

SHORT-TERM REPEATABILITY OF CONTRALATERAL SUPPRESSION OF TRANSIENTLY EVOKED OTOACOUSTIC EMISSIONS: PRELIMINARY RESULTS

W. Wiktor Jedrzejczak^{1,2}, Edyta Pilka^{1,2}, Lukasz Olszewski^{1,2}, Henryk Skarzynski^{1,2}

¹ Institute of Physiology and Pathology of Hearing, Warsaw, Poland

² World Hearing Center, Nadarzyn, Kajetany, Poland

Corresponding author: W. Wiktor Jedrzejczak, World Hearing Center, Institute of Physiology and Pathology of Hearing, Mochnackiego 10 Str., 02-042 Warsaw, Poland, e-mail: w.jedrzejczak@ifps.org.pl

Abstract

Background: The effect of suppression of otoacoustic emissions (OAEs) by contralateral acoustic stimulation (CAS) is very small, on the level of 1–2 dB. At the same time, OAEs are known to have quite high variability across subjects and some fluctuation of the signal between measurements is also present. The purpose of the present study was to investigate short-term repeatability of contralateral suppression of transiently evoked OAEs (TEOAEs).

Material and methods: OAEs were recorded in a group of 10 adults with normal hearing. TEOAEs were recorded using the linear protocol (all stimuli at the same level and polarity); stimulus levels were kept at 65 dB peSPL; and a 60 dB SPL broadband noise was delivered to the contralateral ear as suppressor. Each recording session consisted of three measurements: the first two were made consecutively without taking out the probe ('single fit' mode); the third measurement was made after taking out and refitting the probe ('multiple fit' mode). Global and half-octave values of TEOAE response levels and suppression were investigated. Additionally, as a measure of reliability, standard errors of measurement (SEMs) were analyzed.

Results: Broadband suppression was on average around 0.9 dB, while in the three half-octave frequency bands between 1 and 2 kHz it was 1.2–0.9 dB, 0.6 dB for the 2.8 kHz band, and 0.4 dB for the 4 kHz band. The SEM of suppression for single fit mode was about 0.15 dB for broadband analysis and 0.3 dB for 1 kHz, 0.2 dB for 1.4–2 kHz, 0.3 dB for 2.8 kHz, and 0.4 dB for 4 kHz. For multiple fits, there were only minor differences in SEM between broadband and 1–2.8 kHz, while for 4 kHz the SEM was greater, reaching 0.5 dB.

Conclusions: For a given paradigm, the reliability of suppression of TEOAEs is quite satisfactory for global values and for the 1–2 kHz bands. In this range, the SEM is smaller than the suppression effect. On the other hand, for higher frequencies, the variability is higher, about the same as the measured suppression.

Keywords: transiently evoked otoacoustic emissions • TEOAE • contralateral suppression • reliability • repeatability

LA REPETIBILIDAD A CORTO PLAZO DE LA SUPRESIÓN CONTRALATERAL DE LAS OTOEMISIONES ACÚSTICAS TRANSITORIAS: RESULTADOS PRELIMINARES

Resumen

Introducción: La supresión de otoemisiones acústicas (OAE) durante la estimulación acústica contralateral (CAS) es muy débil, a un nivel de 1-2 dB. Al mismo tiempo, se sabe que OAE tienen diferencias muy grandes entre las personas. También existen las fluctuaciones del señal entre las mediciones. El objetivo del presente trabajo fue examinar la repetibilidad a corto plazo de la supresión contralateral de las otoemisiones acústicas transitorias (TEOAE).

Material y métodos: Las OAE fueron medidas en el grupo de 10 adultos con la audición normal. Las TEOAE fueron registradas con el uso del protocolo lineal (todos los estímulos al mismo nivel y de la misma polaridad); los niveles de los estímulos ascendieron a 65 dB peSPL; el ruido de banda ancha fue suministrado a la oreja opuesta como el supresor. Cada sesión de medición consistió en tres mediciones: las primeras dos fueron hechas sucesivamente sin retirar la sonda (modo de ajuste solo); la tercera fue hecha después de retirar y reinsertar la sonda (modo de ajuste múltiple). Se examinó los valores globales y de media octava de los niveles de respuestas y supresiones. Además, se analizó los errores estándares de medida (SEM).

Resultados: La supresión de banda ancha fue alrededor de 0,9 dB, por término medio, mientras que en 3 bandas de frecuencia de media octava de 1 a 2 kHz fue 1,2–0,9 dB, 0,6 dB para la banda de 2,8 kHz y 0,4 dB para la banda de 4 kHz. SEM de la supresión para el modo de ajuste solo fue alrededor de 0,15 dB para el análisis de banda ancha y 0,3 dB para 1 kHz, 0,2 para

1.4–2 kHz, 0,3 dB para 2,8 kHz y 0,4 dB para 4 kHz. Para el modo de ajuste múltiple solo habían pequeñas diferencias en SEM para los valores de banda ancha y 1–2.8 kHz, y para 4 kHz SEM fue mayor, llegando a 0,5 dB.

Conclusiones: Para el protocolo de medición utilizado, la repetibilidad de la supresión TEOAE es satisfactoria para el análisis de banda ancha y para bandas de frecuencia 1–2 kHz. En este rango SEM es menor que la supresión. Por otra parte, para las frecuencias mayores, la variabilidad es mayor, más o menos al mismo nivel que la supresión.

Palabras clave: otoemisiones acústicas transitorias • TEOAE • supresión contralateral • credibilidad • repetibilidad

КРАТКОСРОЧНАЯ ПОВТОРЯЕМОСТЬ КОНТРАЛАТЕРАЛЬНОЙ СУПРЕССИИ ОТОАКУСТИЧЕСКИХ ЭМИССИЙ, ВЫЗВАННЫХ ТРЕСКОМ: ПРЕДВАРИТЕЛЬНЫЕ РЕЗУЛЬТАТЫ

Изложение

Введение: При контралатеральной акустической стимуляции (CAS) супрессия отоакустических эмиссий (ОАЕ) очень слаба, на уровне 12-дБ. Одновременно известно, что в случае ОАЕ между пациентами существует очень большая вариабельность. Появляются также колебания сигнала между измерениями. Цель настоящей работы заключалась в исследовании краткосрочной повторяемости контралатеральной супрессии отоакустических эмиссий, вызванных треском (ТЕОАЕ).

Материалы и методы: Измерения ОАЕ проводились в группе 10 взрослых людей обладающих нормальным слухом. ТЕОАЕ регистрировалась с помощью горизонтального протокола (все стимулы на одинаковом уровне и с одинаковой поляризацией); уровни стимулов: 65 дБ reSPL; в качестве супрессора в противоположное ухо падал широкополосный шум. Каждая сессия измерений состояла из трех измерений: первые два выполнялись последовательно, зонд не извлекался (режим «единичного приспособления»); третье измерение проводилось после извлечения и повторного размещения зонда (режим «многократного приспособления»). Исследовались глобальные и полуоктавные значения уровней ответов и супрессий. Дополнительно анализировались стандартные погрешности измерений (SEM).

Результаты: Широкополосная супрессия составляла в среднем около 0,9 дБ, в то время как в случае 3 полуоктавных полос частотой 12-кГц составлял 1,20–0,9 дБ, 0,6 дБ в случае полосы 2,8 кГц и 0,4 дБ в случае полосы 4 кГц. SEM супрессии в случае режима единичного приспособления составила около 0,15 дБ для широкополосного анализа и 0,3 дБ для 1 кГц, 0,2 для 1.42-кГц, 0,3 дБ для 2,8 кГц и 0,4 дБ для 4 кГц. В случае режима многократного приспособления появились только незначительные различия SEM для широкополосных значений и 1–2.8 кГц, а для 4 кГц SEM была выше, достигая уровня 0,5 дБ.

Выводы: В случае использованного протокола измерений повторяемость супрессии ТЕОАЕ является удовлетворительной для широкополосного анализа и полос частотой 12-кГц. В этом диапазоне уровень SEM ниже чем уровень супрессии. С другой стороны в случае более высоких частот переменчивость выше, более-менее на таком же уровне, как супрессия.

Ключевые слова: отоакустические эмиссий, вызванные треском • ТЕОАЕ • контралатеральная супрессия • достоверность • повторяемость

KRÓTKOTERMINOWA POWTARZALNOŚĆ SUPRESJI KONTRALATERALNEJ EMISJI OTOAKUSTYCZNYCH WYWOŁANYCH TRZASKIEM: WYNIKI WSTĘPNE

Streszczenie

Wprowadzenie: Supresja emisji otoakustycznych (OAE) przy ktralateralnej stymulacji akustycznej (CAS) jest bardzo słaba, na poziomie 1-2 dB. Jednocześnie wiadomo, że OAE mają bardzo duże różnice międzysobnicze. Występują także fluktuacje sygnału pomiędzy pomiarami. Celem niniejszej pracy było zbadanie krótkoterminowej powtarzalności supresji kontralateralnej emisji otoakustycznych wywołanych trzaskiem (TEOAE).

Materiał i metody: OAE zmierzono w grupie 10 osób dorosłych z normalnym słuchem. TEOAE rejestrowano stosując protokół liniowy (wszystkie bodźce na tym samym poziomie i o tej samej polaryzacji); poziomy bodźców wynosiły 65 dB peSPL; jako supresor do ucha przeciwnego był dostarczany szerokopasmowy szum. Każda sesja pomiarowa składała się z trzech pomiarów: pierwsze dwa wykonywano kolejno bez wyjmowania sondy (tryb „pojedynczego dopasowania”); trzeci pomiar wykonywano

po wyjęciu i ponownym umieszczeniu sondy (tryb „wielokrotnego dopasowania”). Badano wartości globalne i półoktawowe poziomów odpowiedzi i supresji. Dodatkowo, analizowano standardowe błędy pomiaru (SEM).

Wyniki: Szerokopasmowa supresja wynosiła średnio około 0,9 dB, podczas gdy w 3 pasmach półoktawowych częstotliwości od 1 do 2 kHz wynosił 1,2–0,9 dB, 0,6 dB dla pasma 2,8 kHz i 0,4 dB dla pasma 4 kHz. SEM supresji dla trybu pojedynczego dopasowania wynosił około 0,15 dB do analizy szerokopasmowej i 0,3 dB dla 1 kHz, 0,2 dla 1,4–2 kHz, 0,3 dB dla 2,8 kHz i 0,4 dB dla 4 kHz. Dla trybu wielokrotnego dopasowania były tylko drobne różnice w SEM dla wartości szerokopasmowych i 1–2,8 kHz, a dla 4 kHz SEM był większy, osiągając 0,5 dB.

Wnioski: Dla użytego protokołu pomiarowego, powtarzalność supresji TEOAE jest zadowalająca dla analizy szerokopasmowej oraz dla pasm częstotliwości 1–2 kHz. W tym zakresie SEM jest niższy niż supresja. Z drugiej strony, dla wyższych częstotliwości, zmienność jest większa, mniej więcej na takim samym poziomie, jak supresja.

Słowa kluczowe: emisje otoakustyczne wywołane trzaskiem • TEOAE • supresja kontralateralna • wiarygodność • powtarzalność

Introduction

Otoacoustic emissions (OAEs) are now well established objective tests of cochlear function [1]. Recently, substantial research effort has focused on evaluating the influence of the olivocochlear efferent system on OAEs. The medial olivocochlear (MOC) part of this system runs from brainstem to outer hair cells in the cochlea. The role of MOC is not fully understood, but it has been attributed to protection against acoustic trauma [2], improving hearing in noisy environments [3], and also a relationship to attention [4]. In the presence of additional stimuli – ipsilateral, contralateral, or bilateral – the efferent system suppresses OAEs [5,6]. Of most interest is contralateral stimulation by broadband noise [6], as this is the easiest way to measure the effect. For transiently evoked OAEs (TEOAEs), the effect is quite small, only 1–1.5 dB [7,8].

To date, contralateral suppression of OAEs has been studied in several clinical populations. In comparison to normal subjects, the effect differs depending on the group studied: diabetic children [9,10], children with Asperger syndrome [11], and workers at risk of occupational hearing loss [12]. There are also some contradictory results regarding subjects with tinnitus, with some papers finding a difference in comparison to normal subjects [13] while others do not [14].

There are few studies on the variability and repeatability of the MOC effect. Results indicate that, averaged across subjects, variability is up to 0.1 dB [8,15,16]. Many studies of the MOC effect on OAEs have used either custom-built systems (e.g. [15,17]) or a combination of commercial OAE system plus additional noise source (e.g. [8,18]). For some time now, measurement of contralateral suppression has been available in the commercial ILO system by Otodynamics (Hatfield, U.K.). It is therefore of interest to clinicians to know how such a system performs and its measurement reliability (its repeatability). As far as the authors know, there is only one study of ILO reliability using its standard suppression protocol [16] (although the study did involve some minor changes to the protocol: a click stimulus of 60 dB peSPL and contralateral broadband noise of 65 dB SPL, whereas the default uses 65 dB and 60 dB respectively). Details of the procedure used here are described in the ‘Material and Methods’ section. Moreover, there has been no study that has investigated the repeatability of contralateral suppression

of TEOAEs in half-octave bands using the standard clinical protocol. Generally, most studies use only global values of TEOAEs.

The repeatability of TEOAEs themselves has also not been studied much. For example, in one paper [19], it was found that fluctuations in TEOAE levels were typically around 1–2 dB, but in some ears they reached as much as 5 dB. This is well above the usual MOC effect. It therefore seems that variability in TEOAE levels could be important for evaluating MOC function.

Given that measurement of MOC effects using TEOAEs provides the opportunity to study a number of interesting features (even though the effect is small), the purpose of this study was to evaluate the short-term repeatability (single session reliability) of MOC suppression of TEOAEs using the commercially available ILO system.

Material and methods

Measurements were performed on 10 normally hearing adults (5 males and 5 females, age 28–43 years). Each ear was tested, so in total results from 20 ears were used for all analyses. Between-ear effects were not studied and ears were treated as if they were independent. This is obviously a simplification, but it is based on the observation that the OAEs from both ears of the same person are usually quite different [20].

All subjects underwent visual inspection of the ear canal and tympanic membrane of both ears, followed by tympanometry, middle ear reflexes, pure tone audiometry, and OAE measurement. All had pure tone thresholds better than 25 dB HL at 0.5–8 kHz, type A tympanograms (with middle ear compliance between 0.25 and 1.5 mL, and middle ear pressure between –100 and 50 daPa), and no known history of otologic disease. In all subjects, middle ear acoustic reflex thresholds for broadband noise were above 65 dB SPL. The subjects gave written informed consent prior to participation. Research procedures were approved by the Ethics Committee of the Institute of Physiology and Pathology of Hearing, Poland.

OAEs were measured in a sound booth using an ILO 292 system (Otodynamics Ltd.). The standard protocol, with default settings, for measurement of contralateral suppression was used. In the protocol, 65 dB peSPL click

stimuli are delivered to one ear and 60 dB peSPL broadband (white) noise to the contralateral ear. Masker on/off time is 2 s, and a total of 260 OAE sweeps are used. Global and half-octave band values of OAE response levels and signal-to-noise ratios (SNRs) were used for analysis. All recordings had an SNR of at least 6 dB for global values and 3 dB in half-octave bands frequencies from 1 to 4 kHz.

Each recording session consisted of three measurements. The first two were made consecutively without taking out the probe – single-fit mode. The third measurement was made after taking out and refitting the probe – multiple-fit mode. Each measurement took 2–3 minutes, and the whole set of measurements for one ear took up to 10 minutes. Measurement sessions were between 6 am and 4 pm.

For all parameters, the statistical significance of the mean difference between the three measurements was evaluated using two-factor (frequency and measurement) repeated measures ANOVA. As a criterion of significance, a 95% confidence level ($p < 0.05$) was chosen.

Some studies recommend use of the standard error of measurement (SEM) as a measure of reliability [21]. It is based on the formula:

$$SEM = STD \sqrt{1 - r}$$

where STD is the combined standard deviation of the OAE test and its retest and r is the Pearson correlation coefficient. In all calculations the SEM was calculated for absolute values.

Results

TEOAE repeatability

As a first step, TEOAE response levels and TEOAE reliability were investigated. For this purpose, the signals recorded with a 65 dB SPL click stimulus but without contralateral stimulation were analyzed. TEOAE1 and TEOAE2 were made without refitting the probe, and TEOAE3 was made after refitting it. Average broadband response levels were around 12 dB (Figure 1A), SNRs were around 18 dB (Figure 1B), and results for consecutive sessions were very similar. When frequency bands were tested, the levels were

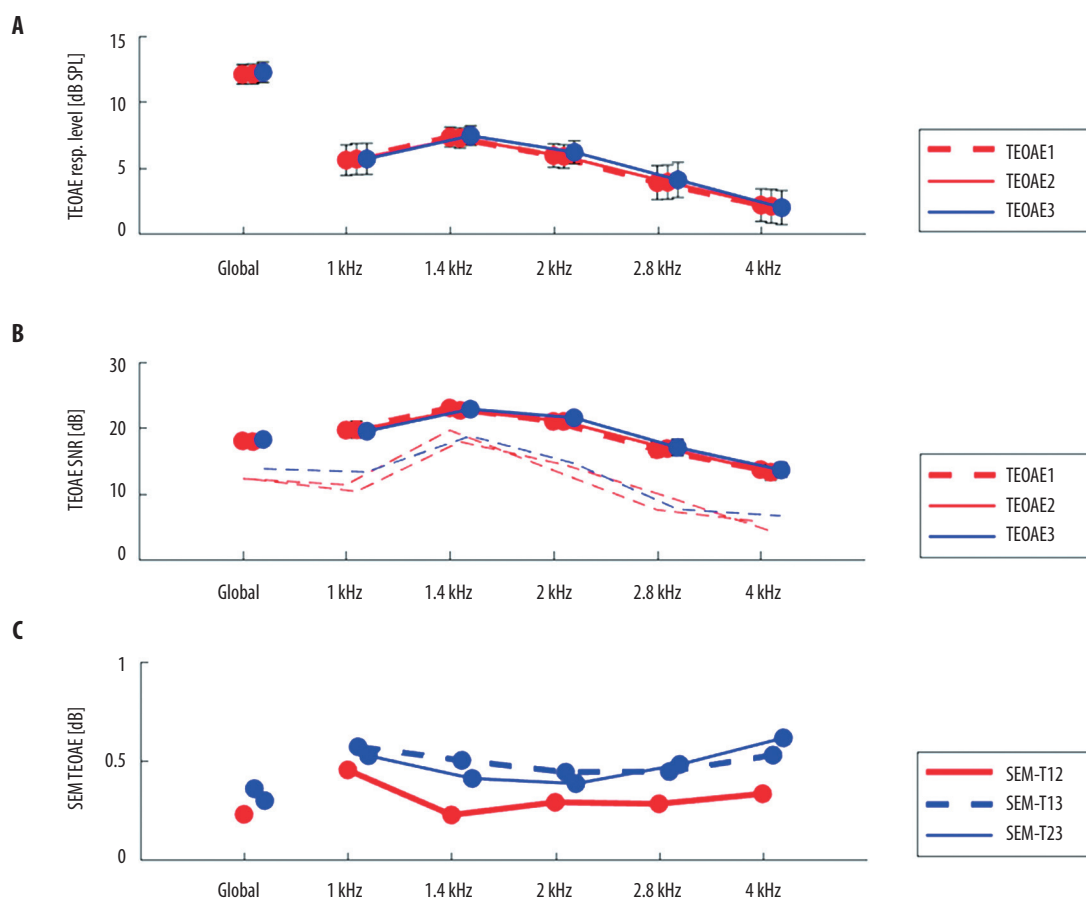


Figure 1. Results from three consecutive measurement sessions of TEOAEs. **(A)** Average global and half-octave band response levels. Whiskers indicate standard errors. **(B)** Average global and half-octave band signal to noise ratios (SNRs) (dashed lines show minimum SNRs for studied data). **(C)** Global and half-octave band standard errors of measurement (SEMs) for TEOAE levels. Differences between sessions 1 and 2 (T12), 1 and 3 (T13), and 2 and 3 (T23) are shown. Data points are slightly offset for clarity

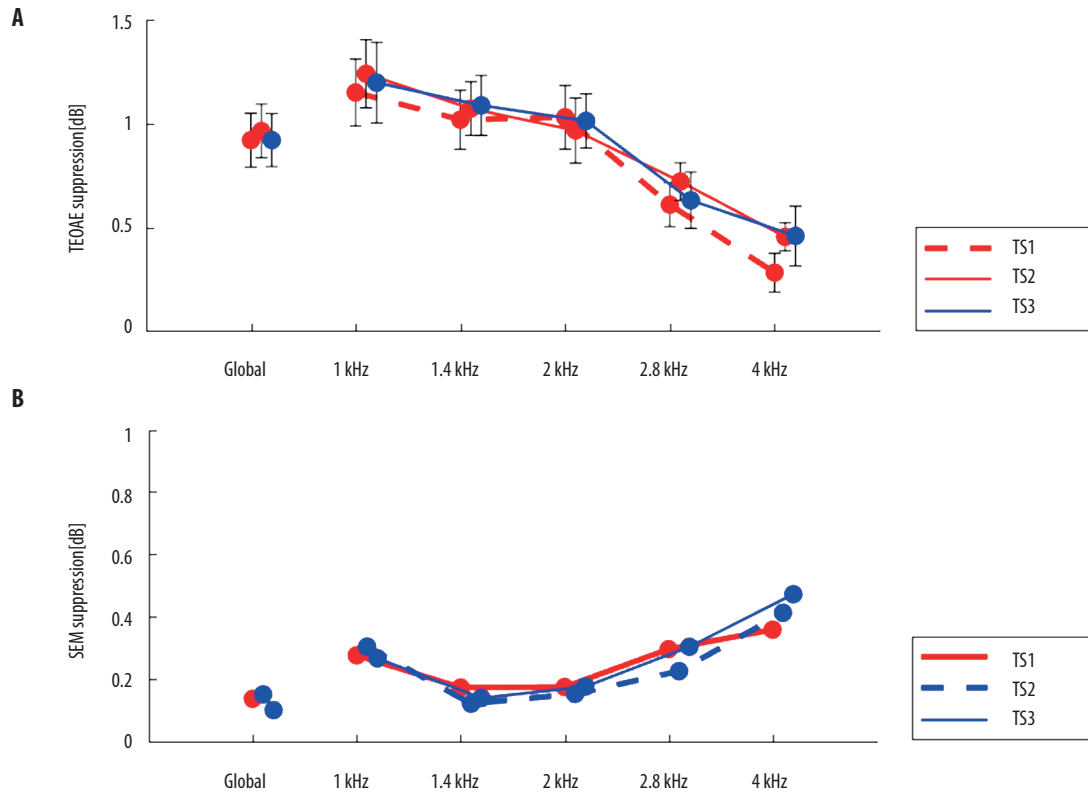


Figure 2. (A) Average global and half-octave band levels of suppression for TEOAEs across three consecutive measurement sessions (TS1, TS2, and TS3). Whiskers indicate standard errors. (B) Global and half-octave band SEMs for differences in suppression between measuring sessions (key as per Figure 1). For clarity, data points are slightly offset

around 5.6 dB for 1 kHz, 7.3 dB for 1.4 kHz, 5.9 dB for 2 kHz, 3.8 dB for 2.8 kHz, and 2.1 dB for 4 kHz. A two-factor repeated measures ANOVA did not show statistically significant differences between TEOAE1, TEOAE2, and TEOAE3, for frequency or for measurement ($p > 0.05$). There were no significant differences for global values either ($p > 0.05$).

SEM was used as a measure of reliability of TEOAEs (Figure 1C). The SEM calculated for sessions 1 and 2 (without refitting the probe) is marked as SEM-T12, and for consecutive sessions SEM-T13 and SEM-T23 (after refitting the probe). The global value of SEM-T12 was 0.22 dB, while the value for SEM-T13 was 0.36 dB and for SEM-T23 it was 0.3 dB. SEM was lowest for the middle frequency bands of 1.4–2.8 kHz and highest for the 1 and 4 kHz bands.

TEOAE contralateral suppression repeatability

Figure 2 shows the results of contralateral suppression of TEOAEs for three consecutive measurements. The amount of suppression was calculated by subtracting the response with contralateral noise from the response without noise (TEOAE1, TEOAE2, and TEOAE3, shown in Figure 1). TS1 and TS2 were made without refitting the probe, and TS3 was made after refitting it.

Broadband suppression was on average around 0.9 dB, while in half-octave frequency bands it was 1.2–0.9 dB in

the three frequency bands between 1 and 2 kHz, 0.6 dB for the 2.8 kHz band, and 0.4 dB for the 4 kHz band (Figure 2A). Generally, the amount of suppression was similar across sessions. A two-factor (frequency and measurement) repeated measures ANOVA showed no statistically significant differences between any of the frequencies or any of the series, including the session where the probe was refitted.

The SEM of suppression for the single fit mode (SEM-S12) was around 0.15 dB for broadband analysis and 0.3 dB for 1 kHz, 0.2 dB for 1.4–2 kHz, 0.3 dB for 2.8 kHz, and 0.4 dB for 4 kHz (Figure 2B). There were only minor differences in SEM for multiple fits (SEM-S13 and SEM-S23) for broadband and for the 1–2.8 kHz bands, while the SEM for 4 kHz was greater, reaching 0.5 dB.

Discussion

In the present work measurements have been made of the short-term reliability of the response level of TEOAEs and the amount of suppression caused by contralateral broadband noise. It should be noted that TEOAEs were here measured at 65 dB in the linear averaging mode, although usually TEOAEs are measured using a level of 80 dB in the nonlinear averaging mode [22]. Note also that in most studies involving OAE suppression measurements, other protocols are used than the one employed here.

Using the present paradigm, the average suppression level was around 1 dB for the broadband signal. This is in agreement with some other studies [16]. In half-octave frequency bands it was also around 1 dB for 1–2 kHz and lower values, around 0.5 dB, were recorded for 2.8–4 kHz. This distribution of the MOC effect across frequencies is similar to [23]; however in that work higher effect levels were found.

As for the reliability of the effect, it was better than 0.2 dB for broadband values and better than 0.3 dB for the 1–2.8 kHz bands, but close to 0.5 dB for the 4 kHz band. In [8, 16], even lower average test differences were found for broadband values: around 0.01–0.05 dB in the first study and 0.11 dB in the second. However, the data spread was quite high. On the other hand, in [17] it was concluded that variability of the MOC effect is quite high and even 1.5–2 dB of suppression is required for the change to be considered significant. The reliability of the MOC effect in particular frequency bands has so far been studied only by [18]. The results were comparable to the present study in that it was concluded that the 0.5–2.5 kHz band gave the best results. The high variability of the MOC effect at 4 kHz in the present study can be attributed to a small MOC effect, which means a correspondingly low SNR at 4 kHz. It is presumed the SNR could be improved by longer averaging. However, in the present study the idea was to use the default protocol and measure how well it performed. The conclusion is that it is quite satisfactory for global values of the evoked signal. Nevertheless, because the effect is so small the most important thing is to get high quality recordings with appropriate SNRs.

The TEOAE response levels exhibited a frequency pattern in which the maximum occurred in the 1.4 kHz half-octave frequency band, similar to other studies using the same equipment [24]. The reliability was around 0.3 dB for the broadband signal and reached 0.5 dB for some frequency bands. It was best at 2 kHz. This is generally consistent with previous studies, especially [25], where reliability was also best at 2 kHz. In [26], similar values of SEM were achieved (less than 1 dB), but the highest SEM values were at 1 kHz, which was attributed to low-frequency noise. Here high frequencies also generated quite high variability as well. In [27], SEMs were much higher, reaching

even 2 dB, but in that study the consecutive measurements were made over a 1-year time-span.

Finally, the limitations of this preliminary study should be mentioned. The group studied was quite small; in addition, studies across longer time-spans are needed. There is also the possibility of a middle-ear muscle reflex confounding the results, as there is the possibility of activation in some subjects even with a 60 dB SPL stimulus [28]. Additionally, some studies have shown that the level of conscious attention may exert an MOC effect on OAEs [4]. This effect is very small and was not controlled here; it is unlikely that control of it would be required in clinical testing.

Nevertheless, this study has arrived at one important finding, that even during a single session the variability of the suppression effect is quite high. Moreover, the suppression effect is only slightly higher than the variability, or sometimes even less so (as for the 4 kHz band).

In the present work the results are shown in decibels, rather than in percent as in some recent work [18]. This approach was in keeping with showing results for a particular system under its default settings, rather than investigating the MOC effect more generally, as has been done in other studies [8,16–18].

Conclusions

The data analysis has revealed that, for the paradigm used, the reliability of suppression of TEOAEs is quite satisfactory for a broadband signal and for half-octave bands between 1 and 2 kHz. For higher frequencies, the variability is higher, and given that the suppression effect is then lower, the variability is of the same size as the suppression effect. In order to measure small suppression effects, measurements must be done carefully so as to minimize noise sources and very strict criteria for detection of OAEs are needed.

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