and 6,000 Hz) according to the Wilcoxon test. (►**Fig. 1A** and ►**Appendix 3**).

The comparative analysis for test and retest of the DPOAE amplitudes with suppression effect did not indicate any statistical difference ($p > 0.05$) according to the Wilcoxon test (►**Fig. 1B** and ►**Appendix 4**), neither did the comparison of the values of the inhibitory effect of the efferent pathway in test and retest ($p > 0.05$) (►**Fig. 2** and ►**Appendix 4**).

The degree of correlation between the test and retest for the amplitude of distortion product was good at 6,000 Hz and excellent at the other frequencies, according to the ICC. The correlation between test and retest of the distortion product with suppression was excellent at all assessed frequencies: 1,500 Hz, 2,000 Hz, 3,000 Hz, and 6,000 Hz. The results indicate the presence of a correlation between the IEEP test and retest for the 1,500 Hz and 2,000 Hz frequencies. The correlation was moderate for 1,500 Hz and poor for 2,000 Hz (►**Table 2**).

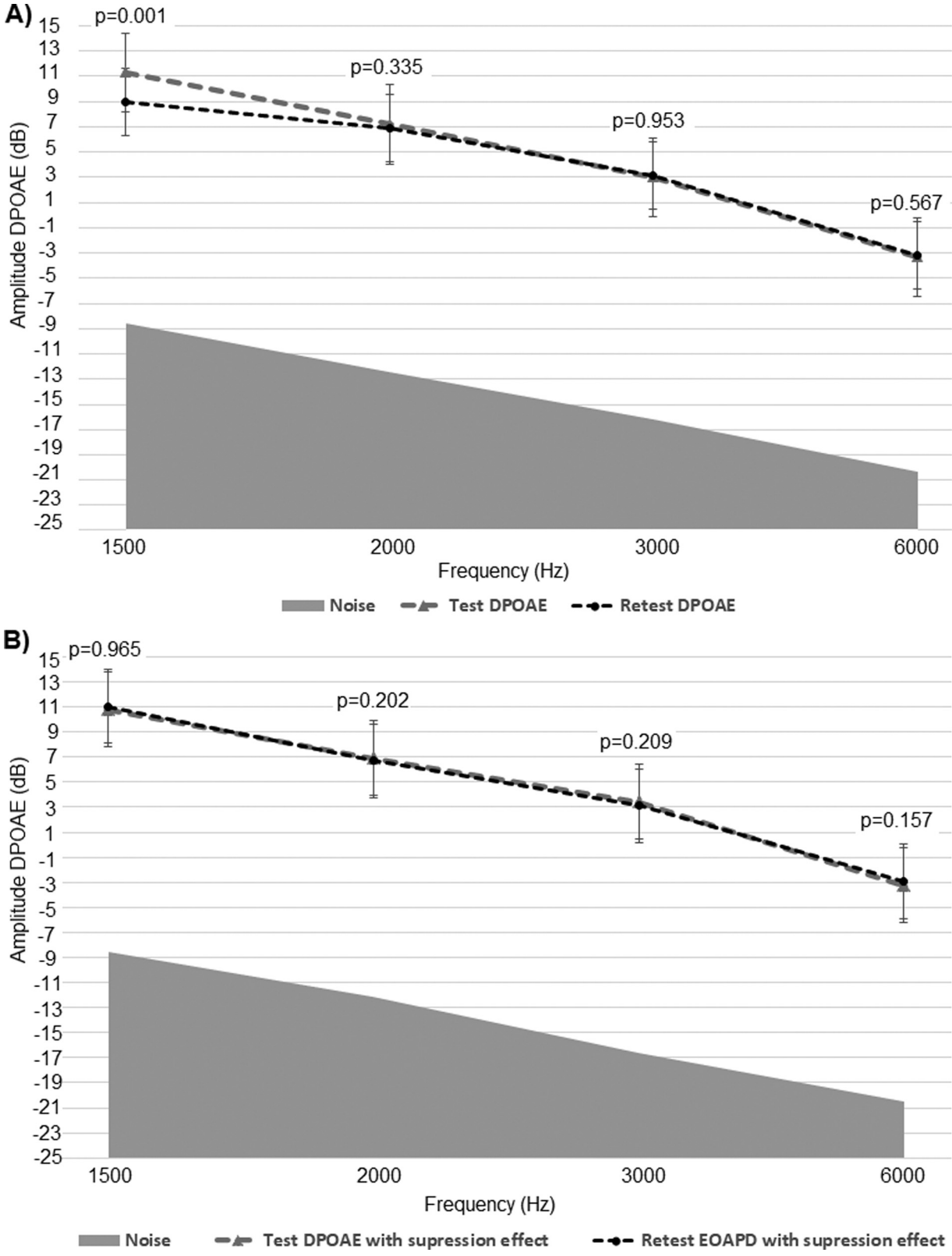

Fig. 1 Test and retest distortion products otoacoustic emissions' amplitudes and distortion product otoacoustic emissions' amplitudes in the test and retest with suppressing noise ($n = 96$ ears)

Discussion

The present study investigated the test-retest reliability of the DPOAE amplitudes, as well as the contralateral inhibition of the DPOAE. Regarding the amplitude of the distortion products without contralateral stimulation in test and retest, this study's findings showed a statistical difference, only at the 1,500 Hz frequency. There are reports in the literature that the

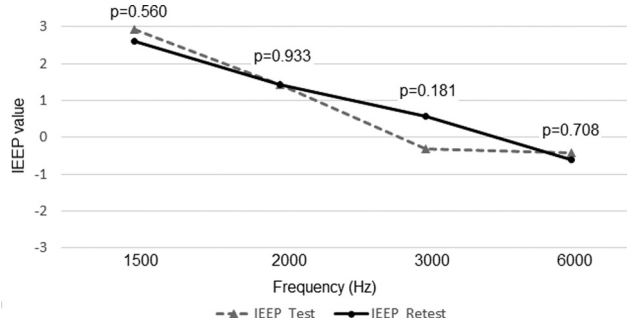

Fig. 2 Test and retest values of the inhibitory effect of the efferent pathway ($n = 96$ ears)

DPOAE amplitudes were similar between sessions, indicating a good test-retest reliability.[5,12,19] Kalaiah et al. (2018)[5] suggest that a variation in the frequencies is expected when the test is repeated. Additionally, studies report an indication of intra- and intersession variability in the DPOAE amplitudes. There have been variations between the frequencies with no tendency observed for it to happen.[5,12]

Zhao and Stephens (1999)[15] researched the DPOAE test-retest to examine the various sources that affect the short- and long-term variability. The authors verified that there were no significant changes in the DPOAE amplitudes in four recording sessions performed in the study. The replicability found was very good; however, in some cases, the general tracing of the distortion products curves was not precisely reproduced at frequencies below 1,000 Hz. Moreover, they reported that in one subject the background noise contributed to the low reliability at the low-frequency band.

Roede et al. (1993)[16] researched the repeatability of the DPOAE in humans with normal hearing and reported that, in general, the DPOAE amplitudes varied more at frequencies below 1,000 Hz and above 6,000 Hz than at the medium-frequency region. Furthermore, they found greater variability around 2,000 Hz in approximately one third of the individuals, and this variability increased in lower levels of stimulus. These findings corroborate the ones found in the present research with a greater variation observed in the 1,500 Hz frequency.

Another study, by Guedes et al. (2002),[6] found greater variation in the high-frequency amplitudes (6,000 Hz and 8,000 Hz) than in low frequencies (1,000 Hz and 2,000 Hz), indicating that these would be the frequencies most affected at first by ototoxic agents, chemicals, and noise, precociously showing the involvement of the outer hair cells.

The variation of the low-frequency DPOAE amplitudes can be caused by noise levels generated by the environment or the person.[15,16] Nevertheless, it must be pointed out that, in the present study, factors that might interfere with the test-retest reliability were controlled. No patient had changes in their hearing or in the middle ear function. The tests were conducted in an acoustically treated room, excluding environmental noises. The participants were seated in comfortable chairs and were instructed not to swallow or move during the tests. The otoacoustic emissions probe was stable; it was correctly adjusted in the outer auditory canal only once, and then its stability remained constant. The protocol used for the level of DPOAE stimulus complied with the recommendations in the literature[16] to avoid the slightest variability in the responses. Therefore, it is unlikely that the variables mentioned interfered with variation in amplitude at the 1,500 Hz frequency, or in any other moment of this study.

Test-retest of DPOAE recording without noise suppression was very important to be stablished prior to the analysis of DPOAE suppression test-retest results.

Kumar et al. (2013)[12] and Kalaiah et al. (2018)[5] found low test-retest reliability in the contralateral stimulation of the DPOAE. They attributed this result to the large confidence intervals for the DPOAE inhibition magnitude,[5,12,14] the attentional state of the participant during the contralateral acoustic stimulation,[5] and the fine structure measurements.[5,14] Kalaiah et al. (2018)[5] reports in their study that the main reason for the poor repeatability of the DPOAE inhibition is the lower frequency of DPOAE measurement resolution at fixed frequencies, suggesting that the measurements at discrete frequencies may not be reliable, especially when the tests are not conducted in a single clinical session. On the other hand, in the present study, no differences were found with statistical significance regarding the amplitude of the distortion products with contralateral stimulation, neither was there any statistical difference in the comparison of the inhibitory effect value of the efferent pathway in the test and retest conditions, which showed a positive finding for its clinical application.

In the present study, the degree of correlation between the test and retest of the distortion products amplitude was

Table 2 Correlation coefficient between test and retest conditions of the distortion product otoacoustic emissions amplitudes with and without suppression, and the inhibitory effect of the efferent pathway

		1,500 Hz	2,000 Hz	3,000 Hz	6,000 Hz
DP	**Degree of correlation (test-retest)**	0.761	0.973	0.957	0.960
	***P*-value**	< 0.001	< 0.001	< 0.001	< 0.001
DP with suppression	**Degree of correlation (test-retest)**	0.930	0.929	0.974	0.979
	***P*-value**	< 0.001	< 0.001	< 0.001	< 0.001
IEEP	**Degree of correlation (test-retest)**	0.563	0.464	0.289	0.281
	***P*-value**	0.010	0.033	0.128	0.153

Abbreviations: DP, distortion product; IEEP, inhibitory effect of the efferent pathway.
p-value = significance probability (intraclass correlation coefficient).

good at the 6,000 Hz frequency, and excellent for the other tested frequencies, as shown in ►**Table 2**. As for the test and retest of the distortion product with contralateral stimulation, the correlation was excellent at all tested frequencies (ICC > 0.90). These findings corroborate those in the study of Kalaiah et al. (2018),[5] who reported that the intrasession reliability was greater at the frequencies of 2,380 Hz and 6,726 Hz, indicating that the DPOAE inhibition is reliable when measured at medium and high frequencies.

In this study, the correlation between the IEEP in test and retest was moderate for 1,500 Hz and poor for 2,000 Hz, and in 3,000 Hz and 6,000 Hz, there was no correlation. This result shows that maybe the IEPP is not the best parameter for analyses of the suppression effect. On the other hand, findings of the present study showed excellent test-retest repeatability for the amplitude of DPOAEs with suppression, and this parameter is good and reliable for suppression effect analysis.[5]

Other studies[16,17,20] also found high DPOAE test-retest repeatability at medium- and high-frequency bands. Franklin et al. (1992)[17] revealed good repeatability at the frequencies of 2,000 Hz to 8,000 Hz, which confirms the DPOAE applicability to analyze the high-frequency region of the cochlea and monitor the hearing in individuals at high risk of auditory dysfunction and are also similar to the findings in the present study.

The usefulness of DPOAE suppression includes the identification of early retrocochlear dysfunction, particularly derived from noise exposure and acquired synaptopathies.

The presence of good repeatability of DPOAE with contralateral suppressing stimulus in individuals with normal hearing, found and described in this study, proves this technique as a powerful tool to be implemented in routine clinical practice. Also, it was relevant to establish parameters that will enable the OAE responses to be compared with individuals with discrete cochlear changes – specifically those taking place at higher frequencies, a region where the TEOAEs cannot identify auditory changes. Furthermore, it makes it possible to investigate the integrity of the medial olivocochlear bundle and achieve an early diagnosis involving dysfunctions derived from different etiologies such as those associated with noise exposure in clinical environments.

Conclusion

The contralateral suppression of the amplitude of DPOEs presented excellent replicability. Thus, it is fair to state that its application proved possible and reliable in clinical practice to evaluate the cochlear and retrocochlear function. It is recommended, with the protocol used in this research, to start DPOAE suppression testing at the 2,000 Hz frequency to obtain better results.

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Conflict of Interests
The authors declare that there is no conflict of interests.

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Appendix 1 Comparative analysis of the left and right ears' distortion product otoacoustic emissions

Descriptive statistics	1,500 Hz								
	DP (dB)		*P*-value	NF (dB)		*P*-value	DP-NF (dB)		*P*-value
	RE	LE		RE	LE		RE	LE	
Mean	11.45	11.13	0.590	−8.45	−8.75	0.587	19.98	19.89	0.743
Median	14.00	13.10		−8.15	−8.25		21.30	20.20	
Minimum	−17.30	−21.10		−19.00	−18.00		0.10	−3.10	
Maximum	23.80	24.20		9.70	1.00		33.90	37.20	
	2,000 Hz								
	DP (dB)		*P*-value	NF (dB)		*P*-value	DP-NF (dB)		*P*-value
	RE	LE		RE	LE		RE	LE	
Mean	7.43	6.94	0.249	−12.40	−12.55	1.000	19.83	19.49	0.357
Median	8.00	8.20		−13.80	−12.90		19.35	20.00	
Minimum	−13.60	−16.60		−17.50	−18.60		0.60	1.00	
Maximum	22.20	20.80		−3.50	−0.80		34.20	34.00	
	3,000 Hz								
	DP (dB)		*P*-value	NF (dB)		*P*-value	DP-NF (dB)		*P*-value
	RE	LE		RE	LE		RE	LE	
Mean	3.28	2.76	0.498	−16.35	−16.12	0.775	19.27	18.88	0.685
Median	4.35	3.70		−16.85	−17.20		20.40	19.65	
Minimum	−16.80	−17.30		−23.90	−22.50		−17.60	−5.40	
Maximum	16.80	15.30		4.00	−5.50		35.50	34.30	
	6,000 Hz								
	DP (dB)		*P*-value	NF (dB)		*P*-value	DP-NF (dB)		*P*-value
	RE	LE		RE	LE		RE	LE	
Mean	−2.90	−3.73	0.800	−20.44	−20.30	0.293	17.54	16.36	0.767
Median	−3.30	−4.40		−21.85	−21.50		18.85	17.85	
Minimum	−30.20	−27.10		−29.10	−28.00		−5.90	−4.60	
Maximum	24.90	13.10		−11.60	−10.70		38.50	38.20	

Abbreviations: DP, Distortion product amplitude; LE, left ear; NF, Noise floor; RE, right ear; p-value (Wilcoxon test).

Appendix 2 Comparative analysis of distortion product otoacoustic emissions with the right and left ear suppression effect

Descriptive statistics	1,500 Hz											
	DP (dB)		*P*-value	NF (dB)		*P*-value	DP-NF (dB)		*P*-value	IEEP (dB)		*P*-value
	RE	LE		RE	LE		RE	LE		RE	LE	
Mean	11.18	10.41	0.266	−6.08	−6.34	0.626	17.26	16.75	0.448	2.72	3.13	0.770
Median	13.05	12.85		−5.75	−6.45		18.35	16.90		2.70	2.75	
Minimum	−13.70	−14.90		−15.80	−17.80		−4.40	0.60		−9.00	−6.00	
Maximum	23.80	23.40		4.30	9.20		39.60	34.90		14.30	16.40	
	2,000 Hz											
	DP (dB)		*P*-value	NF (dB)		*P*-value	DP-NF (dB)		*P*-value	IEEP (dB)		*P*-value
	RE	LE		RE	LE		RE	LE		RE	LE	
Mean	7.18	6.61	0.488	−11.16	−11.50	0.512	18.33	18.12	0.828	1.50	1.38	0.580
Median	6.80	7.25		−11.15	−11.90		17.30	16.75		1.60	1.35	
Minimum	−8.40	−10.40		−19.00	−18.10		6.10	2.50		−8.10	−6.90	
Maximum	22.30	21.00		1.80	0.00		38.00	37.00		15.10	11.50	
	3,000 Hz											
	DP (dB)		*P*-value	NF (dB)		*P*-value	DP-NF (dB)		*P*-value	IEEP (dB)		*P*-value
	RE	LE		RE	LE		RE	LE		RE	LE	
Mean	4.44	2.39	0.069	−16.28	−16.23	0.985	19.94	18.83	0.859	−0.68	0.05	0.254
Median	5.20	3.05		−17.40	−17.05		19.70	19.80		−0.25	0.40	
Minimum	−15.70	−31.50		−23.70	−22.20		−18.30	−11.40		−17.20	−14.20	
Maximum	21.60	15.50		3.00	−3.60		37.20	31.10		8.60	11.60	
	6,000 Hz											
	DP (dB)		*P*-value	NF (dB)		*P*-value	DP-NF (dB)		*P*-value	IEEP (dB)		*P*-value
	RE	LE		RE	LE		RE	LE		RE	LE	
Mean	−2.71	−3.80	0.253	−20.19	−21.06	0.251	17.47	17.26	0.984	0.07	−0.90	0.597
Median	−2.70	−4.45		−21.20	−21.05		18.60	18.35		−0.10	−0.45	
Minimum	−24.20	−25.30		−30.70	−30.60		2.40	−5.10		−9.50	−11.90	
Maximum	25.00	11.60		−10.80	−11.90		38.60	34.40		12.20	8.50	

Abbreviations: DP, distortion product amplitude; IEEP, inhibitory effect of the efferent pathway; LE, left ear; NF, noise floor; RE, right ear; S, suppression.
p-value (Wilcoxon test).

Appendix 3 Comparative analysis of distortion product otoacoustic emissions amplitude in the test and retest condition

Descriptive statistics		1,500 Hz		*P*-value	2,000 Hz		*P*-value	3,000 Hz		*P*-value	6,000 Hz		*P*-value
		Test	Retest		Test	Retest		Test	Retest		Test	Retest	
DP	Mean	11.29	8.99	0.001	7.19	6.89	0.335	3.02	3.12	0.953	−3.31	−3.19	0.567
(dB)	Median	13.25	10.80		8.00	7.65		3.85	4.15		−3.45	−2.75	
	Minimum	−21.10	−18.90		−16.60	−19.80		−17.30	−27.10		−30.20	−34.50	
	Maximum	24.20	23.80		22.20	22.40		16.80	17.30		24.90	25.00	
NF	Mean	−8.60	−8.51	0.866	−12.47	−12.17	0.874	−16.23	−16.62	0.576	−20.37	−20.54	0.799
(dB)	Median	−8.15	−9.00		−13.05	−12.35		−17.00	−17.05		−21.70	−20.65	
	Minimum	−19.00	−16.90		−18.60	−18.20		−23.90	−22.70		−29.10	−31.60	
	Maximum	9.70	3.70		−0.80	5.00		4.00	−6.70		−10.70	−11.70	
DP-NF	Mean	19.93	19.67	0.908	19.66	19.04	0.186	19.07	19.73	0.805	16.95	17.35	0.626
(dB)	Median	20.75	20.05		19.60	19.30		19.90	21.10		18.60	19.55	
	Minimum	−3.10	−11.60		0.60	−2.30		−17.60	−10.20		−5.90	−7.00	
	Maximum	37.20	35.40		34.20	35.30		35.50	36.20		38.50	39.30	

Abbreviations: DP, distortion product amplitude; NF, noise floor; S, suppression.
p-value (Wilcoxon test).

Appendix 4 Comparative analysis of distortion product otoacoustic emissions with suppression in the test and retest conditions

Descriptive statistics		1,500 Hz		*P*-value	2,000 Hz		*P*-value	3,000 Hz		*P*-value	6,000 Hz		*P*-value
		Test	Retest		Test	Retest		Test	Retest		Test	Retest	
DP with suppression (dB)	Mean	10.79	11.04	0.965	6.90	6.69	0.202	3.41	3.10	0.209	−3.26	−2.93	0.157
	Median	13.00	12.35		7.10	7.15		4.40	4.25		−3.35	−2.70	
	Minimum	−14.90	−16.70		−10.40	−29.80		−31.50	−25.90		−25.30	−24.50	
	Maximum	23.80	23.30		22.30	22.10		21.60	16.60		25.00	25.30	
NF with suppression (dB)	Mean	−6.21	−6.04	0.684	−11.33	−11.15	0.605	−16.25	−16.05	0.289	−20.62	−20.89	0.128
	Median	−5.95	−5.70		−11.70	−11.20		−17.25	−16.30		−21.05	−21.95	
	Minimum	−17.80	−15.70		−19.00	−21.50		−23.70	−22.40		−30.70	−31.10	
	Maximum	9.20	7.20		1.80	3.00		3.00	−5.00		−10.80	−9.10	
DP-NF with suppression (dB)	Mean	17.01	17.08	0.709	18.23	17.62	0.660	19.39	19.17	0.242	17.37	17.96	0.128
	Median	17.00	17.50		17.10	17.35		19.70	19.70		18.60	18.70	
	Minimum	−4.40	−5.00		2.50	−18.90		−18.30	−7.50		−5.10	−4.70	
	Maximum	39.60	33.40		38.00	37.60		37.20	33.50		38.60	40.60	
IEEP (dB)	Mean	2.93	2.59	0.560	1.44	1.42	0.933	−0.31	0.56	0.181	−0.42	−0.60	0.708
	Median	2.70	1.70		1.50	1.00		0.30	0.85		−0.25	−0.30	
	Minimum	−9.00	−7.70		−8.10	−13.40		−17.20	−11.90		−11.90	−25.00	
	Maximum	16.40	26.20		15.10	17.60		11.60	8.00		12.20	19.60	

Abbreviations: DP, distortion product amplitude; IEEP, inhibitory effect of the efferent pathway; NF, noise floor.
p-value (Wilcoxon test).