Abstract
The purpose of this study was to evaluate and compare the efficacy of hearing screening tools to identify hearing loss in the older adult population. The test-retest reliability of both the AuDX DPOAE hand-held screener and subjective otoscopic ratings of percent earwax accumulation were evaluated. Additionally, the predictive validity was investigated for five hearing screening tools: the DPOAE hand-held screener, pure-tone screening, screening otoscopy, self-assessment of communication, and case history screening. The research was conducted through typical community hearing screenings on normal-hearing and hearing-impaired volunteer subjects. The screening subjects included 67 adults aged 49 to 89 years. Of those, 44 returned for a full audiologic evaluation. Key findings include: (1) Pure-tone screening had predictive validity for actual hearing loss in the older adult population when a 25 dB HL fence is used; (2) Screening otoscopy ratings were highly reliable across time and raters; (3) Self-assessment scores did not predict compliance with referral recommendations; (4) The AuDX DPOAE hand-held screener proved to be reliable in the overall pass/refer outcome, but lacked predictive validity for actual hearing loss in older adults.

Key Words: Hearing screening, DPOAE, Adult hearing loss, Pure tone screening, Otoscopy, Self-assessment of hearing impairment.


Sumario
El propósito de este estudio fue evaluar y comparar la eficacia de herramientas de identificación auditiva por tamizaje (screening) en la población de adultos mayores. Se evaluó la confiabilidad en la evaluación/re-evaluación utilizando la unidad manual AuDX de emisiones otoacústicas por productos de distorsión (DPOAE) y las estimaciones otoscópicas subjetivas de la acumulación percentual de cerumen. Además, se evaluó la validez predictiva de otras cinco herramientas de tamizaje: la unidad manual de DPOAE, el tamizaje por tonos puros, el tamizaje por otoscopía, la auto-evaluación de la comunicación y el tamizaje por historia clínica. La investigación fue conducida por medio de procedimientos típicos de identificación auditiva en la comunidad, con sujetos voluntarios normo-oyentes y con hipoacusia. La población evaluada incluyó 67 adultos con edades entre 49 y 89 años. De ellos, 44 acudieron para recibir una evaluación audiológica completa. Los hallazgos claves fueron: (1) el tamizaje con tonos puros tuvo validez predictiva para hipoacusia en la población adulta mayor cuando se utilizó un límite inferior de 25 dB HL; (2) las apreciaciones de tamizaje por otoscopía fueron altamente confiables en el tiempo y con los diferentes evaluadores; (3) los puntajes de auto-evaluación no predijeron cumplimiento de la recomendaciones de referencia; y (4) la unidad manual AuDX DPOAE probó ser confiable en el resultado global de pasa/falla, pero no tuvo validez predictiva para hipoacusia en los adultos mayores.

Palabras Clave: Hipoacusia en el adulto, emisión otoacústica por producto de distorsión, tamizaje auditivo, otoscopía, tamizaje por tonos puros, auto-evaluación del trastorno auditivo.

Abreviaturas: DPOAE = emisión otoacústica por producto de distorsión; SAC = auto-evaluación de la comunicación.
A position statement issued by the American Academy of Audiology (AAA) recommends that maximizing the communication skills of older adults become a priority in the field of audiology (Gordon-Salant et al., 1991). An important first step in diagnosing and treating more of the older adult population that has undiagnosed or untreated hearing loss is establishing effective hearing screening methods and programs. Undiagnosed or untreated hearing loss reduces the older adult’s ability to communicate effectively in daily interactions and in critical conversations with physicians, therapists, and caregivers. In addition, undiagnosed or untreated hearing loss can also have significant social and psychological implications, including confusion, inattentiveness, anxiety, withdrawal from social interaction, and depression (Herlost and Humphrey, 1980; Herbst and McConnell, 1982; Lichtenstein, 1992). Unfortunately, even though amplification technology has rapidly improved and is becoming increasingly more accessible, only 18 to 20% of adults over 65 with hearing loss sufficient to impair communication are currently being treated with amplification devices (Weinstein, 2000). More widespread and effective hearing screening programs are essential to better serve the older adult population, which is predicted to reach 39,362,000 by the year 2010 according to Census Bureau predictions (Kricos, 1995).

Recently the United States federal government issued a detailed mandate to health care providers entitled “Healthy People 2010” (Healthy People 2010, 2001). This mandate, led by the National Institutes of Health, includes specific goals for meeting healthcare needs of the United States population in the next decade. Among the goals indicated, the following specifically addressed the need for more efficient identification and management of hearing handicap in the adult population:

28-13. Increase access by persons who have hearing impairments to hearing rehabilitation devices, including hearing aids, cochlear implants, or tactile or other assistive or augmentative devices.
28-14. Increase the proportion of persons who have had a hearing examination on schedule.
28-15. Increase the number of persons who are referred by their primary care physician for hearing evaluation and treatment.
28-16. Increase the use of appropriate ear protection devices, equipment, and practices.
(Healthy People 2010, 2001).

Improving the quality of life and the ongoing productivity of the adult population by ensuring that hearing loss is identified and ameliorated through audiologic intervention is an important and attainable goal.

In this study, five adult hearing screening techniques were evaluated for efficacy when used in real-world screening conditions. The American Speech-Language-Hearing Association’s (ASHA) adult hearing screening recommendations suggest four screening procedures: case history, visual inspection and otoscopy, pure-tone screening, and self-reported hearing disability measures (ASHA, 1997). The current study evaluated these four traditionally used hearing screening procedures along with a newer, commercially available hand-held distortion product otoacoustic emissions (DPOAE) screener that indicates possible hearing loss or ear disease quickly and painlessly without subject behavioral participation. If DPOAEs can be used to successfully screen adults, the accessibility of important, regular hearing screening could be improved, and more adults with hearing loss could be identified at an earlier age. The resulting pass/refer outcomes for the five screening procedures were compared to the actual hearing loss of the subject as measured in a full, follow-up evaluation completed within 25 days of the screening. The purpose of this study was to evaluate the efficacy of case history, otoscopy, pure-tone screening, self-assessment of disability, and the newer DPOAE hand-held screener to identify hearing loss in the older adult population. Predictive validity was examined for all five screening procedures, test-retest reliability was evaluated for DPOAE measurement and for otoscopic examination, and the correlation between self-assessment scores and compliance with a referral recommendation was examined.

METHOD

Subjects

The target population included adults (49 and over) living in Southwest Virginia who were not institutionalized and who participated in activities in a community or church-based seniors or adult program. Three community or church-based programs were identified in the New River Valley area of Virginia, and free hearing screening days were scheduled with the cooperating centers. These screenings were publicized by the investigating clinician and were open to any adult 49 and older participating in the program, without regard to gender, race, or medical status/history. The sample selection is limited by its
inclusion of only those older adults who voluntarily participate in church or community-based social programs, which may not be reflective of the older adult population as a whole. This characteristic of the sample population was not seen as a significant bias in the outcome of objective screening and evaluation procedures, but the sample studied did represent a more mobile, socially interactive subset of the overall population of older adults.

The actual total number of participants at the completion of the three screenings was 67. The pool of participants ranged in age from 49 to 89, with a mean age of 68.9, a median age of 70 and a mode of 74. There were 27 male and 40 female volunteer participants. The screenings and follow-up evaluations were conducted completely free of charge to the participants, by specifically trained graduate clinicians supervised by a licensed audiologist. Appointments for the follow-up evaluation were made at the time of the screening, and parking permits and maps were distributed at that time.

Screening Protocol

The screening protocol was completed in a randomized order. Each participant completed a self-assessment questionnaire, a case history, an otoscopic examination, a pure-tone screening, and two DPOAE screenings in random order. Each of the five screening techniques were scored PASS or REFER, and were conducted in a manner consistent with infection control and universal precautions (Jacobson, 1994; Kemp, et al, 1995; Ballachanda, et al, 1996). The investigating clinicians measured the ambient noise level in the rooms used for the screening before each screening and at one point during the screening using a Quest Model 155 Impulse Precision Sound Level Meter with attached Model OB-145 Octave Band Filter and Type 7023 Condenser microphone. The ambient noise levels were compared to the minimum acceptable standards for hearing screenings established by ANSI (1991). All three screening sites fell within the minimum standards established by ANSI.

1. Hearing Handicap Screening Procedure.

An adult hearing self-assessment was administered in a face-to-face interview format as recommended by ASHA guidelines (1997). A modified version of the “Self-Assessment of Communication” (SAC; Schow and Nerbonne, 1982) was used (Appendix B). The modifications made involved enlarging the print and removing the tester’s scoring guide from the participant form. The clinician instructed the participant to rate each statement on a scale from 1 to 5, with 1 representing “almost never” and 5 representing “practically always.” The clinician read each item aloud to the participant, while he or she looked on, and then the participant used a pen to mark the intended response to each question. Items were repeated as requested. The SAC was scored as recommended by Schow, et al (1990).

2. Otoacoustic Emission Screening Procedure.

Distortion Product Otoacoustic Emissions were measured twice in each ear for each participant. Two new Bio-Logic Model AuDX Basic Handheld DPOAE Screening Meters (580-STKOAE3) were used with the manufacturer's installed screening protocol and calibration. The AuDX is a hand-held, battery-operated, rechargeable unit that can print out screening results and has a 10-test memory. The screen on the AuDX indicates “PASS” or “REFER.” To obtain a “Pass” result, three of the four test frequencies must meet the response conditions, which include minimum distortion product amplitude, minimum amplitude above the noise floor, and maximum noise floor measurement (Bio-logic, 1999). The screening clinicians recorded the pass/fail designation from the display screen. In addition, the down arrows were used to view each frequency tested, and the individual frequencies failed were recorded for each test. The participants were instructed to remain still and quiet during the testing.

3. Pure Tone Hearing Screening Procedure.

A pure-tone screening following ASHA’s standards of screening as described in “Screening for Hearing Disorders-Adults” in Guidelines for Audiologic Screening (1997) was completed for each individual. Calibrated, electrically checked commercial screening audiometers were used. Audiometers used meet ANSI S3.6-1996 requirements for limited-range audiometers, and were calibrated to meet ANSI S3.6-1996 standards. Each participant was instructed to respond to the tones with a raised hand each time he or she heard a tone. After the clinician placed the earphones on the participant, he or she was screened at 25 dB HL at 1000 Hz, 2000 Hz, and 4000 Hz. If the participant did not respond at one of the frequencies, there was one immediate repetition to
ensure participant attention. The participant was scored as a referral if he or she still did not respond to any one of the frequencies in either ear. Any frequencies failed were recorded. The participant was scored as a pass if he or she responded to all frequencies in both ears.

4. Case History Screening Procedure.

A case history was obtained by the clinician through a face-to-face interview format. Questions included those listed in Table 1, which are from ASHA guidelines (ASHA 1997), Hall (2000), and the U.S. Department of Health, Education, and Welfare, Food and Drug Administration (1977).

A participant “PASSED” the case history screening if all answers were negative. A “REFERRAL” is recommended by ASHA for any positive response in the case history for which the individual is not already receiving medical attention (ASHA 1997). A “yes” answer to case history questions regarding sudden or rapid progression of hearing loss, tinnitus accompanied by dizziness, fullness, pain or numbness, chronic dizziness or a spinning sensation, or any drainage or pain from the ear(s) constitutes a referral to a medical practitioner for evaluation. A “yes” answer to noise exposure suggests a referral for audiologic evaluation. A “yes” to ototoxic medications may not indicate a referral, but is important for the analysis of DPOAE results. A “pass” or “refer” on the case history did not change the protocol for the remaining screening.

5. Otoscopy Screening Procedure.

The outer ear was visually examined, and the ear canal was inspected with an otoscope by the clinician. Gowlands Mini Pocket Otoscopes, which cost approximately $40, were used because these inexpensive models would more likely be used in typical community hearing screenings. All screening clinicians were graduate students in either audiology or speech language pathology trained in otoscopic examination. The otoscopic examination served two purposes:

a. Identified the need for medical referral due to drainage, swelling or unknown objects in the ear canal.

b. Identified cerumen blockage percentage, and rated the cerumen (See Table 2).

Cerumen blockage was judged subjectively by visually estimating the percentage of the oval ear canal space that is filled with cerumen. Any blockage of 50% or more (“B” or “C” rating) constituted a “referral” score on this part of the screening. The participant passed this part of the protocol if there was no observable cerumen blockage.

Table 1 Case History Questions

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Do you experience hearing loss?</td>
<td></td>
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<tr>
<td>Have you ever experienced unilateral hearing loss, sudden or rapid progression of hearing loss?</td>
<td></td>
</tr>
<tr>
<td>Do you experience tinnitus, or ringing, clicking, roaring or popping in one or both ears?</td>
<td></td>
</tr>
<tr>
<td>Do you experience acute or chronic dizziness or sensation of spinning?</td>
<td></td>
</tr>
<tr>
<td>Have you had recent drainage from the ear(s) and/or pain or discomfort?</td>
<td></td>
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<tr>
<td>Do you have a history of exposure to noise?</td>
<td></td>
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<tr>
<td>Are you currently taking or have you ever taken intravenous antibiotics, chemotherapy, diuretics, large doses of aspirin, or any drugs that you are aware are ototoxic medications?</td>
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Table 2 Cerumen Rating

<table>
<thead>
<tr>
<th>Rating</th>
<th>Definition / Key for Cerumen Rating</th>
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<tbody>
<tr>
<td>A</td>
<td>Nonoccluded: Cerumen accumulation less than 50%; No noticeable conductive hearing loss.</td>
</tr>
<tr>
<td>B</td>
<td>Excessive: Cerumen accumulation between 50 to 80%; No noticeable conductive hearing loss.</td>
</tr>
<tr>
<td>C</td>
<td>Impacted: Cerumen impaction greater than 80%; Associated with conductive hearing loss at two or more frequencies.</td>
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</tbody>
</table>

Adapted from Ballachanda (1995), and Crandell and Roeser (1993).
screening if he had nonoccluding or absent earwax in both ears (“A” rating). Regardless of the cerumen rating, all participants were encouraged to attend the follow-up appointment.

6. Participant Education.

An educational explanation of the terminology, procedures, and the process of hearing and hearing screening was presented to the participants in familiar language in both written and oral form. Participants were educated on the need for hearing protection and the warning signs of hearing loss or hearing disorders. In addition, the participants were notified of the need for regular screenings, and the specific purpose and content of the follow-up procedure.

Participants were given a “mini-report” after the screening and were offered an appointment time to come to the Radford University Clinics for the follow-up evaluation. Participants were also given the opportunity to ask questions and discuss the hearing screening education handout, hearing protection, and the importance of attending the follow-up session. There were no reminder calls, reminder cards, or other scheduled contact with the screening participants prior to the follow-up appointments. Three of the participants independently called the clinic to reschedule appointments. Of the 67 original screening participants, 44 returned for the audiologic follow-up testing.

Follow-up Audiologic Evaluation

Of the 67 participants who participated in the screenings, 44 returned for the follow-up hearing evaluation appointment. The follow-up evaluations were conducted using established audiologic evaluation procedures adapted into a standard format. A special audiogram form was developed for recording and reporting the outcome of the follow-up audiologic evaluation. The follow-up appointments ranged from 2 to 25 days following the original screening and were conducted in a university speech and hearing clinic setting. The follow-up testing procedure included otoscopic examination with cerumen rating, immittance testing when appropriate, and air and bone conduction testing as outlined on the protocol form. Actual hearing thresholds were measured using air- and bone-conduction testing in a sound-treated booth by a licensed audiologist or a trained graduate clinician supervised directly by a licensed audiologist. The prescribed research protocol follow-up procedures were completed prior to any additional testing, discussion or procedures, including case history interviewing and cerumen removal.

To provide blind testing conditions, prior screening results and information were not made available to the clinicians prior to the completion of the follow-up testing procedures. The follow-up clinicians only knew the name of the client and that he or she was to be tested using the research protocol. At the completion of the appointment, some participants were invited to return to the clinic for a second free appointment to continue other needed testing, cerumen removal, counseling, or discussion of recommendations. The participants were offered copies of the results of the follow-up evaluation, and results and recommendations were discussed with each participant. (See Appendix A for the spreadsheet of the screening and follow-up data).

RESULTS

Descriptive Characteristics of the Screening Sample

In this study, a high response rate to the screening opportunities and high attendance for the optional follow-up examination support the need for greater availability of hearing testing services for this population. In addition, further support of the need for more opportunities for hearing evaluation in the adult population is found in the responses to a question asked of each of the 67 participants: “When was your last hearing screening or hearing test?” Participant responses are summarized in Table 3. Although ASHA (1997) recommends a hearing screening each decade through age 50, and then every 3 years thereafter in the absence of any problems, 70% of the adults who volunteered for this study have not had their hearing checked in 10 years or more. Thirty-eight participants, or 57%, reported that they last had a hearing screening at least 20 years ago, with 21 of these respondents (31% of the sample) reporting that no one had ever screened or tested their hearing at all. Of those 21 people who reported never being screened or tested, 10 returned to the clinic for the full audiologic follow-up. From the follow-up testing, 10 of these 11 individuals (91%) actually had a hearing loss. With the significant impact hearing loss can have on the quality of life and continued productivity for older adults, this apparent absence of readily available, early identification screening opportunities is unacceptable.
Important descriptive attributes of the volunteer screening population were noted from the case history interviewing of the 67 participants, and these are summarized in Table 4. Additionally, the prevalence of recorded cerumen impaction was much lower than reported in prior studies for non-institutionalized adults the same age. Eighty-two percent of the participants had a normal “A” rating for cerumen accumulation in both ears during the screening. This indicates that only 18% of the 67 adults, ranging in age from 49 to 90, had earwax accumulation of 50% or more in at least one ear. Only 6 participants, or 9.0%, had a “C” rating in at least one ear, which indicates a cerumen impaction (80% or more cerumen accumulation). Gleitman, et al (1992) found that 24% of non-institutionalized adults in their study ranging in age from 23 to 89 years had impacted cerumen in at least one ear. From the same study (Gleitman, et al), the incidence of cerumen impaction in the following age ranges of non-institutionalized adults were reported:

- Age in years  Percentage of Cerumen Impaction, at Least One Ear 55-64
- 25% of the overall non-institutionalized sample 65-75
- 34% of the overall non-institutionalized sample 75-84
- 22% of the overall non-institutionalized sample

In the current study, the 6 participants of the 67 screened who were rated as having a cerumen impaction in at least one ear had the following ages in years: 63, 71, 74, 79, 81, and 82. All six of these participants were female.

### Reliability of Screening Protocols

#### DPOAE Reliability

Hall (2000) reported that there were no published studies that examined the reliability of DPOAEs measured in a normal-hearing population in a typical setting by typical clinicians. This current study addressed that need by testing reliability in a typical sample of adults, both with hearing loss and with normal hearing, using commercially available equipment in a typical screening setting by trained graduate student clinicians under the supervision of a licensed clinical audiologist. Using a phi coefficient calculated for the correlation of the pass/fail results of trial A to the results of trial B, the reliability for the DPOAE measurement was determined to be .80. A phi coefficient of .80 or higher shows a strong correlation and supports good test-retest reliability for the overall pass/refer indication.

In addition to the overall reliability, the reliability of the individual frequencies failed was analyzed. This was accomplished by comparing the results of the frequencies failed on trial A for a participant to the frequencies failed in trial B for the same participant. The frequencies failed were recorded from the display following the “View DPOAE Results” prompt on the DPOAE hand-held screener for each screening test com-

### Table 3  Summary of Prior Hearing Screening or Testing

<table>
<thead>
<tr>
<th>Prior Hearing Screening or Testing</th>
<th>Number of the 67 Participants</th>
<th>% of the total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within the last three years</td>
<td>14</td>
<td>21%</td>
</tr>
<tr>
<td>More than 3, but less than 10 years ago</td>
<td>6</td>
<td>9%</td>
</tr>
<tr>
<td>10 to 20 years ago</td>
<td>9</td>
<td>13%</td>
</tr>
<tr>
<td>20 years or more</td>
<td>17</td>
<td>26%</td>
</tr>
<tr>
<td>Those reporting NEVER having a hearing screening or hearing test</td>
<td>21</td>
<td>31%</td>
</tr>
</tbody>
</table>

### Table 4  Characteristics Reported by Screening Participants

<table>
<thead>
<tr>
<th>% of 67 Screening Participants</th>
<th>Characteristics Reported by Screening Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>33%</td>
<td>Chronic dizziness</td>
</tr>
<tr>
<td>51%</td>
<td>Tinnitus, or ringing in the ears.</td>
</tr>
<tr>
<td>18%</td>
<td>Current or prior exposure to ototoxic medication.</td>
</tr>
<tr>
<td>33%</td>
<td>Significant noise exposure.</td>
</tr>
<tr>
<td>70%</td>
<td>Perceive a hearing loss in at least one ear.</td>
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</table>
completed. When comparing the results for the individual frequencies, the correlation between trials A and B was much weaker than for the overall response. The phi coefficients were determined for the right ear test trials and are summarized in Table 5. As seen in Table 6, the phi coefficients calculated for the individual frequencies passed or referred in repeated trials of the DPOAE screener showed only moderate correlation, which suggests poor to moderate test-retest reliability for the individual frequencies.

### Otoscopic Examination Reliability

Another research question in this study addressed the use of otoscopic screening. The reliability of the cerumen rating subjectively observed across different raters and different times was determined using the phi coefficient. Individual raters had variable training backgrounds and varying levels of otoscopic examination experience, which ranged from twenty minutes of practice to twenty years as a licensed professional. Each was trained in the interpretation of cerumen impaction based upon the three part rating scale described earlier (A, B or C). The cerumen ratings from the screenings were compared with the cerumen ratings from the full diagnostic evaluation for the 44 participants who returned. The time span between the two ratings varied from 2 days to 25 days. The phi coefficient for the cerumen ratings as part of the screening otoscopy was .80, which suggests a high positive correlation between the otoscopic cerumen rating across time and rater. The use of a three part rating scale (A, B, C) for determination of excessive cerumen accumulation is a highly reliable method of screening for this type of hearing disorder.

### Predictive Validity of Screening Protocols

In the follow-up evaluation, 89% of the participants had hearing loss in at least one ear, and only 11% (5 individuals) had normal hearing. The outcome patterns of the follow-up evaluations for the 44 returning participants are summarized in Table 6.

One of the most difficult parts of completing this analysis is the ongoing debate of what constitutes a hearing loss in an older adult. As discussed earlier, different authors describe normal hearing in different ways. To more accurately represent the correlation of the DPOAE screener and pure-tone screening to actual hearing loss, the screening outcomes were correlated with the frequency ranges tested by each of these tools. The pure-tone screening method should highly correlate to actual hearing loss in the frequencies screened, which were 1000, 2000 and 4000 Hz. The overall pure-tone screening pass or fail was compared to actual hearing loss as defined as hearing thresholds greater than 25 dB HL at 1000, 2000, or 4000 Hz in either ear. On the other hand, The DPOAE pass/refer outcomes are expected to have a high correlation with the measured presence of hearing loss in the frequencies presented by that tool, which were 2000, 3000, 4000, and 5000 Hz. Due to the preprogramming and standard calibration of the diagnostic audiometer used in the follow-up, the hearing thresholds could not be measured at 5000 Hz, but were measured at 6000 Hz instead. As a result, the overall pass/fail of the DPOAE screener was compared to actual hearing loss as defined as thresholds greater than 25 dB HL at 2000, 3000, 4000, or 6000 Hz in either ear. If the pure-tone screening and DPOAE are highly predictive of actual hearing loss, a phi coefficient of .80 or higher would be expected.

The other three screening tools used in the current study are known to give information other than prediction of hearing loss, and as a result, a weaker correlation coefficient is expected with actual hearing loss. The self-assessment, screening otoscopy and case history screening outcomes were compared with both of the hearing loss definitions indicated above for use with pure-tone screening and DPOAE comparison for the 44 participants who returned for a follow-up evaluation. A weaker phi coefficient is expected, however, because the self-assessment is meant to screen for hearing disability, while otoscopy and case history are most valuable in screening for hearing or ear disorders. These three tools are useful because they provide information other than a prediction of hearing impairment.
Predictive validity of pure-tone screening.

The pure-tone screening used in this study had a moderate positive correlation to the actual hearing loss at 1000 Hz, 2000 Hz, and 4000 Hz, with a phi coefficient of .76. With the widely accepted use of pure-tone screening, this correlation may be somewhat lower than expected, but still shows a positive and acceptable correlation to actual hearing loss for a screening tool. According to Doehring (1996), a correlation coefficient of .75 or greater is acceptable for a screening tool.

DPOAE predictive validity.

Although the DPOAE screener showed high test-retest reliability in this study, the DPOAE pass/fail indication does not show acceptable predictive validity. The phi coefficient calculated for the correlation of the pass/fail outcome to the presence of hearing loss, defined as thresholds greater than 25 dB HL at 2000, 3000, 4000 or 6000 Hz in either ear, was .48. This suggests that the pass/refer outcome of the DPOAE screener, although repeatable, does not consistently predict the presence or absence of hearing loss in adults aged 49 to 89. The lack of validity diminishes further when the DPOAE pass/fail outcome is compared to the pure-tone definition of hearing loss (>25 dB HL at 1000, 2000, or 4000 Hz either ear), with a phi coefficient of .32.

The weak correlation of the DPOAE outcomes to the actual hearing loss is an important finding that warrants further investigation. One possible explanation for the poor correlation of the DPOAE screening outcome to actual hearing thresholds is the nature of the DPOAE measurement. Unlike pure-tone screening, both diagnostic and screening DPOAEs do not measure actual hearing sensitivity. Diagnostic and screening DPOAEs are measurements associated with healthy outer hair cells within the cochlea. There is published evidence that cochlear damage may be present and detectable with DPOAE measurements before any changes in actual hearing thresholds are detected (Bohne and Clark, 1982; Gorga, et al, 1997; Hall, 2000). If this is true for some of the participants in the current study who did not exhibit hearing loss at the failed frequencies, the “refer” score on the DPOAE could be an early sign of hearing loss that will be seen as audiometric threshold changes in the future (Nieschalk, et al., 1998).

Other possible confounding factors in DPOAE measurement may include the presence of poor normal hearing, cerumen accumulation, and tinnitus. Hall (2000) warns that although 25 dB HL hearing thresholds may represent “normal” hearing, the amplitude of the DPOAE response has been shown to diminish in some subjects with thresholds poorer than 15 dB HL. Most of the adult population over 49 will have thresholds poorer than 15 dB. This alone may limit the use of DPOAEs in adult screening, or necessitate changes in the screening criteria programmed into the screening when used with adults. Another factor discussed by Hall is the interference of cerumen accumulation. In an effort to consider this, a second phi coefficient was calculated using only those 35 subjects who had normal hearing at all frequencies tested, and required no further action.
“A” cerumen ratings in the otoscopic examination. This resulted in a phi coefficient of .48 for the correlation of the DPOAE outcome to the actual hearing loss. This reflects absolutely no change from the correlation when the subjects with excessive cerumen were included. Another confounding factor that can interfere with DPOAE measurement is the presence of tinnitus (Hall, 2000). Tinnitus may be a sign of cochlear dysfunction, and DPOAEs are measurements of the functioning of the cochlea. In the current study, 22 participants who returned for the follow-up evaluation indicated during the case history that they suffer from tinnitus. When the participants who suffer from tinnitus are excluded from the data pool for a third DPOAE phi coefficient calculation, a significant change is seen. In fact, if only the 22 participants who did not report tinnitus are used to compare the correlation of the DPOAE outcome to actual hearing thresholds, the phi coefficient is .69, which shows strong correlation for such a small sample size (refer to Table 7).

In summary, the AuDX DPOAE hand-held screener may not be the most appropriate tool for hearing impairment screenings in the general population of adults 49 and older when using the current default screening program established by the manufacturer. Although the AuDX DPOAE screener is reliable overall, it lacks validity when used in a typical screening setting with adults over 49. More research is needed to clearly establish the usefulness of DPOAEs in the adult population, and particularly with hand-held devices. In the current study, the validity improves substantially when tinnitus sufferers are excluded from the sample being screened. Unfortunately, tinnitus is a common problem in the adult population, and would interfere significantly with the usefulness of the AuDX in screening for hearing loss. The DPOAE screener may be helpful in identifying tinnitus and very early warning signs of cochlear dysfunction in adults, but more studies need to be completed to establish the validity for this purpose.

**Otoscopy, Modified SAC Score, and the Case History Screening.**

As anticipated, there is not strong predictive validity of the outcomes on three screening tools used in this study: screening otoscopy, hearing handicap self-assessment score, and the case history screening. These tools are used primarily to screen for hearing disorders and hearing disability, so the correlation to hearing thresholds may not be as strong. These tools provide other invaluable information. The predictive validity of these tools is summarized in Table 8.

<table>
<thead>
<tr>
<th>Screening Tool</th>
<th>Actual thresholds &gt; 25 dB HL at 1000, 2000 or 4000 Hz in Either Ear</th>
<th>Actual thresholds &gt; 25 dB HL at 2000, 3000, 4000, or 5000 Hz in Either Ear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure-tone screening at 1000, 2000 and 4000 HZ at 25 dB HL</td>
<td>.76</td>
<td>.63</td>
</tr>
<tr>
<td>DPOAE Hand-held screener</td>
<td>.32</td>
<td>.48</td>
</tr>
<tr>
<td>Otoscopy</td>
<td>.27</td>
<td>.18</td>
</tr>
<tr>
<td>Self-assessment</td>
<td>.33</td>
<td>.23</td>
</tr>
<tr>
<td>Case History</td>
<td>.16</td>
<td>.10</td>
</tr>
</tbody>
</table>

Table 7  The Influence of Tinnitus on DPOAE Predictive Validity: Phi Coefficients

<table>
<thead>
<tr>
<th>Participants used in DPOAE Hand-held Screener Comparison</th>
<th>Predictive Value of DPOAE if actual hearing loss is defined as thresholds &gt; 25 dB HL at 2000, 3000, 4000, or 5000 HZ in either ear</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Participants who returned for the evaluation (n= 44)</td>
<td>.48</td>
</tr>
<tr>
<td>Only Participants with an “A” earwax rating (n=35)</td>
<td>.48</td>
</tr>
<tr>
<td>Only Participants who do NOT report tinnitus (n=22)</td>
<td>.69</td>
</tr>
</tbody>
</table>

Table 8  Predictive Validity of Hearing Screening Tools: Phi Coefficient
Modified SAC Scores and Follow-up Compliance.

In addition to the lack of predictive validity, the self-assessment scores also did not predict who would return for follow-up evaluation. The modified SAC was administered and scored as recommended by Schow, Smedley, and Longhurst (1990), with a score equal to or greater than 19 constituting a “refer” score. Weinstein (2000) proposed that the use of self-assessment questionnaire scores combined with education of the screening participants will yield the highest follow-through rates. In this comprehensive screening, all 67 participants were educated with written information and face-to-face counseling regarding the prevention and impact of hearing loss, and the successful use of current amplification technology to reduce the disability of hearing impairment. The expected pattern in the self-assessment scores would be that a significantly higher percentage of those who returned for the follow-up evaluation would have had a “refer” score on the modified SAC, indicating that a hearing disability is perceived. However, of the 44 who actually returned for the follow-up evaluation, only 15 had a “refer” (34%) on the modified SAC, and 29 had a passing score on the modified SAC (65%). Of the 23 participants who did not follow-through with the recommended hearing evaluation, 9 had a “refer” (39%) on the modified SAC, and 14 had a passing score on the modified SAC (61%). Clearly, the modified SAC score, while presenting important information about the perception of hearing disability, is not a predictor for whether or not a screening participant in this age range will comply with the recommendation for a free follow-up hearing evaluation.

CONCLUSIONS

Two major conclusions can be drawn from this study:

1. Pure-tone screening is still the most valid method of hearing screening in the adult population. Although DPOAEs hold some promise, the screening criterion for the hand-held DPOAE meter used in this study produced reliable results that lacked predictive validity. Pre-programmed screening criterion must be adjusted and carefully researched in screening trials before handheld DPOAE screeners can be viewed as a valid tool for use in adults. Further, the increased validity of the hand-held DPOAE screener when tinnitus sufferers were excluded suggests that the screener may not be practical for screening the older adult population at large due to the high prevalence of tinnitus complaint. On the other hand, the use of DPOAEs as an objective indicator of tinnitus may be a clinical use that can be further developed through additional research.

2. Cerumen ratings determined in screening otoscopy were shown to have inter-rater reliability even when clinicians were not extensively experienced in otoscopy. The use of a three-part rating scale (A, B, C) for determination of excessive cerumen accumulation is a highly reliable method of screening for this type of hearing disorder. Otoscopy, self-assessment questionnaires, and screening case history do not have predictive validity when compared to hearing thresholds; however, each gives important information that is different from the information gained in pure-tone screening and DPOAEs. These three tools should continue to be a part of any comprehensive adult hearing screening to ensure that hearing disorders and hearing handicap are appropriately screened along with hearing impairment.

Adult hearing screening is critical and screenings must be made more effective and more accessible to older adults. While audiologists and speech-language pathologists continue to debate the appropriate tools to use for screening adults, the appropriate intensity “fence” to establish for hearing screenings, and the most appropriate personnel to perform the screenings, many older adults with hearing loss continue to remain undiagnosed and untreated. The more effective identification and treatment of these individuals must become a priority as the older adult population rapidly grows to its highest level in history.


REFERENCES


Predictive Validity and Reliability of Adult Hearing Screening Techniques/Scudder et al


