Vestibology

Effect of eye lateralization on contralateral suppression of transient evoked otoacoustic emissions

Effetto della lateralizzazione oculare sulla soppressione controlaterale delle emissioni otoacustiche evocate transienti

D. SOI[1], D. BRAMBILLA[2], E. COMIOTTO[2], F. DI BERARDINO[1], E. FILIPPONI[3], M. SOCCI[1], E. SPREAFICO[2], S. FORTI[3], A. CESARANI[1 3]

[1] Dipartimento di Scienze Chirurgiche Specialistiche, Università di Milano, Milan, Italy; [2] Audiology Unit, IRCCS "Eugenio Medea", Bosisio Parini (LC), Italy; [3] Audiology Unit, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Milan, Italy

SUMMARY

Several studies have previously demonstrated that postural changes modify evoked otoacoustic emission. In order to evaluate a possible interaction between eye muscles and ciliated cells in the inner ear, we studied the effects of eye lateralization on the contralateral suppression of transient evoked otoacoustic emissions (TEOAEs). Thirty-eight normal hearing subjects with TEOAEs were recruited. Their TEAOEs at threshold level were recorded with contralateral suppression (white noise) via straight ahead fixation and right or left lateral fixation. Eye lateralization in the same direction of the white noise significantly decreased the suppression at 4 kHz ($p = 0.003$). The signal-to-noise ratio in the suppression condition with straight ahead was 1.54 (± 4.610) dB, while the ratio was 3.48 (± 4.631) dB in the suppression condition with gaze toward the white noise. Eye lateralization seems to reduce the contralateral suppression effect of TEOAEs at 4 kHz. However, further studies are necessary to investigate the possible mechanisms of this phenomenon.

KEY WORDS: TEOAE • Gaze • Contralateral suppression

RIASSUNTO

Alcuni studi hanno precedentemente dimostrato che i cambiamenti nella postura modificano le otoemissioni acustiche evocate. Per valutare una possibile interazione tra i muscoli oculari e le cellule ciliate dell'orecchio interno, abbiamo studiato l'effetto della lateralizzazione oculare sulla soppressione controlaterale delle emissioni otoacustiche evocate transienti (TEOAEs). Sono stati reclutati 38 soggetti normoudenti, con TEOAEs presenti. Le TEOAEs sono state registrate a soglia, con una soppressione controlaterale (rumore bianco), fissando lo sguardo al centro, a destra e a sinistra. La lateralizzazione oculare nella stessa direzione del rumore bianco riduceva significativamente la soppressione delle TEOAEs a 4 kHz ($p = 0,003$). Il rapporto segnale-rumore in condizione di soppressione con lo sguardo fisso al centro era 1,54 (± 4,610) dB e 3,48 (± 4,631) dB con lo sguardo omolaterale rispetto al rumore bianco. La lateralizzazione oculare sembra dunque ridurre l'effetto di soppressione controlaterale delle TEOAEs a 4 kHz, tuttavia, sono necessari ulteriori studi per fornire le possibili spiegazioni.

PAROLE CHIAVE: *TEOAE • Gaze • Soppressione controlaterale*

Acta Otorhinolaryngol Ital 2012;32:170-174

Introduction

In 1946, Kekcheev hypothesized an interaction between posture and auditory perception. In particular, he reported a higher auditory sensitivity when the listener was in a seated position, but not when the listener was in a standing or horizontal position [1]. This was the first of numerous studies that have attempted to evaluate the correlation between postural changes and auditory threshold.

Some authors [2 3] have reported a shift in the pure-tone threshold with different body positions (upright, seated, supine, inverted, right or left positions). Several hypotheses to explain this phenomenon include an increase in cochlear fluid pressure, a change in blood supply to the cochlea and direct contractions by the middle ear muscles [3]. More recently, researchers have begun to pay attention to the correlation between position changes and transient evoked otoacoustic emission (TEOAEs) as it has been demonstrated that postural changes can modify TEOAEs. In fact, a reduction in the peak latencies was observed [4 5] as well as a reduction in amplitudes and the form of a phase shift [6].

The interactions among visual, auditory and vestibular inputs are well known. Several studies have reported that the lateral movement of the eyes influences the ability to localize sound [7-9]. These studies have also shown that changes in the body axes toward the source of optokinetic stimulation modified the orientation of sound lateralization [10], and that vestibular stimulation influenced the perception of auditory space [11]. Moreover, Ferber-Viart et al. demonstrated that visual attention tasks inhibit outer hair cell (OHCs) activity, and that the combination of contralateral acoustic stimulation and visual attention tasks lead to significant reduction in TEOAEs via the medial olivocochlear efferent system [12],

In a previous unpublished pilot study, we observed no significant influence of direct gaze, i.e. with straight ahead, on TEOAEs. Therefore, the aim of this study was to evaluate the possible effect of eye lateralization on contralateral suppression [13] of TEOAEs.

Materials and methods

Subjects

Forty-seven healthy subjects were recruited. All subjects were right-handed and exhibited normal hearing. Pure tone audiometric thresholds were regarded as normal if the mean values for the 500, 1000, 2000 and 4000 Hz frequencies were between 0 and 25 dB hearing level (HL) [14]. None of the subjects had middle ear pathologies, as evidenced by normal tympanometry results and presence of acoustic reflexes to contralateral broad band noise and pure tones. Moreover, patients suffering from disorders of the visual, oculomotor or equilibrium system were excluded. TEOAEs were included in the study.

The first step was to evaluate TEOAEs in the basal condition (with a stimulus of approximately 80 dB peak sound pressure level – pSPL). Six subjects were excluded because either their TEOAEs levels were lower than 3 dB in at least 3 frequencies between 1 and 5 kHz, or because their reproducibility was less than 50% [15].

The remaining subjects were submitted to contralateral suppression of TEAOEs according to Collet's protocol [13]. Veuillet and colleagues suggested that an absolute decrease of less than 0.5 dB in TEAOEs could be taken as a sign of impairment in the crossed medial olivocochlear (MOC) system [16]. Thus, only subjects who reported a suppression of 1 dB or more were recruited. As a result, 3 subjects were excluded. In the final cohort, there were 38 subjects (24 females and 14 males) aged 21-47 years. The mean age was 28.2 ± 8.45 years. This study was approved by the Ethics Committee of the Fondazione IRCCS Ospedale Maggiore Policlinico Mangiagalli e Regina Elena.

Auditory screening

Pure tone audiometry was performed in a soundproof room using an Amplaid A321 audiometer according to ISO 6189 standards. Tympanometry and acoustic reflex recordings were performed in a soundproof room using an Amplaid 702 tympanometer hearing impedance audiometer.

TEOAE recordings

TEOAEs were recorded [17] using an Otodynamics ILO-292 DP system with ILO-V5 software. TEOAEs responses were evoked by trains of non-linear clicks at a rate of 50/sec. Each click stimulus had a duration of 80 µsec. The analysis window was 20 msec, and responses were band-pass-filtered from 0.5 to 6 kHz. Each response was the average of 260 sweeps.

Contralateral suppression

Contralateral suppression was performed according to the Collet protocol [18]: a white noise was delivered to the contralateral ear (left ear) by an ear phone (TDH 49). The suppressor noise was delivered at an intensity of 45 dB SPL. In order to evaluate the presence or the absence of TEOAEs in the right ear during contralateral suppression, all tests utilized the following criteria:

- stimulus stability no less than 65%;
- noise level no more than 40 dB;
- A-B difference (a measure of the noise contained within the response [19]) no less than 2 dB;
- whole-wave reproducibility no less than 50%;
- signal-to-noise ratio (SNR) no less than 60% in at least 2 frequencies.

Gaze

In a dark and silent room, the subjects sat on a chair with their heads were fixed to a headrest. The tests were performed by asking the patients to look at a fixed red light dot on a light bar in front of them. This light was directed to the front, right and left sides of the subject at an angle of 40°. The corrected eye position was monitored by a nystagmography system (EOG amplifier by Nystar).

Procedures

Only the right ear was analyzed because the TEOAE magnitude for the right ear was statistically wider than that for the left ear [20 21]. Furthermore, the level of TEOAEs suppression was significantly higher in the right ear than in the left ear [22].

The protocol was as follows:

1. Determination of TEOAE threshold: determined as the lowest stimulus intensity that evoked an otoacoustic emission of 2 dB or more for at least 2 frequencies, and with at least 49% reproducibility;
2. Recording of basal suppression condition: TEAOEs were recorded at threshold level with contralateral suppression and straight ahead fixation;
3. Recording the contralateral suppression test with lateral gaze (40°): TEAOEs were recorded at threshold level with contralateral suppression and lateral gaze;

Table I. Mean ± SD of controlled variables in four conditions. The statistical comparison for the suppression condition was calculated vs. the basal condition, while the others were evaluated between suppression conditions with or without gaze.

	Basal condition: threshold	Suppression condition: straight ahead	Suppression condition: right gaze	Suppression condition: left gaze
Whole-wave reproducibility	78.03 ± 10.486	70.93 ± 13.408 p < 0.001	73.31 ± 13.924 p = 0.121	70.93 ± 16.620 p = 0.231
A-B difference	4.85 ± 2.104	5.31 ± 2.083 p = 0.201	4.72 ± 1.891 p = 0.383	5.02 ± 1.891 p = 0.219
Stability	87.11 ± 8.627	83.29 ± 14.425 p = 0.074	85.70 ± 9.761 p = 0.523	85.47 ± 12.077 p = 0.424
Noise level	37.99 ± 1.886	37.49 ± 1.115 p = 0.267	38.01 ± 1.784 p = 0.972	35.70 ± 1.995 p = 0.418

4. Tests were conducted three times while the subjects looked at each light dot. The sequence of dot positions (straight ahead, right or left) was randomized to avoid bias. Each test was conducted after a pause of 30 sec to avoid fatigue.

Data analysis

The exact non-parametric two-way Wilcoxon signed-rank test was performed to compare the results obtained in basal condition with those in the contralateral suppression.

The Friedman exact non-parametric ANOVA was used to determine the statistical significance of the variation of SNR obtained with the contralateral suppression with and without lateral gaze. When the Friedman test indicated significant differences, an exact non-parametric two-way Wilcoxon signed-rank test was performed to evaluate the different SNR.

The SPSS® (SPSS Inc., Chicago, IL) programme was used, and a p-value < 0.05 was considered statistically significant.

Results

Table I shows the mean values ± standard deviation as well as the p-values for whole-wave reproducibility, A-B difference, stimulus stability and noise level. There were no significant differences in the different parameters except for reproducibility, and the level of reproducibility was significantly lower in the basal suppression test than in the basal condition. The A-B difference, stability and noise level were the same in the different tests. The lack of different noise levels (p = ns) indicated the absence of environmental bias.

The mean TEOAEs suppression decreased from 11.00 ± 3.867 dB in the basal condition to 8.85 ± 4.103 dB in the suppression condition; the difference was statistically significant ($Z = -4.910$; $p < 0.001$). Table II shows the mean values ± standard deviation (dB) of the SNR by frequencies in the different conditions. Contralateral suppression reduced the SNR at 1 kHz ($Z = -3.833$; $p < 0.001$), 2 kHz ($Z = -3.878$; $p < 0.001$), 3 kHz ($Z = -2.576$; $p = 0.009$) and 4 kHz ($Z = -2.322$; $p = 0.01$). In particular, the mean reductions were 1.79 dB at 1 kHz, 2.30 dB at 2 kHz, 1.34 dB at 3 kHz and 1.25 dB at 4 kHz.

As reported in Table II, the mean TEOAE responses were 8.97 ± 3.960 dB with right gaze and 9.06 ± 4.180 dB with left gaze; neither condition was significantly different from the suppression condition with straight ahead (respectively, $Z = -1.03$ and $Z = -1.565$; p = ns). The Friedman test did not indicate significant differences in contralateral suppression among the different gazes (straight ahead, with right gaze or with left gaze) from 1 kHz to 3 kHz and to 5 kHz. Instead, the different gazes caused significant different suppression at 4 kHz ($\chi^2 = 9.053$, $p = 0.010$). Right lateralization of eyes (i.e., contralateral to the white noise) did not significantly modify the results obtained with contralateral suppression. Instead, left lateralization (i.e., in the same direction as the white noise) significantly decreased the suppression ($Z = -2.860$; $p = 0.003$) at 4 kHz; the mean TEOAE increase was 1.94 dB compared to the TEOAE level in the contralateral suppression with straight ahead.

Discussion

The results herein highlight the interaction between eye muscle activation and TEOAEs, which are the readouts for motile activity by the OHCs [13 20]. In particular, we observed that the activation of extrinsic eye muscle with lateral fixation decreased the contralateral suppression of TEOAEs (i.e., caused a decline of the suppression activity of olivocochlear efferent fibres and consequent modification of the TEOAE amplitudes).

Only the test with gaze toward white suppression noise was statistically different from the that with contralateral suppression with straight ahead, and this difference only existed at th 4 kHz. Thus, the suppression was significantly decreased at 4 kHz if the fixation was homolateral to the noise.

The modifications in TEOAE due to the contralateral sound are mediated via the medial olivocochlear (MOC)

Table II. Mean ± SD of sound noise ratio by frequencies in four different conditions. The statistical comparison for the suppression condition was calculated *vs.* the basal condition, while the others were evaluated between suppression conditions with or without gaze.

Frequency	Basal condition: threshold	Suppression condition: straight ahead	Suppression condition: right gaze	Suppression condition: left gaze
1 kHz	4.70 ± 4.268	2.91 ± 4.161 $p < 0.001$	2.57 ± 5.156 p = ns	2.16 ± 5.113 p = ns
2 kHz	7.53 ± 4.576	5.23 ± 4.634 $p < 0.001$	5.49 ± 5.368 p = ns	5.06 ± 4.87 p = ns
3 kHz	5.43 ± 5.532	4.09 ± 4.990 $p = 0.009$	3.73 ± 5.205 p = ns	4.47 ± 5.695 p = ns
4 kHz	2.79 ± 4.518	1.54 ± 4.610 $p = 0.019$	1.64 ± 4.630 p = ns	3.48 ± 4.631 $p = 0.003$
5 kHz	0.00 ± 3.134	0.00 ± 3.053 p = ns	0.10 ± 3.288 p = ns	0.00 ± 2.844 p = ns

efferent system, which reduces the gain of cochlear amplifier [23]. The suppression activity of the MOC efferent system shows significant variability among subjects [16].
Its function appears gradually in human pre-term neonates and is considered to reach maturity shortly after term birth [24]. This explains the asymmetry of the cochlear mechanism since medial olivocochlear system suppression is more evident on the right side [22]. Furthermore, the MOC efferent system appears to be more functional at low and middle frequencies than at high frequencies in adults [22 25]. It is probably involved in the detection of multicomponent stimuli in noise and increased the levels of detection and discrimination of words amongst noise [26 27].
Our data on the contralateral suppression effect with straight head are consistent with that in the literature [25], which show that contralateral suppression produces better effects at 1 and 2 kHz. This is probably due to the fact that the medial olivocochlear system is better at regulating the speech-in-noise intelligibility at low and middle frequencies than at high frequencies in adults [22 25 28]. This might also explain why the reducing effect of eye lateralization on contralateral TEOAE suppression was significant only at 4 kHz.

Conclusions

Our study shows an effect of eye lateralization only at 4 kHz when the fixation was homolateral to the suppression noise, but further studies are necessary to investigate the possible mechanisms for this phenomenon.

References

1. Kekcheev KK. [*Night vision: how better to see in the dark*]. Moscow: Nauka, 1946.
2. Corso JF. *Bodily position and auditory thresholds*. Percept Mot Skills 1962;14:499-507.
3. Macrae JH. *Effects of body position on the auditory system*. J Speech Hear Res 1972;15:330-9.
4. Phillips AJ, Farrell G. *The effect of posture on three objective audiological measures*. Br J Audiol 1992;26:339-45.
5. Antonelli A, Grandori F. *Long term stability, influence of the head position and modelling considerations for evoked otoacoustic emissions*. Scand Audiol Suppl 1986;25:97-108.
6. de Kleine E, Wit HP, Avan P, et al. *The behavior of evoked otoacoustic emissions during and after postural changes*. J Acoust Soc Am 2001;110:973-80.
7. Otake R, Saito Y, Suzuki M. *The effect of eye position on the orientation of sound lateralization*. Acta Otolaryngol Suppl 2007;559:34-7.
8. Lewald J, Ehrenstein WH. *Auditory-visual shift in localization depending on gaze direction*. Neuroreport 1996;7:1929-32.
9. Lewald J, Ehrenstein WH. *The effect of eye position on auditory lateralization. Experimental brain research*. Experimentelle Hirnforschung 1996;108:473-85.
10. Otake R, Kashio A, Sato T, et al. *The effect of optokinetic stimulation on orientation of sound lateralization*. Acta Otolaryngol 2006;126:718-23.
11. Lewald J, Karnath HO. *Vestibular influence on human auditory space perception*. J Neurophysiol 2000;84:1107-11.
12. Ferber-Viart C, Duclaux R, Collet L, et al. *Influence of auditory stimulation and visual attention on otoacoustic emissions*. Physiol Behav 1995;57:1075-9.
13. Giraud AL, Collet L, Chery-Croze S, et al. *Evidence of a medial olivocochlear involvement in contralateral suppression of otoacoustic emissions in humans*. Brain Res 1995;705:15-23.
14. American Speech-Language-Hearing Association. *Guidelines for manual pure-tone threshold audiometry*. Rockville, MD: ASHA; 2005.
15. Saitoh Y, Sakoda T, Hazama M, et al. *Transient evoked otoacoustic emissions in newborn infants: Effects of ear asymmetry, gender, and age*. J Otolaryngol 2006;35:133-8.
16. Veuillet E, Khalfa S, Collet L. *Clinical relevance of medial efferent auditory pathways*. Scand Audiol Suppl 1999;51:53-62.
17. Kemp DT, Ryan S, Bray P. *A guide to the effective use of otoacoustic emissions*. Ear Hear 1990;11:93-105.
18. Collet L, Veuillet E, Bene J, et al. *Effects of contralateral white noise on click-evoked emissions in normal and sensorineural ears: towards an exploration of the medial olivocochlear system*. Audiology 1992;31:1-7.

[19] Paludetti G, Ottaviani F, Fetoni AR, et al. *Evoked otoacoustic emissions (TEOAEs) in new-borns: normative data*. Int J Ped Otorhinolaryngol 1999;47:235-41.

[20] Aidan D, Lestang P, Avan P, et al. *Characteristics of transient-evoked otoacoustic emissions (TEOES) in neonates*. Acta Otolaryngol 1997;117:25-30.

[21] Khalfa S, Morlet T, Micheyl C, et al. *Evidence of peripheral hearing asymmetry in humans: clinical implications*. Acta Otolaryngol 1997;117:192-6.

[22] Morlet T, Goforth L, Hood LJ, et al. *Development of human cochlear active mechanism asymmetry: involvement of the medial olivocochlear system?* Hear Res 1999;134:153-62.

[23] Zhao W, Dhar S. *The effect of contralateral acoustic stimulation on spontaneous otoacoustic emissions*. J Assoc Res Otolaryngol 2010;11:53-67.

[24] Morlet T, Hamburger A, Kuint J, et al. *Assessment of medial olivocochlear system function in pre-term and full-term newborns using a rapid test of transient otoacoustic emissions*. Clin Otolaryngol Allied Sci 2004;29:183-90.

[25] Veuillet E, Collet L, Duclaux R. *Effect of contralateral acoustic stimulation on active cochlear micromechanical properties in human subjects: dependence on stimulus variables*. J Neurophysiol 1991;65:724-35.

[26] Micheyl C, Maison S, Carlyon RP, et al. *Contralateral suppression of transiently evoked otoacoustic emissions by harmonic complex tones in humans*. J Acoust Soc Am 1999;105:293-305.

[27] Micheyl C, Collet L. *Involvement of the olivocochlear bundle in the detection of tones in noise*. J Acoust Soc Am 1996;99:1604-10.

[28] Giraud AL, Garnier S, Micheyl C, et al. *Auditory efferents involved in speech-in-noise intelligibility*. Neuroreport 1997;8:1779-83.

Received: September 16, 2011 - Accepted: December 12, 2011

Address for correspondence: Stella Forti, Audiology Unit, Ospedale Maggiore Policlinico, via Pace 9, 20122 Milan, Italy. Tel. +39 02 55034055. Fax +39 02 50320756. E-mail: stella.forti@policlinico.mi.it