J Am Acad Audiol 19:293–308 (2008)

Monotic Auditory Processing Disorder Tests in the Older Adult Population

DOI: 10.3766/jaaa.19.4.3

L. Clarke Cox*
Sandra L. McCoy†
Patricia A. Tun‡
Arthur Wingfield‡

Abstract

The purpose of this study was to determine if peripheral hearing loss of varying degrees in elderly subjects affected performance on monotic auditory processing disorder (APD) tests. A battery of monotic APD tests was administered to a group of well-educated and high-functioning older adults who were divided into three subgroups based on hearing acuity but similar in age: (1) normal hearing out to 4000 Hz with a slight high-frequency slope above that point, (2) normal hearing in the speech range but greater high-frequency loss (sloping configuration), and (3) hearing loss in both the low and high frequencies (low/high). The findings documented that subjects with normal hearing in the speech range performed well on all the APD tests. The subjects in the two hearing loss groups, however, performed more poorly on certain tests. The low/high loss subjects did significantly poorer than did the sloping subjects. These data suggest that low/high-frequency peripheral hearing loss is a factor for poor performance on certain monotic APD tests. Results further showed that when cognitive ability and presentation level are held constant, chronological age does not appear to be a contributing factor to performance on the majority of these monotic APD tests. If APD tests are to be administered to elder subjects, peripheral hearing loss configuration needs to be documented. For subjects with low/high-frequency losses, the tester needs to be aware that serious contamination of the results may occur.

Key Words: Aging, cognitive functioning, monotic listening task, speech processing

Abbreviations: APD = auditory processing disorder; CID = Central Institute for the Deaf; LPFS = Low-Pass Filtered Speech; MCR = message-to-competition ratio; PPS = Pitch Pattern Sequence; PTA = pure-tone average; SNHL = sensorineural hearing loss; SNR = signal-to-noise ratio; SRT = speech-recognition threshold; SSI-ICM = Synthetic Sentence Identification—Ipsilateral Competing Message

Sumario

El propósito de este estudio fue determinar si las pérdidas auditivas periféricas de diferentes grados en sujetos mayores afectaban el desempeño en pruebas monóticas para trastornos de procesamiento auditivo (APD).

*Department of Otolaryngology, Boston University School of Medicine; †Department of Psychology and Volen National Center for Complex Systems, Brandeis University; ‡School of Audiology and Speech Sciences, University of British Columbia

L. Clarke Cox, Department of Otolaryngology, Boston University School of Medicine, 720 Harrison Ave., Ste. 601, Boston, MA 02118; Phone: (617) 414-1765; Fax: (617) 638-6424; E-mail: clcox@bu.edu

This work was supported by the WM Keck Foundation and NIH grant AG19714 from the National Institute on Aging.

Una batería de pruebas monóticas para APD fue administrada a un grupo de adultos mayores bien educados y con alto nivel de funcionamiento, quienes fueron divididos en tres subgrupos con base en su agudeza auditiva, pero con edad similares: (1) audición normal hasta 4000 Hz pero con una leve pendiente en las frecuencias agudas por encima de ese punto, (2) audición normal en el rango del lenguaje pero con una pérdida mayor en frecuencias agudas (configuración en caída), y (3) pérdida auditiva tanto en frecuencia agudas como en altas (baja/alta). Los hallazgos documentaron que los sujetos con audición normal en el rango del lenguaje se desempeñaron bien en todas las pruebas APD. Los sujetos en los dos grupos de pérdida auditiva, sin embargo, se desempeñaron más pobremente en ciertas pruebas. Los sujetos de alta/baja rindieron significativamente peor que los sujetos de configuración en caída. Estos datos sugieren que la hipoacusia periférica en frecuencias altas/bajas es un factor de pobre desempeño en las pruebas monóticas en APD. Los resultados mostraron además que cuando la habilidad cognitiva y los niveles de presentación se mantienen constantes, la edad cronológica no parece ser un factor modificador del desempeño en la mayoría de estas pruebas monóticas en APD. Si se han de administrar estas pruebas para APD a adultos mayores, la configuración de la pérdida auditiva periférica debe ser documentada. Para sujetos con pérdidas auditivas en frecuencias bajas/altas el evaluador debe ser conciente de que puede ocurrir una seria contaminación de los resultados.

Palabras Clave: Envejecimiento, funcionamiento cognitivo, tareas monóticas de escucha, procesamiento de lenguaje

Abreviaturas: APD = trastorno de procesamiento auditivo; CID = Instituto Central del Sordo; LPFS = Lenguaje Filtrado con Pasa-Bajo; MCR = tasa de mensaje-competencia; PPS = Secuencia de Patrón Tonal; PTA = promedio tonal puro; SNHL = hipoacusia sensorineural; SNR = tasa señal-ruido; SRT = umbral de reconocimiento del lenguaje; SSI-ICM = Identificación de Frases Sintéticas—Mensaje Competitivo Ipsilateral

Auditory processing of speech entails the reception and perception of the speech stimuli via the auditory periphery to the central auditory nervous system. Historically, auditory processing disorder (APD) tests grew out of early work focused on identifying lesions in the central nervous system. Initial APD assessment was used on children, but in the past two decades there has been documentation of APD occurring in the elderly (Jerger et al, 1989). Given the high prevalence of peripheral hearing loss in this population, the issue of how hearing loss may affect performance on tests of APD has been a matter of study and debate within the community interested in speech processing in older adults. Not only have there been contradictory findings in the literature about the prevalence of APD among older adults (Jerger et al, 1989; Cooper and Gates, 1991), but the effects of peripheral hearing loss on APD performance tests have become an issue of debate as well (Humes et al, 1996). In most studies published on elderly APD performance, hearing configuration, that is, flat versus sloping losses, has not been studied. Typically studies have lumped test subjects by degree of loss rather than configuration. The majority of the data, however, appears to have been gathered from subjects with sloping losses. Recently, Neijenhuis, Tschur, and Snik (2004) studied a group of listeners aged 38–69 years and found that flat hearing loss configurations were detrimental to performance on a Dutch APD battery of tests. But these authors did not look at subjects with sloping hearing loss configuration, and they did not use English test materials.

The relationship of peripheral hearing loss to APD test performance is a key question given the prevalence of peripheral hearing loss among the older adult population.

The present study was designed to examine the effects of normal hearing, sloping loss, and low- plus high-frequency peripheral hearing loss (sensorineural) on APD test performance in older adults, while controlling for potential effects of cognitive ability. Specifically we endeavored to determine if the degree of hearing loss was related to APD performance.

In normal aging there are often declines in both hearing acuity and cognitive function. In large-scale studies these two factors statistically covary, although wide individual differences can be observed in both regards (Baltes and Lindenberger, 1997). Age-related cognitive declines have been well described in the cognitive literature, including reductions in the capacity of working memory (Wingfield et al, 1988; Salthouse, 1991; Baddeley, 1996), attentional difficulties in inhibiting irrelevant stimuli (Hasher and Zacks, 1988; Barr and Giambra, 1990; Stoltzfus et al, 1996), and slowing in many perceptual and cognitive operations (Cerella, 1994; Fisher and Glaser, 1996; Salthouse, 1996). Although there is wide individual variability, the biological changes that accompany the aging process also include an increased incidence of peripheral hearing loss, especially in the higher frequency ranges (*presbycusis*) that are important for the accurate perception of speech. It is well documented that peripheral hearing loss contributes to reduced performance in speech understanding by elderly listeners (Humes et al, 1996; Divenyi and Haupt, 1997a, 1997b). It is also important to note that studies have suggested that APD increases with age in the elderly population (Golding et al, 2006).

Speech processing by older adults has been extensively studied, beginning with the seminal text by Bergman (1980), followed by multiple studies published on various aspects of the issue. Further work documenting the aging auditory system was published by Willott (1991). In the time from Bergman's early work to the present, there has been a plethora of published work on the topic. There have even been several "special" issues in professional journals dedicated solely to the subject, for example, the *Journal of the American Academy of Audiology* in 1996, *Seminars in Hearing* in 2001, the *International Journal of Audiology* in 2003, and *Trends in Amplification* in 2006 (Kricos, 2006; Pichora-Fuller and Singh, 2006).

Research has been oriented toward identifying a site of lesion for the source of the primary complaint of older adults, that is, difficulty hearing/understanding speech in background noise. Typically, three different components of the speech process have been identified and studied: peripheral hearing, central auditory processing, and cognitive processing (Committee on Hearing, Bioacoustics and Biometrics, 1988). Pichora-Fuller and Singh (2006) suggest that all three areas can be combined into what is called lower-level sensory processes and higher-level cognitive processes and that they need to be "unified" when looking at the issues surrounding speech processing in older adults.

In contrast to the integrity of the peripheral auditory pathway that is relatively easy to assess using tympanometry, pure tones, and otoacoustic emissions, the central auditory pathways are more complex and difficult to study in situ. Furthermore, data have shown that there are neurodegenerative changes in the various structures along the central auditory pathways (Frisina and Walton, 2006). There are considerable data supporting decrements in the neural auditory pathways from the cochlear nucleus and brain stem (Kirkae et al, 1964; Hansen and Reske-Nielsen, 1965; Koningsmark and Murphy, 1972) to the midbrain (Ferraro and Minckler, 1977; Casey and Feldman, 1982), thalamic regions (Kirkae et al, 1964), and the cerebral cortex (Brody, 1955; Hansen and Reske-Nielsen, 1965). Along with age-related peripheral hearing loss and cognitive decline, consequent changes in central auditory processes have been proposed as an important contributing source to older adults' increased difficulty understanding speech.

One of the difficulties inherent in the investigation of these issues is that the three proposed functional levels (*peripheral*, *central*, and *cognitive*) are not easily isolated and studied independent of each other. This may be one reason why there has been disagreement in the past as to the usefulness of tests of auditory processing disorder in the older adult population. In part this uncertainty may arise because APD test results may potentially be contaminated by peripheral hearing loss or cognitive decline.

Earlier studies have documented the sensitivity of APD testing to peripheral hearing loss. For example, Miltenberger, Dawson, and Raica (1978) report that all of the APD tests administered to a group of subjects with sensorineural hearing loss (SNHL) were affected to some degree by the loss. They conclude that although APD tests could be administered to individuals with SNHL, caution would be needed to interpret the results. There are additional suggestions in the literature that even mild, relatively flat SNHL could impact the outcome on the APD tests (Neijenhuis et al, 2004). Neijenhuis and company conclude that APD tests should not be used on patients with flat configuration SNHL without understanding that the probability of contamination exists.

Several studies have suggested that changes in central auditory processing may appear in older adults independent of peripheral hearing loss (e.g., Jerger et al, 1989; Stach et al, 1991). For example, Rodriquez, DiSarno, and Hardiman (1990) studied cognitively intact older adults with good hearing and found that APD was present in some subjects despite normal hearing acuity. They report that the occurrence of APD was independent of both cognitive status and linguistic competence. In support of this view, Jerger and colleagues (1989) looked at 130 older adults to assess the contributions of cognitive, central, and peripheral factors to their speech understanding. Jerger and colleagues report that roughly 50 percent of their subjects showed APD, while approximately 40 percent had cognitive deficits. The congruency between APD and cognitive deficits was only 63 percent. These authors conclude that APD and cognitive deficits were relatively independent of each other and that neither factor by itself was sufficient to account for the speech understanding difficulties experienced by elderly listeners.

Cooper and Gates (1991) administered a battery of APD tests to 1000 older adults aged 64–93 years from the Framingham Heart Study. These authors report that the prevalence of APD among the elderly was far lower than had previously been reported, suggesting that APD is not an automatic consequence of chronological age. Some support for the independence of APD from peripheral hearing loss can be seen in a finding that older adult cochlear implant recipients resemble their young counterparts with regard to speech comprehension performance (Horn et al, 1991; Waltzman et al, 1993). Because the process of cochlear implantation involves bypassing the damaged cochlea and providing direct stimulation to the auditory nerve, young and older cochlear implant patients would have similar peripheral auditory input following implantation. If older adults have deficits beyond the peripheral auditory system, then their postimplant speech understanding performance should be poorer than that of young adults, which was not the case. Although suggestive, these results should be treated with caution because of the small number of subjects in the study.

Thus, whereas some studies have attributed APD to effects of peripheral hearing loss (e.g., Humes et al, 1996), others have suggested that a single site of disorder is likely not the cause of poorer speech understanding in the elderly (Jerger et al, 1989). This absence of a clear picture regarding speech understanding in adult aging may be due to its complexity—multiple factors contribute to decreased speech understanding in older adults, including peripheral hearing loss, age-related changes in cognitive function, and declines in central auditory processes (Committee on Hearing, Bioacoustics and Biometrics, 1988; Pichora-Fuller et al, 1995). Research has also been hindered by methodological inconsistencies such as the use of different APD tests in different studies, heterogeneous participant groups, and in some studies, lack of control for the effects of peripheral hearing loss.

The purpose of the present study was to investigate the contribution of peripheral hearing loss configuration to performance on APD tests with older adult listeners while holding cognitive abilities constant. This control is important because previous studies on the prevalence of APD among older adults have not always assessed cognitive functioning. To this end we chose a group of healthy, community-dwelling older adults who were high functioning in terms of cognitive ability. Participants in the three hearing groups were equated as closely as possible on age and, important for our purposes in this study, did not differ on measures of cognitive abilities such as working memory, speed of processing, or verbal ability.

An important feature of this study was the range and configuration of hearing acuity tested. We included participants ranging from normal hearing acuity to those with sensorineural hearing loss of mild or moderate degree. Among the participants with hearing loss, some had hearing losses restricted to the high frequencies (sloping configuration), and others had hearing loss across the full test frequency range. We selected this range of hearing acuity in order to investigate how APD test performance might be influenced by the type of hearing loss commonly encountered in the older adult population, in terms of both severity and configuration.

In addition to potential contamination by differences in cognitive function, many of the tests used to assess APD have used concurrent presentation of test materials to both ears, whether in the form of dichotic or binaural presentations. These testing paradigms are somewhat problematic in that they can be influenced by slight asymmetries in hearing sensitivity in any given participant, as well as by the "right ear effect" (a right ear advantage for speech [Wilson and Jaffe, 1996; Divenyi and Haupt, 1997a; Roup et al, 2006]). In the present study we chose to take advantage of the evolution of APD assessment, which includes the availability of more recent, monotic APD tests not yet extensively used with older adults. These included the QuickSIN Speech-in-Noise test (Etymotic Research, Elk Grove Village, Ill., 2001) and the Random Gap Detection Task (Auditec of St. Louis, St. Louis, Mo., 2000). In so doing, we utilized both established and newly available monotic APD tests in order to tap the several features commonly associated with APD: difficulty with time-compressed speech, degraded speech, comprehension of speech in noise, and temporal integration.

MATERIALS AND METHOD

Participants

Participants were 45 older adults, 30 women and 15 men, ranging in age from 66 to 85 years (M = 74.4, SD = 4.9). Using criteria described in the following section, the participants were divided into three groups based on their hearing acuity: a group of 15 adults with *normal hearing in the 500–4000 Hz range* (Group 1), a group of 15 adults with *high-frequency (sloping) hearing loss* (Group 2), and a group of 15 adults with both *low- and high-frequency (low/high) hearing loss* (Group 3). To ensure that all test subjects had hearing loss no poorer than the moderate category in the essential speech range, no one exceeded 50 dB HL through 4000 Hz. All participants were healthy community-dwelling volunteers who received a monetary honorarium for their participation. The participants in all three groups were native speakers of American English, and all reported themselves to be in good health, with no known history of stroke, Parkinson's disease, or other neuropathology that might compromise their ability to carry out the research tasks. All study protocols and procedures were approved by the Institutional Review Boards at Brandeis and Boston universities.

All three hearing groups had good verbal ability as assessed by the Shipley Vocabulary Test (Group 1: M = 14.9, SD = 2.1; Group 2: M = 16.3, SD = 2.4; Group 3: M = 15.0, SD = 2.5 [Zachary, 1986]), and they did not differ significantly among each other ($F[2,42] = 1.60$, n.s.). The three groups were also comparable in their years of formal education (Group 1: M = 14.3 years, SD = 2.9; Group 2: M = 16.3 years, SD = 2.8; Group 3: M = 15.8 years, SD = 2.1; $F[2,42] = 2.40$, n.s.). The participants in Groups 2 and 3 did not differ significantly in age (Group 2: M = 75.5 years, SD = 4.0; Group 3: M = 76.7 years, SD = 5.0; $t[28] = 0.47$, n.s.), although Group 1 (M = 71.1 years, SD = 4.2) was somewhat younger than both Groups 2 ($t[28] = 2.98$, $p < .01$) and 3 ($t[28] = 3.32$, $p < .01$). Nevertheless, the three groups were all similar in their cognitive ability measures.

Auditory Testing

Following otoscopic inspection, tympanometry was carried out on all participants using the GSI 38 Auto Tymp (Grason-Stadler, Inc., Madison) to document middle ear integrity and to help rule out conductive hearing loss. All participants met the criterion of middle ear pressure no worse than –150 daPa. Distortion product otoacoustic emissions were obtained using the AuDx (Bio-logic Systems Corp, Mundelein, Ill.) to help confirm cochlear hearing loss and to reject participants with possible auditory neuropathy (Starr et al, 1996).

An audiologic evaluation was carried out using a GSI 61 Clinical Audiometer (Grason-Stadler, Inc.) by way of standard audiometric techniques in a sound-attenuated testing room. Prior to testing, information was obtained about history of family hearing loss, surgery, and excessive noise exposure. Speech-recognition thresholds (SRTs) were tested using a recorded Central Institute for the Deaf (CID) W-1 list of spondees (Auditec), and results are outlined in Table 1. Word-recognition ability in quiet was assessed using Northwestern University Auditory Test No. 6 (NU-6) recorded materials (Auditec), and results are shown in Table 1. All participants met or exceeded the criterion of a good word-recognition score (>88%) in quiet for the test ear.

Participants were divided into the three distinct groups based on two pure-tone threshold averages: a speech-frequency pure-tone average (PTA) at 500, 1000, and 2000 Hz (the "speech-frequency PTA") and a high-frequency PTA at 4000 and 6000 Hz (the "high-frequency PTA"). By looking at subjects with different configurations and degrees of hearing loss, it was reasoned that the effects of peripheral hearing loss on APD could be teased out. The 15 participants in Group 1 had speech-frequency PTAs ranging from 3.3 to 18.3 dB HL (M = 12.6, SD = 3.9) and high-frequency PTAs ranging from 15 to 37.5 dB HL (M = 23.2, SD = 8.3) in the better (test) ear, which was the right ear for five of the 15 participants. The 15 participants from Group 2 (sloping SNHL) had speech-frequency PTAs ranging from 8.3 to 21.7 dB HL (M = 16.6, SD = 3.7) and high-frequency PTAs ranging from 40 to 67.5 dB HL (M = 48.3, SD = 8.5) in the better (test) ear, which was the right ear for six of the participants. Finally, the 15 participants in Group 3 (low/high SNHL) had speech-frequency PTAs ranging from 25 to 35 dB HL (M = 28.4, SD = 2.9) and high-frequency PTAs ranging from 35 to 70 dB HL (M = 54.2, SD = 10.8) in the better (test) ear, which was the right ear for 10 of the participants. Mean hearing thresholds (250–6000 Hz) for the three hearing groups are shown in Figure 1.

Cognitive Testing

Cognitive function was assessed using three standard tests of performance commonly used in the cognitive aging literature

Table 1. Descriptive Characteristics of Participant Groups

Participant Characteristics	Group 1 (N = 15)		Group 2 (N = 15)		Group 3 (N = 15)	
	M	SD	M	SD	M	SD
Age*	71.1	4.2	75.5	3.9	76.7	5.0
Education (years)	14.3	2.9	16.3	2.8	15.8	2.1
Hearing measures (test ear)						
PTA (500, 1000, 2000 Hz) in dB HL**	12.6	4.0	16.6	3.7	19.2	7.7
PTA (4000 and 6000 Hz) in dB HL**	23.2	8.3	48.3	8.5	54.2	10.8
SRT in dB HL**	15.7	5.9	20.3	9.7	28.3	7.2
Word recognition (% correct)	99.7	1.0	97.9	4.7	96.5	5.6
Forward word span	4.2	0.9	4.2	0.8	4.1	0.6
Backward word span	3.6	0.8	3.9	0.9	3.9	0.5
Symbol copying	119.1	25.8	112.5	21.1	113.8	20.3
Symbol substitution	52.8	10.2	50.3	9.1	55.9	11.4
Trails A	37.3	13.0	40.2	8.7	37.5	9.2
Trails B	104.9	51.0	82.6	26.2	76.0	21.8

Note: PTA = pure-tone average; SRT = speech-recognition threshold.

* Groups differ ($p < .01$); ** Groups differ ($p < .001$)

as measures of important cognitive domains that are sensitive to aging effects (Salthouse, 1991; Kausler, 1994):

1. Forward and Backward Word Span, an assessment of working memory based on the Wechsler (1981) digit span test but which has been shown to be more sensitive to adult age (Wingfield et al, 1988). Participants hear a series of unrelated words presented at a rate of one per second with instructions to repeat them back either in the order in which they were heard (forward span) or in the reverse order (backward span), with the number of words progressively increased until the participant fails to give a correct recall on two attempts.

2. The Digit Symbol Substitution subscale of the *Wechsler Adult Intelligence Scale—Review* (Wechsler, 1981). In this test of processing speed, participants are shown a set of written digits, for which they must quickly substitute corresponding symbols from a coding key during a period of 90 sec. A baseline measure of copying speed is also obtained, taken as the number of symbols that each participant could copy in 90 sec (Strondt, 1976; Tun et al, 1997).

3. The Trail Making Test (Reitan, 1958, 1992). This test is commonly used as an index of executive control processes (Lezak, 1995; Mitrushina et al, 1999). Trails A requires searching for a sequence of numbered visual targets, a task in which processing speed is a heavy contributor (Salthouse, 2000). The primary element of the Trails B task is the switching of attention between two types of targets, numbers and letters. As such, Trails B involves scheduling and coordinating the task components, shifting attention between two dimensions, and placeholding of the task (Mitrushina et al, 1999).

The performance scores for each of the three hearing groups are shown in Table 1. There were no significant differences between any of the three groups on any of the cognitive measures.

Auditory Processing Disorder Tests

Because APD can be produced by disorders at various levels in the auditory pathway, a battery of tests is commonly used to assess the various levels of auditory function in the ascending pathways. Seven monotic APD tests were utilized to represent five presumed areas of difficulty associated with APD:

1. The *degraded speech measure* used was the Low-Pass Filtered Speech (LPFS) test (Auditec).

2. The *auditory temporal sequencing measure* used was the Pitch Pattern Sequence (PPS)—Adult test (Auditec, 2004).

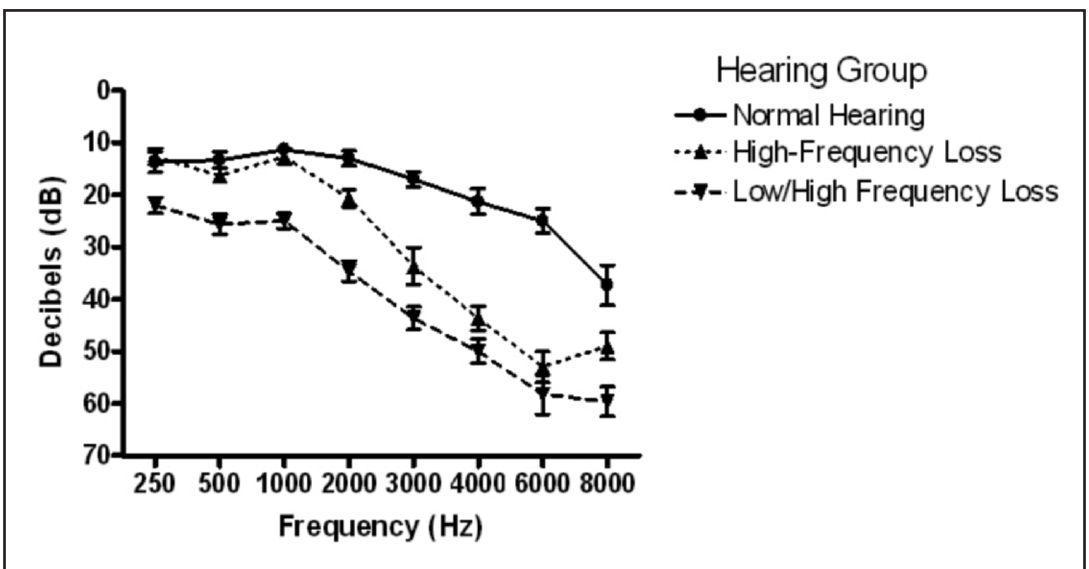

Figure 1. Mean audiometric configurations of the three study groups.

3. The *speech comprehension in noise measures* included the QuickSIN Speech-in-Noise Test (Version 1.3 [Etymotic Research]) and the Synthetic Sentence Identification—Ipsilateral Competing Message (SSI-ICM [Auditec]).

4. The *time-compressed speech measures* used were the Time-Compressed Sentence test and the NU-6 Time-Compressed Speech test (Auditec).

5. The *temporal integration measure* used was the Random Gap Detection Task (Auditec [Keith, 2001]).

Procedures

The seven-test APD test battery was administered during a single testing session lasting approximately 1.5 hours. Participants were tested individually in a sound-attenuated testing booth. Stimuli were delivered monaurally to the better (test) ear using E-A-RTONE 3A (E-A-R Auditory Systems, Aearo Company, Indianapolis) insert earphones. In order to avoid the undesirable effects of distortion that can occur at high presentation levels, none of the APD tests was presented at a level that exceeded 80 dB HL. It should be noted that each individual test carries specific presentation levels, that is, LPFS = 35–40 dB SL, QuickSIN = 70 dB HL, PPS = 50 dB SL, SSI-ICM = comfortable level, and time compressed = 46 dB SL. While we endeavored to adhere to each recommended presentation level, we did not exceed 80 dB HL in any instance. The format for individual APD presentation was administered in a standardized fashion according to the testing instructions supplied with the tests. The participant's responses were recorded manually by the examiner on the appropriate scoring sheets. During the test period, each subject was given the opportunity for a brief rest after approximately one half of the testing was complete. The sequence of each specific test was counterbalanced across all subjects to avoid any potential contamination from order effects.

Degraded Speech

For the Low-Pass Filtered Speech test ("Filtered Speech"), participants heard one word at a time and were required to repeat back each word as it was heard. One 50-word list (NU-6) was administered at 40 dB SL (re: SRT), filtering out sound greater than 750 Hz; responses were scored for percent correct.

Temporal Sequencing

For the Pitch Pattern Sequence test (*N.B.*—this test is also known in the literature as the frequency pattern test), participants listened to tone triads made up of combinations of a low-pitched tone and a high-pitched tone. For example, the tone triad they heard may have been a *high–high–low* sequence or a *low–high–low* sequence. They were required to identify the combination that they had heard. Sixty sets were administered at 50 dB SL (re: 1000 Hz pure-tone threshold). Responses were scored for percent correct and then corrected for reversals, and then these two were summed for total percent correct. Reversals occur when the subject reverses the order of the stimuli presented, that is, low–high–low is presented, but the subject repeats high–low–high.

Temporal Integration

The Random Gap Detection Task consists of multiple sequences of tonal stimuli separated by varying degrees of temporal gaps ranging from 2 to 20 msec. The subject must determine if the there is indeed a gap of silence between the various stimuli. The subjects must complete a screening portion of the test before actual testing begins. Once testing begins, the lowest gap in time that the subject can correctly identify is documented.

Speech Comprehension in Noise

The SSI-ICM ("Synthetic Sentences") is a closed-set task where participants hear sentence-like strings that are not grammatical (e.g., "Go change your car color is red"). There were 10 sentences in total, which were printed on a large card. Participants heard one sentence at a time and were asked to identify each sentence heard by choosing it from the card in front of them. Stimuli were administered at 50 dB SL (re: SRT); 10 sentences were given at each of four message-to-competition ratios (MCRs): +10 dB, 0 dB, –10 dB, and –20 dB. A percent correct score was calculated for each MCR.

For the Speech-in-Noise test ("QuickSIN"), participants heard short sentences (e.g., "A white silk jacket goes with any shoes") and were required to repeat the sentence back. Each set contained six sentences. Each sentence had five key terms worth one point each, yielding a total of five points per sentence. The QuickSIN was administered at 70 dB HL; two sets were given to each participant, and performance across the two sets was averaged, yielding an average signal-to-noise ratio (SNR) loss.

Time-Compressed Speech

For the Time-Compressed Sentence test ("Compressed Sentences"), participants heard short sentences (e.g., "The boy fell in the water") and were required to repeat them back. Each sentence had three key words worth one point each. The test was administered at 40 dB SL (re: SRT). Ten sentences were administered at each of two compression rates, 40 percent and 60 percent; a percent correct score was calculated for each rate. For the Time-Compressed Speech test ("Compressed Words"), participants heard a 50-word list, one word at a time, and were required to repeat back each word as it was being heard. The test was administered at 45 dB SL (re: SRT). One 50-word list was administered at each of two compression rates, 30 percent and 60 percent; a percent correct score was calculated for each rate.

RESULTS

Performance on the APD Tests

For each participant, a score was calculated that reflected (1) percentage correct for five of the APD tests (Filtered Speech, Pitch Pattern Sequence, Synthetic Sentences, Compressed Sentences, and Compressed Words) and (2) an SNR loss for QuickSIN. Table 2 presents the mean performance for the three hearing groups on each of the APD tests included in our analyses.

We need to note that we encountered unforeseen difficulties with the test of auditory temporal integration, that is, the

Table 2. Mean Scores on Auditory Processing Disorder Tests for Participant Groups

Test	Group 1 (N = 15)		Group 2 (N = 15)		Group 3 (N = 15)	
	M	SD	M	SD	M	SD (P Value)
Time-Compressed Speech						
Compressed Sentences (40%)	97.6%	2.7	95.6%	6.8	93.8%	8.1 (n.s.)
Compressed Sentences (60%)	87.1%	8.0	84.2%	6.4	76.7%	13.9 ($p < .02$)
Compressed Words (30%)	91.2%	5.9	92.0%	4.0	89.9%	5.0 (n.s.)
Compressed Words (60%)	79.5%	7.6	74.8%	12.4	67.3%	10.2 ($p < .02$)
Degraded Speech						
Low-Pass Filtered Speech	69.1%	9.4	56.3%	19.5	54.1%	18.4 ($p < .02$)
Speech Comprehension in Noise						
QuickSIN	2.7 SNR	2.2	4.0 SNR	1.2	3.8 SNR	1.5 (n.s.)
SSI-ICM (0 dB MCR)	87.3%	12.2	90.0%	12.0	87.3%	10.3 (n.s.)
SSI-ICM (–10 dB MCR)	75.3%	13.0	75.3%	12.5	68.5%	18.6 (n.s.)
SSI-ICM (–20 dB MCR)	56.2%	9.6	58.3%	15.9	53.3%	12.3 (n.s.)
Temporal Sequencing						
Pitch Pattern Sequence	96.8%	6.4	97.6%	5.5	94.0%	10.0 (n.s.)

Note: MCR = message-to-competition ratio; n.s. = not significant; SSI-ICM = Synthetic Sentence Identification—Ipsilateral Competing Message.

Random Gap Detection Task (Keith, 2001). Eight of the 15 participants in the normal hearing group, seven of the 15 in the high-frequency hearing loss group, and three of the 15 in the low/high hearing loss group failed the screening portion of the test and could not be given the full test. Because of the low and unequal numbers of individuals who completed this test it was excluded from analysis.

We first carried out a single multivariate analysis of variance (MANOVA) on the six APD tests (10 measures) using the three hearing groups as the between-subjects variable. The main effect of hearing group was significant for Compressed Sentences (60%): $F(2,42) = 4.79$, $p < .019$, Eta = 0.173; Compressed Words (60%): $F(2,42) = 5.34$, $p = .009$, Eta = 0.203; and Filtered Speech: $F(2,42) = 8.38$, $p < .01$, Eta = 0.285. These results show that hearing status affected performance on these three APD tests.

Bonferroni's adjustment was next carried out on the data to further determine if the above pattern continued. All three of the above tests that achieved significance with conventional MANOVA also reached significance at the .02 level (Compressed Sentences @ 60%, $p = .019$; Compressed Words @ 60%, $p = .007$; Filtered Speech, $p = .001$) for the low/high hearing loss group. Group 3 performed more poorly than Groups 1 and 2; however, these latter two groups did not differ significantly from each other. For Compressed Words (60%), the only significant difference was between Group 1 and Group 3. For Filtered Speech, Group 1 performed significantly better than both Groups 2 and 3; however, these latter two groups did not differ from each other.

As we indicated, it was our desire to equate our three hearing groups on age as closely as possible. Because Group 1 was somewhat younger than the two other groups, we carried out analyses including chronological age as a covariate in order to control for potential effects of age. The effect of age failed to reach significance for any of the APD tests: Filtered Speech, $F(1,41) < 1.0$; Pitch Pattern Sequence, $F(1,41) < 1.0$; QuickSIN, $F(1,41) < 1.0$; Synthetic Sentences (0 dB MCR), $F(1,41) = 2.50$, n.s.; Synthetic Sentences (–10 dB MCR), $F(1,41) = 3.13$, n.s.; Synthetic Sentences (–20 dB MCR), $F(1,41) < 1.0$; Compressed Sentences (40%), $F(1,41) < 1.0$; Compressed Sentences (60%), $F(1,41) < 1.0$; Compressed Words (30%), $F(1,41) < 1.0$; Compressed Words (60%), $F(1,41) < 1.0$.

We compared our results to normative data for those APD tests where data were available. Only Compressed Speech data at 60 percent in Group 3 exhibited results that would be considered "positive" for APD. (Scores were lower than two standard deviations from normative values.)

Hearing and Cognitive Measures as Predictors of Performance on APD Tests

To further investigate the role of low-frequency hearing, high-frequency hearing, age, and cognitive measures in predicting performance on the individual tests, we carried out separate regression analyses for each APD test. Although as intended, all three participant groups had excellent cognitive function, there was some variability in cognitive test scores within the full participant group. Therefore, to investigate the extent to which different cognitive measures predicted performance within these high-functioning adults, we included the various cognitive tests in the regression. The first set entered in each analysis consisted of speech-frequency hearing measures (pure-tone thresholds at 500, 1000, and 2000 Hz in the better ear). The second set consisted of high-frequency hearing measures (pure-tone thresholds at 4000 and 6000 Hz in the better ear). The third set, which we refer to as *memory*, consisted of scores for Forward and Backward Word Spans. The fourth set, *complex speed measures*, was made up of scores for Digit Symbol Substitution and Trail Making. The fifth set, *verbal ability*, was made up of the score on the Shipley Vocabulary Test. Thus, the regression equation obtained for the memory, speed, and vocabulary measures reflected the portion of the variance that is accounted for after the influence of hearing measures. Finally, we added *chronological age* to determine whether age might account for any further variance beyond that accounted for by the above factors. These sets were regressed on performance for each APD test as the dependent variable, using a hierarchical stepwise regression method.

Table 3 shows the results of the regression analyses including the adjusted R^2, change in R^2, and p values for entry of the predictor sets in regressions on each APD test. The

Table 3. Regression Analyses Showing Predictors of Performance on Auditory Processing Disorder Tests

Variable Predictor	R^2	Change in R^2	P Value
Low-Pass Filtered Speech			
Low-Frequency Hearing	0.28		< .01
High-Frequency Hearing	0.28	0.00	n.s.
Memory	0.21	0.00	n.s.
Complex Speed Measures	0.30	0.02	n.s.
Verbal Ability	0.33	0.03	n.s.
Age	0.33	0.00	n.s.
Pitch Pattern Sequence			
Low-Frequency Hearing	0.04		n.s.
High-Frequency Hearing	0.04	0.00	n.s.
Memory	0.06	0.02	n.s.
Complex Speed Measures	0.13	0.07	n.s.
Verbal Ability	0.24	0.11	n.s.
Age	0.38	0.14	< .05
QuickSIN			
Low-Frequency Hearing	0.02		n.s.
High-Frequency Hearing	0.04	0.01	n.s.
Memory	0.15	0.12	n.s.
Complex Speed Measures	0.19	0.04	n.s.
Verbal Ability	0.19	0.00	n.s.
Age	0.21	0.02	n.s.
SSI-ICM (0 dB MCR)			
Low-Frequency Hearing	0.01		n.s.
High-Frequency Hearing	0.02	0.01	n.s.
Memory	0.02	0.01	n.s.
Complex Speed Measures	0.03	0.00	n.s.
Verbal Ability	0.03	0.00	n.s.
Age	0.03	0.00	n.s.
SSI-ICM (–10 dB MCR)			
Low-Frequency Hearing	0.14		< .05
High-Frequency Hearing	0.20	0.06	n.s.
Memory	0.21	0.02	n.s.
Complex Speed Measures	0.26	0.05	n.s.
Verbal Ability	0.35	0.08	n.s.
Age	0.36	0.01	n.s.
SSI-ICM (–20 dB MCR)			
Low-Frequency Hearing	0.02		n.s.
High-Frequency Hearing	0.03	0.02	n.s.
Memory	0.08	0.05	n.s.

Table 3.
Continued

Variable Predictor	R^2	Change in R^2	P Value
Complex Speed Measures	0.09	0.01	n.s.
Verbal Ability	0.18	0.10	n.s.
Age	0.21	0.03	n.s.
Time-Compressed Sentences (40%)			
Low-Frequency Hearing	0.10		n.s.
High-Frequency Hearing	0.14	0.04	n.s.
Memory	0.20	0.06	n.s.
Complex Speed Measures	0.21	0.01	n.s.
Verbal Ability	0.23	0.02	n.s.
Age	0.23	0.00	n.s.
Time-Compressed Sentences (60%)			
Low-Frequency Hearing	0.21		< .01
High-Frequency Hearing	0.24	0.03	n.s.
Memory	0.31	0.08	n.s.
Complex Speed Measures	0.32	0.01	n.s.
Verbal Ability	0.35	0.03	n.s.
Age	0.36	0.02	n.s.
Time-Compressed Words (30%)			
Low-Frequency Hearing	0.02		n.s.
High-Frequency Hearing	0.03	0.01	n.s.
Memory	0.05	0.02	n.s.
Complex Speed Measures	0.08	0.04	n.s.
Verbal Ability	0.13	0.05	n.s.
Age	0.14	0.01	n.s.
Time-Compressed Words (60%)			
Low-Frequency Hearing	0.21		< .01
High-Frequency Hearing	0.21	0.00	n.s.
Memory	0.22	0.01	n.s.
Complex Speed Measures	0.35	0.13	n.s.
Verbal Ability	0.52	0.17	< .01
Age	0.52	0.00	n.s.

Note: MCR = message-to-competition ratio; n.s. = not significant; NU-6 = Northwestern University Auditory Test No. 6; SSI-ICM = Synthetic Sentence Identification—Ipsilateral Competing Message.

speech-frequency hearing measures were a significant predictor for Filtered Speech, Synthetic Sentences (–10 MCR), Compressed Sentences (60%), and Compressed Words (60%), where they accounted for approximately 15–30 percent of the variance.

Importantly, we did not see a significant role for the high-frequency hearing loss as a predictor. The influence of the cognitive measure was negligible in these analyses. Verbal ability was a significant predictor only for Compressed Words (60%), where it accounted for approximately 17 percent of the variance. In general, age did not emerge as an important factor in APD performance. The only APD test where age was a significant predictor for performance was Pitch Pattern Sequence, suggesting age-related effects of temporal processing (Schneider and Pichora-Fuller, 2001).

It should be noted that with the SSI-ICM, one would expect that the MCR ratio at –20 dB would be a predictor because –10 dB was. In reviewing the data, however, it appears that the –20 dB condition is very difficult, and it is possible that we see a floor effect with the outcome.

DISCUSSION

Our primary goal in this study was to examine the effect of peripheral hearing loss on a number of tests for auditory processing disorder in older adults, controlling for age and cognitive abilities. Results from these tests support and extend the findings from several previous studies and further clarify the relationship between peripheral hearing loss and performance on APD tests. Hearing loss in the speech range was shown to play an important role in APD performance, but age had little effect.

It is not surprising that peripheral hearing loss affected the performance of elderly patients on APD tests in this study. There has been a tradition and reports in the literature of such an occurrence with both behavioral and electrophysiological APD tests (Musiek and Lamb, 1994). What this study has shown, however, is that the degree of hearing loss is critical when administering APD tests and that there is variability in the specific tests administered. For example, there are APD tests (PPS and QuickSIN) where performance does not appear to be degraded by peripheral hearing loss. On the other hand, the SSI-ICM, Low-Pass Filtered Speech, and Time-Compressed Speech tests do appear to be influenced by peripheral hearing loss.

As noted earlier, assessment of the central auditory pathway is typically carried out using speech stimuli. This opens the door to contamination of the results by peripheral hearing loss, a condition commonly found among older adults. Some studies have attempted to control for hearing loss by comparing young and older listeners with so-called normal hearing acuity. The problem with this approach is that even if one finds older adults with "normal" hearing acuity (pure-tone thresholds <25 dB HL), few studies have used older adults with pure-tone thresholds as good as the young normal-hearing adults, whose pure-tone thresholds can be as low as 0–10 dB HL. In the present study we attempted to control for the effect of peripheral loss by examining performance on APD tests as a function of the degree and configuration of the hearing loss in a group of older participants ranging in age from 66 to 85. By dividing the participants into three groups based on hearing sensitivity (normal across all frequencies, hearing loss only above 2000 Hz, and hearing loss across the frequency range), we found that peripheral hearing loss did impact outcome on selected APD tests.

The three APD tests that were affected by greater degree of (low/high) hearing loss shared some common characteristics. For example, the stimuli utilized in Filtered Speech produce primary speech information in the region below the 750 Hz "cutoff" frequency. It would thus seem logical that persons whose hearing loss included the lower frequencies (Group 3) would have a greater handicap in test performance due to the decrease in the critical low-frequency information available. This could also be true for the Pitch Pattern Sequence test because the stimuli for this test are below 2000 Hz.

The Compressed Words (60%) test also appears to be sensitive to low-frequency hearing loss, for Group 3 had more difficultly with the task. Although the reason for the poorer performance with low-frequency hearing loss with time-compressed speech may not be apparent, the act of time compression does affect the quality and richness of speech (e.g., Heiman et al, 1986). The outcome of losing critical components of speech from time compression apparently produces similar results as those seen for Filtered Speech.

One could argue that simply raising the presentation level for participants in Group 3 should compensate for their poorer performance. However, this is not the case, for the tests with the poorest performance were given at sensation level, not at a set presentation level in dB HL. That is, for Filtered Speech, Pitch Pattern Sequence, and Compressed Words, signal delivery was higher (by 10–15 dB) for Group 3 than for the other two hearing groups.

Another explanation for the poorer

performance by the low/high hearing loss group is found in recent human and animal studies. Lockwood and colleagues (Lockwood et al, 1998; Lockwood et al, 1999) have shown with human neuroimaging studies that with high-frequency hearing loss, the human brain can "rewire" low-frequency connections to adapt and compensate for the SNHL. Specifically, they have shown that in subjects with high-frequency hearing loss the brain appears to reinnervate itself with low-frequency pathways allowing for recognition of high-frequency stimuli. Mammalian animal studies have shown similar findings (Willott et al, 1985; Willott, 1991). These data would suggest that in older adults with high-frequency hearing loss, the potential for hearing critical high-frequency information exists. On the other hand, however, low-frequency hearing loss subjects would not be able to pick up on the soft, high-frequency information associated with the consonants that are essential for understanding speech. This finding would also help explain why it is so difficult for older adults to understand speech in background noise. As the majority of background noise tends to be low frequency in nature, it would mask the critical information that had been rewired to the low-frequency region of the brain.

Based on the above discussion, it would seem plausible that "positive" APD findings for older adults may result from the effects of peripheral hearing loss. Our data, however, would suggest that peripheral hearing loss may influence APD test outcome primarily when there is low- and high-frequency hearing loss in the mild to moderate category. It would appear that the high-frequency hearing loss with relatively good hearing for the lower frequencies typical of presbyacusis may not significantly impact APD tests if the degree of hearing loss is mild and there is approximately normal hearing acuity in the critical speech range. Our results are clear in showing that peripheral hearing loss needs to be considered when certain APD tests are being administered to older adults, with hearing in the speech-frequency range (500–2000 Hz) as a key predictor.

Our results do not provide support for the notion that APD necessarily increases with advancing age, independent of peripheral hearing and cognitive function. Like Cooper and Gates (1991), who tested more than 1000 elderly subjects and showed no significant effect of age, we found that chronological age did not contribute to performance for the majority of our APD tests, after accounting for effects of hearing loss and cognitive function. Only for Pitch Pattern Sequence did chronological age account for additional variance beyond that associated with hearing, memory, speed, and verbal ability, implicating age-related changes in temporal processing ability.

CONCLUSION

This study explored the issue of how peripheral hearing loss may affect performance on auditory processing disorder tests in older adults. Our data have clearly documented the contribution of low- and high-frequency peripheral SNHL to performance on certain monotic APD tests. These findings indicate that future studies using APD tests with older adults should include careful consideration of both the degree and the configuration of the hearing loss. Older adults with normal hearing acuity or hearing loss restricted to the high-frequency range may be candidates for monotic APD testing. However, when using Filtered Speech, Compressed Sentence, or Compressed Word tests on older adults with mild to moderate hearing loss, clinicians should be aware of the potential for these test results to be contaminated by low- and high-frequency hearing losses.

Acknowledgment. Marianne Colangelo is thanked for help in data collection.

REFERENCES

Baddeley A. (1996) Exploring the central executive. *Q J Exp Psychol* (Colchester) 49A:5–28.

Baltes PB, Lindenberger U. (1997) Emergence of a powerful connection between sensory and cognitive functions across the adult life span: a new window to the study of cognitive aging? *Psychol Aging* 12:12–21.

Barr RA, Giambra LM. (1990) Age-related decrement in auditory selective attention. *Psychol Aging* 3:597–599.

Bergman M. (1980) *Aging and the Perception of Speech*. Baltimore: University Park Press.

Brody H. (1955) Organization of cerebral cortex. III. A study of aging in the human cerebral cortex. *J Com Neuro* 10:511–556.

Casey MA, Feldman ML. (1982) Aging in the rat medial nucleus of the trapezoid body. I. Light microscopy. *Neurobiol Aging* 3:187–195.

Cerella J. (1994) Generalized slowing and Brinley plots. *J Gerontol B Psychol Sci Soc Sci* 49:65–71.

Committee on Hearing, Bioacoustics and Biometrics. (1988) Speech understanding and aging. *J Acoust Soc Am* 83:859–893.

Cooper JC, Gates GA. (1991) Hearing in the elderly—the Framingham cohort, 1983–1985: part II. Prevalence of central auditory processing disorders. *Ear Hear* 12(5):304–311.

Divenyi PL, Haupt KM. (1997a) Audiological correlates of speech understanding deficits in elderly listeners with mild-to-moderate hearing loss: I. Age and lateral asymmetry effects. *Ear Hear* 18(1):42–61.

Divenyi PL, Haupt KM. (1997b) Audiological correlates of speech understanding deficits in elderly listeners with mild-to-moderate hearing loss: II. Correlation analysis. *Ear Hear* 18(1):100–113.

Ferraro JA, Minckler J. (1977) The human lateral leminiscus and its nuclei. *Brain Lang* 4:277–294.

Fisher DL, Glaser RA. (1996) Molar and latent models of cognitive slowing: implications for aging, dementia, depression, development, and intelligence. *Psychon Bull Rev* 3:458–480.

Frisina RD, Walton JP. (2006) Age-related structural and functional changes in the cochlear nucleus. *Hear Res* 217:216–223.

Golding M, Taylor A, Cupples L, Mitchell P. (2006) Odds of demonstrating auditory processing abnormality in the average older adult: the Blue Mountains Hearing Study. *Ear Hear* 27:129–138.

Hansen CC, Reske-Nielsen E. (1965) Pathological studies in presbyacusis. *Arch Otolaryngol Head Neck Surg* 82:115–132.

Hasher L, Zacks RT. (1988) Working memory, comprehension and aging: a review and a new view. In: Bower GH, ed. *The Psychology of Learning and Motivation: Advances in Research and Theory*. San Diego: Academic Press, 123–225.

Heiman GW, Leo RJ, Leighbody G, Bowler K. (1986) Word intelligibility decrements and the comprehension of time-compressed speech. *Percept Psychophys* 40:407–411.

Horn RM, Nozza RJ, Politsky JN. (1991) Audiological and medical considerations for children with cochlear implants. *Am Ann Deaf* 136(3):82–86.

Humes LE, Coughlin M, Talley E. (1996) Evaluation of the use of a new compact disc for auditory perceptual assessment in the elderly. *J Am Acad Audiol* 7:419–427.

Jerger J, Jerger S, Oliver T, Pirozzollo F. (1989) Speech understanding in the elderly. *Ear Hear* 10(2):79–89.

Kausler DM. (1994). *Learning and Memory in Normal Aging*. San Diego: Academic Press.

Keith RW. (2001) *The Random Gap Detection Test*. St Louis: Auditec of St. Louis.

Kirkae I, Sato T, Shitara T. (1964). A study of hearing in advanced age. *Laryngoscope* 74:205–220.

Koningsmark BW, Murphy EA. (1972) Volume of the ventral cochlear nucleus in man: its relationship to neural population and age. *J Neuropathol Exp Neurol* 31:304–316.

Kricos P. (2006) Audiologic management of older adults with hearing loss and compromised cognitive/psychoacoustic auditory processing capabilities. *Trends Amplif* 10:1–28.

Lezak MD. (1995) *Neuropsychological Testing*. 3rd edition. New York: Oxford University Press.

Lockwood AH, Salvi RJ, Coad ML, et al. (1998) The functional neuroanatomy of tinnitus: evidence for limbic system links and neural plasticity. *Neurology* 50:114–120.

Lockwood AH, Salvi RJ, Coad ML. (1999) The functional anatomy of the normal human auditory system: responses to 0.5 and 4.0 kHz tones at varied intensities. *Cereb Cortex* 9:65–76

Miltenberger G, Dawson G, Raica A. (1978) Central auditory testing with peripheral hearing loss. *Arch Otolaryngol Head Neck Surg* 104:11–15.

Mitrushina MW, Boone KB, D'Elia LF. (1999) *Handbook of Normative Data for Neuropsychological Assessment*. New York: Oxford University Press.

Musiek FE, Lamb L. (1994) Central auditory assessment: an overview. In: Katz J, ed. *Handbook of Clinical Audiology*. Baltimore: Williams and Wilkins, 197–211.

Neijenhuis K, Tschur H, Snik A. (2004) The effect of mild hearing impairment on auditory processing tests. *J Am Acad Audiol* 15:6–16.

Pichora-Fuller MK, Schneider B, Daneman M. (1995) How young and old adults listen to and remember speech in noise. *J Acoust Soc Am* 97:593–607.

Pichora-Fuller MK, Singh G. (2006) Effects of age on auditory cognitive processing: implications for hearing aid fitting and audiologic rehabilitation. *Trends Amplif* 10:29–59.

Reitan RM. (1958) Validity of the Trail Making Test as an indicator of organic brain damage. *Percep Motor Skill* 8:211–216.

Reitan RM. (1992) *Trail Making Test: Manual for Administration and Scoring*. Tucson, AZ: Reitan Neuropsychology Laboratory.

Rodriquez GP, DiSarno NJ, Hardiman CJ. (1990) Central auditory processing in normal-hearing elderly adults. *Audiol* 29:85–92.

Roup CM, Wiley TL, Wilson RH. (2006) Dichotic word recognition in young and older adults. *J Am Acad Audiol* 17:230–240.

Salthouse TA. (1991) *Theoretical Perspectives on Cognitive Aging*. Hillsdale, NJ: Erlbaum.

Salthouse TA. (1996) The processing-speed theory of adult age differences in cognition. *Psychol Rev* 103:403–428.

Salthouse TA. (2000) Measures of processing speed. *Bio Psy* 54:35–54.

Schneider BA, Pichora-Fuller MK. (2001) Age-related changes in temporal processing: implications for speech perception. *Sem Hear* 22:227–239.

Stach BA, Loiselle LH, Jerger JF. (1991) Special hearing aid considerations in elderly patients with auditory processing disorders. *Ear Hear* 12:131S–138S.

Starr A, Picton TW, Sininger Y, et al. (1996) Auditory neuropathy. *Brain* 119:741–753.

Stoltzfus ER, Hasher L, Zacks RT. (1996) Working memory and aging: current status of the inhibitory view. In: Richardson J, ed. *Counterpoints in Cognition: Working Memory and Human Cognition*. New York: Oxford University Press, 66–68.

Strondt M. (1976) Speech and coding effects in relation to age and ability level. *Dev Psychol* 12:177–178.

Tun PA, Wingfield A, Lindfield K. (1997) Motor-Speed Baseline for the Digit-Symbol Substitution Test. *Clin Gerontol* 18:47–51.

Waltzman S, Cohen N, Shapiro W. (1993) The benefits of cochlear implantation in the geriatric population. *Arch Otolaryngol Head Neck Surg* 108(4):329–333.

Wechsler D. (1981) *Wechsler Adult Intelligence Scale—Review*. San Antonio: Psychological Corporation.

Willott JF. (1991) *Aging and Auditory System: Physiology and Psychophysics*. San Diego: Singular.

Willott JF, Pankow D, Paris Hunter K, Kordyban M. (1985) Projections from the anterior ventral cochlear nucleus to the central nucleus of the inferior colliculus in young and aging. *J Comp Neurol* 237:545–551.

Wilson RH, Jaffe MS. (1996) Interactions of age, ear, and stimulus complexity on dichotic digit recognition. *J Am Acad Audiol* 7:358–364.

Wingfield A, Stine EAL, Lahar CJ, Aberdeen JS. (1988) Does the capacity of working memory change with age? *Exp Aging Res* 14:103–107.

Zachary R. (1986) *Shipley Institute of Living Scale, Revised Manual*. Los Angeles: Western Psychological Services.