J Am Acad Audiol 7: 339–345 (1996)

Evidence against the Influence of Aging on Distortion-product Otoacoustic Emissions

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Abstract

Previous research has reported reduced otoacoustic emission amplitude as a function of age. In each study, however, interpretation of findings was confounded by age-related hearing loss. The present study was designed to re-evaluate the contribution of age and peripheral hearing loss on the prevalence and amplitude of distortion-product otoacoustic emissions (DPOAEs) by controlling for degree of peripheral hearing loss. Twenty subjects were divided into four age ranges. All subjects in each group had 15 dB HL or better thresholds from 0.25 through 8 kHz and normal immittance findings. DPOAE audiograms recorded at three intensity levels and input/output functions recorded at six discrete frequencies showed no significant differences in amplitude or noise level between age groups. Findings indicate that when the degree of peripheral hearing loss is adequately controlled, there is no direct effect of advanced age on DPOAE measures. Clinical implications are discussed.

Key Words: Aging, otoacoustic emissions, outer hair cells

A significant amount of literature exists that documents changes in the auditory system as a consequence of aging. Structural changes have been reported at nearly every level of the auditory system. Age-related alterations of the outer and middle ear include loss of elasticity in the pinna and external auditory canal (Maurer and Rupp, 1979), increased pinna size (Tsai et al, 1958), a stiffened and more translucent tympanic membrane (Maurer and Rupp, 1979), stiffening of the ossicular chain (Goodhill, 1969), and degeneration of the middle ear muscles and ossicles (Etholm and Belal, 1972; Belal and Stewart, 1974). Changes in the inner ear and central auditory pathways are, however, the primary source of hearing impairment in the elderly. Histopathologic studies have documented degeneration of the sensory hair cells and supporting cells (Johnsson and Hawkins, 1972), degeneration of the stria vascularis (Pauler et al, 1988), decrease in the number of functional spiral ganglia and VIIIth nerve fibers (Wright and Schuknecht, 1972), loss of elasticity of the basilar membrane (Schuknecht, 1974), thickening of the tectorial membrane (Schuknecht, 1974), and a reduced cochlear blood supply (Jorgenson, 1961).

Age-related changes throughout the auditory system have important implications in auditory assessment of the elderly patient. The influence of aging on aural immittance measures (Hall, 1975, 1982), pure-tone audiometry (Jerger, 1973; Surr, 1977), speech recognition scores (Townsend and Bess, 1980; Jerger et al, 1989), central auditory testing (Rodriguez et al, 1990), and electrophysiology (Ford et al, 1979; Jerger and Hall, 1980; Pfefferbaum et al, 1984; Woods and Clayworth, 1986) are well documented, suggesting that clinical interpretation of such measures may be more powerful when findings are compared to normative data for the age group in question.

Otoacoustic emissions (OAEs) may provide further information about physiologic changes in auditory function associated with age. A substantial amount of research suggests that OAEs are produced by the motile activity of the outer hair cells (Mountain, 1980; Kim, 1984; Zenner, 1986; Brownell, 1990). Consequently, damage to outer hair cells due to excessive noise exposure,

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ototoxic drug treatment, or anoxia is associated with the reduction or disappearance of OAEs (Kim et al, 1980; Zurek, 1985; Schmiedt, 1986; Lonsbury-Martin et al, 1993). If this is true in presbycusis, OAEs may be a noninvasive way of examining cochlear function as a function of age and degree of hearing loss.

Several investigators have reported abnormal OAEs associated with advancing age, suggesting that clinical OAE measurements may be more accurately interpreted using age-adjusted normative values. Bonfils et al (1988) reported an age-related decline in the prevalence of transient-evoked otoacoustic emissions (TEOAEs) in age groups from less than 10 years to approximately 88 years. Responses were detected in all ears of subjects less than 60 years old. Above this age, the prevalence of TEOAE fell to 35 percent. In a similar study, TEOAEs were measured in 166 ears from individuals ranging in age from 6 weeks to 83 years (Collet et al, 1990). Results supported those of Bonfils et al (1988) in that the presence of TEOAEs decreased with advancing age. In both of these studies, however, older subjects had some degree of hearing loss, especially at the high frequencies. Therefore, the drop in TEOAE prevalence in the older age groups may have been caused largely by the hearing loss and not by age alone.

More recent investigations have attempted to examine the direct effect of age on distortion-product otoacoustic emissions (DPOAEs) by better controlling for the confounding effects of peripheral hearing loss. Lonsbury-Martin et al (1991) measured DPOAEs in 60 ears from individuals ranging in age from 31 to 60 years. Their findings revealed a tendency for older ears to generate smaller amplitude DPOAEs, particularly at the highest frequencies. Although their mean data showed audiometric thresholds equal to or better than 20 dB HL for all groups, there was a large range in some groups. All subjects within the 30- to 40-year age group had audiometric thresholds less than or equal to 20 dB HL between 0.25 and 8 kHz. In the older groups, however, 7 of 10 subjects had elevated thresholds at 3, 4, and/or 8 kHz. Thus, as with the earlier TEOAE studies, there was a significant age effect on audiometric thresholds.

In the most comprehensive study to date, Stover and Norton (1993) measured spontaneous emissions, stimulus frequency emissions, TEOAEs, and DPOAEs in 42 subjects ranging in age from 20 to 80 years. All subjects had pure-tone thresholds equal to or better than 25 dB HL in the frequency range from 0.25 to 4 kHz. Results revealed significant differences in the various OAE measures between age groups. As with previous studies, however, the degree of peripheral hearing loss was not adequately controlled. While all subjects met the criteria for "audiometrically normal hearing," defined as thresholds between −10 and 25 dB HL, there was considerable variability within this range. Even within the specified range of normal, decreased hearing sensitivity was significantly correlated with increasing age. Moreover, audiometric thresholds above 4 kHz were not considered in subject selection criteria. It was reported, however, that subjects who had normal hearing above 4 kHz produced higher amplitude OAEs of all types. Using an analysis of covariance, the authors found that there were no age effects independent of hearing sensitivity on any type of OAE measure. Thus, with the effects of sensitivity differences removed, age alone did not account for a significant portion of the variability in the data. Consequently, an analysis of the effects of age on OAE measures is not complete without careful control of high-frequency thresholds.

The present study was designed to address the shortcomings of past research by rigorously controlling for degree of peripheral hearing loss. The primary goal was to distinguish between the contribution of age and peripheral hearing loss on the prevalence and amplitude of DPOAEs. If DPOAEs are normal as long as hearing is normal, regardless of age, this would mean that reported decreases in the prevalence and amplitude of DPOAEs in older ears are primarily the result of reduced hearing sensitivity. On the other hand, if DPOAEs are "abnormal" in older subjects, even when hearing is better than 15 dB HL, this would imply that age-induced alterations exist in cochlear mechanics, predominantly the outer hair cells, which cannot be detected by conventional pure-tone measures. If this is true, age-adjusted normative data may be necessary for accurate interpretation of DPOAEs in elderly patients.

METHOD

Subjects

A total of 20 subjects was evaluated (2 male, 18 female). Subjects were divided into groups representing the following age ranges: 20 to 29 years (n = 5, mean age = 24.2), 50 to 59 years (n = 5, mean age = 53.4), 60 to 69 years (n = 5, mean age = 64.6), and 70 to 79 years (n = 5, mean age = 73.2).

Pure-tone thresholds at octave and selected half-octave frequencies from 0.25 through 8 kHz did not exceed 15 dB HL for any subject. All participants had speech recognition scores better than 90 percent and normal immittance findings. In addition, all subjects reported a negative history of ototoxic drug treatment, excessive noise exposure, middle ear disease, and family history of hearing loss. The ear with the best audiologic thresholds was selected as the test ear. If there was no difference between ears, the test ear was chosen randomly.

Procedure

All testing was conducted in a double-walled sound-treated booth during a single experimental session lasting approximately 1 hour. OAE measures were recorded using the Virtual Model 330 Otoacoustic Emissions Test Instrument and associated software (Version 1.8).

The measurement of DPOAEs was conducted by acquiring both DPOAE "audiograms" and a series of input/output (I/O) functions. Audiograms were collected in 12 steps per octave at stimulus levels of 55, 65, and 75 dB SPL, with the geometric mean of f_1 and f_2 extending from 0.5 to 8 kHz. In this manner, 49 discrete DPOAE frequencies were tested for each intensity level of the primaries to increase the likelihood of detecting age-related differences. Sixteen time averages were recorded per octave interval. The protocol incorporated an f_2/f_1 ratio of 1.21 and equilevel primaries (L1 = L2), consistent with the reported parameters of Lonsbury-Martin et al (1991). Two consecutive averages for each intensity level were recorded to examine reliability and to ensure a stable response measure.

Unlike the DPOAE audiogram, which evaluates a variety of frequencies at a single presentation level, the I/O test presents signals at a variety of intensity levels for a single frequency. I/O functions were generated by incrementing primary stimuli in 2-dB steps from 30 to 76 dB SPL. In this manner, 24 intensity levels were tested for each frequency level of the primaries. Responses were collected at 1, 2, 3, 4, 6, and 8 kHz, referring to the geometric mean of the primary frequencies. Two consecutive averages at each frequency were recorded to examine reliability and to ensure a stable response measure.

RESULTS

Immittance and Audiometric Thresholds. In accordance with subject selection criteria, immittance findings were within the clinically normal range for all subjects. Analysis of variance (ANOVA) was used to compare means of the immittance battery. Results showed no significant differences among age groups on measures of static compliance, peak middle ear pressure, estimated ear canal volume, and ipsilateral and contralateral acoustic reflex thresholds at 1 kHz ($p > .05$). Additionally, all subjects met criteria of audiometric thresholds at or better than 15 dB HL for octave and selected half-octave frequencies from 0.5 through 8 kHz. ANOVA indicated that there were no significant differences in threshold as a function of age ($p > .05$).

DPOAE Audiograms. Average DPOAE amplitudes across frequency in response to 55, 65, and 75 dB SPL primaries for each age group are shown in Figure 1. Data are plotted against noise levels averaged across all subjects. Dashed lines indicate ±1 standard deviation around the mean DPOAE amplitude for subjects in the 20- to 29-year age group.

Figure 1 shows that all groups had measurable DPOAEs above the corresponding noise floor of the recording system in response to all input levels. Responses were repeatable across two trials for all subjects, with correlations ranging from 0.855 to 0.991. These data indicate that all groups generated similar DPOAE response curves and the variability of the response was similar among groups. ANOVA testing of the means of the grouped data was based on a two-factor mixed design, with the between-subjects variable being age group and the level of the test stimulus being the within-subjects variable. Group differences were evaluated at each DPOAE data point ranging from 0.5 through 8 kHz. Results of statistical analyses of DPOAE audiogram values obtained using 55 dB SPL primary tones indicated no significant differences between groups at any of the 49 data points along the frequency curve. At an input level of 65 dB SPL, however, significant differences were noted between groups at 7 of 49 data points ($p < .05$). Four of the 7 data points were located below 1 kHz (0.53, 0.63, 0.75, 0.79 kHz), while the remaining 3 were above 6 kHz (6.35, 6.73, 7.13 kHz). Fisher's least significant difference was used to detect differences in group means for factors age and frequency. Post-hoc analyses revealed that, in the low-frequency

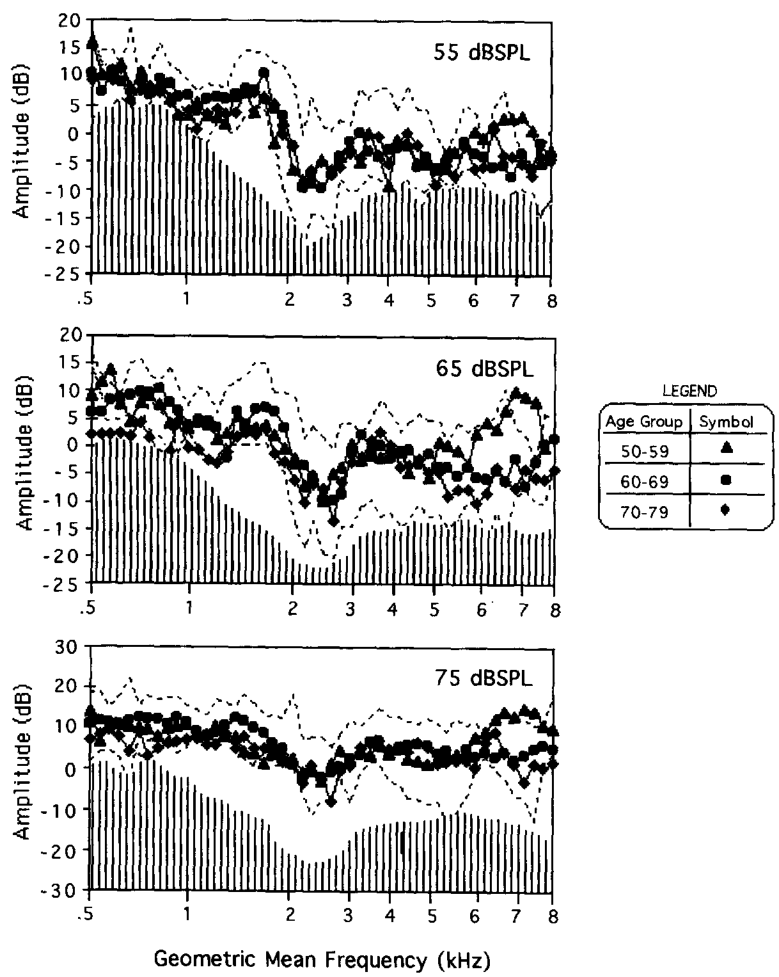

Figure 1 Average DPOAE amplitude across frequency in response to 55, 65, and 75 dB SPL primaries for each age group.

region, subjects in the 70- to 79-year group exhibited lower amplitude DPOAEs than younger subjects. In the higher frequency region, the 50- to 59-year group differed from the 20- to 29-, 60- to 69-, and 70- to 79-year age groups. Mean DPOAE amplitude values within this region were significantly greater for the 50- to 59-year group. Finally, a significant difference between groups was observed at one frequency (0.71 kHz) for DPOAE audiograms recorded using an input level of 75 dB SPL. At this data point, the 70- to 79-year group had significantly lower amplitude values as compared to the younger groups.

I/O Functions. Mean I/O functions for each age group at each test frequency are plotted in Figure 2. In these graphic representations, the mean data for each of the three groups of older subjects are plotted against the average I/O data of the 20- to 29-year old group. Dashed lines indicate ± 1 standard deviation from the mean of the youngest subjects. Noise floors represent an average of all subjects within each age group. Statistical comparisons of emission amplitude between groups at each intensity level ranging from 30 through 76 dB SPL revealed few significant findings. Upon visual inspection of Figure 2, the largest differences between groups are observed at 1 and 6 kHz. Four of the 24 intensities examined at 1 kHz (50, 56, 62, and 66 dB SPL) showed statistically significant group differences. Post-hoc findings were similar to DPOAE audiogram results in that, at 1000 Hz, the 70- to 79-year group had significantly lower amplitude values than the 20- to 29-, 50- to 59-, and 60- to 69-year age groups. At 6 kHz, however, no statistically significant differences were seen at any intensity, reflecting the greater variability in the response of the 20- to 29- and 50- to 59-year groups at this test frequency. Large intersubject variability in the

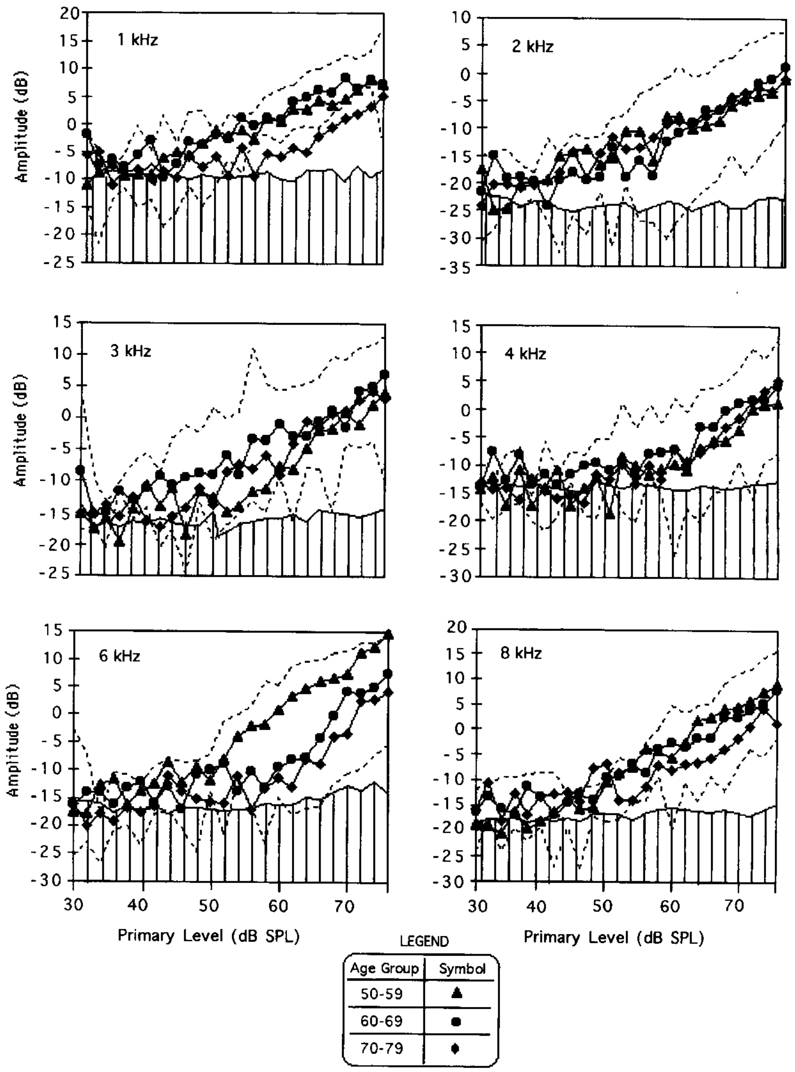

Figure 2 Mean I/O functions for each age group at six discrete test frequencies.

response of the 20- to 29-year group was also noted at 2, 3, and 4 kHz. At the remaining test frequencies, 2 of the 24 intensities tested were significantly different at 4 kHz (36 and 50 dB), with the 60- to 69-year group showing significantly higher amplitude values, and 1 at 8 kHz (32 dB), with the 50- to 59-year group showing a significantly lower amplitude. No statistically significant differences in DPOAE amplitude were seen at any intensity at 2 and 3 kHz ($p > .05$).

DISCUSSION

Previous research has reported reduced OAE amplitude as a function of age. Results of the present investigation, however, do not support such findings. This discrepancy in findings is likely attributed to methodologic issues relating to degree of peripheral hearing loss. In the present study, all subjects had 15 dB HL or better thresholds from 0.25 through 8 kHz. Although the majority of previous studies attempted to control for the confounding effect of hearing sensitivity, none were successful in recruiting a subject pool demonstrating normal hearing sensitivity at all frequencies without significant differences in thresholds between age groups. Since it is well established that hearing loss produces decreased OAE amplitude, which is systematically related to the degree of sensitivity loss (Bonfils et al, 1990; Kemp et al, 1990; Nielsen et al, 1993; Kimberley et al, 1994), it is likely that previously reported OAE amplitude differences may solely reflect reported variability in audiometric thresholds. Present results showed no significant age effect on audiometric thresholds among groups. Thus, when the degree of peripheral hearing loss is adequately controlled, there is no direct effect of age on DPOAE measures.

Although pooled findings reveal no overall significant differences in DPOAE measures between groups, there were several data points along the 65 dB SPL DPOAE audiogram and 1 kHz I/O function for which group differences were present. Results cannot be explained by immittance or audiometric threshold findings. Because the small number of data points showing significant group differences were not consistent across frequency or intensity levels and occurred at isolated frequency points, it is likely that these results are artifactual. Additional findings support this argument. First, if age has a direct effect on DPOAE amplitude, we would expect to see decreased DPOAE magnitude primarily for higher frequency regions among elderly adults since these frequencies are the first to be affected in presbycusis. Accordingly, we would expect to see the greatest effects among the oldest subjects since they would be most likely to demonstrate subclinical sensory degeneration. Post-hoc findings of the present data, however, indicated that the 70- to 79-year group showed significantly lower amplitude DPOAEs versus younger groups in regions at or below 1 kHz as opposed to higher frequency regions. Second, all statistically significant points were located in areas below 1 kHz or above 6 kHz. Numerous investigators have reported that below 1.5 kHz, ambient noise in combination with physiologic noise make low-frequency DPOAEs difficult to measure unless a large number of time averages are used (Probst and Hauser, 1990; Lonsbury-Martin et al, 1991; Gorga et al, 1993; Hotaling et al, 1994). It has also been suggested that DPOAEs at 6 kHz or higher frequencies may be artifactual (Arjmand, 1994; Gorga, 1994; Hotaling et al, 1994), and do not appear to be well correlated with auditory thresholds (Probst and Hauser, 1990). Thus, all differences between groups occurred within areas of the frequency continuum for which the validity of DPOAE responses is questionable.

Technical problems such as the presence of crosstalk, standing waves, and instrument distortion, primarily at high frequencies and high stimulus input levels, have been reported using similar instrumentation to that used in the present study (Hotaling et al, 1994; Siegel, 1994, 1995). It is unlikely that our data were significantly influenced by stimulus level since results were consistent across three input levels and there was minimal variability in DPOAE audiogram data. However, until technical issues such as crosstalk and standing waves are resolved, DPOAE measures, especially data collected at high frequencies, should be interpreted with caution in a clinical setting. In addition, data suggest that our I/O measures should be interpreted cautiously due to the large intersubject variability of the 20- to 29-year group, which may have decreased the likelihood of detecting significant differences between groups.

Stover and Norton (1993) highlighted the importance of adequately controlling for both age and hearing sensitivity, particularly in the high-frequency region, in order to understand their separate contributions to OAE measurement. Although findings must be considered somewhat preliminary due to the small number of subjects in each experimental group, our data support these recommendations and offer additional evidence that age-adjusted norms are not necessary to the interpretation of OAE results.

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