J Am Acad Audiol 12: 80–85 (2001)

Aging and Contralateral Suppression Effects on Transient Evoked Otoacoustic Emissions

Teralandur K. Parthasarathy*

Abstract

Transient evoked otoacoustic emissions (TEOAEs) were recorded in 30 normal-hearing subjects to nonlinear clicks while continuous contralateral broadband noise (CBBN) was presented at 40, 50, 60, and 70 dB HL. Thirty subjects between 20 and 79 years were divided systematically into six-decade age groups, five subjects per group. All subjects in each group had hearing thresholds of 20 dB HL or better for the test frequencies from 0.25 to 8.0 kHz and normal acoustic immittance findings. The results provide evidence that contralateral suppression at varying levels of CBBN is interactive with age. Except for subjects in the age ranges between 60 and 69 and 70 and 79 years of age, an increase in CBBN from 40 to 70 dB in 10-dB steps resulted in an average increase in suppression from about 0.5 to 3.5 dB SPL. In addition, the contralateral suppression at 60 and 70 dB HL was significantly greater for subjects between 20 and 59 years of age than for subjects between 60 and 79 years of age.

Key Words: Aging, otoacoustic emissions, outer hair cells, peripheral hearing loss, suppression effect

Abbreviations: ANOVA = analysis of variance, CAP = compound action potential, CBBN = contralateral broadband noise, CNS = central nervous system, MOS = medial olivocochlear system, OAEs = otoacoustic emissions, OHCs = outer hair cells, TEOAEs = transient evoked otoacoustic emissions

Transient evoked otoacoustic emissions (TEOAEs) are low-level sounds emitted by the ear in response to brief stimuli, such as clicks or tone bursts, that can be measured with a low-noise, sensitive microphone in the external ear canal (Kemp, 1978). TEOAEs are frequency-dispersive responses and seem to originate from cochlear outer hair cells (OHCs) (Kemp, 1978; Kim, 1984; Zurek, 1985). The existence of TEOAEs provides clear evidence that the cochlear OHCs actively participate in the processing of an acoustic signal. The motility of the OHCs is likely responsible for the sharp frequency sensitivity and selectivity of the cochlear partition vibration (Johnstone et al, 1986; Brownell, 1990; Ruggero and Rich, 1991). Because otoacoustic emissions (OAEs) are absent or decreased when OHCs are damaged (Zurek, 1985; Lonsbury-Martin et al, 1993), they are potentially a valuable addition in clinical audiology as a noninvasive, fast, objective test for evaluating the cochlear status. The OHCs receive a rich efferent innervation (Rasmussen, 1946) from the central nervous system (CNS), and the changes in OAEs with external stimulation reflect the influence of the CNS on the biomechanical dynamics of the cochlea (Veuillet et al, 1991).

A substantial amount of research literature exists to document changes in both the peripheral and central auditory systems as a function of age (Johnsson and Hawkins, 1972; Belal and Stewart, 1974; Raza et al, 1994; Zhang and Oertel, 1994; Williot, 1996). In fact, physiologic changes in the inner ear and central auditory pathways are the primary source of hearing impairment in the elderly (Johnsson and Hawkins, 1972; Wright and Schuknecht, 1972; Brant and Fozard, 1990). Thus, OAEs provide valuable information about the physiologic changes in the OHCs as a function of age (Collet et al, 1990). In addition, OAEs can be used to determine interactions between the two ears

*Department of Special Education and Communication Disorders, Southern Illinois University at Edwardsville, Edwardsville, Illinois

Reprint requests: Teralandur K. Parthasarathy, Department of Special Education and Communication Disorders, Southern Illinois University at Edwardsville, Room 1300, Founders Hall, Edwardsville, IL 62026-1147

by measuring the efferent-mediated suppression following the presentation of additional stimuli to the same, opposite, or both ears (Collet et al, 1990; Ryan et al, 1991; Veuillet et al, 1991; Berlin et al, 1993a, 1995; Wen et al, 1993).

The suppression effect is mediated by the efferent neural pathway, in particular, the crossed, myelinated medial olivocochlear system (MOS) that terminates primarily on the OHCs (Rasmussen 1946; Collet et al, 1990; Veuillet et al, 1991). Activation of the MOS is likely to elevate auditory thresholds and suppress responses of the OHCs to a variety of stimuli (Galambos, 1956; Warren and Liberman, 1989).

Many research studies have been devoted to the efferent-mediated suppression effect by measuring TEOAEs in the stimulated ear (Collet et al 1990; Veuillet et al, 1991; Berlin et al, 1993b, 1995; Hood et al, 1996). The overall decrement in emission level observed in humans is consistent with the suppression of cochlear and compound action potential (CAP) activity observed in animals (Liberman, 1989; Puel and Rebillard, 1990). The majority of reported studies on the TEOAE suppression effect have used continuous contralateral broadband noise (CBBN) (Collet et al, 1990; Berlin et al, 1993b; Wen et al, 1993). Several other studies (Collet et al, 1990; Veuillet et al, 1991; Berlin et al, 1993b) have shown that suppression is not likely related to artifacts caused by middle ear muscle contraction or crossover from the contralateral stimulus ear. Indeed, suppression is present in subjects without middle ear acoustic reflexes but is absent in subjects who have undergone a vestibular neurectomy (Williams et al, 1994).

Although TEOAE suppression associated with contralateral stimuli between 70 and 75 dB SPL is relatively small, on average close to 3 dB, the suppression is elicited consistently (Veuillet et al, 1991). Subjects vary considerably in the amount of suppression, but the large majority of normal-hearing subjects show efferent-meditated suppression effect over some time period of the response. Thus, whereas few subjects exhibit suppression effects of as much as 5 to 10 dB over time periods between 8 and 18 msec and frequency ranges (Berlin et al, 1993b), patients with auditory nerve and/or lower brainstem lesions show a complete lack of suppression (Berlin et al, 1993a).

Subject age and intensity of contralateral noise level are two important variables to consider in the measurement of OAEs and interpretation of the efferent-mediated suppression effect. Studies related to the level characteristics of TEOAEs and distortion product OAEs as a function of age clearly indicate that when the degree of peripheral hearing loss is rigorously controlled, there is no direct effect of advanced age on the level of OAEs (Strouse et al, 1996; Dorn et al, 1998; Parthasarathy, 2000). On the other hand, Castor et al (1994) reported an age-related decline in the suppression of TEOAEs in the presence of a continuous CBBN at 30 dB SL. The suppression level with a CBBN was significantly smaller for subjects in the age range between 70 and 88 years than in subjects between 20 and 39 years. Unfortunately, interpretation of their findings was likely confounded by an age-related high-frequency hearing loss for subjects between 70 and 88 years.

In addition to the age factor, the amount of efferent-mediated TEOAEs suppression is directly related to the intensity of the contralateral stimulus. When click intensity is held constant, the level of the suppression effect increases as a function of increases in the suppressor noise level (Hood et al, 1996). In addition, when clicks are used to elicit TEOAEs during efferent-mediated suppression measurement, broadband stimuli are considered most effective (Berlin et al, 1993b). Collet et al (1990) and Veuillet et al (1991) evaluated the suppression effect to linear clicks close to 60 to 63 dB peak SPL while continuous CBBN level was presented ranging from 0 to 50 dB SPL. No significant changes were observed for noise levels below 30 dB SPL. However, a significant suppression effect, close to 3 dB, was observed for noise levels between 30 and 50 dB SPL. In addition, the suppression effect varied considerably in degree but was consistently present in normal-hearing subjects (Collet et al, 1990).

Hood et al (1996) measured the efferent-mediated suppression effects of TEOAEs in normal-hearing subjects ranging in age from 12 to 59 years. TEOAEs were recorded in response to linear clicks between 50 and 70 dB peak SPL in 5-dB steps while continuous contralateral white noise was presented at 10 dB above or below the click level. Independent of click intensity level, the suppression of TEOAEs increased from a mean suppression of 0.33 dB, when the contralateral suppressor noise was 10 dB below the click, to a mean suppression of 1.38 dB, when the suppressor noise was 10 dB above the click intensity level. Furthermore, for a constant 60 dB SPL suppressor noise level, the suppression was significantly greater for click intensities of 60 dB SPL and below.

Although OAE levels are correlated with age, hearing thresholds, click intensity, and intensity of the CBBN (Bonfils et al, 1988; Collet et al, 1990; Lonsbury-Martin et al, 1991; Berlin 1993b; Stover and Norton, 1993; Kimberley et al, 1994; Hood et al, 1996), important factors controlling OAE levels are not completely understood. Evaluating the suppression effect on OAE level as a function of age at varying levels of CBBN is one of the few ways to determine the efferent activity of the MOS that is implicated in the ability to hear in noisy backgrounds (Liberman, 1989; Musiek and Hoffman, 1990; Micheyl and Collet, 1996). The objective of the present study, therefore, was to systematically evaluate the TEOAE suppression effect as a function of age at varying levels of CBBN by rigorously controlling for the degree of peripheral hearing loss.

METHOD

Subjects

A total of 30 subjects were evaluated in this study (4 males, 26 females). Subjects were divided into six groups (n = 5 in each group), representing the following age ranges in years: 20 to 29 (mean = 26.8), 30 to 39 (mean = 34.3), 40 to 49 (mean = 46.7), 50 to 59 (mean = 57.2), 60 to 69 (mean = 64.5), and 70 to 79 (mean = 73.8). All subjects met the following inclusion criteria: (1) physically and neurologically normal based on subject interview; (2) negative family history of hearing loss and neurologic problems; (3) negative history of ototoxic drug use, excessive noise exposure, middle ear disease, and metabolic diseases associated with hearing loss; (4) external auditory canals free from obstruction based on an otoscopic examination; (5) normal hearing sensitivity at or better than 20 dB HL for both ears at octave intervals from 0.25 to 8.0 kHz; (6) speech recognition scores better than 90 percent for both ears; (7) normal acoustic immittance results for both ears; and (8) measurable TEOAEs in both ears. The ear with the best hearing sensitivity was selected as the test ear. However, if there was no difference in hearing sensitivity between ears, the test ear was chosen randomly to control for the ear or order effect.

Procedure

All testing was conducted in a double-walled, sound-treated booth during a single experimental session lasting approximately 1.5 hours. The initial part of the experimental session included the audiologic evaluation to determine candidacy. If a subject met the selection criteria noted above, TEOAEs were recorded using the ILO88 Otodynamic Analyzer (software version 4.20B). The eliciting stimuli consisted of a conventional nonlinear click delivered at about 80 dB peak SPL at a repetition rate of 50 clicks/sec. Probe fit for each subject was assessed by closely examining the stimulus spectrum in the ear canal and by adjusting the probe assembly to produce minimal ringing and a flat frequency response. The response was acquired using the standard nonlinear differential averaging technique to minimize stimulus and other artifacts. The two-averaged TEOAE waveforms of each memory buffer (Fig. 1), composed of 260 accepted click trains, were automatically cross-correlated and used to determine the reproducibility of the measured TEOAEs by the software. Final averages were accepted when the reproducibility was at 70 percent or greater. Stimulus stability was maintained at greater than 80 percent. TEOAEs were recorded with and without continuous CBBN stimulation ranging from 40 to 70 dB HL in 10-dB steps. The CBBN was generated by a Grason-Stadler 33 middle ear analyzer and presented randomly via an insert earphone to the subject's ear. To ensure that a constant CBBN intensity was maintained, the sound pressure level of the continuous CBBN was monitored during TEOAEs testing by using a probe microphone (ER-10B) placed deep in the external ear canal. To potentially minimize the contribution of the middle ear muscle reflex, the maximum level of CBBN was presented at 70 dB HL. TEOAEs expressed in dB SPL were first measured from 2.5 to 20 msec, using the full-octave power analysis program provided by

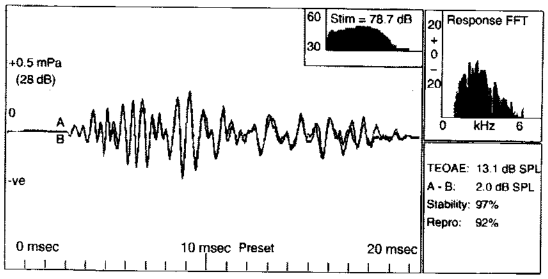

Figure 1 TEOAE response obtained from a 24-year-old female. The stimulus level was stable at approximately 78.7 dB SPL, and the average SPL of the A and B waveforms was 13.1 dB SPL.

the Otodynamics ILO88. Thereafter, the suppression reported in this article was derived by subtracting the emission levels with CBBN from emission levels without CBBN.

RESULTS

Audiometric Thresholds and Immittance Measures

Analysis of variance (ANOVA) was used to compare the mean audiometric thresholds for frequencies from 0.25 to 8.0 kHz and confirmed that, as required by the subject selection criteria, there were no significant differences in audiometric thresholds as a function of age ($p > .05$). In addition, other ANOVA test results showed no significant differences among the six age groups on measures of peak middle ear pressure, ear canal volume, static acoustic immittance, or ipsilateral or contralateral acoustic reflex thresholds for both tones (0.5 and 1.0 kHz) and broadband noise ($p > .05$).

TEOAE Measures

TEOAEs were present in 100 percent of subjects in each age group. ANOVA was used to compare mean TEOAE levels in dB SPL as a function of age. The mean overall emission levels as a function of age measured without the CBBN ranged from 10 to 12 dB SPL. The results of ANOVA showed no significant differences in the level of TEOAEs as a function of age ($p > .05$). In addition, TEOAE level as a function of hearing threshold in 5-dB steps between 0 and 20 dB across all frequencies and age decades was evaluated. Test results showed no significant differences in emission levels as a function of audiometric threshold ($p > .05$).

Figure 2 illustrates the average suppression of emission level as a function of age and CBBN level. Except for subjects in the age range between 60 and 79 years, an increase in the CBBN level from 40 to 50 dB HL resulted in an increase in the mean suppression from 0.5 to 1.0 dB, and the overall mean suppression level increased from 0.5 to 3.5 dB SPL with an increase in the level of CBBN from 40 to 70 dB HL. In contrast, for subjects between 60 and 69 and 70 and 79 years of age, with an increase in the CBBN from 40 to 70 dB HL, the mean suppression effect increased from 0.5 dB to 0.9 dB SPL. Intersubject variability in the amount of suppression, as indicated in Figure 2 by the error bars (± 2 SEM), is nearly identical across

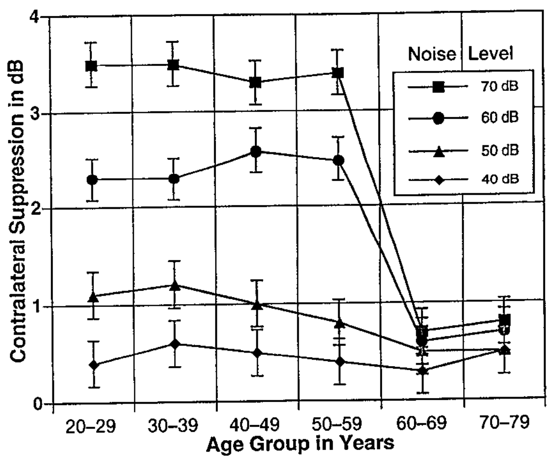

Figure 2 Mean amount of contralateral suppression on TEOAE levels as a function of age and broadband noise level in 30 normal-hearing subjects. Error bars represent ± 2 standard error of the mean (SEM).

subjects in the six age groups. The results of ANOVA showed a significant interaction effect between age and noise level ($p < .05$). A post hoc Tukey's analysis of the interaction effect showed that the suppression of emissions with CBBN at 60 and 70 dB HL was significantly greater for subjects in each age group between 20 and 59 years than for subjects between 60 and 69 and 70 and 79 years of age.

DISCUSSION

The OAE level can be influenced by such factors as probe fit, noise, signal characteristics, age, hearing sensitivity, and suppression effects of the MOS. This study clearly demonstrated differential changes in efferent-mediated TEOAE suppression as a function of age and CBBN levels. Except for the two groups of subjects in the age range 60 to 69 and 70 to 79 years of age, when the level of CBBN was progressively increased from 40 to 70 dB HL, TEOAE suppression generally increased from 0.5 to 3.5 dB SPL. Although direct comparison of suppression effects of this study with other studies is difficult because of the differences in subject ages, suppressor noise levels, eliciting stimuli levels, and the type of clicks, the findings of the present study are in good agreement with previous results (Collet et al, 1990; Veuillet et al, 1991; Berlin et al, 1993b; Hood et al, 1996), which have shown a consistent increase in the suppression effect, ranging from 0.33 to 3 dB, as a function of increases in the level of the contralateral noise from 30 to 80 dB SPL.

In this study, for subjects in the age range between 60 to 79 years, an increase in CBBN levels from 40 to 70 dB HL resulted in a minimal increase in suppression from 0.5 to 0.9 dB SPL. However, similarly, Castor et al (1994), using linear clicks with 30 dB SL contralateral white noise, reported an equivalent attenuation of TEOAEs close to –2.17 dB in the 20 to 39 years age group and –0.36 dB in the 70 to 78 years age group. These minor disparities in results are likely a consequence of the methodologic differences in computing the suppression effect. That is, the present study obtained differences in TEOAE levels in dB between conditions with and without noise employed in this study, whereas Castor et al (1994) computed the equivalent attenuation in dB, which was determined by taking the attenuation of an ipsilateral stimulation equivalent to the effect seen with a 30 dB SL broadband noise. Also, the subjects of the present study exhibited no obvious age-related high-frequency hearing loss (i.e., they had normal hearing equal to or less than 20 dB HL versus an average 45 dB HL for subjects in the Castor et al [1994] study between 70 and 78 years of age).

The results from the present study have shown that a continuous CBBN can activate the MOS and differentially suppress the TEOAEs as a function of age. A minimal increase in the suppression level of TEOAEs with an increase in the CBBN from 40 to 70 dB HL for subjects between 60 and 69 and 70 and 79 years of age is likely a consequence of the effects of aging on MOS neurons or on OHCs, which may become less sensitive to the efferent-mediated suppressive effects. Thus, it appears that the efferent control of OHCs may become functionally impaired with aging. The decreasing efficiency of the MOS might, in part, explain the increasing difficulties of speech understanding in noise with aging.

Interpretation of the test findings related to suppression reported above, like those of previous suppression studies, may be potentially confounded by factors related to the middle ear acoustic reflex and acoustic crossover, particularly at the higher CBBN levels. In this study, middle ear muscle reflex contraction for the CBBN at 70 dB HL cannot be completely ruled out. However, acoustic crossover of the continuous CBBN was less likely since insert earphones with an interaural attenuation of 60 to 90 dB (Killion et al, 1985) were used in this study.

CONCLUSIONS

First, except for subjects in the age ranges between 60 and 69 and 70 and 79 years of age, an increase in CBBN from 40 to 70 dB HL in 10-dB steps resulted in an increase in the suppression effect on ipsilaterally recorded TEOAEs from 0.5 to 3.5 dB SPL. Second, the suppression effect on TEOAE levels with CBBN at 60 and 70 dB HL was significantly greater for subjects in the age range between 20 and 59 years of age than for subjects between 60 and 69 and 70 and 79 years of age. Although findings must be considered preliminary due to the small sample size in each group, the results provide clear evidence that the contralateral suppression effect at varying levels of noise is interactive with age. Thus, the present study has demonstrated that subject age and CBBN level are two important variables to consider in the measurement and interpretation of the efferent-mediated TEOAEs suppression effect. The decreasing efficiency of the MOS might, in part, explain the increasing difficulties of speech understanding with aging.

Acknowledgment. The author wishes to thank Dr. Gerald Popelka, Dr. Martin Robinette, and three anonymous reviewers for helpful suggestions regarding an earlier version of this manuscript. Portions of this paper were presented at the 2000 American Auditory Society Convention, Scottsdale, AZ.

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