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VARIABILITY OF HIGH-FREQUENCY DISTORTION PRODUCT OTOACOUSTIC EMISSIONS MEASURED BY THE SMARTOAE DEVICE: PRELIMINARY STUDY

Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

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Abstract

Background: Distortion product otoacoustic emissions (DPOAEs) are usually measured in a frequency range up to 8 kHz, although some systems permit measurements up to 16 kHz. For any test to be reliable it is important to determine its repeatability. Therefore in the present study DPOAE recordings were made using the SmartOAE system with a focus on the repeatability of high-frequency DPOAEs.

Material and methods: DPOAEs were measured in subjects with normal hearing from 0.25 to 16 kHz. Recordings were made at frequencies of 0.5, 0.75, 1, 1.5, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.5, 14, and 16 kHz. Each recording session consisted of three measurements: the first two performed without removing the probe from the ear (single fit mode), and the third after removing and re-inserting it into the ear canal (multiple fit mode). Recordings from 15 ears were made.

Results: In single fit mode, the biggest fluctuations were obtained at 0.75, 8, 11, 12.5, and 14 kHz – the largest was 2.8 dB. In the multiple fit mode, greater variability was obtained compared to measurements made without removing the probe – the largest reached 3.4 dB.

Conclusions: Even though the measured signals significantly exceeded the noise floor, differences between measurements for some frequencies still reached as high as 3.4 dB. Our work confirms the usefulness of testing very high DPOAE frequencies (>8 kHz), but at the same time some caution is needed when interpreting the results.

Key words: Otoacoustic emissions • reliability • high frequencies

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REPRODUCIBILIDAD DE LAS MEDICIONES DE EMISIONES DE PRODUCTOS DE DISTORSIÓN NO LINEAL – PRUEBAS PRELIMINARES

Resumen

Introducción: Las Emisiones de Productos de Distorsión no Lineal (EOApd) generalmente se miden en un rango de frecuencia de hasta 8 kHz. Sin embargo, algunos sistemas ya permiten mediciones de hasta 16 kHz. Para que la prueba sea confiable, es importante determinar su reproducibilidad, de ahí la verificación del registro DPOAE en modos de ajuste único y múltiple de la sonda en el canal auditivo externo.

Material y métodos: Las DPOAE se midieron en sujetos con audición normal en el rango de 0.25 kHz a 16 kHz. El registro se realizó para frecuencias de 0.5; 0,75; 1; 1,5; 2; 3; 4; 5; 6; 7; 8; 9; 10; 11; 12,5; 14 y 16 kHz. Cada sesión de medición consistió en tres mediciones. Las dos primeras se realizaron sin quitar la sonda del oído y la tercera después de quitarla y volver a insertarla en el canal auditivo. 15 audiciones fueron finalmente calificadas para el análisis.

Resultados: En el modo de ajuste único de sonda, las mayores fluctuaciones se obtuvieron para 0,75 kHz y para frecuencias más altas (8, 11, 12 y 14 kHz). En el modo de ajuste múltiple de sonda, se obtuvo una mayor variabilidad en comparación con las mediciones realizadas sin retirar la sonda.

Conclusión: La medición a frecuencias más altas parece confiable debido a la gran distancia entre el nivel de respuesta y el ruido.

Palabras clave: Emisión otoacústica • reproducibilidad • altas frecuencias.

ПОВТОРЯЕМОСТЬ ИЗМЕРЕНИЙ ОТОАКУСТИЧЕСКОЙ ЭМИССИИ НА ЧАСТОТЕ ПРОДУКТА ИСКАЖЕНИЯ – ПРЕДВАРИТЕЛЬНЫЕ ИССЛЕДОВАНИЯ

Аннотация

Введение: Отоакустическая эмиссия на частоте продукта искажения (DPOAE) обычно измеряется в диапазоне частот до 8 кГц. Однако некоторые системы уже позволяют проводить измерения до 16 кГц. Для того чтобы обследование было достоверным, важно определить его повторяемость, следовательно, необходима проверка регистрации DPOAE в режимах подбора одного и нескольких зондов во внешнем слуховом канале.

Материалы и методы: Обследование DPOAE было проведено у лиц с нормальным слухом в диапазоне от 0,25 кГц до 16 кГц. Регистрация проводилась на следующих частотах: 0,5; 0,75; 1; 1,5; 2; 3; 4; 5; 6; 7; 8; 9; 10; 11; 12,5; 14 и 16 кГц. Каждое обследование состояло из трех измерений. Первые два были выполнены без удаления зонда из уха, а третий после удаления и повторной его установки в ушной канал. Для окончательного анализа было отобрано 15 ушей.

Результаты: В режиме однократного введения зонда самые большие флуктуации были получены для 0,75 кГц и для более высоких частот (8, 11, 12 и 14 кГц). В режиме многократного введения зонда получено больший уровень изменчивости по сравнению с измерениями, проведенными без удаления зонда.

Выводы: Измерение в диапазоне более высоких частот кажется надежным из-за большого расстояния уровня ответа и шума.

Ключевые слова: Отоакустическая эмиссия • повторяемость • высокие частоты

POWTARZALNOŚĆ POMIARÓW EMISJI PRODUKTÓW ZNIEKSZTAŁCEŃ NIELINIOWYCH – BADANIA WSTĘPNE

Streszczenie

Wprowadzenie: Emisje produktów zniekształceń nieliniowych (DPOAE) zazwyczaj mierzone są w paśmie częstotliwości do 8 kHz. Jednakże niektóre systemy pozwalają na pomiary już do 16 kHz. Aby badanie było wiarygodne, istotne jest ustalenie jego powtarzalności, stąd w niniejszej pracy podjęto próbę weryfikacji DPOAE w trybie pojedynczego i wielokrotnego dopasowania sondy w kanale słuchowym zewnętrznym.

Materiał i metoda: DPOAE zmierzono u osób ze słuchem prawidłowym w zakresie od 0,25 kHz do 16 kHz. Rejestracji dokonano dla częstotliwości 0,5; 0,75; 1; 1,5; 2; 3; 4; 5; 6; 7; 8; 9; 10; 11; 12,5; 14 i 16 kHz. Każda sesja pomiarowa składała się z trzech pomiarów. Pierwsze dwa były wykonywane bez wyjmowania sondy z ucha, a trzeci po wyjęciu i ponownym jej włożeniu do kanału słuchowego. Do analiz ostatecznie zakwalifikowano 15 uszu.

Wyniki: W trybie pojedynczego dopasowania sondy największe fluktuacje uzyskano przy 0,75; 8; 11; 12,5 i 14 kHz – największa wyniosła 2,8 dB. W trybie wielokrotnego dopasowania sondy uzyskano większą zmienność w porównaniu do pomiarów wykonanych bez wyjmowania sondy – największa osiągnęła 3,4 dB.

Wnioski: Mimo że zmierzone sygnały znacznie przekraczały poziom szumu, różnice między pomiarami dla niektórych częstotliwości wciąż osiągały nawet 3,4 dB. Uzyskane wyniki potwierdzają przydatność testowania bardzo wysokich częstotliwości DPOAE (>8 kHz), ale jednocześnie wskazują na potrzebę zachowania ostrożności przy interpretacji wyników.

Słowa kluczowe: Emisja otoakustyczna • powtarzalność • wysokie częstotliwości

Abbreviations

OAEs – otoacoustic emissions
DPOAE – distortion product otoacoustic emission
BIAP – International Bureau for Audiophonology

Background

Otoacoustic emissions (OAEs) make it possible to diagnose certain sensory pathologies within the peripheral auditory structures [1–4]. Slight disturbances to auditory function can affect OAEs and cause an alteration in their amplitude or other properties, even when no changes can be observed in standard audiometric tests [5–8]. In particular, hearing losses at the highest frequencies (up to 16 kHz, a region where hearing damage first occurs [9]), can affect OAEs measured at lower frequencies [10–12]. Consequently, OAEs are often used as a warning flag of preclinical changes happening in the cochlea [10–12].

In clinical practice a commonly used OAE is the distortion product otoacoustic emission (DPOAE), which is a good hearing indicator for frequencies above 1 kHz [13]. Most of the measurement systems available on the market offer DPOAE recording in the frequency range 1 to 8 kHz. However, there are some commercial devices designed for OAE measurements above 8 kHz, e.g. the SmartOAE from Intelligent Hearing Systems, USA, or the HearID system from Mimosa Acoustics, USA. The higher frequency capability seems to be an important option and might be useful for detecting early hearing damage caused by noise or ototoxic drugs [14–26]. In addition, extension of the frequency band in DPOAE measurement might be helpful in diagnosing people with chronic diseases such as diabetes, renal failure, or juvenile chronic arthritis [27–30]. There are also possibilities for use in patients with tinnitus [11,31–34] or children with middle ear dysfunction [35] who have had changes in their hearing at high frequencies.

Because DPOAE measurements can be affected by many factors, it is important to determine the reliability of a given test method, that is, determine its repeatability [36]. Most of the work on repeatability of DPOAE measurements has examined frequencies from 1 to 8 kHz [37–45], although there are some reports in which measurements above 8 kHz have been used [35,46–48]. In this earlier work, the findings have been that variability is lowest in the range 1 to 6 kHz, with higher variability below and above that range. Findings of the effects of probe fit in the ear canal have also been considered, comparing variability of single fits (repeated measurements without removal of the probe from the ear) and multiple fits (measurement after removal and re-insertion of the probe). The time interval between fits has also been studied. In all these approaches, the results are equivocal. Some authors do not see any statistically significant difference between measurements performed in different probe fit modes [37–38,40–41,43], while others observe that the highest reproducibility comes from the single probe fit mode [39] and over short time intervals [42,44]. For the multiple fit mode and for long intervals between successive measurements, reliability appears to drop significantly [39,42,44]. Nevertheless, when measurements performed at different time intervals are compared, DPOAEs generally demonstrate high stability [37,41,43].

The aim of this study was to compare the differences between DPOAE measurements under different probe fit modes for frequencies extending from 0.5 kHz to 16 kHz using a commercially available device.

Material

The measurements were performed on 8 otolaryngologically healthy people (6 female, 2 male) of age 26.7 ±5.2 years. All had hearing thresholds below 25 dB HL in the frequency range 0.125–16 kHz.

Methods

Testing included otoscopic assessments, audiograms aimed at excluding hearing loss, tympanometry, and DPOAE measurements. Hearing thresholds better than 20 dB HL were taken to represent normal hearing, in accordance with the BIAP scale [49].

A standard test tone of 226 Hz was used for the tympanograms. Acoustic reflexes were determined at 0.5–4 kHz for ipsi and contralateral tones at 75–120 dB. Evaluation of the tympanograms was based on the classification of Jerger and Liden et al. [50,51]. The Williams test [52–53] was used to assess the patency of the Eustachian tube. DPOAE measurements were performed in those without pathology of the middle ear or Eustachian tube and whose hearing thresholds did not exceed the age standard.

DPOAE measurements were performed using the default protocol of the SmartOAE system (Intelligent Hearing Systems, USA), using software version 4.53. DPOAEs were measured at 2f1–f2, where f2 > f1, f2/f1 = 1.2, and L1 and L2 were at 65 and 55 dB SPL respectively. The f2 frequencies were chosen as 0.5, 0.75, 1.5, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.5, 14, and 16 kHz. For the final analysis, only results for which the DPOAE level was at least 3 dB above the noise floor were used [54], giving results for 15 ears (8 left, 7 right). The measuring session consisted of three recordings: the first two were performed using a single probe fit, without removing the probe from the ear canal (DPOAE1 and DPOAE2); while the third was done after removing and re-inserting the probe into the auditory canal (DPOAE3, multiple fit mode). In analysing the results, both the magnitude and signal-to-noise ratio were calculated.

For statistical analysis the Wilcoxon test was used since most values did not have a normal distribution, and also because the groups were too small to use a *t*-test for dependent samples. The analyses were performed in the StatSoft Statistica 7.1 package, where differences assumed to be statistically significant if $p < 0.05$.

There was no statistically significant difference between air conduction thresholds in left and right ears, and so the results are presented as mean values for both ears combined.

Research procedures were approved by the Ethics Committee of the Institute of Physiology and Pathology of Hearing, Poland, and all participants gave written informed consent.

Results

Figure 1 shows the mean DPOAE response amplitudes and noise levels for three consecutive measurements performed in each of the probe fitting modes. The DPOAE_1 and DPOAE_2 measurements were performed in the single probe fitting mode, and DPOAE_3 after removal and reinsertion of the probe. For most frequencies, the response levels were higher than the noise by more than 10 dB.

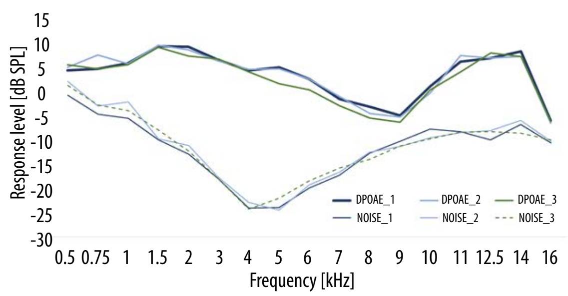

Figure 1. Mean DPOAE response amplitudes and noise levels for three measurements: two performed in single fit mode (DPOAE_1 and DPOAE_2) and one in multiple probe fit mode (DPOAE_3)

Figure 2 compares mean differences in DPOAE amplitudes between each probe fitting mode over the frequency range from 0.5 to 8 kHz. In the single probe fit mode, statistically significant differences (as shown by Diff12) occurred only at 0.75 kHz ($p = 0.03$), reaching 2.8 dB. At 8 kHz, the difference between DPOAE_1 and DPOAE_2 reached 1.3 dB, while for other frequencies the differences did not exceed 1 dB. However, for multiple probe fits (comparing DPOAE_1 with DPOAE_3), the most susceptible frequency was 5 kHz, with a statistically significant difference ($p = 0.04$) of 3.4 dB. There were no other significant differences (although for 8 and 6 kHz the differences were

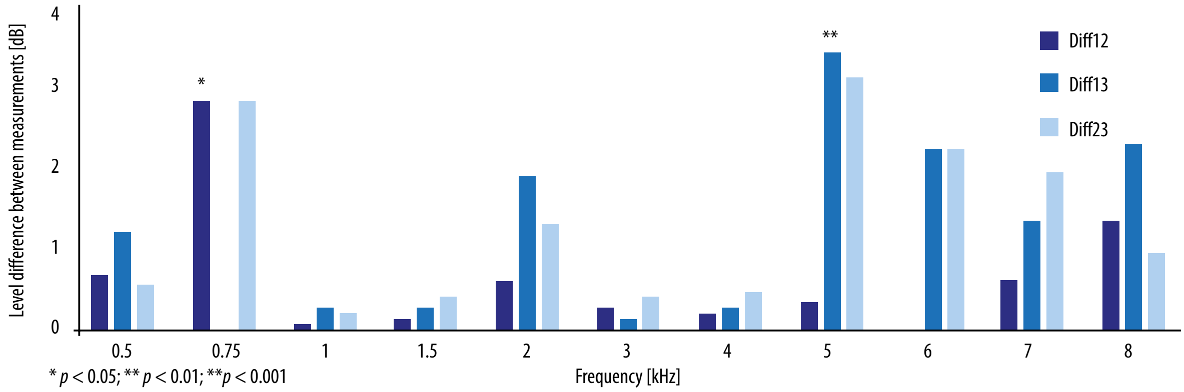

Figure 2. Comparison of differences for mean DPOAE amplitudes in single fit mode (Diff12 and Diff13) and multiple probe fit mode (Diff23) in the frequency range 0.5 to 8 kHz

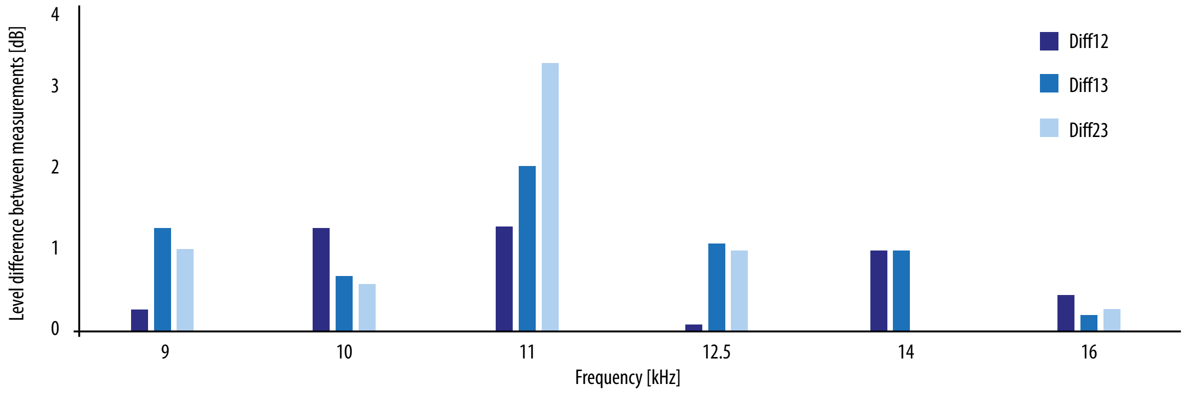

Figure 3. Comparison of differences for mean DPOAE amplitudes in single fit mode (Diff12 and Diff13) and multiple probe fit mode (Diff23) in the frequency range 9 to 16 kHz

about 2 dB, less than 2 dB for 0.5, 2, and 7 kHz, and less than 1 dB elsewhere). Differences between DPOAE_2 and DPOAE_3 were not statistically significant (for 5 kHz it was about 3 dB; for 7 kHz it was 1.9 dB, and for 0.75 and 6 kHz 2.8 dB and 2.2 dB respectively).

Figure 3 compares differences in mean DPOAE amplitudes for both probe fitting modes for frequencies from 9 to 16 kHz. There were no statistically significant differences between single or multiple probe fitting. Differences between DPOAE_1 and DPOAE_2 at 10, 11, and 14 kHz were about 1 dB, and for other frequencies they were less than this. The difference between DPOAE_1 and DPOAE_3 reached 2 dB at 11 kHz, about 1 dB at 9, 12.5, and 14 kHz, and the remaining differences were even smaller. When comparing DPOAE_2 and DPOAE_3, the largest difference (more than 3 dB) occurred at 11 kHz, while for 9 and 12.5 kHz the value was only 1 dB.

Discussion

The aim of this study was to assess the variability of DPOAE measurements made with the SmartOAE system (Intelligent Hearing Systems, USA) using different probe fitting modes in the external auditory canal for frequencies from 0.5 to 16 kHz.

Analysis of the DPOAE responses showed they were similar to those presented by other authors [46,48]. As shown in Figure 1, a minimum in magnitudes was observed at frequencies near 8 or 9 kHz and a maximum for frequencies near 11 or 12 kHz. A substantial decrease in DPOAE amplitude was noted at 16 kHz. The noise levels were similar to the results found in the works cited, with a minimum at around 4 kHz.

In the single probe fit mode the largest differences in DPOAE amplitudes were obtained for low frequencies (0.75 kHz), followed by 8 kHz and the high frequency range (11, 12, and 14 kHz). This confirms reports of other authors [39,41,43,45–46], although in some studies the fluctuations between measurements were definitely higher than in those here. It was also confirmed that the best repeatability is in the frequency band from 1 to 7 kHz [37,39–40,42–43,45–46]. However, compared to Wagner et al. [40] and Roede et al. [43], we found one completely different result for 6 kHz. Both papers described considerable fluctuations at this frequency, whereas in our study no significant differences were found between successive measurements.

In the multiple fit mode, the highest variability was obtained for the frequencies of 0.5 and 2 kHz, with some variability also for the range 5–8 kHz and higher frequencies (9, 11–14 kHz). In general, the variability we saw was less than in previous work describing differences between measurements made after removal and reinsertion of the probe [41,43,45–47]. However, it is difficult to make comparisons with other studies, particularly where there is different measuring equipment and types of probes.

Conclusions

In conclusion, even though differences between measurements for some frequencies reached as much as 3.4 dB, all DPOAEs significantly exceeded the noise floor. This finding confirms the usefulness of testing at very high frequencies (>8 kHz), although at the same time there is some need for caution when interpreting the results. Efforts to improve the measurement paradigm (e.g. by increasing the number of averages) might be worthwhile in achieving even greater repeatability.

It is also worth emphasising that the differences observed between the results presented in this work and those in other articles may be due to the size of the sample used, or to the use of other equipment for OAE recording.

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