

Distortion-product otoacoustic emission phase shift test (Shift-DPOAE) – methodology of measurements and interpretation of results in example cases

Przesunięcie w fazie otoemisji akustycznych produktów zniekształceń nieliniowych ślimaka (Shift-DPOAE) – metodologia badania i interpretacja wyników na przykładach

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ABSTRACT:

Objective: The objective of the study was to present the methodology and interpretation of the results of distortion-product otoacoustic emission phase shift (Shift-DPOAE) measurements in healthy subjects and patients with Meniere's disease in remission or during the attack.

Material and methods: Shift-DPOAE measurements were performed in two healthy subjects with no otological or neurological problems as well as in six patients diagnosed with Meniere's disease. Results obtained from all eight subjects are presented. Detailed otoscopy, impedance audiometry, pure tone audiometry, DPOAE, and Shift-DPOAE tests were performed in all subjects.

Results: Normal results of Shift-DPOAE measurements obtained from two healthy subjects as well as normal (two subjects) and abnormal (four subjects) Shift-DPOAE results obtained from patients with Meniere's disease are presented in order to thoroughly discuss the methodology and interpretation of Shift-DPOAE measurements.

Conclusions: Shift-OAE is a promising diagnostic tool with a great clinical potential for diagnostics and monitoring of Meniere's disease in patients whose hearing has not yet been damaged. The test is completely non-invasive and can be carried out immediately after the onset of disease attack with symptoms still present at the time of the test; in addition, the procedure takes just several minutes.

KEYWORDS:

distortion-product otoacoustic emission, hearing loss, Meniere's disease, phase shift, tinnitus, vertigo

STRESZCZENIE:

Cel: Przedstawienie metodologii badania oraz prezentacja wyników przesunięcia w fazie otoemisji akustycznych produktów zniekształceń nieliniowych ślimaka (Shift-DPOAE), wykonanego u osób zdrowych i z potwierdzoną chorobą Meniere'a w fazie remisji oraz w ostrej fazie choroby w czasie ataku.

Materiał i metody: Badanie Shift-DPOAE zostało wykonane u dwóch osób z prawidłowym słuchem i bez żadnych problemów otologicznych i neurologicznych (osoby zdrowe) oraz u sześciu z klinicznie zdiagnozowaną chorobą Meniere'a. W sumie w pracy prezentowano wyniki uzyskane u ośmiu osób. U wszystkich badanych wykonano następujące badania: dokładną otoskopię, audiometrię impedancyjną, audiometrię tonalną, tradycyjne badanie DPOAE oraz Shift-DPOAE.

Wyniki: Zaprezentowano i omówiono prawidłowe wyniki Shift-DPOAE uzyskane u dwóch osób zdrowych oraz wyniki prawidłowe (dwie osoby) i nieprawidłowe (cztery osoby) uzyskane u pacjentów z chorobą Meniere'a, w celu dokładnego omówienia metodologii i interpretacji badania Shift-DPOAE.

Wnioski: Shift-OAE to obiecujące badanie z dużym potencjałem klinicznym w diagnostyce i monitorowaniu choroby Meniere'a u pacjentów, u których słuch nie został jeszcze uszkodzony. Jest ono całkowicie nieinwazyjne, może być przeprowadzone zaraz po ataku choroby w trakcie trwania objawów, a jego wykonanie zajmuje zaledwie kilka minut.

SŁOWA KLUCZOWE: choroba Meniere'a, niedosłuch, otoemisje akustyczne, przesunięcie w fazie, szum uszny, zawroty głowy

ABBREVIATIONS

FFT – Fourier Transform
OAE – otoacoustic emissions
SNR – signal-to-noise ratio

INTRODUCTION

Otoacoustic emissions (OAEs) are sounds generated by external auditory hair cells within the cochlea of the inner ear and transmitted across the middle ear to the external auditory meatus where they can be recorded using a sensitive probe. The test is completely non-invasive and takes little time to complete. In recent years, researchers focused on assessing OAE phase shifts (Shift-OAE) caused by the changes in intracranial pressure as well as by the changes in cochlear pressure as those observed in Meniere's disease [1–8]. Test prerequisites include unremarkable outcomes of otoscopic examination and normal function of the middle ear, a hearing threshold of < 30 dB HL within the frequency range under investigation, i.e. 500–1000 Hz, and OAEs being recorded in the frequency band of around 1000 Hz. Shift-OAEs can be measured using a click stimulus (Shift-TEOAE) or as phase shifts of the products of non-linear distortions occurring within the cochlea (Shift-DPOAE).

Aim

The objective of the study is to present the methodology and interpretation of the results of distortion-product otoacoustic emission phase shift (Shift-DPOAE) measurements in subjects with normal hearing and no otological or neurological problems and patients with confirmed Meniere's disease in remission or in acute phase of the disease (i.e. during the attack). Example normal results obtained from two healthy subjects as well as normal and abnormal results obtained from patients with Meniere's disease are presented and discussed in detail.

MATERIAL AND METHODS

Shift-DPOAE measurements were carried out in subjects with normal hearing and no otological or neurological problems (two healthy subjects) as well as in six patients with clinical diagnosis of Meniere's disease.

Methodology of Shift-DPOAE measurements

Careful otoscopic examinations were performed prior to Shift-DPOAE measurements to ensure no pathological lesions or wax were present within the external auditory meatus and that the tympanic membrane was normal. The correct function of the middle ear was confirmed by impedance audiometry tests. Pure tone audiometry tests confirmed that the hearing thresholds at 1000 Hz were below 30 dB HL. Conventional DPOAE measurements were also performed to ensure that otoacoustic emissions could be recorded in the frequency band of around 1000 Hz as this was the necessary condition for the investigation of emission phase shifts.

Shift-DPOAE tests were carried out using an Echodia Elios device and Echosoftware (Echodia, Clermont-Ferrand, France). Two tones at frequencies of f1 and f2 (1000 Hz and 1204 Hz, respectively) and intensity of 70 dB SPL were delivered to the external auditory meatus to evoke DPOAEs at 2f1–f2 (796 Hz). The complete Shift-DPOAE examination consisted of three consecutive DPOAE measurements, each being performed in a specific body position in the following order: with patient seated at 90° relative to horizontal ground level (hereinafter referred to as vertical position), with patient lying at 0° position relative to horizontal ground level (hereinafter referred to as horizontal position) and then again with the patient seated (hereinafter referred to as 2nd vertical position for the sake of differentiation from the same position during the first measurement). A tilting table was used to change patient's position from the 90° sitting position to the 0° lying position (relative to horizontal ground level). In each position, DPOAEs were measured 30 seconds after position change. In addition, subjects were asked to swallow saliva after changing their body position.

Analysis of Shift-DPOAE results

Phase shifts in DPOAEs were measured between the vertical and the horizontal position. Fast Fourier Transform (FFT) algorithm was used in the analysis of DP signals recorded within the external auditory meatus. The signal-to-noise ratio (SNR) required for a given DPOAE measurement to be considered a registered acoustic emission was > 6 dB. A total of 4–5 DPOAE measurements were made in each position, and the averaged results for each position were included in the analysis. Phase shifts were analyzed for vertical → horizontal and horizontal → 2nd vertical position changes.

Shift-DPOAE results of > 40° were considered pathological (positive); results of about 35° were considered diagnostically inconclusive, and results of < 30° were considered normal (negative).

RESULTS

Normal Shift-DPOAE results

Figs. 1.–4. present the Shift-DPOAE results obtained from two healthy subjects with no otological and neurological disorders (Figs. 1. and 2. for subjects #1 and #2, respectively) and two patients previously diagnosed with Meniere's disease who had not experienced the attacks of the disease for a relatively long time (Figs. 3. and 4. for subjects #3 and #4, respectively). In the healthy subjects, the results were within the normal range. The same was true for Shift-DPOAE results obtained from patients with Meniere's disease in remission.

Abnormal Shift-DPOAE results

Figs. 5.–8. present the Shift-DPOAE results obtained from patients with clinical diagnosis of Meniere's disease during the disease attack presenting with the characteristic triad of symptoms including vertigo, hearing loss, and tinnitus or the aural fullness sensation in the first two of these patients (Figs. 5. and 6. for subjects #5 and #6, respectively), vertigo with aural fullness in the third patient (Fig. 7., subject #7), and hearing loss with tinnitus in the fourth patient (Fig. 8., subject #8).

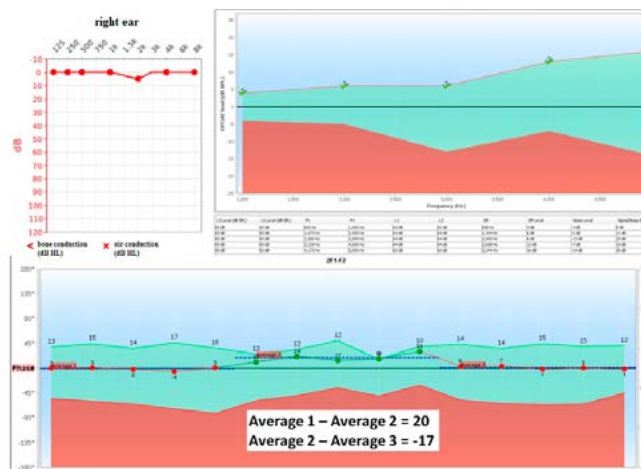


Fig. 1. Results of pure tone audiometry (left upper graph), distortion products otoacoustic emissions (DPOAE) (right upper graph), and phase shift distortion-product otoacoustic emissions (Shift-DPOAE) (bottom graph) in a healthy subject without any otologic or neurologic problems (subject #1). The Shift-DPOAE result is normal.

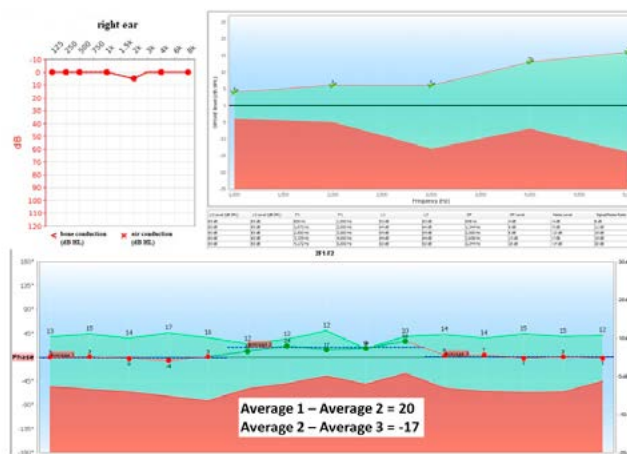


Fig. 2. Results of pure tone audiometry (left upper graph), distortion products otoacoustic emissions (DPOAE) (right upper graph), and phase shift distortion-product otoacoustic emissions (Shift-DPOAE) (bottom graph) in a healthy subject without any otologic or neurologic problems (subject #2). The Shift-DPOAE result is normal.

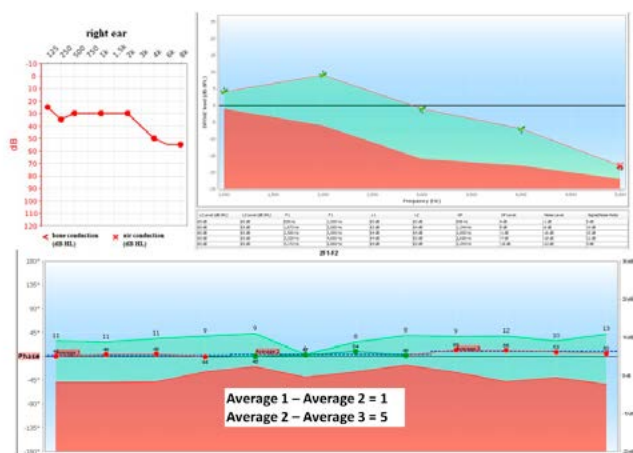


Fig. 3. Results of pure tone audiometry (left upper graph), distortion products otoacoustic emissions (DPOAE) (right upper graph), and phase shift distortion-product otoacoustic emissions (Shift-DPOAE) (bottom graph) in a patient with Meniere's disease in remission stage – the absence of symptoms (subject #3). The Shift-DPOAE result is normal.

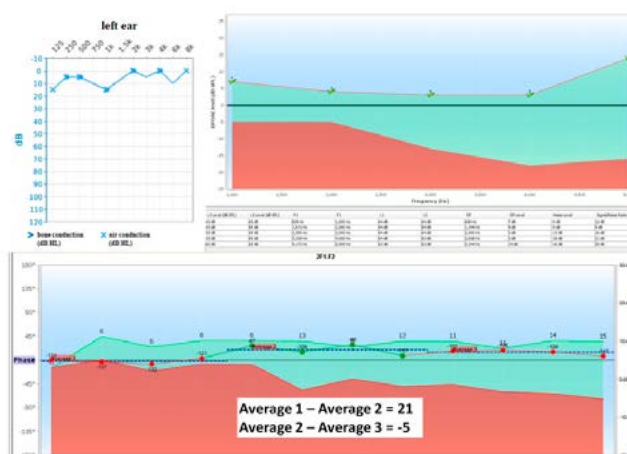


Fig. 4. Results of pure tone audiometry (left upper graph), distortion products otoacoustic emissions (DPOAE) (right upper graph), and phase shift distortion-product otoacoustic emissions (Shift-DPOAE) (bottom graph) in a patient with Meniere's disease in remission stage – the absence of symptoms (subject #4). The Shift-DPOAE result is normal.

DISCUSSION

Sounds generated by external auditory cells within the cochlea of the inner ear (OAEs) respond to pathological changes leading to stapedial footplate being fixated within the round window [9] or to the basal membrane being stiffened by increased intracranial [1, 3–5] or intracochlear pressure, and thus Shift-OAEs can be used in the diagnostics of endolymphatic hydrops (Meniere's disease) [6, 7]. The response consists in a characteristic phase shift in the OAE at about 1000 Hz as also observed in this study.

A change from the sitting (vertical) to the lying (horizontal) position results in an increase in intracochlear pressure; this increase is overly pronounced in acute Meniere's disease [7, 8] or in intracranial pressure changes [1–4, 6, 10, 11]. Since stabilization of otoemission measurements recorded in a particular body position is achieved about 30 seconds after position change [10], DPOAE measurements

in this study were recorded after this time in each position. In addition, subjects were asked to swallow saliva after changing their body position to ensure that the pressure within the middle ear was stable and equal to the external ambient pressure [9, 12, 13].

According to literature reports, OAE phase shifts observed upon changes in body position are overly pronounced in Meniere's disease patients [7, 8]. Avan et al. [7] demonstrated a significant increase in Shift-DPOAE values in acute-phase Meniere's disease in a vast majority of subjects (93.33%), declaring this increase to be specific for this subject group. Pathological values were also measured in several patients in remission (28.13% of asymptomatic patients examined). At the same time, the authors proposed that Shift-DPOAE be used in patients suspected of having Meniere's disease and presenting with fluctuating hearing loss and tinnitus yet with no vestibular symptoms. A confirmed pathological DPOAE phase shift would signal potential inner ear fluid balance disorders

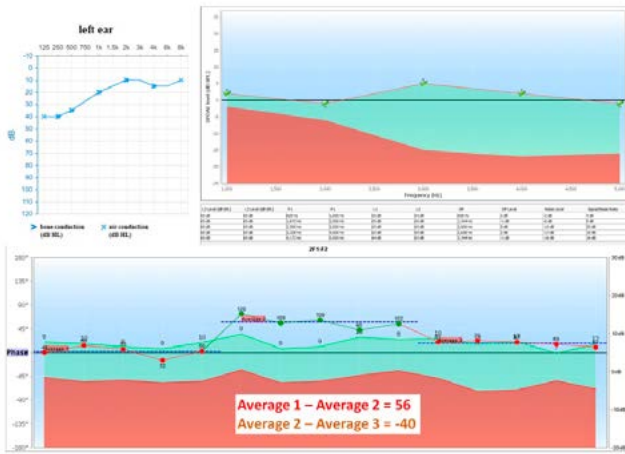


Fig. 5. Results of pure tone audiometry (left upper graph), distortion products otoacoustic emissions (DPOAE) (right upper graph), and phase shift distortion-product otoacoustic emissions (Shift-DPOAE) (bottom graph) in a patient with Meniere's disease at the time of a typical attack of Meniere's disease, with triad of vertigo, hearing loss, and tinnitus (subject #5). The Shift-DPOAE result is abnormal.

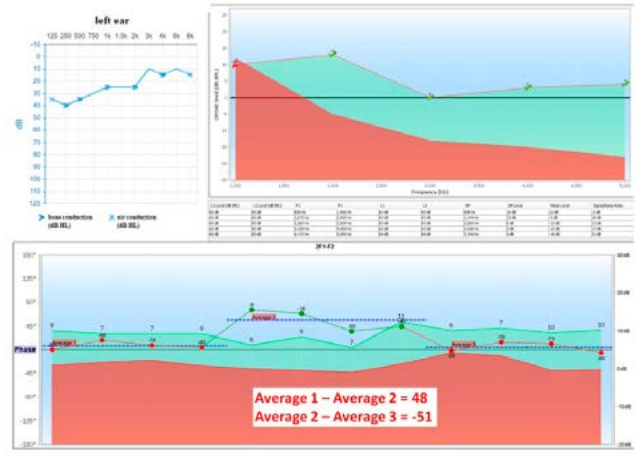


Fig. 6. Results of pure tone audiometry (left upper graph), distortion products otoacoustic emissions (DPOAE) (right upper graph), and phase shift distortion-product otoacoustic emissions (Shift-DPOAE) (bottom graph) in a patient with Meniere's disease at the time of a typical attack of Meniere's disease, with triad of vertigo, hearing loss, and tinnitus accompanied by sensation of aural fullness (subject #6). The Shift-DPOAE result is abnormal.

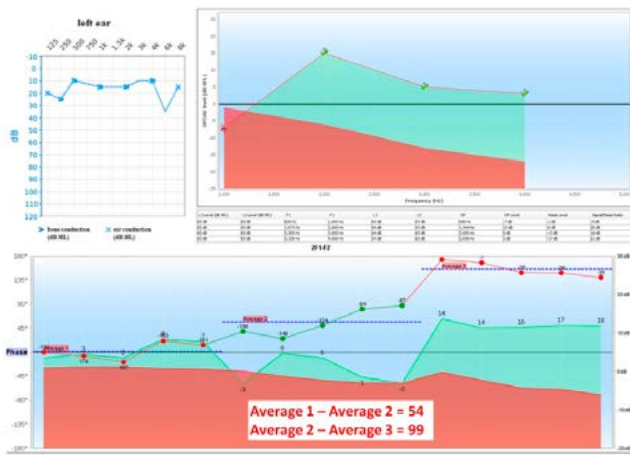


Fig. 7. Results of pure tone audiometry (left upper graph), distortion products otoacoustic emissions (DPOAE) (right upper graph), and phase shift distortion-product otoacoustic emissions (Shift-DPOAE) (bottom graph) in a patient with Meniere's disease at the time of an attack of Meniere's disease, with vertigo accompanied by sensation of aural fullness (subject #7). The Shift-DPOAE result is abnormal.

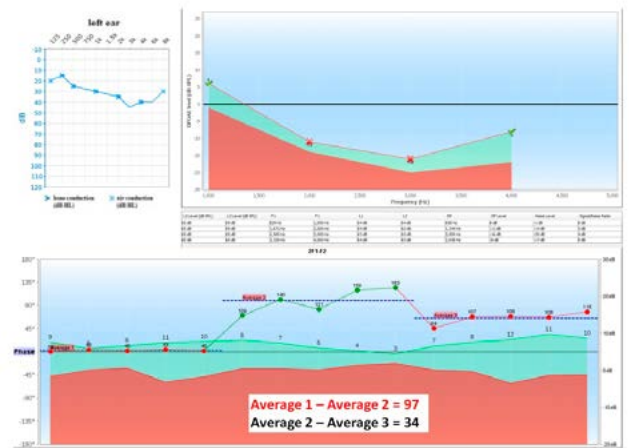


Fig. 8. Results of pure tone audiometry (left upper graph), distortion products otoacoustic emissions (DPOAE) (right upper graph), and phase shift distortion-product otoacoustic emissions (Shift-DPOAE) (bottom graph) in a patient with Meniere's disease at the time of an attack of Meniere's disease, with hearing loss and tinnitus (subject #8). The Shift-DPOAE result is abnormal.

and provide an indication for wider diagnostics as in the case of subject #8 in this study. However, such changes in Shift-DPOAE values are not observed in all patients, and therefore the diagnostic value of the test in such cases may be limited [7]. The absence of pathological changes in patients diagnosed with Meniere's disease yet presenting with no disease symptoms (disease remission) is presented in cases of subjects #3 and #4 in this study. Mom et al. [8] confirmed pathological TEOAE results within the affected ear during the symptomatic period in 86.96% of subjects diagnosed with Meniere's disease. At the same time, normal Shift-TEOAE results were obtained in 100% of healthy ears examined (control).

Some authors suggested that Shift-DPOAE may be of value in the monitoring of Meniere's disease [6, 14–16]. However, as almost all diagnostic examinations, Shift-OAE measurements have certain limitations. In Meniere's disease, progression in hearing damage

occurs over time and following recurrent disease attacks, making it impossible to further record otoacoustic emissions. According to Mom et al. [8], this holds true for 1/3 of patients with this disease, and therefore Shift-OAE measurements are not always practicable in patients with long-lasting Meniere's disease and significant hearing damage.

CONCLUSIONS

Shift-OAE is a promising diagnostic tool with a great clinical potential for diagnostics and monitoring of Meniere's disease in patients whose hearing has not yet been damaged. The test is completely non-invasive and can be carried out immediately after the onset of disease attack with symptoms still present at the time of the test; in addition, the procedure takes just several minutes.

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