Pure-Tone Audiometric Threshold Test-Retest Variability in Young and Elderly Adults

Variabilité test-retest du seuil audiométrique tonal chez les jeunes adultes et les aînés

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ABSTRACT

Audiometric threshold test-retest variability was studied in three age groups: young adults aged 22-34 years, older adults aged 50-63 years, and seniors aged 65-81 years. Audiometeric thresholds were tested at six frequencies (250, 500, 1000, 2000, 4000, and 8000 Hz) utilizing supraaural and insert transducers. No statistically significant differences were found in test-retest differences at 250, 500, and 1000 Hz as a function of age group or transducer ($p > .05$). Statistically significant group, transducer, and group by transducer effects were found at 2000 and 8000 Hz, 2000 Hz, and 4000 Hz ($p < .05$), respectively. These results were speculated to be due to changes in the aging ear canal structure combined with inherent variability in the transducer coupling characteristics. The outcomes of this study suggest caution should be exercised when interpreting audiometric threshold test-retest changes in adult listeners.

ABRÉGÉ

La variabilité test-retest du seuil audiométrique a été étudiée chez trois groupes d'âge : les jeunes adultes de 22 à 34 ans, les adultes mûrs de 50 à 63 ans, et les aînés de 65 à 81 ans. On a mesuré les seuils audiométriques à six fréquences (250, 500, 1 000, 2 000, 4 000 et 8 000 Hz) au moyen de transducteurs supra-auraux et internes. On n'a relevé aucune différence statistiquement significative pour les différences test-retest à 250, 500 et 1 000 Hz en fonction du groupe d'âge ou du transducteur ($p > .05$). On a par contre relevé des effets statistiquement significatifs selon le groupe, le transducteur et groupe-transducteur à 2 000 et 8 000 Hz, 2 000 Hz et 4 000 Hz ($p < .05$), respectivement. Ces résultats supposent des changements de la structure vieillissante du canal auditif, de pair avec la variabilité inhérente des caractéristiques de couplage des transducteurs. Les résultats de cette étude suggèrent qu'il faut être prudent dans l'interprétation des changements test-retest du seuil audiométrique chez les écoutants adultes.

KEY WORDS: pure-tone threshold • test-retest variability • earphones • elderly

Pure-tone threshold audiometry is one of the foundations of audiologic assessment. It is the standard procedure used in determining auditory sensitivity and plays an integral role in diagnostic interpretation and in the planning of (re)habilitative programs. Inherent assumptions underlying pure-tone audiometry are that persons provide an appropriate response when a stimulus is audible and that responses are repeatable upon retesting.

Numerous studies have suggested that both behavioural and physiological changes accompany aging (Cobb, Jacobson, Newman, Kretschmer, & Donnelly, 1993; Davis, Ostri, & Parving, 1990; Lutman, 1990; Quaranta, Salonna, & Longo, 1990; Willott, 1996). Further, these changes may compromise an elderly person's auditory sensitivity and their ability to provide appropriate responses in a consistent fashion over time. Schuknecht (1974) noted specific histopathologic and morphologic changes in the aging peripheral auditory system. The changes include hair cell damage, atrophic changes in the stria vascularis, mechanical alterations in the cochlear duct, and the loss of spiral ganglion cells and/or damage to cochlear neurons. Central nervous system changes may include loss of myelin, hyperostosis of the internal auditory meatus (Grimes, 1995), reduced neuron counts (Brody, 1955), circulatory problems (Hinchcliffe, 1990; Kasten & McCrosky, 1982) as well as other factors such as cerebral atrophy, reduced dendritic branching, and decreased effectiveness of neurotransmitter substances (Kauffman, 1994).

Behavioural variables which may affect an elderly person's ability to provide consistent audiometric responses include the effect of physical discomfort, antagonism toward the task (Yantis, 1994), and difficulty in attending to the required task (Green, 1972). Mauer and Rupp (1979) considered the elderly to be "difficult to test" and recommended that standard audiometric test procedures be modified to ensure valid findings.

Presumably, all the above age-related histopathologic and morphologic changes cited above could contribute to the observation that hearing sensitivity decreases with age. The behavioural aspects, on the other hand, would seem to effect the reliability of audiometric findings. In addition, the repeatability of audiometric test results should also vary due to the unreliability of audiometric earphones. That is, irrespective of the age of the listener, there is variability associated with the coupling of the stimulus transducer (i.e., supraaural or insert earphones) to the auditory mechanism (Zwislocki et al., 1988). Audiometric test-retest variability among elderly listeners should, therefore, be dependent upon changes in the aging auditory system, behavioural variables, and inherent unreliability of audiometric earphones.

To date, to the best of our knowledge, no studies have examined pure-tone auditory threshold variability in elderly listeners. The purpose of the present study was, therefore, to examine pure-tone audiometric threshold test-retest variability in elderly listeners using both supraaural and insert earphone transducers.

Method

Participants

Forty young and elderly adults participated. The young group of participants consisted of 20 adults ranging in age from 22 to 34 years (M = 25.7 years, SD = 3.4). The second group of participants consisted of 10 old adults ranging in age from 50 to 63 years (M = 54.9 years, SD = 3.7). The oldest group of listeners was comprised of 10 adult participants ranging in age from 65 to 81 years (M = 69.9 years, SD = 5.6). All participants were screened for normal middle ear functioning as defined by American Speech-Language-Hearing Association standards (American Speech-Language-Hearing Association, 1990). Normal hearing thresholds were not a prerequisite for participation in the study. The hearing sensitivity of all of the participants was consistent with young normal hearing adults and aging adults as determined by Willott's formulated profile of hearing loss (Willott, 1991).

The Mini-Mental State (Folsten, Folsten, & McHugh, 1975) was administered to all participants in the old and oldest groups as a means of assessing their cognitive mental status. A score of 21 or higher was an inclusion criterion for the elderly participants as scores of 20 or less are not found in normal cognitive function with elderly people (Folsten et al., 1975).

Apparatus

Two transducers were used. They were a TDH-50P supraaural earphone housed in an M-51 cushion and an Etymotic Research ER-3A insert earphone coupled to a foam insert (Etymotic Research model ER-14A). Transducers were used according to manufacturer's specifications.

Participants were tested in a sound-treated audiometric booth which met specifications for permissible ambient noise (American National Standards Institute, 1991). Six test pure-tone stimuli (250, 500, 1000, 2000, 4000, and 8000 Hz) were generated by a clinical audiometer (Grason Stadler GSI 61) meeting American National Standards Institute specifications (American National Standards Institute, 1996) and routed to each earphone.

Procedure

Two graduate students in audiology tested the pure-tone thresholds of the participants according to the modified Hughson-Westlake technique (Hughson & Westlake, 1944). All participant's audiometric thresholds were determined for the six test frequencies. The better ear of each participant was chosen as the test ear. If both ears had approximately the same thresholds, the test ear was selected in a counterbalanced fashion. As well, test frequencies, transducers, and the first order of testers were counterbalanced across sessions.

After the test session, a short break (approximately 20 minutes) was provided for all participants who were retested the same day. All other participants (a mixture of all three age groups tested) were retested within four months of the first session due to scheduling constraints. In all cases, the second experimenter was unaware of the test results. For all participant test-retest audiometric thresholds were obtained for each of the six test frequencies for both earphones. Signed test-retest differences were calculated by subtracting retest from test thresholds. Six separate unpaired t-tests were calculated to determine if there were significant differences in mean test-retest difference score between the participants who were retested on the same day versus those who were retested four months later. An alpha level of 0.008 was adopted to correct for the compounding error attendant with multiple t-tests. No significant differences were found ($p >$ .008). The nonsignificant probability values ranged from (0.10 to 0.96). In other words there can be some assurance that there was no variability introduced from changing hearing sensitivity between those that were tested several months following the original test.

Results

Table 1 presents a summary of the means and standard deviations of the signed test-retest differences as a function of group and transducer for the six test frequencies. Figures 1, 2, and 3 show the means and standard deviations of the signed test-retest differences as a function of group and transducer for the test frequencies of 2000, 4000, and 8000 Hz, respectively.

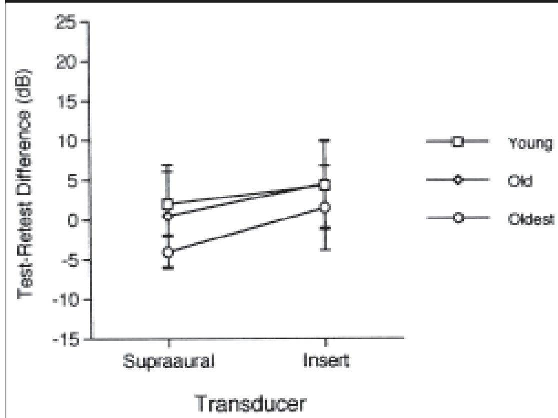
The main purpose of this study was to determine if the signed test-retest differences in audiometric thresholds differ as a function of group and transducer. Toward that end, a mixed two-factor analysis of variance (ANOVA) was conducted separately for each test frequency to examine test-retest differences as a function of group and transducer. Results of the ANOVAs are shown in Table 2. No significant main effects or interaction of main effects were found at 250, 500, and 1000 Hz. That is, there were no differences in test-retest audiometric threshold differences between the three groups or transducers. A significant main effect of group was found at 2000 and 8000 Hz ($p < .05$). A significant main effect of transducer was also found at 2000 Hz ($p < .05$). That is, a greater test-retest difference was observed with the insert earphones at 2000 Hz. Finally, a significant group by transducer interaction was observed at 4000 Hz ($p < .05$).

Table 1. Means (and Standard Deviations) of Signed Test-Retest Audiometric Threshold Differences (dB) as a Function of Age Group (young, old, and oldest), Transducer, and Test Frequency.

	Transducer					
	Supraaural			Insert		
Frequency (Hz)	Young	Old	Oldest	Young	Old	Oldest
250	1.0 (5.0)	-5.0 (8.5)	-2.5 (5.9)	0.25 (8.8)	-2.0 (7.1)	-0.50 (9.3)
500	1.5 (4.6)	-2.0 (7.9)	-2.5 (5.4)	1.0 (7.7)	-0.5 (4.4)	1.0 (4.6)
1000	1.5 (5.2)	3.5 (5.2)	0.5 (6.4)	1.3 (4.6)	1.0 (7.4)	0.00 (3.3)
2000	2.0 (4.1)	-0.50 (6.4)	-4.0 (2.1)	4.3 (5.5)	4.5 (5.5)	1.5 (5.3)
4000	0.5 (4.3)	3.0 (9.5)	0.00 (6.7)	-0.75 (2.9)	-2.5 (2.6)	5.5 (9.0)
8000	2.3 (6.0)	6.0 (6.9)	7.8 (7.1)	1.3 (3.6)	2.0 (5.4)	12.8 (9.4)

Note. The young group was comprised of 20 participants 22-34 years old; the old group consisted of participants 50-63 year old; and the oldest group included participants 65-81 years old.

Figure 1. Means of the signed test-retest differences as a function of group and transducer for the test frequency of 2000 Hz. Error bars represent plus/minus one standard deviation of the mean.



Note. The young group was comprised of 20 participants 22-34 years old; the old group consisted of 10 participants 50-63 years old; and the oldest group included 10 participants 65-81 years old.

In order to examine the significant between-group effect at 2000 Hz (see Figure 1), separate Scheffé pair-wise comparisons were undertaken for each transducer. Those results are shown in Table 3. For the supraaural transducer, a significant difference was found between the young group and the oldest group ($p < .05$). All other pair-wise comparisons were nonsignificant ($p > .05$).

At 4000 Hz, the significant interaction of group by transducer (see Figure 2) was examined with single-*df* comparisons and Scheffé pair-wise comparisons (see Table 4). Three single-*df* comparisons were used to examine within-group differences in test-retest threshold differences between transducers (see Table 4). Significantly higher test-retest differences were found for the oldest group with the insert earphone ($p < .05$). There were no significant differences between transducers for the young and old groups ($p > .05$). Between-group effects were also examined with Scheffé pair-wise comparisons at 4000 Hz for each transducer (see Table 5). A significant difference was found between the test-retest difference in thresholds with the insert earphone between the oldest group and the other young and old groups ($p < .05$). All other pair-wise comparisons were nonsignificant ($p > .05$). The post hoc analyses revealed that the significant interaction of group by transducer at 4000 Hz was essentially caused by the significantly higher test-retest variability displayed by the oldest group of listeners with the insert earphone.

The significant main effect of group at 8000 Hz (see Figure 3) was examined with Scheffé pair-wise comparisons (see Table 6). The analysis revealed that the oldest group of listeners had significantly greater test-retest variability than the other two

Table 2. Two-Way ANOVA for Signed Test-Retest Auditory Threshold Differences by Age Group and Transducer as a Function of Frequency.

	Main Effect						Two-Way Interaction		
Frequency (Hz)	Age Group			Transducer			Age Group X Transducer		
	df	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
250	2, 37	1.69	0.20	1, 37	0.85	0.36	2, 37	0.65	0.53
500	2, 37	1.08	0.35	1, 37	1.58	0.22	2, 37	1.07	0.35
1000	2, 37	1.32	0.28	1, 37	1.47	0.23	2, 37	2.29	0.12
2000	2, 37	5.44	0.0085*	1, 37	12.7	0.0010*	2, 37	0.89	0.42
4000	2, 37	1.21	0.31	1, 37	0.16	0.70	2, 37	7.71	0.0016*
8000	2, 37	15.2	0.0001	1, 37	0.00	1.00	2, 37	2.16	0.13

Note. *considered significant at $p < 0.05$.

groups ($p < .05$). There was no significant difference in test-retest audiometric threshold differences between the young and old group of listeners ($p > .05$).

Table 3. Scheffé Pair-Wise Comparisons of Between-Group Mean Test-Retest Auditory Threshold Differences as a Function of Transducer at 2000 Hz.

Transducer	Group Comparison	Mean Difference	Critical Difference	*p*
Supraaural	Young vs. Old	2.5	4.4	0.36
	Young vs. Oldest	6.0	4.4	0.0053*
	Old vs. Oldest	3.5	5.1	0.23
Insert	Young vs. Old	-0.25	5.4	0.99
	Young vs. Oldest	2.8	5.4	0.43
	Old vs. Oldest	3.0	6.2	0.47

Note. *considered significant at $p < 0.05$.

Table 4. Single-df Comparisons Investigating Within-Group Mean Test-Retest Auditory Threshold Differences Between Transducers at 4000 Hz.

Group	Mean Difference	df	F	p
Supraaural Earphone				
Young	1.2	1, 19	2.44	0.14
Old	5.5	1, 19	3.77	0.084
Oldest	5.5	1, 19	5.21	0.048*

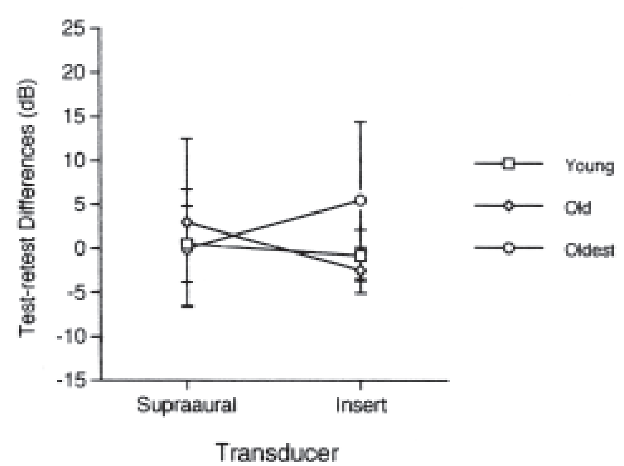
Note. *considered significant at $p < 0.05$.

Table 5. Scheffé Pair-Wise Comparisons of Between-Group Mean Test-Retest Auditory Threshold Differences as a Function of Transducer at 4000 Hz.

Transducer	Group Comparison	Mean Difference	Critical Difference	*p*
Supraaural	Young vs. Old	-2.5	6.4	0.61
	Young vs. Oldest	0.50	6.4	0.98
	Old vs. Oldest	3.0	7.4	0.59
Insert	Young vs. Old	1.8	5.0	0.67
	Young vs. Oldest	-6.2	5.0	0.011*
	Old vs. Oldest	-8.0	5.8	0.0046*

Note. *considered significant at $p < 0.05$.

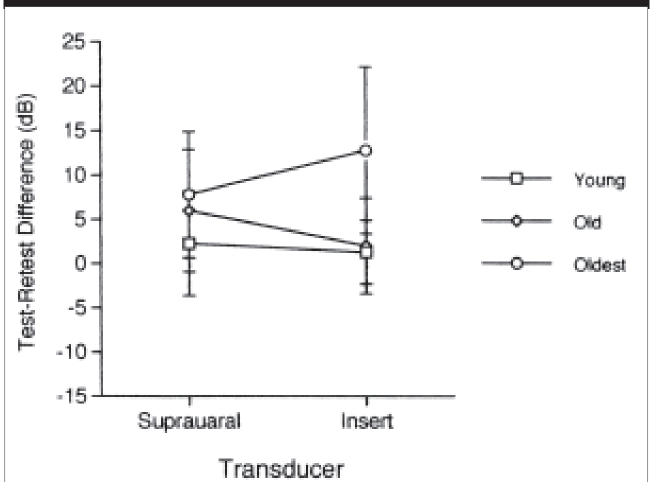
Figure 2. Means of the signed test-retest differences as a function of group and transducer for the test frequency of 4000 Hz. Error bars represent plus/minus one standard deviation of the mean.



Note. The young group was comprised of 20 participants 22-34 years old; the old group consisted of 10 participants 50-63 years old; and the oldest group included 10 participants 65-81 years old.

Critical differences for ascertaining whether two sets of auditory thresholds are different at a 95% confidence level as a function of frequency were computed from the standard deviations of test-retest differences. In cases where the omnibus and post hoc analyses failed to reveal significant between and/or within group differences (see above), data were collapsed across age group and/or transducers. Table 7 displays the critical difference values. These critical differences suggest test-retest

Figure 3. Means of the signed test-retest differences as a function of group and transducer for the test frequency of 8000 Hz. Error bars represent plus/minus one standard deviation of the mean.



Note. The young group was comprised of 20 participants 22-34 years old; the old group consisted of 10 participants 50-63 years old; and the oldest group included 10 participants 65-81 years old.

threshold variability in the 10 - 14 dB range (assuming a 5 dB step size) could be due to chance alone at 250, 500, and 1000 Hz. In other words, one would need to observe a 15 dB difference in test-retest audiometric threshold to be 95% confident that the difference is real and not due to measurement variability. At frequencies of 2000, 4000, and 8000 Hz, differences between two audiometric thresholds from an individual of 5 to 20 dB would have to be observed before one could be 95% confident that the difference is real and not due to measurement variability. The actual critical difference varies as a function of group and transducer.

Table 6. Scheffé Pair-Wise Comparisons of Between-Group Mean Test-Retest Auditory Threshold Differences at 8000 Hz.

Group Comparison	Mean Difference	Critical Difference	*p*
Young vs. Old	-2.2	4.3	0.42
Young vs. Oldest	-8.5	4.4	<0.0001*
Old vs. Oldest	-6.3	5.1	0.011*

Note. *considered significant at $p < 0.05$.

Table 7. Critical Differences at a 95% Confidence Level for Auditory Threshold Differences (dB) as a Function of Frequency, Group, and Transducer.

Frequency (Hz)	Group	Transducer	Critical Difference (dB)
250	Young, Old, and Oldest	Supraaural and Insert	14.7
500	Young, Old, and Oldest	Supraaural and Insert	11.8
1000	Young, Old, and Oldest	Supraaural and Insert	10.3
2000	Young	Supraaural	8.0
2000	Old	Supraaural	12.5
2000	Oldest	Supraaural	4.1
2000	Young, Old, and Oldest	Insert	10.6
4000	Young, Old, and Oldest	Supraaural	12.5
4000	Young and Old	Insert	5.7
4000	Oldest	Insert	17.5
8000	Young and Old	Supraaural and Insert	10.7
8000	Oldest	Supraaural and Insert	16.5

Note. The young group was comprised of 20 participants 22-34 years old; the old group consisted of 10 participants 50-63 years old; and the oldest group included 10 participants 65-81 years old.

Discussion

The purpose of this study was to examine auditory threshold test-retest variability in elderly listeners, relative to young adults, using both supraaural and insert earphones. This was done by determining if the signed test-retest differences differed as a function of age group and transducer. The results of this study suggested that there was significant test-retest variability of audiometric pure-tone thresholds between the young (22-34 year olds), old (50-63 year olds), and oldest adult listeners (65-81 years olds). These age effects were found to be significant only at frequencies higher than 1000 Hz (i.e., 2000, 4000, and 8000 Hz).

There are a number of factors which could have contributed to the significant test-retest variability found in this study. The first contributing factor could have been transducer variability resulting from the method used to couple the stimulus to the auditory system. The supraaural and insert earphones used in this study both have different coupling characteristics. Differences in the method of coupling of the transducer to the ear could have resulted in changes in the level of the stimuli which, in turn, could have caused variability in threshold responses across groups.

Zwislocki et al. (1988) stated that supraaural earphones can be unreliable at low, mid, and high frequencies due to the acoustic coupling between the sound source and the tympanic membrane. Zwislocki et al. noted that variability can occur at low frequencies due to air leaks between the earphone cushion and the pinna. Mid frequency variability can be due to unstable amounts of sound pressure enhancement in the mid frequencies. Also, variability at high frequencies can be due to listener to listener variability in earphone position and the anatomy of the pinna and cartilaginous ear canal.

Zwislocki et al. (1988) stated that insert earphones have some advantages over supraaural earphones in that inserts are less susceptible to air leaks. Insert earphones also minimize some of the wave effects and increase interaural attenuation. Yet Zwislocki et al. noted insert earphones create substantial variability due to intersubject differences in ear canal geometry, eardrum impedance, and controlling for exact insertion depth. Clark and Roeser (1988) discussed further complications with insert earphones including obtaining an adequate seal, variations in ear canal size, and possible frequency response limitations.

A second contribution of variability in the study could be due to physiological differences between the younger and older participants. Hinojosa and Naunton (1980) summarized a number of tissue changes that occur to the aging ear canal including a reduction of cell production, aging of extracellular substances (elastic tissue, cartilage, and bone), and extracellular deposition of various materials. Weinstein (1994) further discussed changes to the aging auditory system which cause degeneration to the outer and middle ear noting structural changes to the tissue lining, ceruminal gland atrophy, tympanic membrane stiffening, degeneration of the incudomalleal and incudostapedial joints of the ossicles, and tensor tympani and stapedius muscle atrophy. These changes have been shown to affect the higher frequencies first in aging adults as shown by Willott's profile of hearing loss (Willott, 1991). The changes in the aging ear canal structure combined with the inherent variability in the transducer coupling characteristics could have caused an increase or decrease in the sound pressure level at the tympanic membrane. The variable sound pressure levels could, therefore, contribute to an increase in test-retest variability in the elderly in the higher frequencies.

Other listener variables, as discussed earlier, are behavioural factors which suggest that the elderly population may be difficult-to-test. These include emotional motivation, physical discomfort, difficulty in attending, fatigue, and antagonism about the test process. Overall, an interaction effect between the physiological and behavioural factors could have resulted in the observed outcome of increased test-retest variability in the higher frequencies for the oldest group compared to the young and old adult groups. For example, the interaction between coupler effects and anatomical variation in the senior group could be responsible for both the greater test-retest difference at 8000 Hz and the lesser change at 2000 Hz. The key consideration are the acoustic interaction between transducer type, stimulus frequency and aging changes.

According to the outcomes found in this study, no significant variability was found in the lower frequencies between the three groups tested. This finding is similar to the results reported by Stuart, Stenstrom, Tompkins, and Vandenhoff (1991) which examined the test-retest audiometric threshold variability with supraaural and insert earphones among children and young adults. Stuart et al. found that a 10-15 dB change in test-retest variability would be necessary to be 95% confident the difference did not occur due to the variability of measurement error. The performance of the young adult listeners is very similar between the Stuart et al. study and this study. There was, however, greater test-retest variability in audiometric threshold for the oldest group of listeners in this study. That is, for the most part critical differences for a 95% confidence level were in the order of 10-15 dB for all listeners except at 4000 and 8000 Hz where a difference of 20 dB would have to be observed for the oldest group for one to confident that the difference was not due to inherent transducer coupling variability, subject variability, or instrument variability.

In conclusion, the findings of this study suggest that test-retest audiometric threshold variability is significantly larger at higher frequencies for geriatric listeners above 65 years of age compared to the younger adult/older adult age groups. Based on these findings, audiologists with adult patients should be aware of test-retest audiometric threshold variability as a function of transducer and patient age. Caution should be taken when interpreting high frequency audiometric threshold variability in the elderly population. It is suggested that more research in geriatric audiology should be conducted in the future to enhance the current pure-tone air conduction assessment tools. In particular, further research should be conducted to examine the differences in transducer coupling procedures and physiological differences between younger adult and older adult age groups versus seniors. It may prove to be the case that assessment of geriatric patients should be modified in the future to reduce test variability (Orange, MacNeill, & Stouffer, 1997).

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