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The Contribution of Auditory Processing to Adult Age Differences in Memory Performance

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THE CONTRIBUTION OF AUDITORY PROCESSING TO ADULT AGE DIFFERENCES IN MEMORY PERFORMANCE

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ABSTRACT

Recently, there has been increased interest in the changes in neuropsychological functioning which are associated with normal aging. Understanding age differences in neuropsychological functioning is of particular importance in the discrimination of normal aging from the early onset of Alzheimer's Disease or other age-associated dementia. Older adults have been observed to perform more poorly than younger adults on several auditory memory measures which are commonly included in neuropsychological batteries. Age associated declines on these measures have been reported even in the absence of dementia or other health concerns.

To date, explanations for these age differences have focused on a decline in cognitive processing efficiency. For example, older adults may have a diminished working memory capacity or a diminished working memory processing speed. However, another potential contributing factor to age differences in auditory memory performance may be subtle age associated degradation of the central auditory system. Age associated impairment has been widely reported on tests of both central and peripheral auditory processing. The purpose of the present investigation was to examine the degree to which auditory processing efficacy mediated age associated decline on auditorially presented measures of memory.

Twenty-eight independently living adults over sixty years of age and thirty-two adults between eighteen and thirty years of age were administered a battery of standardized memory and auditory tests which have been found to be sensitive to age. Tests of both peripheral and central auditory functioning were included in the battery. Peripheral auditory decline involves loss of hearing sensitivity and reflects primarily cochlear involvement, while central auditory decline involves a loss of speech intelligibility and reflects primarily central nervous system dysfunction. The auditory battery included the Pure Tone Threshold, Speech Perception in Quiet, Speech Perception in Noise, Low Pass Filtered Speech, Time Compressed Speech, and the Synthetic Sentence Identification Test. Memory measures were all auditorially administered, and included the California Verbal Learning Test and the Logical Memory, Verbal Paired Associates, and Digit Span subtests of the Wechsler Memory Scale-Revised.

Age associated decline was observed on all auditory and memory measures. Age related deficits were especially apparent during the encoding stage of memory processing, which is consistent with the auditory processing hypothesis. Multiple regression analysis was then used in order to examine age differences in memory processing after age differences in auditory processing had been partialled out. Results indicated that in some instances, age no longer accounted for a significant portion of the variance in memory performance when auditory variables had been factored into the equation. In other instances, auditory variables greatly reduced the portion of the variance uniquely accounted for by age. Several auditory variables consistently emerged as significant predictors of memory performance, and these variables appeared to coincide with

complaints commonly made by older individuals regarding their hearing, namely, that others often speak too softly, mumble, and speak too quickly.

Implications include the importance of ruling out subtle sensory dysfunction in older individuals presenting with memory complaints. While older adults may be aware that they sometimes experience difficulty remembering auditorially presented information, they may attribute these lapses to impaired cognitive functioning rather than to a form of sensory dysfunction. These individuals may benefit from an audiological consultation for recommendations regarding the appropriateness of various auditory compensatory strategies.

CHAPTER I

INTRODUCTION

Age differences in memory performance have been well-established using laboratory measures of memory. More recently, as researchers have increased efforts to differentiate early-onset dementia from normal aging, interest in age-associated memory differences has extended to include age differences in performance on neuropsychological measures of memory. Neuropsychological assessment batteries typically include measures of auditory and visual memory. Given that the measures of auditory memory are auditorially administered, one limiting factor in this area is that studies have generally not taken into account the role of auditory sensory degradation. Since older adults typically experience degradation of the auditory system, auditory processing efficacy may play a role in performance on auditorially administered measures of memory, perhaps by influencing memory processes through the mediation of encoding efficiency. Similarly, visual sensory processing degeneration may be associated with poorer performance on measures of visual memory. However, many assessment batteries include purely visual processing measures in addition to visual memory measures, thus allowing differentiation between sensory and memory deficits in visually administered tasks. In contrast, measures of pure auditory functioning have generally not been included in assessment batteries. The

purpose of the present study was to examine the relationship between age associated decline in auditory processing and performance on several auditorially administered neuropsychological measures of memory.

Models of memory have focused on how information is stored and transmitted through a series of separate memory systems or stages, namely, sensory memory, short-term or working memory, and long-term memory (Atkinson & Schiffrin, 1968). Information in sensory memory is encoded in raw sensory form, and is typically retained for less than 1 second. For example, visual information is held in a visual sensory buffer called "iconic memory," while auditory information is retained in an auditory sensory buffer called "echoic memory" (Anderson, 1990). Approximately four items can be briefly retained in sensory memory (Sperling, 1963), and older adults have consistently been shown to perform more poorly than younger adults on measures of sensory memory (Walsh, 1976; Walsh & Thompson, 1978). Short-term or working memory is a memory system with a limited capacity, and retention of information is of a short duration. In other words, only a limited amount of information can be maintained in short term memory at one time, and once information enters this store, it is subject to displacement or decay unless actively maintained through rehearsal (Brodie & Prytulak, 1975). Working memory is a preferred term because the system appears to function as a work space for manipulating and combining information rather than simply holding it (Hitch & Baddeley, 1976). This manipulating and combining of information is referred to as elaboration, and the amount of elaboration of information in working memory determines the likelihood that the information will be retained in long-term memory as well as the facility of retrieval

from long-term memory (Anderson, 1990). Long-term memory may be thought of as a permanent memory store with unlimited capacity.

Even in the absence of dementia or other age-associated pathology, increased age is associated with decreased performance on many measures of memory, such as word recall and story recall. Free recall of word lists has often been used in assessing age differences in memory. Subjects are auditorially, or sometimes visually, presented with lists of words, and asked to recall as many of those words as possible after hearing each list. For example, Erber (1974) presented a list of 24 words to be remembered for later recall to young (19-30 years) and elderly (65-74) women. Young women recalled significantly more words than the older women. Schonfield (1965) examined age differences in word recall and recognition by presenting to subjects aged 20-79 years two lists of 24 words to be remembered. Memory was assessed for one list using free recall, while memory for the other list was measured using recognition. Results indicated that there was no age-associated impairment on recognition memory, but there was a consistent decline in free recall associated with increased age. Results of these studies are consistent with other studies in the aging literature that found age related declines on recall performance but small or no changes in recognition performance across age (Arenberg, 1976; Hultsch, 1975; Taub, 1977). Olafsson and Backman (1993) measured age differences in recall of random as compared to semantically organizable word lists. Older subjects recalled fewer words than the younger subjects in both recall conditions. Older subjects also benefited to the same extent as younger subjects from the opportunity to organize the words in order to enhance recall. Another study (Kynette, Kemper,

Norman, & Cheung, 1990) examined age differences in recall for lists of 1-, 2-. or 3-syllable words. Older subjects recalled fewer words in all three conditions, and the performance of older subjects as compared to younger subjects was not disproportionately lowered by the requirement to recall longer words.

Story recall involves auditorially or visually presenting a short passage, and then asking subjects to recall as much of the passage as possible. The stories typically have previously been divided into idea units, which are units of the text which express a single simple idea. Each idea unit has been rated according to its importance to the overall content of the story; idea units are typically divided into groups which are considered to be of high, medium, or low importance level. In recalling the stories, subjects most frequently recall the main ideas and forget the less important details; in other words, they generally recall more idea units of high importance, and omit idea units of lower importance. This pattern has been termed the "levels effect" (Brown & Smiley, 1977). It has been demonstrated that in comparison to younger adults, older adults recall fewer idea units of all three importance levels, so that older adults' recall is poorer than that of younger adults for main ideas as well as for nonessential details (Petros, Norgaard, Olson, & Tabor, 1989). In other words, older adults recall less overall while retaining the ability to differentiate main ideas from nonessential details; the levels effect is present, although fewer idea units overall are recalled. These age differences are especially pronounced for expository versus narrative text, and for adults with low versus high verbal ability (Petros, et al., 1989; Hartley, 1986).

Story recall has also been used to assess patients with probable Alzheimer's Disease (AD). Haut, Demarest, Keefover, and Rankin (1994) reported that patients with mild probable AD recalled less than same-age controls, but retained the ability to differentiate ideas of high importance from low importance ideas. Patients classified as having severe probable AD recalled less overall than those with mild AD. In addition, these severe AD patients were unable to differentiate main ideas from nonessential details. These results suggest that the impairment of semantic processing which is associated with advanced AD involves the encoding and consolidation processes of working memory (Haut, et al., 1994).

Much research has been focused on identifying changes in neuropsychological functioning which can be expected over the course of normal aging (Mittenberg, Seidenberg, O'Leary, & DiGiulio, 1989), as well as differentiating memory loss associated with normal aging from that associated with early onset dementia such as Alzheimer's Disease (Flicker, Ferris, & Reisberg, 1993). The studies that examined changes in neuropsychological functioning associated with normal aging have compared the performance of neuropsychologically unimpaired younger and older adults on standard neuropsychological tests. Following is a brief description of several such neuropsychological measures, all of which are presented auditorially.

A commonly used type of neuropsychological instrument measures memory for word lists. Examples of this type of test are the California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987) and the Rey Auditory-Verbal Learning Test (RAVLT; Rey, 1964). These tests both provide information about immediate memory

capacity, auditory verbal learning, amount of memory disruption associated with learning new material (proactive interference), and the retention of recent learning. On both tests, one word list is presented over several trials, with recall measured after each presentation. These trials provide information about immediate memory span, as well as the rate of learning. After these trials, a second word list comprised of different words is presented, and recall is measured. Recall of the original word list is then measured, which provides a measure of interference in memory associated with having learned new material. A delayed recall trial of memory for the original list measures retention of recently learned material and retrieval ability.

Specifically, the California Verbal Learning Test (Delis, et al., 1987) includes 5 learning trials, each of which consists of the presentation of a list of 16 words. These words can be organized into 4 categories of 4 words each. On each learning trial, the word list is auditorially presented in the same order at a rate of 1 word per second. After each of the learning trials, subjects recall as many words as possible in any order. An interference list of 16 words is then presented, and recall of the interference list measured. Half of the words on the interference list belong to either of 2 of the 4 categories on the original list, and the other half of the words on the interference list belong to 2 categories unrelated to any of the 4 categories on the original list. After recalling the interference list, subjects are again asked to recall the original list. Cued recall of the original list is then measured by asking subjects to recall as many items as possible when the word categories from the original list are identified for them. Finally, free recall of the original list, cued recall (categories provided) of the original list, and

recognition memory for the original list are measured after a 30-minute temporal delay. The recognition list contains all 16 words from the original list, 4 words from the interference list which belonged to the same categories as were included in the original list, 4 words from the interference list which did not belong to any of the categories included on the original list, 4 words which were on neither the original list nor the interference list but which did belong to the categories included in the original list (semantically related distracters), 8 words which were on neither list but are phonetically similar to words included in the original list (i.e. chimes/chives, grill/drill), and finally, 8 words which were on neither list and are neither semantically nor phonetically related to any of the words which were on the lists.

The Rey Auditory-Verbal Learning Test (RAVLT; Rey, 1964) consists of a list of 15 words, which are auditorially presented in the same order over 5 learning trials at a rate of 1 word per second. After each of the learning trials, subjects are asked to freely recall the words in any order. After these 5 learning trials, an interference list of 15 words is presented, and recall of the interference list is measured. Subjects are then asked to freely recall the original list without hearing it repeated. All responses are recorded in the order recalled. There is a 10-second rest interval between each list. In addition, ten minutes after the final post-interference recall trial, subjects read a story which contains words from the original list. They are to circle all the words they recognize as being from the original list.

Another frequently administered test is the Digit Span subtest of the Wechsler Memory Scale (WMS; Wechsler, 1945), the Wechsler Memory Scale-Revised (WMS-R;

Wechsler, 1987), the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1955), and the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981). On all versions of this task, subjects are asked to recall a series of digits in the correct presentation order. On every 2nd trial, the number of digits per sequence is increased by 1. Administration is discontinued after failure on both items of a given trial. The Digit Span Forward score is the total number of items correctly recalled in the order of presentation, while the Digit Span Backward score is the total number of items recalled in the reverse order of presentation.

Another common neuropsychological measure is the Logical Memory subtest of the WMS (Wechsler, 1945) and the WMS-R (Wechsler, 1987). This subtest is similar to laboratory measures of story memory. Subjects listen to 2 prose passages which, for scoring purposes, have been divided into individual idea units. Immediately upon hearing each passage, subjects are requested to recall the passage as close to verbatim as possible. Specific scoring guidelines are provided in the WMS-R administration and scoring manual (Wechsler, 1987). Immediate recall is the number of idea units recalled immediately after hearing each passage, while delayed recall is the number of idea units recalled 30 minutes after hearing the passages. Each passage contains 65 words and is divided into 25 idea units.

Haut, Petros, and Frank (1990), following the procedure outlined by Johnson (1970), rated each idea unit in the two WMS-R passages according to its level of importance to the overall meaning of its respective passage. Thirty-five undergraduate students indicated which idea units could most easily be omitted without destroying the

overall meaning of the passage. Each idea unit is classified as being of high, medium, or low importance. By making it possible to measure whether subjects recall more high than low importance idea units (i.e. the presence or absence of the levels effect) this classification allows the examination of the organizational and semantic processes involved in memory functioning. In other words, a subject who recalls more main ideas than nonessential details has retained the ability to abstract the underlying semantic structure of the passage.

Another test of verbal memory is the Paired Associate Learning (PAL) subtest of the WMS (Wechsler, 1945), later named the Verbal Paired Associates (VPA) subtest on the WMS-R (Wechsler, 1984). Subjects are auditorially presented with 8 pairs of words, 4 of which are classified as difficult pairs because of their dissimilarity (i.e. OBEY-INCH), and 4 of which are classified as easy pairs because of their semantic relatedness (ROSE-FLOWER). Subjects are then read the first word of each pair, and requested to recall the appropriate associate. This entire procedure is repeated for at least 3 trials using the same word pairs. If, after 3 trials, the examinee responds to all items correctly, administration of the immediate memory portion of the subtest is discontinued. If, after 3 trials, the examinee has not learned all the pairings, testing is continued by presenting the same word pairs up to 3 more times. If, after 6 trials, the examinee has not learned all the pairings, testing is discontinued. The WMS-R included the addition of a 20-minute delayed recall condition in order to distinguish between subjects who can learn new information but have a rapid rate of forgetting (impaired retention or impaired retrieval) and subjects who have an encoding deficit (impaired acquisition or learning). Subjects

with impaired retention or retrieval would be expected to experience more difficulty on the delayed recall condition of the VPA, while subjects with impaired acquisition or learning would be expected to experience difficulty on the immediate recall condition. Scoring immediate recall involves adding the number of correctly recalled difficult items summed across trials to one half the number of correctly recalled easy items summed across trials. Similarly, scoring delayed recall requires adding the number of correctly recalled difficult items to one half the number of correctly recalled easy items.

The Extended Paired Associate Test (EPAT; Trahan, Larrabee, Quintana, Goethe, & Willingham, 1989) is a modification of the PAL subtest of the WMS. On the EPAT, both immediate and 30-minute delayed recall are included. In addition, 4 difficult word pairs were added to the PAL to address the restricted variance arising from the original PAL subtest often yielding floor effects on the easy word pairs for subjects with intact or relatively intact cognitive functioning. The scoring procedure for the EPAT is the same as that outlined above for the PAL and the VPA.

Age-associated declines in performance have been observed on many of the measures described above. For example, DesRosiers and Ivison (1988) administered Forms 1 and 2 of the Paired Associate Learning (PAL) subtest of the Wechsler Memory Scale (WMS) to 500 (Form 1) and 600 (Form 2) subjects stratified into ten-year age bands ranging from 20 to 79 years of age. As outlined above, the PAL subtest consists of 4 easy word pairs and 4 difficult word pairs. Subjects are presented with the first word of each pair and are required to recall the correct associate for each word. Subjects are given up to 6 chances to correctly recall all 8 associates. Sex of subjects was balanced equally

both within and across age groups. Excluded from the study were individuals with psychiatric or neurological conditions, suspected history of alcohol or drug abuse, or diabetes. Subjects were patients in a medical center, primarily drawn from the obstetrics, gynecology, orthopedics, and endocrinology wards. Immediate recall was measured. Age and sex were treated as between-subject factors for the easy and hard associates. While a sex effect was observed only on form 2, with women outperforming men on easy pairs, strong age effects were observed across easy and hard associates on both forms. As age increased, PAL performance decreased. There were no significant age by sex interactions.

Similar age differences have been reported on the Extended Paired Associates Test (EPAT), which has the same format as the PAL, but has an additional 4 difficult word pairs added. Trahan, Larrabee, Quintana, Goethe, & Willingham (1989) administered the EPAT to a standardization sample of 306 adults between the ages of 18 and 91. Excluded were individuals with known history of neurological disease or major psychiatric illness, cerebrovascular disease or stroke, transient ischemic attack, head trauma with loss of consciousness, seizures, tumors or infectious disease involving the central nervous system, drug or alcohol abuse, psychosis, or major depression. All subjects were nonhospitalized, and showed no evidence of mental deficiency based on past academic and occupational attainment. Most had at least a high school education. Analysis of variance showed significant differences between age groups for both immediate and delayed recall. While there were no differences observed in either immediate or delayed performance between the 18-29 and 30-49 age groups, subjects in the 50-69 age group performed significantly

poorer than the 2 younger groups on both immediate and delayed recall. Over age 70, an even more dramatic performance decrement was observed.

Villardita, Cultrera, Cupone, & Rejia (1985) presented several of these neuropsychological tests to 40 men and women with 8 to 13 years of education and similar sociocultural backgrounds. There were 10 subjects each in the following age groups: 15-24, 45-54, 55-64, and 65-74 years. Excluded were individuals with deficits of visual or auditory acuity, hypertension, left-handedness, individuals taking medication, or who had a history of myocardial infarct, congestive cardiocirculatory decompensation, obstructive respiratory disease with attacks of dyspnea, liver disease, kidney disease, obesity, metabolic disorders, nervous disease or psychiatric syndromes. All subjects scored at least 23 on the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975), which is a brief measure assessing short term memory functioning (e.g. immediate and short delayed recall of three words, ability to follow simple instructions) as well as mental orientation for time, place, and situation. There are 30 points possible on the Mini Mental State Examination. Other neuropsychological tests administered by Villardita et al. (1985) included the Digit Span subtest of the WAIS, the second passage from the Logical Memory subtest of the WMS, the auditorially administered version of the Continuous Performance Task, and the Supraspan Test. Because the latter measure is unpublished and therefore not widely used or studied, adequate information regarding reliability and validity is not available. However, results are of interest because of the test's procedural similarity to the CVLT and the RAVLT. The Digit Span subtest measures working memory capacity as indicated by the number of digits the subject can

recall in the original or reverse order of presentation. No significant age differences were observed on Digit Span forward or backward. The Logical Memory subtest requires subjects to recall verbatim a short narrative passage immediately after presentation as well as after a 20-minute delay. Here, subjects over 45 years of age recalled significantly less than subjects under 25 years of age on both immediate and delayed testing. After age 45, performance appeared to remain stable, with no significant differences in recall being found between subjects aged 45-54, 55-64, or 65-74 years. On the Supraspan Test, subjects were presented the same list of 10 words over 5 trials and were required to recall as many words as possible after each presentation. This was followed 30 minutes later by a delayed recall trial. Significant deficits in immediate recall were first observed in the group aged 55-64 years. Performance fell drastically for the 65-74 year-old group. Deficits in delayed recall on the Supraspan Test were first observed in the 45-54 year-old group, with performance remaining relatively stable after that age. The auditory continuous performance task required subjects to listen to a series of auditorially presented letters, and respond by pressing a key only when a specified letter was presented. No significant age differences were observed on this measure.

Albert, Duffy, and Naeser (1987) administered a battery of neuropsychological tests including the Logical Memory subtest of the WMS-R to subjects ranging in age from 30 to 85, with about 20 subjects per decade. The subject groups did not include individuals with hypertension, coronary artery disease, lung disease, kidney disease, cancer, alcoholism, psychiatric illness, learning disabilities, severe head trauma, or epilepsy. Performance for delayed recall on the Logical Memory subtest was observed to

decline during the decade of the 40's, and remain relatively stable thereafter. Auditory attention/concentration was assessed using the Auditory Continuous Performance Test, in which subjects were presented with a series of auditorially presented letter names and required to respond by pressing a key only when the letter "A" was presented. Consistent with previous findings (Villardita et al., 1985), no age-associated performance decline was observed on this measure. Other authors have also reported stable scores on both immediate and delayed recall on the Logical Memory subtest of the WMS-R after late in the fifth decade (Mitrushina & Satz, 1989; Van Gorp, Satz, & Mitrushina, 1990; Villardita, et al., 1985).

Ardila and Rosselli (1989) administered a battery of neuropsychological tests to 346 Colombian Spanish-speaking adults in the age ranges 55-60, 61-65, 66-70, 71-75, and 76 or older. Subjects were also classified by educational level and sex. Subjects scored at least 23 on the Mini-Mental State Examination, were not demented, and had no history of neurological or psychiatric problems, including cerebrovascular accidents, head trauma, epilepsy, or Parkinson's disease. Auditorially administered tests included the Digit Span (forward and backward) subtest of the WAIS, the Logical Memory (immediate and delayed) subtest of the WMS, and the Verbal Learning Curve (Luria, 1966). The latter test is similar to the California Verbal Learning Test in that it involves immediate and delayed recall of a word list, as well as providing information about the number of trials required to learn the list. While the word lists on the California Verbal Learning Test are comprised of 16 words, the word list for the Verbal Learning Curve consists of only 10 words. The Auditory Vigilance Test was also administered. There was no age-associated

decline observed on Digit Span forward or backward. On the Logical Memory subtest of the WMS, these authors reported that performance steadily decreased with age on both immediate and delayed recall in these subjects. This contrasts with other studies which reported a decline in performance on the WMS beginning in the 4th decade, while performance remained stable thereafter (Albert et al., 1987; Villardita et al., 1985). An age-associated decline after age 55 was also observed for the immediate and delayed memory for 10 words on the Verbal Learning Curve (Luria, 1966), although age was not significantly related to the number of trials necessary to learn the 10 words. Age was not related to performance on the Auditory Vigilance Test.

Cullum, Butters, Troster, and Salmon (1990) administered a test battery including the Digit Span (forward and backward) subtest of the WMS-R, the Logical Memory (immediate and delayed) subtest of the WMS-R, and the Verbal Paired Associates (immediate and delayed) subtest of the WMS-R. Subjects were ages 50-70 (26 females, 21 males) and ages 75-95 (20 females and 12 males). Age groups did not differ in educational level. Excluded were individuals with a history of stroke, head injury, learning disability, major psychiatric disorder, major medical illness, substance abuse, or who were taking medication which may affect memory performance (i.e., benzodiazepines or antidepressants). Individuals taking antihypertensive medication were allowed to participate. No significant age differences in performance were observed on Digit Span, while the older group scored significantly lower on Logical Memory (immediate and delayed), as well as on Verbal Paired Associates (immediate and delayed). Savings scores were calculated on the Logical Memory and Verbal Paired Associates subtests by dividing

the delayed recall score by the immediate recall score and multiplying by 100. The older subjects showed significantly lower savings scores on the Verbal Paired Associates subtest, while the rate of forgetting for the older group did not significantly differ from that of the younger group on the Logical Memory subtest.

Whelihan and Lesher (1985) administered a test battery including the Philadelphia Geriatric Center Delayed Memory test (Whelihan, Lesher, Kleban, & Granick, 1984), which is a modification of the Logical Memory subtest of the WMS. Subjects formed 3 groups. The intact young-old group (21 females and 10 males) ranged in age from 60 to 70 years, had a mean of 12.45 years of education, and scored at least 90% correct on the Philadelphia Geriatric Center Extended Mental Status Questionnaire (EMSQ; Whelihan et al., 1984). The intact old-old group (36 females and 12 males) ranged in age from 76 to 92 years, had a mean of 10.18 years of education, and scored at least 90% correct on the EMSQ. The impaired old-old group (53 females and 14 males) ranged in age from 76 to 92 years, had a mean of 8.62 years of education, and scored below 70% correct on the EMSQ. On the delayed memory task, the intact young-old group recalled significantly more information than the intact old-old group, while the intact old-old group significantly outperformed the impaired old-old group.

Robinson-Whelan and Storandt (1992) administered the Logical Memory subtest of the WMS (immediate and delayed recall) to healthy and mildly demented subjects. Mildly demented subjects, 25 men and 26 women, were identified by semi-structured clinical interview with the subject as well as with a collateral source, and were considered to have mild dementia based on the Washington University Clinical Dementia Rating

(CDR; Berg, 1984). The nondemented group was comprised of 15 men and 49 women who showed no evidence of dementia on the CDR. Excluded were those with conditions which might cause cognitive impairment, such as depression, stroke, severe hypertension, or overmedication. On both immediate and delayed recall, the nondemented group recalled more than did the demented group. Age was negatively correlated with both immediate and delayed recall for both demented and nondemented subjects. While immediate and delayed recall were highly correlated, age also had a significant but modest effect on delayed recall beyond that accounted for by immediate recall. It appeared that the rate of information loss did not differ between mild dementia and normal aging, leading these authors to conclude that the performance decline on prose recall typically observed in demented subjects is likely due to a disruption in the encoding process.

Mitrushina, Satz, Chervinsky, & D'Ella (1991) reported the performance of 156 subjects ages 57-85 on the Rey Auditory-Verbal Learning Test (RAVLT; Rey, 1964; Lezak, 1983). Ninety-four female and 62 male subjects were divided into 4 age groups: 57-65, 66-70, 71-75, and 76-85 years old. All subjects had a Mini-Mental State Exam score above 24, and individuals with a history of neurological or psychiatric disorders were excluded. Subjects were also screened according to the number and category of physical symptoms endorsed on a health status questionnaire. Groups did not significantly differ in education or WAIS-R Full Scale IQ. On the RAVLT, the number of words recalled decreased as age increased, for all 5 learning trials. All 4 groups showed similar primacy and recency effects. The rate of learning over the 5 trials, as indicated by the increment of retained words from Trial 1 to Trial 5, was similar for the 4 age groups.

Forgetting rates, reflected by the amount of information from the original list lost after the interference trial, were also similar for the 4 groups. While the number of words which could be freely recalled had decreased with increasing age of subjects, the number of words recognized in the subsequent story passage was similar for the 4 age groups. In sum, a decrement in number of words recalled on each learning trial was associated with increasing age, while other aspects of performance remained intact. These authors did not compare the performance of these older subjects with performance of subjects under the age of 57.

Another study compared performance of younger and older subjects on the RAVLT, the Logical Memory subtest of the WMS (immediate and 45-minute delay), and the Digit Span subtest of the WAIS-R, as part of a larger neuropsychological test battery (Hinkin, Cummings, Van Gorp, Satz, Mitrushina, & Freeman; 1990). Fourteen subjects were neurologically intact elderly males (mean age=70; s.d.=6.00), and an additional 14 were young neurologically intact male controls (mean age=35.86; s.d.=5.92). Neither group had a history of any neurologic, psychiatric, or substance abuse disorders. The groups did not significantly differ in educational attainment (mean=15.50 years). On the RAVLT, the older group showed significantly poorer performance relative to the younger group on the total number of words learned across the 5 learning trials. In addition, the older group was more susceptible to retroactive interference, indicated by poorer performance than the younger subjects on word recall of the original list following presentation and recall of the distracter list. On the Logical Memory subtest of the WMS, older subjects performed significantly worse on delayed recall than younger adults. Older

subjects' performance on immediate recall was not significantly lower than younger subjects' performance, but there was a trend toward significance. This pattern of results on the immediate recall may have resulted from the small sample size, the use of the statistically conservative Bonferroni correction of alpha, and the relatively high educational level of the subjects. The two groups did not differ significantly on the Digit Span subtest of the WAIS-R, although there was a trend toward impaired performance in the elderly group.

Cognitive explanations for such age-associated memory deficits have focused on working memory processing. It has been hypothesized that older adults have diminished overall working memory capacity, thereby processing information less efficiently (Light & Anderson, 1985; Crossley & Hiscock, 1992). For example, some authors have reported that older adults perform more poorly than younger adults on tests of digit span, which are presumed to measure working memory capacity (Light & Anderson, 1985). However, other authors found no difference between young and old adults on tests of digit span (Ardila & Rosselli, 1989; Villardita, et al., 1985). To further explore this issue, Jurden, Laipple, and Jones (1993) examined age differences in the types of errors made on the Digit Span test. Error types included intrusion errors (introducing nonstimulus digits), omission errors (omitting stimulus digits), and transpositions (transposing stimulus digits). No age associated decline in simple working memory capacity was found, as increased age was not associated with increased errors of the intrusion or omission type. However, the group of subjects aged 75 years and older made significantly more transposition errors than the younger subjects. Jurden et al. concluded that performance on the Digit Span test

may reflect two distinct components, namely a digit storage/recall component, and a serial position storage/recall component. The greater number of transposition errors associated with increased age presumably implicates an age associated compromise of processing efficiency during the serial processing component of the task as compared to the simple storage capacity component. Therefore, it appears that simple working memory capacity, or the number of items which can be held in working memory, does not adequately explain age associated memory deficits.

Daneman and Carpenter (1980) have presented an alternative measure of short-term memory which is proposed to reflect functional working memory capacity. This measure of working memory capacity is said to be functional because unlike digit span, which simply reflects the number of items which can be concurrently held in working memory, Daneman and Carpenter's measure reflects the amount of information which can be retained in working memory while the working memory system is engaged in the processing and storage functions required for discourse comprehension. In order to comprehend spoken or written material, the listener or reader must simultaneously store information from preceding text and integrate it with subsequent text. For example, pronominal references and previously presented idea units must be maintained in working memory and integrated with incoming information (Daneman & Carpenter, 1980). It has been proposed that the rapid encoding and storage of preceding material compete for a shared limited capacity, and that if the decoding of incoming information interferes with storage of previous text, the result would be the functional equivalent of a smaller storage capacity.

Daneman and Carpenter (1980) suggested that the demands which are placed on the processing component of working memory functioning by simple capacity measures such as Digit Span may not be great enough to be sensitive to individual differences in discourse comprehension. Instead, it is necessary to measure functional capacity with a task which places demands on both the processing and the storage components of working memory. These authors developed the reading span test to measure both of these simultaneous working memory functions. Reading span is the maximum number of sentences which can be processed while maintaining in working memory the last word of each sentence. Each sentence is 12-16 words long and ends with a noun. Subjects are asked to read sets of sentences aloud, and recall the last word of each sentence in correct serial order.

Daneman and Carpenter (1980) found that working memory span significantly correlated with reading comprehension. Light and Anderson (1985) measured reading span of 25 young (ages 21-34 years) and 25 older (ages 56-80 years) adults according to Daneman and Carpenter's (1980) procedure outlined above, and found that the young adults had significantly larger reading spans than the older adults. However, Light and Anderson (1985) found no evidence that age differences in span measures of working memory capacity (e.g. digit span, reading span) accounted for age differences in prose recall. In contrast, Tun, Wingfield, and Stine (1991) reported that a working memory span test such as that outlined by Daneman and Carpenter (1980) was a good predictor of recall for spoken text both with and without a secondary task. In fact, working memory span was a considerably better predictor of recall than age was (Tun, et al., 1991). These

authors tested both reading span and listening span, and young adults performed better than older adults in both modalities. The span score used in predicting recall for any given subject was whichever span score (reading or listening) was greater (Tun, et al., 1991). Contradictory findings have been reported by Hartley (1986), who found no age differences in working memory capacity between young students (ages 18-28 years), elderly students (ages 61-75 years), or elderly nonstudents (ages 63-75) as measured by the reading span test. Hartley (1986) used sets of 2-6 sentences, and presented each set size 3 times. Reading span was defined as the highest number of sentences for which final words were recalled in proper order on 2 out of 3 trials. Listening span was not measured.

More recently, Just and Carpenter (1992) expanded upon the functional capacity theory of working memory. They proposed that working memory capacity may be thought of as the amount of activation resources available. These capacity limitations in amount of activation available constrain language comprehension, and are thought to be an important source of individual differences in language comprehension. Just and Carpenter (1992) pointed out that discourse comprehension requires active processing at the lexical level, along with storage of propositions from previous text, the theme of the text, and a representation of the ongoing text. It was proposed that both processing and storage rely on activation within working memory, and that working memory capacity may be conceptualized as the maximum amount of activation available for both the storage and processing components of working memory. When the activation capacity is exceeded, there is a reduction in activation resources allocated to both working memory

functions. In other words, elements which were maintained in storage no longer maintain their activation in working memory, and continued processing of new text is slowed. Therefore, individuals with smaller activation resources process language more slowly, and more often forget needed text representations later in the text when those earlier representations are needed for successful language comprehension. Older adults are proposed to have smaller activation resources, and age effects are especially evident in texts which place large demands on working memory capacity. For example, texts which have ambiguous text units early on which are resolved later in the text require the maintenance of the ambiguous information in working memory until the ambiguity is resolved. Also, longer distances between a pronoun and its antecedent require continued activation of the antecedent for a longer period of time. Age differences are particularly evident under these types of language comprehension demands, and these differences may be attributed to a lowered working memory capacity as measured by the amount of activation available within the working memory system (Just & Carpenter, 1992).

An alternative cognitive explanation for age differences in memory suggests that older adults may execute mental operations more slowly, thereby limiting the efficiency of working memory operations (Salthouse, 1990). When subjects process auditorially presented information, their working memory processing capacity must be divided between continuous rapid auditory encoding, and maintaining previously presented information in working memory (Kintsch & van Dijk, 1978). Rapid execution of working memory operations including encoding should increase the amount of capacity yet available for other processing demands of the task. Conversely, older adults' slower rate

of executing mental operations may limit the functional capacity of working memory. A discrete working memory capacity must be shared by several working memory processes involved in comprehension and memory. If one of these processes becomes less efficient, and thus makes heavier processing demands, working memory capacity becomes less available for other processes.

For example, the elderly may require increased processing resources simply to decode a single word, leaving less processing capacity yet available for higher order integrative processes, such as maintaining memory for the just previously decoded word and for the preceding phrase (Perfetti & Hogaboam, 1975). Such limitations on the capacity available for other working memory processes would reduce the ability to integrate incoming information with information which has previously been activated as well as with information which could be accessed from long-term memory. This reduced elaborative processing during the encoding phase would impair memory for the incoming information.

Petros, Zehr, and Chabot (1983) investigated whether age-associated slowing in memory access speed reflected a general cognitive slowing, or whether the deficits increased proportionately with the difficulty of the tasks. The speed of word encoding (encoding physical features of a word), speed of lexical access (accessing the name of a word), and speed of semantic memory access (accessing categorical information about a word) were compared for young and old adults. Subjects were presented with two words and asked to determine whether the stimuli were physically identical (e.g. CAT/CAT), had the same name (e.g. CAT/cat), or belonged to the same semantic category (e.g.

CAT/DOG). Previous work with younger adults found larger latencies for category decisions than for name decisions and larger latencies for name decisions than for physical decisions. Petros et al. (1983) found that in relation to younger adults, elderly adults required more time to access information from long-term memory, and the size of the age difference was largest when retrieving category information when compared to name or physical information.

Madden (1985) conducted a variation of the study just described, in which 16 younger and 16 older adults were presented with a series of word pairs and asked to respond according to whether the two words had approximately the same meaning. Approximately half of the words required a "yes" response, and of these, the word pairs were either physically identical (BUTTON/BUTTON), were the same words presented in different cases (COPY/copy), or were synonyms (target/GOAL). The older subjects had longer response latencies when compared to the younger adults. In contrast to the results obtained by Petros et al. (1983), the response time for the older adults was not disproportionately higher when accessing categorical information as compared to physical or lexical information. Rather, the slower response rates of the older adults remained constant across decision type. In other words, there was no significant interaction between age and decision type. Madden (1985) pointed out that the disproportionate age associated slowing associated with accessing categorical information reported by Petros et al. (1983) may have reflected differences in comparison and decision making processes rather than age differences in pure memory retrieval time. Madden's (1985) results are supportive of a generalized age associated slowing in information processing speed.

Because encoding discourse requires retrieving word names and meanings from long-term memory (Perfetti & Lesgold, 1977), slower semantic access speed may limit elderly adults' available processing capacity so that incoming information is not processed as deeply or as elaborately as information processed by younger adults, thus impairing retention of the information in long-term memory. If aging results in a slowing of the rate at which memory encoding operations are executed, then presenting information at a faster rate should magnify the size of the age differences observed. To examine this hypothesis, Petros, Norgaard, Olson, and Tabor (1989) measured story memory of prose passages presented to college-age and elderly adults at 3 rates of presentation. It was reasoned that if age differences are due to heavy processing demands made on working memory from simply decoding the information, the extra decoding time afforded by a slower rate of presentation would eliminate the overloading of working memory capacity in older adults such that older adults' recall memory would be better for material presented at slower rates. Although slower rates of presentation were associated with better recall in both age groups, the size of the age difference in recall was similar across the three rates of presentation.

Stine, Wingfield, and Poon (1986), however, conducted a study which supported the hypothesis regarding cognitive slowing in elderly adults. These authors felt that a faster presentation rate than that used by Petros et al. (1989) would be necessary to differentially decrease the memory of older and younger adults. Also, memory for sentences rather than memory for passages was measured. Stine et al. (1986) reported that older adults did in fact show disproportionately poorer sentence recall than younger

adults when speech rate was increased beyond normal limits. Whereas Petros et al. (1989) presented prose passages at rates of 120, 160, and 200 words per minute, Stine et al. (1986) presented sentences at rates of 200, 300, and 400 words per minute. Subsequent research has consistently shown that presenting information at a faster rate impairs memory for prose as well as memory for sentences, and that the performance of older adults is disproportionately impaired by a rapid presentation rate (e.g. >240 words per minute) when compared to the performance of younger adults (Riggs, Wingfield, & Tun, 1993; Tun, Wingfield, Stine, & Mecsas, 1992; Wingfield, Wayland, & Stine, 1992; Wingfield, Tun, & Rosen, 1995).

Tun et al. (1992) examined immediate recall for prose passages which were presented at varied speech rates, which ranged from 140 to 280 words per minute. A dual-task paradigm was used, which required the subjects to concurrently complete a picture recognition task during the presentation of some of the narrative passages to be recalled. Presumably, if subjects allocated more processing resources to complete the primary task, this should be reflected by relatively poorer performance on the concurrently performed secondary task as compared to performance on the secondary task alone. While older individuals showed poorer recall on the primary task at the faster presentation rates, an increased presentation rate did not lead to their performance on the concurrent secondary task being disproportionately lowered as compared to the younger subjects. In other words, while the older adults showed poorer recall at faster presentation rates, an increased presentation rate of the primary task did not adversely affect their performance on the secondary task to a greater degree than that shown by the younger subjects. The

authors concluded that results provided evidence for age associated slowing of processing operations, while arguing against a decline in attentional capacity.

Wingfield et al. (1992) examined sentence memory in 24 older and 24 younger adults, by varying the presentation rate of the speech signal and by including sentences which contained either normal or abnormal speech prosody. Speech prosody includes such features as intonation, word stress, loudness, timing, and pitch. Half of the stimulus sentences were presented using normal prosody, while half contained prosody which obscured the meaning of the sentence. For example, the sentence, "Because she was a romantic/ lighting the candle on the table became a ritual" was changed to, "Because she was a romantic lighting/ the candle on the table became a ritual." Sentences were presented at normal rates and at 60 and 80 percent time compression, and subjects were asked to repeat the sentences verbatim. Results indicated that detrimental effects of an increased presentation rate and of abnormal speech prosody were particularly evident in the older subjects. Therefore, it is possible that older adults rely on the natural features of speech to a greater degree than younger adults do, perhaps to compensate for a decline in working memory processing efficiency.

Wingfield et al. (1995) provided further evidence that aging is associated with an increased reliance on the natural features speech and also with a slower processing speed for auditory information. Eighteen older and eighteen younger subjects were presented with prose passages. The passages were periodically interrupted in order for free recall to be measured. Passages were presented at varying rates (150, 220, and 285 words per minute), and the passages were interrupted at either random intervals which did not reflect

natural speech syntax, or at intervals which were chosen to be consistent with the natural syntactic structure of the passages. The older adults showed poorer recall associated with increased presentation rate, and also with random interruption of the passages. Thus, older adults showed evidence of reduced working memory processing speed and a greater reliance on the natural features of speech as compared to the younger subjects.

Riggs, Wingfield, and Tun (1993) examined age differences in memory for prose which was varied in rate and predictability. Eighteen older and eighteen younger adults were presented with prose passages, and free and cued recall and recognition were measured. On both the free and cued recall measures, older subjects recalled less than younger subjects, and their recall was more affected by increased speech rates and by decreased predictability of the prose passages as compared to younger subjects. While the performance of younger subjects was also reduced by these factors, the effects were particularly evident for older subjects. Both groups recalled more during cued as compared to free recall conditions. For recognition memory, predictability and presentation rate significantly affected memory performance, but older adults were not disproportionately affected by these factors as compared to younger subjects. Results suggested that the increased processing demands of more complex tasks negatively affect memory performance, and that older subjects are particularly affected by these demands.

In order to explore whether age associated decline in cognitive functioning is reflective of impairment in generalized as compared to localized domains, Salthouse, Fristoe, and Rhee (1996) explored the relative independence of age-related declines on several neuropsychological measures. They administered an assessment battery which

included measures of frontal lobe functioning, visual-spatial/constructional abilities, verbal memory, and visual-perceptual processing speed. Results indicated that perceptual processing speed accounted for substantial variability in performance in the other domains. In fact, perceptual processing speed completely accounted for age related variability in the executive functioning and visual-spatial/constructional measures. However, the relationship between age and verbal memory continued to be significant even after age differences in processing speed had been accounted for. Therefore, slower processing speed did not completely account for variability in memory performance. Results emphasized the importance of general factors such as processing speed in understanding age differences in cognitive functioning, and suggested that age associated decline in several cognitive domains may not be fully explainable by localized compromise of brain functioning. Salthouse et al. (1996) offered two possible explanations for the existence of a general factor which can account for age associated decline in cognitive functioning. First, it is possible that neuropsychological measures presumed to measure distinct cognitive domains are also sensitive to the functioning of a common region of the brain which is vulnerable to aging, such as the frontal region. Second, it is possible that broad systemic factors such as demyelination, reduced availability of certain neurotransmittors, or cerebrovascular problems may affect many neuroanatomical regions, and are thus reflected by performance on many neuropsychological measures presumed to measure distinct functions.

Existing data suggests that working memory capacity, working memory efficiency, as well as processing speed are important sources of age differences in auditory memory.

However, the contribution of age differences in sensory processing to individual differences in cognitive processing has largely been overlooked. While working memory efficiency and processing speed are important factors in age associated declines in auditory memory, sensory variables such as peripheral and central auditory functioning may also play an important role in the facility with which incoming auditory information is decoded. Discourse comprehension requires temporarily holding information in working memory while integrating speech sounds into words, those words into semantic units, and integrating those semantic units with previously and subsequently presented information, as well as with information from long-term memory. Thus, a subtle decline in the ease of speech understanding may influence the amount of processing resources available for cognitive processing beyond speech recognition, such as that required by tasks on neuropsychological tests.

In previous unpublished work by the present author, measures of auditory processing predicted prose recall in a population of young adults. Sensory variables may also contribute to age differences in memory. For example, the impaired auditory sensory functioning commonly associated with age (Thompson, 1987) may hinder the ease with which incoming auditory information may be encoded, thereby limiting the working memory capacity yet available for further processing such as rehearsal or integration with previous knowledge. Neuropsychological assessment batteries typically include measures of auditory memory, and age is associated with a decline in performance on these measures. Age differences are also observed on measures of central and peripheral auditory processing. Because neuropsychological measures of auditory memory are

administered auditorially, it is hypothesized that observed age-associated declines on these measures is in part reflective of age-associated declines in central and peripheral auditory processing.

While the majority of memory and aging research has not addressed the auditory status of the subjects, some studies which examined adult age differences in cognition have attempted to exclude subjects with sensory impairment by excluding subjects with self-reported hearing loss (Riggs, Wingfield, & Tun, 1993; Tun, Wingfield, & Stine, 1991; Wingfield, Wayland, & Stine, 1992). Similarly, another study which examined the role of cognitive slowing and diminished processing resources associated with normal aging used pure-tone auditory thresholds in order to exclude participants with sensory dysfunction (Tun, Wingfield, Stine, & Mecsas, 1992).

In addition, there has been exploratory work on the correlation of sensory and cognitive impairments in normal aging (Lindenberger & Baltes, 1994). Colsher and Wallace (1990) conducted a population-based exploratory study which examined the relationship between sensory and cognitive functioning. Participants in the Iowa 65+ Rural Health Study (1155 men with a mean age of 73.7 years, and 1942 women with a mean age of 74.8 years) completed an interview which included measures of physical health, mood, sensory functioning, and cognitive functioning. Mood was measured using the Center for Epidemiologic Studies Depression Scale (Radloff, 1977). Overall health status was examined by using an enumeration of lifetime history of major illnesses such as stroke, hypertension, diabetes, and cancer. The measure of vision was a self-report of whether the participant could read ordinary newsprint and whether the participant could

recognize a friend from across the street. The auditory measure consisted of self-reports of difficulty hearing another person talking in a quiet room without seeing the other person's face, and frequency of finding that others spoke too softly, seemed to mumble, or were difficult to understand in a large group or on the telephone. Cognitive measures included the Short Portable Mental Questionnaire (Pfeiffer, 1975), self-reported memory problems, self-rated memory, and performance on a 20-item recall task (National Institute on Aging, 1986). Subjects were divided into 3 age groups (65-74, 75-84, 85+ years).

Subjects in the youngest age group performed better than the older subjects on both the recall memory task and the mental status examination. Women in the youngest age group reported fewer memory problems than the older women, while for men there was no age difference in self-reported memory problems. Self-reported problems with hearing increased with age for both women and men. Self-reported hearing problems were associated with poorer performance on the mental status examination, and the 20-item recall task. In addition, subjects with the most self-reported hearing problems also reported the most memory problems and gave the poorest ratings to their own memories. These findings remained significant after age, education, health status, and depressive symptoms were accounted for in the analysis. The relationship between vision and cognitive functioning did not remain significant after controlling for age, education, health status, and depressive symptoms. These authors point out that their study is limited by its reliance on self-report measures of sensory and cognitive functioning, and that more formal measures need to be obtained (Colsher & Wallace, 1990).

Lindenberger and Baltes (1994) explored the role of auditory and visual functioning in cognitive aging among the very old. Subjects were German-speaking community-dwelling and institutionalized individuals. Ages ranged from 70 to 103 years, and subjects were divided into 6 age groups (70-74, 75-79, 80-84, 85-89, 90-94, 95+ years) with 13 men and 13 women in each group. Auditory status was assessed by measuring pure-tone thresholds at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. Auditory thresholds were obtained separately for the right and left ears.

Cognitive status was assessed using measures of speed, reasoning, knowledge, and memory. Speed measures included a timed digit-letter substitution task, a timed digit-symbol substitution task, and a speeded picture matching task. Reasoning measures included a figural analogies task which required choosing a visual stimulus to complete an analogy, a letter series task which involved choosing what letter should come next in a series, and a practical problems task which involved solving every day problems such as reading a bus schedule or medication instructions. Knowledge measures included a series of practical knowledge questions such as how to make an emergency telephone call, a task which involved discriminating a word from a series of nonwords, and a test of word knowledge. The cognitive measures were combined into 1 overall measure labeled intelligence.

Memory tests consisted of activity recall, memory for text, and memory for paired associates. Activity recall consisted of asking the subjects to recall as many of the 8 previously administered tests as possible. Memory for text consisted of a short narrative text which was simultaneously presented both visually and auditorially (the subjects were

provided with a copy of the text to read as the story was read aloud); free and cued recall were assessed immediately following presentation of the text. Memory for associates was measured using a list of 8 pairs of nouns; after initial presentation of the pairs, the subjects were presented with the first word of each pair and asked to recall the correct associate. This procedure was then repeated for a second trial using the same word pairs.

Results were consistent with a model in which sensory functioning indirectly mediates intellectual functioning (Lindenberger & Baltes, 1994). Age alone accounted for 40.8 percent of the variance in intelligence, vision alone for 41.3 percent, and hearing alone for 34.5 percent. Age, vision, and hearing together accounted for 52 percent of the variance in intelligence. A nonsignificant portion of the variability in intelligence was uniquely accounted for by age in this sample of subjects within a restricted age range. Both vision and hearing had significant unique effects in explaining the variability in cognitive functioning. The strength of the relationship between sensory functioning and cognitive functioning did not increase with increasing age in this sample of subjects aged 70 to 103 years. Education level was also a significant predictor of cognitive functioning, but was a less powerful predictor of cognitive functioning than were age, vision, or hearing. Vision and hearing were also more powerful predictors of cognitive function than processing speed was.

Lindenberger and Baltes (1994) offered 3 hypotheses regarding possible mechanisms by which sensory functioning may have mediated cognitive performance. First, impaired sensory and cognitive performance may reflect a general physiological deterioration of the brain which is associated with aging. This is the hypothesis favored by

the authors (Lindenberger & Baltes, 1994). Second, sensory impairment may contribute to deprivation of cognitive stimulation and thus lead to cognitive impairment over time. This hypothesis would suggest that cognitive abilities such as knowledge or fluency, which these authors presume to be especially involved in social interaction, would be more highly correlated with sensory degradation than would be cognitive abilities less necessary in social interaction. This pattern was not observed. Third, sensory performance factors may play a role in the test administration. This last hypothesis would predict that hearing would be more strongly associated with scores on cognitive measures which rely on auditory input, and vision more strongly associated with scores on cognitive measures which rely on visual input. This pattern was not observed, suggesting that test-specific sensory performance demands did not explain the relationship between sensory and cognitive functioning (Lindenberger & Baltes, 1994).

These results (Lindenberger & Baltes, 1994) indicate that there is an important link between sensory functioning and cognitive performance. However, this work may be limited by 2 factors. First, the subject group included only subjects aged 70-103 years, and it is not possible to examine the correlation between sensory and cognitive functioning earlier in the course of normal aging, or to compare the relation to that obtained in a group of younger adults. Secondly, this work examined only the role of peripheral auditory functioning (e.g. pure-tone thresholds), and central auditory processing measures were not obtained.

In studying auditory processing, two types of hearing loss are distinguished. One is a loss of sensitivity, affecting hearing for sounds of low intensities, and involving

peripheral auditory functioning (Davignon & Leshowitz, 1986). The other is a loss of speech discrimination skill, affecting the understandability of speech, and involving neural degeneration in areas of central auditory functioning (Davignon & Leshowitz, 1986). While peripheral hearing loss involves the cochlea, middle, and outer ear, central auditory functioning involves the auditory association areas of the cortex (Gordon & Ward, 1995). A test of peripheral functioning is the pure tone test, which measures the hearing threshold for each ear at given frequencies. Hearing thresholds are defined as the intensity of tones at given frequencies which a subject can detect on at least 2 of 3 trials. Intensity is measured in metric decibels (dB).

Tests of speech discrimination ability, which is reflective of central auditory functioning, typically involve the discrimination of speech under various difficult- listening conditions involving competing background noise or a speech signal which is temporally-altered or frequency-altered, thereby reducing the redundancy of the speech signal. While both types of hearing loss are associated with aging, performance of older adults on tests of central auditory processing appears to decrease independently of peripheral hearing loss, as evidenced by the fact that reduction in word discrimination scores in elderly adults exceeds what would be expected given their level of peripheral hearing loss (Thompson, 1987). For example, when a speech signal is degraded or when there is background noise, older adults have more difficulty understanding speech than would be expected given their peripheral hearing scores. It has further been reported (Humes, Watson, Christensen, Cokely, Halling, & Lee, 1994; Rodriguez, DiSarno, & Hardiman, 1990; Schum, Matthews, & Lee, 1991) that while pure-tone audiometry does

not directly measure the ability to code speech sounds, the degree of peripheral hearing loss is strongly correlated with speech recognition under normal listening conditions; however, under more difficult listening conditions, such as those which include background noise, age associated decline in speech recognition appears to be independent of peripheral auditory functioning. Humes and Christopherson (1991) examined auditory functioning in young-old (aged 65-75) and old-old (aged 76-86 years) hearing impaired subjects, in young normal hearing adults, and in young adults for whom sensory hearing loss was simulated using spectrally shaped masking noise. Results indicated that peripheral hearing loss was the primary factor in speech recognition deficits. However, the old-old subject group showed significantly poorer performance on central auditory measures than the other groups did, despite having a similar degree of peripheral hearing loss. Therefore, it appeared that there was a decline in central auditory functioning associated with advanced age.

Peripheral auditory processing appears to show first a gradual loss, with loss rapidly accelerating as age increases (Marshall, 1981). Central auditory processing ability appears to decline in the fifth or sixth decade, with a sharp decline in the seventh decade (Bergman, Blumenfeld, Cascardo, Dash, Levitt, & Margulies, 1976; Humes & Christopherson, 1991).

To determine whether auditory processing functioning is related to age differences in neuropsychological functioning, it is necessary to use auditory tests which reliably discriminate between elderly and young adults. A battery of such tests was compiled for

use in the present study. Following is a brief description of each auditory test used, as well as a summary of age differences typically observed on each test.

Auditory Tests

The Pure Tone Test involves presenting a series of tones at specified frequencies and determining the lowest intensity tone (measured in decibels; dB) which the subject can reliably perceive at each frequency. Right and left ears are tested separately. Subjects are asked to raise their hand when they hear a tone. At each frequency, an initial tone is presented, and if the subject responds correctly, the subsequent tone is presented at an intensity level which is 10 dB lower than the previous tone. If the subject fails to perceive the tone at a given presentation level, the intensity is increased by 5 dB; this is referred to as an ascending trial. The hearing threshold for each frequency is the lowest intensity at which tones can be distinguished on 2 out of 3 ascending trials for that frequency. The Pure Tone test is considered to be a measure of peripheral hearing loss. Decline in performance is typically associated with age (Marshall, 1981).

The Discrimination of Speech in Quiet requires subjects to repeat aloud stimulus words presented in an optimal listening condition. Each ear is tested individually and the test provides a percent correct score for each ear. While performance typically decreases with age (Bergman et al., 1976; Konkle, Beasley, & Bess, 1977), some authors feel that this may be due in part to peripheral hearing loss; such reduced scores may reflect lower hearing sensitivity rather than a reduced ability to comprehend speech (Thompson, 1987; Marshall, 1981). Generally, speech discrimination in quiet begins to decline in the sixth

decade, while speech discrimination in more difficult listening conditions declines much earlier, in the fourth decade (Hayes, 1979).

The Discrimination of Speech in Noise requires subjects to repeat aloud stimulus words which are presented to each ear individually with competing noise within the speech frequency range being simultaneously presented to the same ear which is receiving the speech stimulus. A percent correct score is obtained for each ear. Beginning around age fifty, performance typically decreases as age increases. Decline in performance on this test is usually greater than would be expected given subjects' hearing thresholds, suggesting the involvement of central auditory processing (Thompson, 1987). Schum, Matthews, and Lee (1991) administered the Speech in Noise test, the Speech in Quiet test, and obtained pure-tone thresholds for elderly subjects with sensorineural hearing loss. It was found that while performance on the pure tone audiometry nearly completely accounted for decline in Speech in Quiet performance, subjects performed significantly worse on the Speech in Noise test than would have been predicted by their degree of sensorineural hearing loss. It has also been found that older adults with intact sensorineural functioning (as measured by pure tone thresholds) perform more poorly on this task than younger adults (Cheesman, Hepburn, Armitage, & Marshall, 1995).

The Low Pass Filtered Speech test requires subjects to repeat aloud stimulus words which have had part of their frequency spectrum removed. Much of the speech frequency has been deleted so that only the lowest frequencies are presented. Each ear is tested individually. Scores are percent correct. Elderly subjects have more difficulty discriminating filtered speech than younger subjects do (Thompson, 1987; Palva &

Jokinen, 1970; Marshall, 1981). Decline in performance typically begins in the fifth or sixth decade, with a sharp decline in the seventh decade (Bergman et al., 1976). It was reported that older subjects with intact sensorineural hearing functioning showed significantly poorer speech discrimination ability on this task as compared to younger subjects (Cheesman, Hepburn, Armitage, & Marshall, 1995).

The Time Compressed Speech test requires subjects to repeat aloud stimulus words presented to each ear individually. Here, speech sounds occur at a rate which is faster than usual because small temporal segments of the stimulus words have been deleted, and the remaining segments have been put together so that the sound is continuous. Thus, rapid speech is achieved with no change in frequency. Again, scores are percent correct. Aged subjects have greater difficulty understanding time compressed speech than young subjects do, and performance decrements of aged subjects is greater than would be expected given their peripheral hearing thresholds (Konkle et al., 1977; Sticht & Gray, 1969; Thompson, 1987). Additionally, discrimination of time compressed speech becomes even more difficult for elderly subjects as the amount of time compression increases (Sticht & Gray, 1969).

The Synthetic Sentence Identification (SSI) test requires subjects to listen for and correctly identify a series of nonsensical sentences from a typed list 10 nonsensical sentences (e.g. SMALL BOAT WITH A PICTURE HAS BECOME), each of which is presented simultaneously with an ipsilateral competing message. That is, a continuous story, which is the competing message, is presented to one ear, and subjects must identify nonsense sentences which are periodically presented to the same ear during the story.

Subjects are provided with a list of the nonsensical sentences, and are asked to identify the sentences from that list as the sentences are presented. For each ear, there are 10 trials at each of the 3 presentation levels, which are 30dBSL, 40dBSL, and 50dBSL. Rodriguez, DiSarno, and Hardiman (1990) reported that the SSI is a sensitive measure of age associated central auditory decline. These authors administered the SSI and the Speech in Quiet test to older adults who demonstrated normal performance on pure tone thresholds. It was found that while the older adults had excellent speech recognition under quiet listening conditions with no distraction, they had considerably more difficulty on the SSI than that which would have been expected based on their pure tone thresholds and their intact speech discrimination skills under optimal listening conditions. Findings were consistent with earlier research, which also demonstrated an age associated decline on this measure (Jerger & Hayes, 1977; Shirinian & Arnst, 1982). The SSI is presently one of the most commonly used central auditory tests in the elderly population, as it minimizes the influence of peripheral auditory dysfunction. It is also used in calculating the Central-Peripheral Ratio.

The Central-Peripheral Ratio is calculated separately for each ear by determining the subject's best score (expressed as percentage correct) for that ear on the SSI, and subtracting that score from the subject's score for the same ear on the Speech in Quiet test, which is also expressed as percentage correct. Because the SSI is a central auditory measure and the Speech in Quiet test is a peripheral auditory measure, lower Central-Peripheral Ratio (C-P Ratio) scores reflect hearing loss that is primarily peripheral, while higher scores reflect hearing loss that is primarily central. Specifically,

C-P Ratios of less than 0 reflect peripheral hearing loss, C-P Ratios ranging from 0-20 reflect mixed peripheral and mixed hearing loss, and C-P Ratios of greater than 20 reflect central auditory hearing loss.

In sum, there has recently been increased interest in changes in neuropsychological functioning associated with normal aging. Age differences in neuropsychological test performance are of growing importance in the discrimination of normal aging from the early onset of Alzheimer's Disease and other age-associated dementia. Age-associated impairment has been observed on several auditorially presented neuropsychological tests of auditory memory. While most explanations for age differences in auditory memory performance have focused on age deficits in cognitive processing efficiency, one potential contributing factor to these age differences is that performance of older adults on auditorially presented neuropsychological tests is influenced by age-associated degradation of the central auditory system. For example, it has been demonstrated (Riggs et al., 1993; Tun et al., 1992) that a stimulus presentation rate which is increased through the use of time compression techniques (removing small temporal segments from the speech signal) reduces the memory performance of older adults. It has also been demonstrated (Thompson, 1987) that time compression of single words reduces speech understanding in the older adult population. While many assessment batteries include measures of visual processing efficacy in addition to measures of visual memory in order to clarify whether difficulty on visual memory tasks is related to degradation of more basic visual processing systems or whether such difficulties are more reflective of reduced efficacy of the higher order memory systems, the role of auditory processing efficacy in mediating age

associated decline in auditory memory performance has not been routinely considered. Although test batteries typically include measures of auditory memory, the role of auditory sensory functioning has been largely neglected. The purpose of the present investigation was to examine the role of peripheral and central auditory processing in age deficits in memory performance on commonly used neuropsychological tests of auditory memory.

CHAPTER II

METHOD

Participants

Thirty-two 18-29 year old undergraduate students taking psychology courses at the University of North Dakota participated for course credit. Twenty-eight independently living subjects between 60 and 81 years of age were paid $10 each for their participation. Elderly adults with a history of stroke or other form of neurological insult were not asked to participate, nor were older subjects scoring less than 23 on the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975).

Materials

Neuropsychological measures included the Digit Span, Logical Memory, and Verbal Paired Associates subtests of the Wechsler Memory Scale-Revised (WMS; Wechsler, 1987). The Digit Span subtest consists of a sequence of digits that range from 2 to 8 digits in length. Subjects were required to listen to each sequence and repeat the sequence in the exact order in which it was presented. There are 2 sequences presented at each length. The test also requires subjects for some of the sequences to repeat the digits in reverse order to that in which they were presented. The Logical Memory subtest consists of 2 short passages, each of which is 66 words in length. Subjects listen to each passage and an immediate verbatim recall is obtained, followed by a second recall 20

minutes after presentation. The Verbal Paired Associates subtest consists of a set of 8 word pairs, 4 of which are labeled easy pairs (e.g. METAL-IRON) and 4 of which are labeled difficult pairs (e.g. CRUSH-DARK). After subjects have listened to the word pairs, the first word of each pair is presented and subjects are asked to recall the second word of the pair in response to the first word of the pair. This procedure is repeated up to 6 times until all 8 items are correct on the same trial. In addition, delayed recall for the word pairs is assessed 20 minutes after initial presentation.

Subjects also completed the California Verbal Learning Test (CAVLT; Delis, Kramer, Kaplan, & Ober, 1987). This tests consists of two lists, each containing 16 shopping items from each of four categories, which are fruits, clothing, tools, and spices and herbs. Items are arranged so that no two items from the same category are presented consecutively. Five consecutive learning trials are administered using List A. This involves reading the List A to the subject and requesting free recall of the list after each presentation. Immediately after the five learning trials, an interference list of 16 shopping items, List B, is presented. Immediate free recall of this list is requested. Of the four-item categories of List B, two are different from List A (fish, kitchen utensils), and two overlap with List A (spices and herbs, fruits). Immediately after free recall of List B, free recall of List A is required. The partial category overlap between List A and List B provides information about whether semantically similar items to those in List A cause more interference than items which are not similar to list A. This trial is followed by a cued recall trial in which the subject is provided with each of the four semantic categories of List A items in order to facilitate recall. After 20 minutes, free recall, cued recall, and

recognition are tested for List A. The recognition trial involves presenting 44 shopping items, 16 of which were on List A, and 28 of which were not. Of the 28 items which were not on List A, four items were on List B and belong to the same semantic categories which were on List A, and four items were on List B but belong to semantic categories which were not on List A. Four items were not previously presented on List A or List B, but belong to similar semantic categories as those on List A. Eight items were not previously presented and belong to dissimilar semantic categories as those on List A. Finally, eight items have phonological similarities to individual words from List A. With the exception of the recognition trial, each trial of the California Verbal Learning Test is scored by counting the number of correct responses, the number of perseverations (repeated items), and the number of intrusions (nonlist items). Scoring the recognition trial involves counting the number of hits, misses, correct rejections, and false alarms.

The CVLT was recently critically reviewed (Elwood, 1995), and several issues were raised. It was pointed out that the present norms are inadequate because of a small, highly educated reference group. As a result, the norms were thought to be inflated when compared to the actual performance of the general population. Also, information regarding reliability of the CVLT was felt to be inadequate. Analysis for the present study did not compare individual's performance to the normed reference group. Rather, age differences in raw scores were examined. Therefore, the inadequate norms for the CVLT should not greatly affect interpretation of the present results. It was further pointed out (Elwood, 1995) that several of the recall measures on the CVLT are interdependent; for example, the number of semantically clustered responses is related to absolute recall, and

the number of items recalled in the delayed conditions is related to performance on the initial recall trials. For these reasons, several of Elwood's (1995) recommendations were followed in the present study. First, supplemental analyses were conducted which attempted to control for the dependent nature of various measures (i.e. the rate of errors were expressed relative to the number of total responses, memory retention was expressed as a proportion of the number of words recalled earlier). In addition, the auditory presentation of the word lists was audiotaped to ensure consistency in administration. This attempt at standardized administration was also consistent with suggestions made by Elwood (1995).

Other psychological measures administered in the present study included the Beck Depression Inventory (Beck, 1967), the Wahler Physical Symptom Inventory (Wahler, 1983), and the Vocabulary subtest of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981). The Beck Depression Inventory consists of 21 items. Each item contains a set of statements which describe increasing levels of a particular depressive symptom. For each item, subjects choose the statement which most applies to them. Scores on the Beck Depression range from 0-63. The Wahler Physical Symptoms Inventory consists of 42 items, each of which states a physical symptom. Subjects indicate the frequency with which they experience each physical symptom, with choices ranging from "almost never" to "nearly every day." Scores on the Wahler Physical Symptoms Inventory range from 0-210. The Vocabulary subtest of the WAIS-R consists of 35 words of increasing difficulty. Subjects are auditorially and visually presented with each word and asked to verbally provide a short definition. Testing is discontinued after 5

consecutive incorrect responses. Each item is scored according to guidelines provided in the WAIS-R manual, and responses may receive 0, 1, or 2 points. The maximum score possible on this measure is 70. Auditory tests were conducted using a GSI 17-23 audiometer and TDH-49 headphones mounted in MXAR-41 cushions. Tests were conducted in a quiet, noise controlled room with a background noise level of 25 decibels Hearing Level (dBHL) or less. Auditory tests were presented through headphones using a tape recorder. All tests were calibrated before use with each subject. The pure tone test was administered to obtain sensory hearing thresholds for each ear at 500, 1000, and 2000 Hertz (Hz). Hearing threshold is typically defined as the lowest intensity at which the subject is able to correctly detect the stimuli on at least 2 of 3 trials.

All subjects were then administered the Speech In Quiet Test, in which 25 phonemically balanced (PB) words are presented to each ear under optimal listening conditions (no alteration or degradation of speech signal, no background noise). Subjects are instructed to repeat back the word which was presented. If they are unsure of a word, they are instructed to guess. Words are presented at a level of 40 dB Sensation Level (dBSL). This presentation level is 40dB above a given subject's mean pure tone threshold from 500-2000 Hz. This presentation level is commonly used to ensure optimal performance on the speech in quiet tasks. The Pure Tone test and the Speech in Quiet test are measures of peripheral auditory functioning.

Central auditory measures included the Synthetic Sentence Identification (SSI) test, the Time Compressed Speech test, the Filtered Speech test, and the Speech Perception in Noise test. The SSI requires subjects to listen for and correctly identify a

nonsensical sentence from a typed list 10 nonsensical sentences (e.g. SMALL BOAT WITH A PICTURE HAS BECOME), each of which is presented simultaneously with an ipsilateral competing message. That is, a continuous story, which is the competing message, is presented to one ear, and subjects must identify nonsense sentences which are periodically presented to the same ear during the story.

The Time-Compressed Speech test requires subjects to repeat aloud stimulus words presented to each ear individually. Speech sounds occur at a rate which is faster than usual because small temporal segments of the stimulus words have been deleted, and the remaining segments have been put together so that the sound is continuous. Thus, rapid speech is achieved with no change in frequency. Subjects are encouraged to guess when they are unsure of a word. The Filtered Speech test requires subjects to recognize stimulus words which have had part of their frequency spectrum removed, so that only the lowest speech frequencies remain. Each ear is tested individually. Subjects are asked to repeat the stimulus words, and to guess when unsure.

Finally, the Speech in Noise test requires subjects to identify stimulus words which are presented to each ear individually with competing noise within the speech frequency range being simultaneously presented to the same ear which receives the speech stimulus. Again, subjects are required to repeat back the words that they hear, and to guess when unsure of a word.

<u>Procedure</u>

Subjects were tested individually in a quiet, noise-controlled room. Older subjects were first asked to complete consent forms, followed by the Mini Mental State

Examination (MMSE; Folstein, Folstein, & McHugh, 1975). All subjects scored greater than 23 on the MMSE. The Pure Tone Test was then administered. Pure tone threshold, which is the lowest intensity at which a subject correctly reports hearing a tone 2 out of 3 times, was measured separately for right and left ears at 500, 1000, and 2000 Hertz (Hz). Three of the neuropsychological tests administered involved a delayed recall trial. These tests were the Logical Memory (LM) and Verbal Paired Associates (VPA) subtests of the Wechsler Memory Scale-Revised (WMS-R; Wechsler, 1987), and the California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987). All remaining memory tests, auditory tests, and questionnaires were arranged into three test blocks so as to best fit between initial and delayed recall trials of the LM, VPA, and CVLT. These three test blocks were administered in counterbalanced order. Remaining auditory tests included the Speech in Quiet test, the Synthetic Sentence Identification Test, the Staggered Spondaic Word Test (SSW), the Time Compressed Speech test, the Filtered Speech test, the Binaural Fusion test, and the Speech Perception in Noise test. The Digit Span subtest of the WMS-R (Wechsler, 1987), and Vocabulary subtest of the Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981) were also included in the test blocks. Additional measures were the Beck Depression Inventory (Beck, 1967) and the Wahler Physical Symptoms Inventory (Wahler, 1973). The procedure for younger subjects was the same as that for older subjects, with the exception that younger subjects were not administered the Mini Mental State Examination.

CHAPTER III

RESULTS

Demographic Variables

There were 32 subjects in the younger age group and 28 subjects in the older group. The older subjects had significantly more years of education than the younger group $t(58)=-5.61$, $p<.01$. In addition, the older group obtained significantly higher WAIS-R vocabulary scores than the younger group $t(58)=-3.26$, $p<.01$. The older and younger subjects did not significantly differ on level of depression as measured by the Beck Depression Inventory $t(58)=1.61$, $p>.05$, or on general health as measured by the Wahler Physical Symptoms Inventory $t(58)=-.55$, $p>.05$. Group means and standard deviations for these variables are presented in Table 1.

Age Differences on Auditory Processing Measures

Means, standard deviations, and ranges of auditory measures are presented in Table 2. A series of analyses were completed in order to compare the two age groups on auditory processing performance. In all analyses, there were 32 subjects in the younger group and 28 subjects in the older group, with the exception of the analysis completed for the Filtered Speech test, which had 32 subjects in the younger group and 26 in the older group. This measure was not obtained for two of the older subjects because of difficulty with the equipment. Pure tone thresholds were obtained for each ear at 500, 1000, and

Table 1

Means and Standard Deviations for Demographic Variables

Demographic Variables	Young	Old
Age	20.84	68.36
	(6.11)*	(11.06)
Education Level	13.97	16.39
	(.97)	(2.22)
Vocabulary	51.19	56.36
	(5.78)	(6.50)
Beck Depression Inventory	3.19	1.93
		(3.60)
	(2.18)	
Wahler Physical Symptoms Inventory	28.94	32.29
		(15.20)
	(30.18)	

*Note: Standard deviations appear in parentheses

2000 Hz. These frequencies were selected because they are the frequencies for speech sounds. The hearing threshold at a given frequency was defined as the lowest intensity of sound (measured in metric decibels) which could be distinguished on 2 of 3 trials. Pure tone averages were calculated by obtaining the mean of the pure tone thresholds at 500,

1000, and 2000 Hz for each ear. Thus, each subject had a pure tone average for the right ear and a pure tone average for the left ear. The lower the pure tone average, the better the subject's performance on this measure of sensory hearing functioning. The younger group showed significantly better performance on both the right and left pure tone averages $t(58)=-7.80, p<.05$; $t(58)=-8.24, p<.05$, respectively. The younger subjects performed significantly better than the older subjects on the Speech in Quiet Test.

Table 2
Means, Standard Deviations, and Ranges for Auditory Variables

	Elderly			Young			
Auditory Variables	Mean	SD	Range	Mean	SD	Range	t
Pure-Tone Threshold R**	27.20	12.17	0-58	7.87	6.52	-10-20	-7.80*
Pure-Tone Threshold L	26.43	11.01	8-60	7.80	6.11	-10-20	-8.24*
Speech in Quiet R	80.14	19.79	8-100	93.12	4.79	80-100	3.60*
Speech in Quiet L	87.57	13.96	44-100	96.00	4.77	84-100	3.21*
Speech in Noise R	30.07	14.56	8-72	47.78	20.22	20-92	3.84*
Speech in Noise L	30.82	13.64	4-60	47.38	18.79	20-96	3.85*
Time Compressed R	46.43	19.97	0-76	60.63	16.70	16-88	3.00*
Time Compressed L	43.29	16.87	0-76	63.78	16.14	0-88	4.80*
Filtered Speech R	49.69	19.17	16-80	66.75	12.63	40-92	4.07*
Filtered Speech L	32.62	19.16	4-68	50.63	16.31	4-84	3.87*
SSI Right 30 dB SL	69.29	35.16	0-100	83.75	21.81	0-100	1.94
SSI Right 40 dB SL	81.07	33.26	0-100	98.39	5.83	70-100	2.85*
SSI Right 50 dB SL	86.43	30.82	0-100	99.03	5.39	70-100	2.24*
SSI Left 30 dB SL	83.21	27.63	0-100	88.13	25.71	1-100	.71
SSI Left 40 dB SL	86.07	30.35	0-100	98.07	1.08	80-100	2.16*
SSI Left 50 dB SL	88.57	28.51	0-100	99.03	5.39	70-100	2.01*

* Indicates variables for which there are significant age differences
** R = right ear, L = left ear

(measured in percentage of correct responses) for both the right ear $t(58)=3.60$, $p<.05$ and the left ear $t(58)=3.21$, $p<.05$. The younger subjects performed significantly better than the older subjects on the Speech in Noise Test (measured in percent correct) for both the right ear $t(58)=3.84$, $p<.05$, and the left ear ear $t(58)=3.85$, $p<.05$.

On the Time-Compressed Speech Test (measured in percentage of correct responses), the younger subjects again had better performance than the older subjects for the right ear $t(58)=3.00$, $p<.05$, and the left ear $t(58)=4.80$, $p<.05$. On the Filtered Speech Test (measured in percent correct), the younger group performed significantly better than the older group for both the right ear $t(56)=4.07$, $p<.05$ and the left ear $t(56)=3.87$, $p<.05$. There was no significant difference in percentage of correct responses between younger and older subjects on the Synthetic Sentence Identification Test (SSI) at 30dB SL; this was true of the right ear $t(58)=1.94$, $p>.05$, and the left ear $t(58)=.71$, $p>.05$. At 40dB Sensation Level (40 dB SL, which is 40 dB above the pure tone average), younger subjects performed significantly better on the SSI than the older subjects for both the right ear $t(58)=2.85$, $p<.05$, and the left ear $t(58)=2.16$, $p<.035$. At 50dB SL, the younger group performed significantly better than the older group for the right ear $t(58)=2.24$, $p<.05$, and for the left ear $t(58)=2.01$, $p=.05$.

Age Differences on the California Verbal Learning Test (CVLT)

For each subject, the number of words correctly recalled on each of the 5 learning trials was computed. Also computed for each learning trial were the number of perseverations (words recalled more than one time per trial), the number of intrusions (extralist words produced at time of recall), and the number of semantically clustered

responses (2 or more words from the same semantic category recalled consecutively). A 2 (age) X 5 (trials) mixed analysis of variance was computed separately for number of correct responses, number of perseverations, number of intrusions, and number of cluster responses. Subsequent analyses were completed using the Tukey procedure. This procedure is recommended for controlling Type I error when all pairwise comparisons are to be made (Myers & Well, 1991).

The analysis of the number of words correctly recalled revealed significant main effects for age $F(1,57)=25.78$, $p<.01$, and trials $F(4,228)=188.88$, $p<.01$. Means and standard deviations are presented in Table 3. Subsequent analyses revealed that across all 5 learning trials, younger subjects (mean=12.406) recalled more words than older subjects (mean=9.89). Both age groups recalled significantly more words on each consecutive learning trial until Trial 5, when recall was not significantly higher than on Trial 4. There was no significant age X trials interaction $F(4, 228)=.61$, $p>.05$.

Because analysis of absolute performance on learning trials does not take into account that the older subject group began Trial 1 at a lower level of performance, individual slopes and intercepts were computed for each subject to indicate rate of learning for each subject. The mean slope for the young (mean=1.3065) was not significantly different from the mean slope for older (mean=1.3679) subjects, $t(57)= -.45$, $p>.05$, thus supporting the results above in which there was no significant age X trial interaction on the learning trials. The groups did significantly differ on the intercept values $t(57)=5.08$, $p<.01$, such that the younger group had higher intercept values than the older subjects,

Table 3
Mean Number of Words Recalled on the Learning Trials of the California Verbal Learning Test as a Function of Age

Learning Trials	Young	Elderly
Learning Trial 1	8.71	6.21
	(2.02)*	(1.89)
Learning Trial 2	11.93	9.39
	(2.03)	(2.11)
Learning Trial 3	13.13	10.43
	(2.54)	(2.43)
Learning Trial 4	14.10	11.35
	(2.09)	(2.44)
Learning Trial 5	14.16	12.07
	(2.27)	(2.21)

*Note: Standard deviations appear in parentheses

consistent with the significant main effect of age reported above. In other words, younger recalled more words on each trial than the older subjects did.

A 2 (age) X 5 (trials) mixed analysis of variance of the number of perseverations for each learning trial resulted in a significant main effect of trials $F(4,232)=4.30$, $p<.01$. Means and standard deviations are presented in Table 4. Subsequent analysis revealed that there were significantly fewer perseverations in Trial 1 than there were in Trial 3, Trial 4, and Trial 5. The number of perseverations in Trials 3-5 did not significantly differ from each other, nor did the number of perseverations in Trial 1 significantly differ from the number of perseverations in Trial 2. There was no significant age X trial interaction $F(4,232)=1.26$, $p>.05$.

Analysis of the number of intrusions for each learning trial revealed a significant main effect of age $F(1,58)=5.89$, $p<.05$, and a marginal main effect of trial $F(4,232)=2.37$, $p=.054$ (see Table 5). Younger subjects (mean=.137) had significantly fewer intrusions overall than older subjects did (mean=.379). Although only marginally significant, the number of intrusions made by both groups tended to decrease across trials, especially from Trial 1 to Trial 2, and from Trial 4 to Trial 5. There was no significant age X trials interaction $F(4,232)=.94$, $p>.05$.

Table 4
Mean Number and Mean Proportion of Perseverations on the Learning Trials of the California Verbal Learning Test as a Function of Age

Learning Trials	Young		Elderly	
	Mean	MP*	Mean	MP
Learning Trial 1	.219 (.659)**	.019 (.054)	.107 (.315)	.011 (.032)
Learning Trial 2	.594 (1.103)	.041 (.073)	.286 (.535)	.026 (.048)
Learning Trial 3	.938 (1.544)	.057 (.087)	.500 (.839)	.040 (.069)
Learning Trial 4	.625 (1.680)	.034 (.078)	.571 (.879)	.040 (.062)
Learning Trial 5	.563 (1.134)	.036 .069	.750 (1.351)	.049 (.082)

*Note: MP = Mean proportion of perseverations
**Note: Standard deviations appear in parentheses

Due to the often wide variation in the number of items recalled by different subjects on the 5 learning trials, Crosson, Novack, Trenerry, and Craig (1988) have suggested that the absolute number of perseverations and intrusions is not meaningful for statistical comparison (i.e. the presence of 1 intrusion for a subject who recalled 12 items is not of equal significance as the presence of 1 intrusion for a subject who recalled only 2 items). Therefore, the number of perseverations and intrusions for each trial may be expressed as the proportion of the total response output for each trial. This is calculated

Table 5
Mean Number and Mean Proportion of Intrusions on the Learning Trials of the California Verbal Learning Test as a Function of Age

Learning Trials	Young		Elderly	
	Mean	MP*	Mean	MP
Learning Trial 1	.219 (.553)**	.025 (.000)	.571 (.920)	.089 (.134)
Learning Trial 2	.219 (.491)	.018 (.044)	.286 (.535)	.032 (.065)
Learning Trial 3	.125 (.336)	.008 (.022)	.357 (.559)	.034 (.056)
Learning Trial 4	.094 (.390)	.004 (.018)	.393 (.567)	.033 (.049)
Learning Trial 5	.031 (.177)	.002 .010	.286 (.659)	.021 (.045)

*Note: MP = Mean proportion of intrusions
**Note: Standard deviations appear in parentheses

by dividing the number of perseverations or intrusions by the total response output (summed total of correct responses, perseverations, and intrusions).

The analysis of the proportion of perseverations on each of the 5 learning trials revealed a significant main effect of trial $F(4,232)=3.58$, $p<.01$ (see Table 4). Subsequent analysis showed that the proportion of perseverations on Trial 5 and Trial 3 were significantly greater than the proportion of perseverations on Trial 1. There were no significant differences between any other trials, nor was there a significant age X trial interaction $F(4,232)=.89$, $p>.05$.

The analysis of the proportion of intrusions on each of the 5 learning trials revealed a significant main effect for age $F(1,58)=7.40$, $p<.01$, and a main effect for trial $F(4,232)=25.78$, $p<.01$ (see Table 5). Younger subjects (mean=.011) had a significantly lower proportion of intrusions relative to the older subject group (mean=.042). Across trials, there was a greater proportion of intrusions on Trial 1 than on Trials 2-5. The proportion of intrusions on Trials 2-5 did not significantly differ. In addition, there was a significant age X trials interaction $F(4,232)=2.78$, $p<.05$. Subsequent analysis indicated that for the younger subject group, the proportion of intrusions did not significantly differ across trials. That is, the younger subjects had approximately the same proportion of intrusions on each of the 5 learning trials. For the older subject group, there was a significantly higher proportion of intrusions on Trial 1 relative to Trials 2-5. The proportion of intrusions for Trials 2-5 did not significantly differ for the older subject group. In addition, the younger group had a significantly lower proportion of intrusions than the older group on Trial 1, Trial 3, and Trial 4. These results suggest that for older

adults, the CVLT is most sensitive to intrusions on the initial learning trial, when subjects have had only one opportunity to hear the list. Older subjects, for whom the task was relatively more difficult, made more intrusive errors after the initial presentation. Their number of intrusions may have been reduced after a repeated presentation (Trial 2) familiarized them with the list.

The analysis of the number of semantically clustered responses for each learning trial revealed a significant main effect of trial $F(4,212)=47.76$, $p<.01$ (see Table 6). Subsequent analysis indicated that there were fewer semantically clustered responses on

Table 6
Mean Number and Mean Proportion of Clustered Responses as a Function of Age and Learning Trials on the CVLT

Learning Trials	Young		Elderly	
	Mean	MP*	Mean	MP
Learning Trial 1	2.704 (2.233)**	.416 (.286)	2.107 (1.449)	.467 (.250)
Learning Trial 2	4.667 (2.869)	.541 (.288)	3.571 (1.989)	.519 (.232)
Learning Trial 3	5.444 (3.641)	.556 (.323)	4.357 (2.628)	.565 (.302)
Learning Trial 4	6.296 (3.911)	.589 (.339)	5.286 (2.307)	.646 (.252)
Learning Trial 5	7.222 (3.755)	.671 .294	5.679 (3.309)	.631 (.316)

*Note: MP = Mean proportion of semantically clustered responses
**Note: Standard deviations appear in parentheses

Trial 1 (mean=2.406) than on Trials 2-5 (means=4.119, 4.901, 5.791, and 6.451 respectively). In addition, there were fewer semantically clustered responses on Trial 3 than on Trials 4 and 5. There was no significant difference between the number of clusters on Trial 2 and Trial 3, nor between the number of clusters on Trial 4 and Trial 5. There was no significant main effect of age $F(1,58)=2.56$ $p>.05$, nor was there a significant age X trial interaction $F(4,212)=.55$, $p>.05$.

Because the younger subjects consistently recalled more items on the 5 learning trials than the older subjects did, the younger subjects had the opportunity to make a greater number of semantically clustered responses. In order to equate the 2 groups in terms of the number of possible semantically clustered responses, Crosson et al (1988) recommended that the number of actual semantically clustered responses be expressed as the proportion of the total number of possible clustered responses, which is calculated according to the number of responses made by a particular subject on a particular trial.

The analysis of the proportion of semantically clustered responses for the 5 learning trials revealed a significant main effect of trial $F(4,208)=12.50$, $p<.01$ (see Table 6). Subsequent analysis revealed that the proportion of clustered responses was greater for Trial 5 (mean=.651) than for Trial 1, Trial 2, and Trial 3 (means=.442, .530, and .561, respectively). Trials 1 and 2 did not significantly differ from each other, while Trial 3 was significantly greater than Trial 1. Trial 4 (mean=.618) and Trial 5 did not significantly differ. There was no significant main effect of age $F(1,58)=.00$, $p>.95$, and no significant age X trial interaction $F(4,208)=.68$, $p>.05$.

T-tests were conducted to examine age differences in the number of words correctly recalled, the number of perseverations, the number of intrusions, and the number of semantic clusters for List B, the interference list (see Table 7). The analysis of the absolute number of correctly recalled words revealed that younger subjects recalled

Table 7
Means for Correct Responses, Perseverations, Intrusions, and Clustered Responses as a Function of Age on List B of the CVLT

	t	Young	Elderly
Correct Responses	7.813	5.393 (2.055)**	4.72* (1.892)
Perseverations	.063	.286 (.246)	-1.66 (.713)
Perseverations as Proportions	.007	.028 (.027)	-1.72 (.065)
Intrusions	.125	.500 (.336)	-2.23* (.882)
Intrusions as Proportions	.014	.815 (.040)	-2.31* (.160)
Clustered Responses	2.926	1.29 (1.979)	3.89* (1.013)
Clustered Responses as Proportions	.526	.325 (.278)	2.83* (.248)

* $p<.05$
**Note: Standard deviations appear in parentheses

significantly more words than the older subjects $t(58)=4.72$, $p<.01$. There was no significant age difference in the absolute number of perseverations on the List B trial $t(58)=-1.66$, $p>.05$. Similarly, there was no significant age difference in the number of perseverations on List B expressed as the proportion of total response output for that trial $t(58)=-1.72$, $p>.05$. Older subjects had a significantly higher absolute number of intrusions than younger subjects $t(58)=-2.23$, $p<.01$. Similarly, older subjects had significantly more intrusions than younger subjects when intrusions were expressed as the proportion of total response output for that trial $t(58)=-2.3$, $p<.05$. In addition, older subjects had a significantly lower number of semantically clustered responses than the younger subjects on List B $t(58)=3.89$, $p<.01$. When clustered responses were expressed as the proportion of the total number of possible clustered responses, older subjects again had significantly fewer semantically clustered responses $t(58)=2.83$, $p<.01$.

The number of correct responses, perseverations, and intrusions for the delayed recall trials were each subject to a 2 (age) X 2 (delay: short delay versus long delay) X 2 (test type: free recall versus cued recall) mixed analysis of variance. The analysis for correct responses revealed a significant main effect of age $F(1,58)=22.41$, $p<.01$, with younger subjects producing more correct responses than older subjects (means=13.58 and 10.70, respectively). There was also a significant main effect of test type $F(1,58)=8.96$, $p<.01$, with subjects performing significantly better on the cued recall trials (mean=12.40) than on the free recall trials (mean=11.88). Means and standard deviations are presented in Table 8. There was a significant age by test type interaction $F(1,58)=8.45$, $p<.05$.

Subsequent analysis indicated that age differences were smaller for cued recall than for free recall.

Table 8
Mean Number of Correct Responses on Delayed Recall Trials of the CVLT as a Function of Age

Delayed Recall Trials	Young	Elderly
Short Delay Free Recall	13.250 (2.170)*	10.179 (3.056)
Short Delay Cued Recall	13.781 (2.136)	11.143 (2.460)
Long Delay Free Recall	13.781 (2.044)	10.321 (3.411)
Long Delay Cued Recall	13.531 (2.578)	11.143 (2.785)

*Note: Standard deviations appear in parentheses

To examine memory retention after learning, the number of items remembered on each of the delayed recall trials was converted to the proportion of the highest learning trial. Means and standard deviations are presented in Table 9. There was only a marginal effect of age $F(1,57)=2.91$, $p=.09$, such that on the delayed recall trials, the younger subjects (mean=.925) recalled a greater proportion of their original learning than the older subjects (mean=.869). There was a significant main effect of test type $F(1,57)=9.13$, $p<.01$, such that subjects recalled a greater proportion of their original learning on cued delayed recall trials (mean=.921) than on free delayed recall trials (mean=.873). There was a significant age X test type interaction $F(1,57)=6.32$, $p<.05$. Subsequent analysis revealed that age differences were smaller for cued recall than for free recall.

Table 9
Mean Number of Words Recalled on Delayed Recall Trials of the CVLT Expressed as a Proportion of the Highest Learning Trial

Delayed Recall Trials	Young	Elderly
Short Delay Free Recall	.903 (.096)*	.819 (.180)
Short Delay Cued Recall	.939 (.103)	.914 (.158)
Long Delay Free Recall	.938 (.078)	.831 (.254)
Long Delay Cued Recall	.919 (.146)	.912 (.169)

*Note: Standard deviations appear in parentheses

The analysis of the number of perseverations for the delayed recall trials showed a significant main effect of test $F(1,58)=20.95$, $p<.01$, such that subjects had fewer perseverative errors on the cued recall trials (mean=.018) than on the free recall trials (mean=.295). There was no significant main effect of age $F(1,58)=.95$, $p>.05$, nor was there a significant age X trial interaction $F(1,58)=.29$, $p>.05$. Means and standard deviations are presented in Table 10.

The analysis of perseverations expressed as the proportion of the total response output for the delayed recall trials showed a significant main effect of test $F(1,58)=20.47$, $p<.01$, with a greater proportion of perseverative errors being made on free recall than

Table 10
Mean Number and Mean Proportion of Perseverations as a Function of Age and Delayed Recall Trials on the CVLT

Delayed Recall Trials	Young		Elderly	
	Mean	MP*	Mean	MP
Short Delay Free Recall	.219 (.491)**	.017 (.037)	.429 (.790)	.035 (.064)
Short Delay Cued Recall	.000 (.000)	.000 (.000)	.036 (.189)	.003 (.015)
Long Delay Free Recall	.281 (.581)	.020 (.041)	.250 (.701)	.016 (.042)
Long Delay Cued Recall	.000 (.000)	.000 (.000)	.036 (.189)	.003 (.013)

*Note: MP = Mean proportion of total response output that was perseverations
**Note: Standard deviations appear in parentheses

(mean =.022) on cued recall (mean =.002). There was no significant main effect of age $F(58)=1.05$, $p>.05$, and no significant main effect of delay $F(58)=.88$, $p>.05$, nor was there a significant age X delay interaction $F(58)=1.66, p>.05$. Means and standard deviations are presented in Table 10.

The analysis of the number of intrusions for the delayed recall trials revealed a significant main effect of age $F(1,58)=14.87$, $p<.01$, with older subjects having more intrusions (mean=.973) than younger subjects (mean=.156). There was a significant main effect of delay $F(1,58)=8.56$, $p<.01$, which showed that there were more intrusions on the long delay trial (mean=.676) than on the short delay trial (mean=.453). There was a

significant age X delay interaction $F(1,58)=2.98$, $p<.01$. Subsequent analysis revealed no effect of delay for younger subjects, whereas older adults had a significantly higher number of intrusions on long delayed recall than on short delayed recall. In addition, the age differences in number of intrusions were more pronounced for long delayed recall than short delayed recall. Means and standard deviations are presented in Table 11.

Table 11
Mean Number and Mean Proportion of Intrusions as a Function of Age and Delayed Recall Trials on the CVLT

Delayed Recall Trials	Young		Elderly	
	Mean	MP*	Mean	MP
Short Delay Free Recall	.125 (.336)**	.008 (.023)	.643 (.951)	.068 (.136)
Short Delay Cued Recall	.187 (.535)	.013 (.037)	.857 (1.145)	.074 (.120)
Long Delay Free Recall	.187 (.397)	.013 (.028)	1.071 (1.412)	.121 (.222)
Long Delay Cued Recall	.125 (.336)	.009 (.024)	1.321 (1.588)	.109 (.138)

*Note: MP = Mean proportion of total response output that was intrusions
**Note: Standard deviations appear in parentheses

The analysis of the proportion of total response output that was intrusions for the delayed recall trials showed a significant main effect of age $F(58)=10.11$, $p<.01$, with the younger subjects having a lower proportion of intrusive errors (mean=.011) than the older subjects (mean=.093). There was also a significant main effect of delay $F(58)=7.25$,

$p<.01$, with subjects making a higher proportion of intrusive errors on the long delayed recall (mean=.063) than on the short delayed recall (mean=.041). There was a significant age X delay interaction $F(58)=7.01$, $p<.05$. Subsequent analysis revealed that the effects of delay were more pronounced for the older subjects than for the younger subjects, and that the effect of age was more pronounced on the long delay trial than on the short delay trial. Means and standard deviations are presented in Table 11.

The analysis of the number of semantically clustered responses on the delayed recall trials revealed a significant main effect of age $F(57)=17.33$, $p<.01$, with the younger subjects (mean=8.290) generating a higher number of semantic clusters than older subjects (mean=5.429). In addition, there was a significant main effect of delay $F(57)=4.08$, $p<.05$. Subjects had a higher number of semantically clustered responses on the long delay trial than on the short delay trial. Means and standard deviations are presented in Table 12.

The analysis of semantically clustered responses expressed as a proportion of total response output on the delayed recall trials revealed a significant main effect of age $F(1,57)=5.27$, $p<.05$, with the younger subjects producing more semantically clustered responses (mean=.825) than the older subjects (mean=.693). There was a significant age X delay interaction $F(1,57)=4.28$, $p<.05$. Subsequent analysis revealed that the younger subjects produced more semantically clustered responses than the older subjects, and that this was more pronounced on the long delay recall trial than on the short delay recall trial. Means and standard deviations are presented in Table 12.

Table 12
Mean Number and Mean Proportion of Semantically Clustered Responses as a Function of Age and Delayed Recall Trials on the CVLT

Delayed Recall Trials	Young		Elderly	
	Mean	MP*	Mean	MP
Short Delay Free Recall	7.677 (3.321)**	.778 (.271)	5.357 (2.360)	.716 (.222)
Long Delay Free Recall	8.903 (3.026)	.871 (.235)	5.500 (2.912)	.669 (.291)

*Note: MP = Mean proportion of total response output that was semantically clustered
**Note: Standard deviations appear in parentheses

A t-test was conducted to examine age differences in the number of correct responses on the recognition trial. Results revealed that the older subjects correctly recognized fewer List A recognition items than the younger subjects $t(58)=2.68$, $p<.01$. Means and standard deviations are presented in Table 13. The types of distracter items on the recognition list consisted of: (1) B list words, shared category (from 2 of the same categories used on List A); (2) B lists words, nonshared category (from 2 different categories than those used on List A); (3) words which were on neither list, but belonged to one of the categories used on List A; (4) words which were on neither list, but were phonemically similar to List A items; and (5) semantically and phonemically unrelated distracter words. T-tests were conducted to examine age differences for each of the

Table 13
Mean Number of Correct Responses and Error Types on the CVLT Recognition Trials as a Function of Age

	t	Young	Elderly
Correct Recognition	15.25	14.29 (1.11)**	2.68* (1.65)
Error Type 1: List B-Related	.25	.46 (.92)	-1.01 (.69)
Error Type 2: List B-Related	.00	.179 (.00)	-2.59* (.39)
Error Type 3: Extralist-Related	.09	.46 (.53)	-2.24* (.74)
Error Type 4: Phonemically Similar	.06	.14 (.25)	-1.03 (.36)
Error Type 5: Extralist-Unrelated	.00	.00 (.00)	.00 (.00)

* $p<.05$
**Note: Standard deviations appear in parentheses

5 error types. There was no significant difference between the younger and older groups on the first error type (words from the B list which belonged to the same semantic category as the correct learning list words) $t(58)= -1.01$, $p>.05$. On the second error type (words from the B list, different semantic category from the learning list), the older subjects made significantly more errors than the younger subjects $t(58)=-2.59$, $p<.05$. On the third error type (words from neither list, shared category with the learning list), older subjects again made significantly more errors than the younger subjects $t(58)=-2.24$,

$p<.05$. On the fourth error type (phonemically similar words), there was no significant difference between younger and older subjects $t(58)=-1.03$, $p>.05$. On the fifth error type (neither list, semantically and phonemically unrelated), there was no significant difference between younger and older subjects $t(58)=.00$, $p>.05$. Means and standard deviations for each of the 5 types of errors are presented in Table 13.

Age Differences on the Wechsler Memory Scale-Revised (WMS-R) Subtests

A t-test was conducted to examine age differences on the Digit Span subtest of the WMS-R. Results revealed that the younger subjects performed significantly better (mean=8.69) than the older subjects (mean=7.00) on Digits Forward $t(58)=3.73$, $p<.05$. Younger subjects also performed significantly better (mean=7.44) than older subjects (mean=6.11) on Digits Backward $t(58)=2.62$, $p<.01$.

On the Verbal Paired Associates subtest, subjects obtained 4 scores, which reflected the proportion of easy and difficult word pairs correctly recalled for both immediate and delayed recall. A 2 (age) X 2 (level of difficulty) X 2 (immediate versus delayed recall) mixed analysis of variance was conducted on these measures. Subsequent analyses were completed using the Tukey procedure. Means and standard deviations are presented in Table 14. The analysis revealed a significant main effect of age $F(1,58)=13.75$, $p<.01$. The younger subjects (mean=.9408) recalled a significantly higher proportion of correct associations than the older subjects (mean=.8315). There was a main effect of delay $F(1,58)=14.72$, $p<.01$, with subjects performing better on the delayed recall trials (mean=.915) than on the immediate recall trials (mean=.865). There was a significant main effect of item difficulty $F(1,58)=54.97$, $p<.01$, such that subjects correctly

recalled more easy pairs (mean=.965) than difficult pairs (mean=.808). There was a significant age X delay interaction $F(1,58)=10.02$, $p<.01$. Subsequent analysis revealed larger age differences on immediate than delayed testing. A significant age X difficulty interaction, $F(1,58)=15.39$, indicated that age differences were larger for difficult pairs than easy pairs.

Table 14
Mean Proportion of Associates Recalled at Immediate and Delayed Recall on Verbal Paired Associates as a Function of Age

	Young	Elderly
Immediate Recall Easy Associates	.971 (.050)*	.932 (.145)
Immediate Recall Difficult Associates	.901 (.105)	.637 (.257)
Delayed Recall Easy Associates	.984 (.061)	.973 (.079)
Delayed Recall Difficult Associates	.906 (.165)	.786 (.278)

*Note: Standard deviations appear in parentheses

The immediate and delayed recall trials for Story A and Story B of the Logical Memory subtest were each scored for the presence or absence of the gist of each idea unit, according to the guidelines provided in the WMS-R manual. Each of the stories had previously been divided into individual idea units, as detailed in the manual. These idea units were later divided into 3 levels of importance (for further details, see Haut et al., 1990). Story A contained 8 high importance idea units, 8 medium importance idea units,

and 8 low importance idea units. Story B contained 7 high importance idea units, 8 medium importance idea units, and 7 low importance idea units.

For both immediate and delayed recall of each story, the proportion of idea units correctly recalled at each level of importance was calculated for each subject. A 2 (age) X 2 (story) X 3 (level of importance) mixed analysis of variance was performed on the recall scores. Subsequent analyses were completed using the Tukey procedure. Means and standard deviations are presented in Table 15. The analysis revealed a significant main of age $F(1,58)=32.47$, $p<.01$, with the younger subjects (mean=.563) recalling a significantly higher proportion of idea units than the older subjects (mean=.391). There effect was a

Table 15
Mean Proportion of Idea Units Recalled on Logical Memory as a Function of Age, Importance Level, and Delay Condition

Trial Type	Young		Elderly	
	Story A	Story B	Story A	Story B
Immediate Recall				
High Importance	.770	.590	.665	.464
	(.131)*	(.196)	(.226)	(.195)
Medium Importance	.551	.531	.379	.336
	(.155)	(.193)	(.203)	(.164)
Low Importance	.444	.571	.290	.408
	(.211)	(.221)	(.212)	(.193)
Delayed Recall				
High Importance	.730	.555	.598	.415
	(.149)	(.213)	(.239)	(.215)
Medium Importance	.504	.553	.304	.275
	(.192)	(.167)	(.168)	(.153)
Low Importance	.382	.567	.194	.362
	(.207)	(.237)	(.167)	(.192)

*Note: Standard deviations appear in parentheses

main effect of importance level $F(2,116)=58.06$, $p<.01$. Subsequent analysis revealed that subjects recalled a higher proportion of high importance idea units (mean=.603) than medium (mean=.436) and low (mean=.410) importance idea units. The proportion of medium and low importance idea units recalled did not significantly differ. There was no significant age X importance level interaction $F(2,116)=2.44$, $p>.05$.

There was no significant main effect of story $F(1,58)=.97$, $p>.05$. There was a significant story X importance level interaction $F(2,116)=40.85$, $p<.01$. Subsequent comparisons revealed that for Story A, a larger proportion of idea units was recalled at the high importance level (mean=.695) than was recalled at the medium importance level (mean=.441), which was significantly higher than the low importance level (mean=.333). For Story B, a higher proportion of idea units was recalled at the high importance level (mean=.510) than at the medium importance level (mean=.424), and recall at the medium importance level did not significantly differ from recall at the low importance level (mean=.477). In addition, more high importance idea units were recalled from Story A than from Story B, while more low importance idea units were recalled from Story B than from Story A. There was no significant age X story interaction $F(1,58)=.86$, $p>.05$.

There was a significant main effect of delay $F(1,58)=16.11$, $p<.01$, with subjects recalling a higher proportion of idea units on the immediate recall trials than on the delayed recall trials. There was a significant delay X story interaction $F(1,58)=6.37$, $p<.05$. Subsequent analysis revealed that memory for Story A was better than memory for Story B on immediate recall but not for delayed recall. Immediate recall was better than

delayed recall for both Story A and Story B. There was no significant age X delay interaction $F(1,58)=2.97$, $p>.05$.

<u>Multiple Regression Analyses</u>

The above analyses clearly demonstrated the presence of age differences on auditory processing and memory measures. The major intent of the present study was to measure the degree to which age differences in auditory memory functioning would be reduced after differences in auditory processing efficacy was accounted for, in other words, to examine the independent contribution of age beyond that which could be attributed to a decline in sensory functioning. Because auditory processing and auditory memory decline are both strongly correlated with increased age, a series of multiple regression analyses were conducted in order to examine the amount of variance still accounted for by age after auditory variables were accounted for. This was accomplished by first computing a series of multiple regressions with age alone as the predictor variable. Next, multiple regression analyses were conducted including auditory predictor variables alone. All analyses including auditory variables were conducted separately for right ear measures and left ear measures in order to more easily consider effects of laterality in auditory processing. This same series of analyses was completed for each dependent variable, so that the regression analysis for each dependent variable included age alone, right ear variables alone, age with right ear variables, left ear variables alone, and age with left ear variables.

Predictor variables are listed in Table 16, and bivariate correlations are presented in Table 17. Because the pure tone thresholds for the right and left ears were highly

Table 16
Predictor Variables for the Multiple Regression Analyses

Predictors for Right Ear Analyses	Predictors for Left Ear Analyses
Age*	Age*
Pure Tone Average	Pure Tone Average
Central-Peripheral Ratio Right Ear	Central-Peripheral Ratio Right Ear
Central-Peripheral Ratio Left Ear	Central-Peripheral Ratio Left Ear
Speech in Noise Right Ear	Speech in Noise Left Ear
Time Compressed Speech Right Ear	Time Compressed Speech Left Ear
Filtered Speech Right Ear	Filtered Speech Left Ear

* Analyses were completed both with and without age

Table 17
Intercorrelations of the Predictor Variables

	PTA	SSIR	SSIL	SNR	SNL	TCR	TCL	FSR	FSL
PTA**	----	.465*	.346*	-.552*	-.536*	-.545*	-.634*	-.574*	-.639*
SSIR**		----	.402*	-.516*	-.376*	-.595*	-.423*	-.381*	-.448*
SSIL			----	-.430*	-.312*	-.475*	-.433*	-.256*	-.373*
SNR**				----	.660*	.370*	.395*	.417*	.432*
SNL					----	.318*	.467*	.406*	.538*
TCR**						----	.754*	.613*	.616*
TCL							----	.581*	.628*
FSR**								----	.680*
FSL									----

* indicates significant correlations at the .05 level
** PTA = Pure tone threshold averaged across right and left ears;
SSIR and SSIL = Synthetic Speech Identification Test for the right and left ears;
SNR and SNL = Speech in noise for the right and left ears;
TCR and TCL = Time Compressed Speech for the right and left ears;
FSR and FSL = Filtered Speech for the right and left ears

correlated, one pure tone threshold measure was created for each subject by obtaining the mean of the threshold values for the two ears. This measure was labeled as the pure tone

average. The Central-Peripheral Ratio (C-P Ratio) was calculated separately for each ear by subtracting the maximum score on the SSI for that ear from the Speech in Quiet score for that ear. Higher scores are reflective of primarily central auditory involvement, while lower scores are reflective of primarily peripheral auditory involvement. Because of the relatively low correlation between the SSI scores for the left and right ears, as well as the importance of the C-P Ratio in determining central and peripheral auditory functioning in older adults, both right ear and left ear scores for the C-P Ratio were included in the regression analyses for right and left ears. The other auditory processing variables chosen as predictor variables were Speech in Noise, which involves perception of speech which has been subjected to a combination of spectral and amplitude distortion; Filtered Speech, which involves the perception of speech which has been subjected to spectral distortion; and Time Compressed Speech, which involves the perception of speech which has been subjected to temporal alteration. Scores on the latter 3 measures are presented as percentage of correct responses. Predictor variables were chosen which reflected peripheral auditory processing (Pure Tone Average and high scores on the central peripheral ratio of PBMax) and central auditory processing (Speech in Noise, low scores on the Central Peripheral Ratio, Filtered Speech, and Time Compressed Speech).

The simultaneous or standard multiple regression procedure was chosen in order to examine the amount of variance uniquely accounted for by age after auditory variables had been accounted for. In a simultaneous multiple regression procedure, the contribution of each predictor variable is evaluated after all the other predictors have been entered. Therefore, the analysis provides information about what each predictor variable

adds after all other predictors have been accounted for; in other words, the values reflect the unique portion of variance accounted for by each predictor variable. Because shared or overlapping variance is not assigned to any individual variable, it is possible for individual predictors which are correlated with other predictor variables to appear unimportant to a solution. Therefore, each individual predictor may account for only a small portion of unique variance, while several such predictors may collectively account for a more substantial portion of the variance than the sum of the unique variance values accounted for by each individual predictor variable (Tabachnick & Fidell, 1989). For this reason, it is important to consider the correlations between individual predictor variables and the dependent variables (Tabachnick & Fidell, 1989). In Table 18 and 19 are presented the correlations of the memory measures and the predictor variables. Two correlation matrices were completed, one including right ear auditory variables, and the other including left ear auditory variables. In addition, the amount of variance accounted for by the total set of predictor variables is included in the text for each dependent variable.

Digit Span Forward was subject to a series of simultaneous multiple regression analyses. The effect of age alone accounted for a significant amount of variance (19.39%) in Digit Span Forward performance as shown in Table 20. The regression coefficient estimates the amount of change in the dependent variable associated with one unit of change in the predictor variable. The beta weight is a standardized slope coefficient which allows comparison of the predictive strength of each of the predictor variables. The r^2 is the partial correlation that reflects the percentage of variance accounted for by each

Table 18
Bivariate Correlations of Independent and Dependent Variables-Right Ear

	Age	PTA	SSIR	SSIL	SNR	TCR	FSR
LM Imm	-.5279**	-.4626**	-.3339**	-.5334**	.3112*	.4658**	.3481**
LM Del	-.6198**	-.5677**	-.3841**	-.4049**	.4242**	.4504**	.4465**
LM Ret	.3415*	.3444**	.1575	-.0914	-.2844**	-.0640	-.2250
DSF	-.4403**	-.3685**	-.2365	-.2106	.1209	.0758	.1848
DSB	-.3258*	-.3075*	-.0657	-.2183	-.0197	.0533	.0129
PA Imm	-.5144**	-.4873**	-.4844**	-.2773*	.3623**	.3549**	.4065**
PA Del	-.2651*	-.3604**	-.2232	-.2707	.2119	.4296**	.3447**
PA Ret	-.3724*	-.2662*	-.3771**	-.1616	.2392	.0700	.1533
CVLT LT	-.5361**	-.5353**	-.3636**	-.4399**	.3702**	.3707**	.3898**
CVLT SD	-.4111**	-.3668**	-.0791	-.2815**	.1095	.2971*	.3379**
CVLT LD	-.5305**	-.5865**	-.3891**	-.3747**	.3488**	.4103**	.4147**
CVLT Ret	.0720	.2462	.1411	.1605	-.2238	-.0961	-.0290
CVLT Rec	-.3325**	-.3362**	-.3544**	-.0393	.2268	.0358	.1796

* $p < .05$
** $p < .01$

Note: LM=Logical Memory, Imm=Immediate Recall, Del=Delayed Recall, Ret=Memory Retention, DSF=Digit Span Forward, DSB=Digit Span Backward, PA=Paired Associates, CVLT LT=Learning Trials, CVLT SD=Short Delayed Recall, CVLT LD=Long Delayed Recall, Rec=Recognition

Table 19
Bivariate Correlations of Independent and Dependent Variables-Left Ear

	Age	PTA	SSIR	SSIL	SNL	TCL	FSL
LM Imm	-.5279**	-.4626**	-.3339**	-.5334**	.2841*	.4859**	.4153**
LM Del	-.6198**	-.5677**	-.3841**	-.4049**	.4942**	.5155**	.6252**
LM Ret	.3415**	.3444**	.1575	-.0914	-.4386**	-.1739	-.4588**
DSF	-.4403**	-.3685**	-.2365	-.2106	.3169*	.2353	.3183*
DSB	-.3258*	-.3075*	-.0657	-.2183	.0287	.1974	.1442
PA Imm	-.5144**	-.4873**	-.4844**	-.2773*	.4218**	.4534**	.4848**
PA Del	-.2651*	-.3604**	-.2232	-.2707*	.2295	.4578**	.4177**
PA Ret	-.3724**	-.2662*	-.3771**	-.1616	.3510**	.1094	.2649*
CVLT LT	-.5361**	-.5353**	-.3636**	-.4399**	.3883**	.5338**	.5604**
CVLT SD	-.4111**	-.3668**	-.0791	-.2815*	.1151	.3821**	.3308*
CVLT LD	-.5305**	-.5865**	-.3891**	-.3747**	.3735**	.5814**	.4680**
CVLT Ret	.0720	.2462	.1411	.1605	-.2211	-.0960	-.0949
CVLT Rec	-.3325**	-.3362**	-.3544**	-.0393	.3337**	.1921	.1996

* $p < .05$
** $p < .01$

Note: LM=Logical Memory, Imm=Immediate Recall, Del=Delayed Recall, Ret=Memory Retention, DSF=Digit Span Forward, DSB=Digit Span Backward, PA=Paired Associates, CVLT LT=Learning Trials, CVLT SD=Short Delayed Recall, CVLT LD=Long Delayed Recall, Rec=Recognition

Table 20
Multiple Regression for Digit Span Forward

Factor	Coefficient	Beta	t	r^2
Age Alone	-.0002	-.4403	-3.734*	.1939
Right Ear Auditory Variables Without Age				
FSR	.0162	.1516	.891	.0118
C-P Ratio L	-.0135	-.2467	-1.664	.0410
C-P Ratio R	-.0140	-.3198	-1.881	.0523
SNR	-.0274	-.2856	-1.729	.0442
PTA	-.0630	-.4222	-2.478*	.0908
TCR	-.0438	-.4479	-2.303*	.0785
Age with Right Ear Variables Entered First				
Age	.0001	-.3077	-1.702	.0413
Left Ear Auditory Variables Without Age				
FSL	.0138	.1412	.755	.0093
C-P Ratio L	-.0052	-.0949	-.637	.0066
C-P Ratio R	-.0033	-.0756	-.483	.0038
SNL	.0092	.0884	.548	.0049
TCL	-.0144	-.1445	-.785	.0101
PTA	-.0352	-.2362	-1.255	.0258
Age With Left Ear Variables Entered First				
Age	-.0001	-.3681	-1.966	.0598

* $p < .05$

predictor variable after all the other predictor variables in the equation have been accounted for. A second simultaneous multiple regression analysis was completed including right ear auditory variables as predictor variables without age included in the equation. This set of predictors accounted for 28.57% of the variance. As can be seen in Table 20, Pure Tone Average and Time Compressed Speech right accounted for significant amounts of unique variance in Digit Span Forward performance (9.08% and 7.85%, respectively). Examination of the beta weights shows that as sensory thresholds increased, Digit Span Forward performance decreased. As Time Compressed Speech performance improved, Digit Span Forward performance decreased. A third multiple regression analysis was completed by entering right ear variables first and then allowing age to enter the equation. This set of predictors accounted for 28.70% of variability. As can be seen in Table 20, age did not account for a significant amount of unique variance when right ear variables were included in the equation. A fourth multiple regression analysis was completed using left ear auditory variables without age included in the analysis. This set of predictors accounted for 16.58% of the variance. No left ear auditory variables accounted for significant unique portions of variance (.38%-2.58%). When age was included as a predictor along with the left ear auditory variables, age did not account for a significant proportion of variance (5.98%) beyond that accounted for by the left ear variables. That set of predictors collectively accounted for 22.56% of the variance.

Digit Span Backward was subject to a series of simultaneous multiple regression analyses. The effect of age alone accounted for a significant amount of variance (10.62%)

in Digit Span Backward performance as indicated in Table 21. A second simultaneous multiple regression analysis was completed using right ear auditory variables without age. This set of variables accounted for 22.38% of variance. It can be seen in Table 21 that the C-P ratio for the left ear, Speech in Noise for the right ear, and the Pure Tone Average accounted for significant percentages of unique variance, accounting for 6.2%, 6.6%, and 13.9%, respectively. Examination of the beta weights reveals that high scores on C-P ratio (which indicate more difficulty with central than peripheral auditory processing) for the left ear were associated with poorer performance on Digit Span Backward. As performance on Speech in Noise increased, performance on Digit Span Backward decreased. Finally, as the hearing thresholds of the Pure Tone Average increased, performance on Digit Span Backward decreased. A third multiple regression analysis was completed by entering right ear variables first and then allowing age to enter the equation. This set of predictors accounted for 24.87% of the variance. As can be seen in Table 21, age did not account for a significant amount of unique variance (2.5%) beyond that which was accounted for by right ear auditory variables. A fourth multiple regression was conducted using left ear auditory variables. This set of predictors accounted for 17.09% of the variance. As can be seen in Table 21, Pure Tone Average accounted for a significant amount of unique variance (8.2%), with performance on Digit Span Backward decreasing as sensory thresholds increased. A fifth multiple regression was computed by entering left ear variables first followed by age. Age did not account for a significant portion of unique variance (2.7%) beyond that accounted for by left ear variables. This set of predictors accounted for 19.8% of the variance.

Table 21
Multiple Regression for Digit Span Backward

Factor	Coefficient	Beta	t	r^2
Age Alone	-.0001	-.3258	-2.624*	.1062
Right Ear Auditory Variables Without Age				
FSR	-.0132	-.1171	-.679	.0070
C-P Ratio L	-.0176	-.3047	-2.026*	.0624
C-P Ratio R	-.0030	-.0650	-.377	.0022
SNR	-.0353	-.3493	-2.084*	.0662
PTA	-.0822	-.5223	-3.021*	.1389
TCR	-.0212	-.2062	-1.045	.0166
Age with Right Ear Variables Entered First				
Age	-.9648	-.2392	-1.289	.0250
Left Ear Auditory Variables Without Age				
FSL	-.0007	-.0069	-.037	.0000
C-P Ratio L	-.0130	-.2249	-1.515	.0373
C-P Ratio R	.0036	.0782	.501	.0041
SNL	-.0303	-.2748	-1.710	.0475
TCL	-.0034	-.0321	-.175	.0005
PTA	-.0665	-.4225	-2.251*	.0824
Age With Left Ear Variables Entered First				
Age	-.9977	-.2474	-1.298	.0270

* $p < .05$

A series of simultaneous multiple regression analyses were completed for immediate recall on the Verbal Paired Associates subtest of the WMS-R (see Table 22). Immediate recall was calculated by averaging the proportion of easy and difficult word associates recalled on the immediate recall trial. When age alone was included in the

Table 22
Multiple Regression for Verbal Paired Associates Immediate Recall

Factor	Coefficient	Beta	t	r^2
Age Alone	-.1520	-.5144	-4.586*	.2646
Right Ear Auditory Variables Without Age				
FSR	.0013	.1588	1.011	.0129
C-P Ratio L	-.0002	-.0487	-.356	.0016
C-P Ratio R	-.0011	-.3077	-1.960	.0484
SNR	-.0001	-.0175	-.114	.0002
PTA	-.0040	-.3425	-2.177	.0597
TCR	-.0009	-.1160	-.646	.0053
Age with Right Ear Variables Entered First				
Age	-.0938	-.3145	-1.897	.0431
Left Ear Auditory Variables Without Age				
FSL	.0007	.0870	.546	.0035
C-P Ratio L	.0002	.0493	.389	.0018
C-P Ratio R	-.0007	-.2190	-1.644	.0320
SNL	.0012	.1521	1.108	.0145
TCL	.0014	.1832	1.169	.0162
PTA	-.0022	-.1898	-1.184	.0166
Age With Left Ear Variables Entered First				
Age	-.0920	-.3086	-1.934	.0421

* $p < .05$

equation, it accounted for a significant amount of variance (26.46%). When right ear auditory variables without age were included as predictor variables, no right ear auditory variables significantly predicted immediate recall performance (.02%-5.97%). Collectively, that set of predictors accounted for 35.7% of the variance. When age was

added to the equation after right ear variables had been entered, age did not account for a significant amount of unique variance (4.31%) beyond that accounted for by right ear variables. That set of predictors accounted for 40.02% of the variance. Next, a multiple regression analysis was computed including left ear auditory variables as predictors. No left ear auditory variables contributed significantly to the prediction of immediate memory performance on the Verbal Paired Associates subtest. Collectively, they accounted for 39.56% of the variance. When age was stepped into the equation, age did not account for a significant amount of variance (4.21%). That combination of variables accounted for 43.77% of the variance.

The delayed recall performance on the Verbal Paired Associates subtest was subject to a series of multiple regression analyses (see Table 23). Delayed recall performance was calculated by averaging the proportion of easy and difficult word associates for the delayed recall trial. When age alone was included in the equation, it accounted for a significant amount of variance (7.03%). When right ear auditory variables were included as predictor variables in the equation without age, no auditory variables accounted for a significant portion of unique variance. The right ear auditory variables collectively accounted for 24.65% of the variance. When age was included in the equation which included right ear variables, age no longer accounted for a significant amount of the variance (.2%), and the set of predictors accounted for 24.88% of the variance. A multiple regression analysis was then computed including left ear auditory variables as predictors, and this set of predictors accounted for 27.86% of the variance. Time Compressed Speech for the left ear accounted for a significant portion of unique variance

Table 23
Multiple Regression for Verbal Paired Associates Delayed Recall

Factor	Coefficient	Beta	t	r^2
Age Alone	-.0658	-.2651	-2.094*	.0703
Right Ear Auditory Variables Without Age				
FSR	.0002	.0316	.186	.0005
C-P Ratio L	-.0002	-.0606	-.409	.0024
C-P Ratio R	.0005	.1628	.958	.0135
SNR	.0006	.0088	.053	.0000
PTA	-0.0023	-.2325	-1.365	.0275
TCR	0.0023	.0012	1.867	.0515
Age with Right Ear Variables Entered First				
Age	-.0183	-.0729	-.393	.0023
Left Ear Auditory Variables Without Age				
FSL	.0010	.1535	.882	.0110
C-P Ratio L	-.0002	-.0450	-.325	.0015
C-P Ratio R	.0002	.0843	.579	.0047
SNL	-.0002	-.0334	-.223	.0007
TCL	.0024	.3702	2.161*	.0661
PTA	-.0012	.0017	-.630	.0056
Age With Left Ear Variables Entered First				
Age	.0010	.0042	.023	.0000

* $p < .05$

(6.61%). When age was added to the equation along with the left ear auditory variables, it no longer accounted for a significant portion of unique variance, and the set of predictors accounted for 27.87% of the variance.

A memory retention score on the Verbal Paired Associates subtest of the WMS-R was calculated for each subject by subtracting the delayed recall score from the immediate recall score and dividing that value by the immediate recall score. This memory retention score was subject to a series of multiple regression analyses (see Table 24). When age alone was included as a predictor variable, a significant portion of the variance was accounted for (13.87%). A second multiple regression analysis was completed including right ear auditory variables, and these predictors together accounted for 22.29% of the variance. Significant predictors were the C-P Ratio for the right ear (11.43%) and Time Compressed Speech Test for the right ear (6.71%). Examination of the beta weights revealed that higher scores on the C-P Ratio for the right ear were associated with poorer performance on the memory retention measure, indicating that central as compared to peripheral auditory processing deficits were associated with poor memory retention performance. As scores increased on Time Compressed Speech right, memory retention performance decreased on the Verbal Paired Associates subtest. A third multiple regression analysis was completed including age after the right ear auditory variables were included. Age was not a significant predictor in this equation, accounting for 4.19% of the variance. That set of predictors accounted for 26.48% of the variance. Another multiple regression analysis was completed with left ear auditory variables. None of these variables contributed significant portions of unique variance, and collectively, the set of predictors accounted for 22.43% of the variance. When age was added to the equation after the left ear auditory variables were included, age accounted for a significant portion

Table 24
Multiple Regression for Verbal Paired Associates Retention

Factor	Coefficient	Beta	t	r^2
Age Alone	-.1506	-.3724	-3.056*	.1387
Right Ear Auditory Variables Without Age				
FSR	.0012	.1054	.610	.0057
C-P Ratio L	-.0005	-.0888	-.590	.0053
C-P Ratio R	-.0022	-.4728	-2.739*	.1143
SNR	-.0005	-.0519	-.310	.0015
PTA	-.0034	-.2107	-1.218	.0226
TCR	-.0044	-.4142	-2.098*	.0671
Age with Right Ear Variables Entered First				
Age	-.1277	-.3099	-1.688	.0419
Left Ear Auditory Variables Without Age				
FSL	.0009	.0834	.462	.0032
C-P Ratio L	.0004	6.489	.005	.0000
C-P Ratio R	-.0014	-.2952	-1.956	.0582
SNL	.0029	.2618	1.684	.0431
TCL	-.0026	-.2381	-1.341	.0273
PTA	-.0015	-.0913	-.503	.0038
Age With Left Ear Variables Entered First				
Age	-.1542	-.3744	-2.082*	.0619

* $p < .05$

of the variance (6.19%), with increased age associated with poorer performance on the memory retention measure. That set of predictors accounted for 28.62% of the variance.

A series of multiple regression analyses were completed for immediate recall on the Logical Memory subtest of the WMS-R (see Table 25). This score was the mean of

Table 25
Multiple Regression for Logical Memory Immediate Recall

Factor	Coefficient	Beta	t	r^2
Age Alone	-.0001	-.5279	-4.733*	.2787
Right Ear Auditory Variables Without Age				
FSR	.0033	.0484	.316	.0012
C-P Ratio L	-.0140	-.4021	-3.015*	.1512
C-P Ratio R	.0002	.0086	.056	.0000
SNR	-.0044	-.0729	-.490	.0029
PTA	-.0247	-.2595	-1.693	.0343
TCR	.0083	.1331	.760	.0069
Age with Right Ear Variables Entered First				
Age	-.0001	-.4737	-3.089*	.0979
Left Ear Auditory Variables Without Age				
FSL	.0041	.0667	.418	.0021
C-P Ratio L	-.0132	-.3790	-2.985*	.1060
C-P Ratio R	-.0002	-.0057	-.042	.0000
SNL	-.0045	-.0677	-.493	.0029
TCL	.0109	.1711	1.090	.0223
PTA	-.0198	-.2088	-1.301	.0201
Age With Left Ear Variables Entered First				
Age	-.0001	-.4388	-2.855*	.0850

* $p < .05$

the immediate recall scores for Story A and Story B for each subject. Age alone was a significant predictor of immediate recall, and accounted for 27.87% of the variance. Increased age was associated with poorer performance on immediate recall. A second analysis was completed including right ear auditory variables as predictors. This set of

predictors accounted for38.93% of the variance. The C-P ratio for the left ear was a significant predictor, and accounted for 15.12% of the variance. Higher scores on the C-P ratio left were associated with poorer performance on immediate recall, indicating that central auditory deficits had the more deleterious consequences on immediate prose memory. When age was added to the equation which already contained right ear auditory variables, age was a significant predictor of immediate recall, and accounted for 9.79% of the variance. That set of predictors accounted for 48.72% of the variance. In an analysis which included left ear auditory variables without age, 39.36% of the variance was accounted for. The C-P ratio for the left ear accounted for a significant (10.60%) unique portion of the variance. Again, higher scores on the C-P ratio were associated with poorer performance on immediate recall. When age was added to the equation which included left ear auditory variables, age was a significant predictor, accounting for 8.50% of the variance. As age increased, immediate prose memory performance decreased. That set of predictors accounted for 47.86% of the variance.

Multiple regression analyses were also conducted for delayed recall on the Logical Memory subtest of the WMS-R (see Table 26). Delayed recall scores were calculated by averaging each subject's delayed recall scores for Story A and Story B. Age alone was a significant predictor, and accounted for 38.43 percent of the variance. A second multiple regression analysis was completed including right ear auditory variables as predictors, and 39.78% of the variance was accounted for. Pure tone average was a significant predictor of delayed prose recall, and accounted for 6.63 percent of unique variance. As hearing sensory thresholds increased, delayed prose memory performance decreased. Next, a

Table 26

Multiple Regression for Logical Memory Delayed Recall

Factor	Coefficient	Beta	t	r
Age Alone	-.0002	-.6199	-5.964*	.3843
Right Ear Auditory Variables Without Age				
FSR	.0091	.1228	.793	.0076
C-P Ratio L	-.0069	-.1825	-1.358	.0222
C-P Ratio R	-.0008	-.0269	-.174	.0004
SNR	.0037	.0563	.372	.0017
PTA	-.0371	-.3606	-2.346*	.0663
TCR	.0040	.0598	.339	.0014
Age with Right Ear Variables Entered First				
Age	-1.2392	-.4645	-2.892*	.0878
Left Ear Auditory Variables Without Age				
FSL	.0230	.3370	2.249*	.0526
C-P Ratio L	-.0053	-.1404	-1.184	.0146
C-P Ratio R	-.0003	-.0068	-.054	.0000
SNL	.0106	.1451	1.135	.0134
TCL	.0035	.0504	.339	.0012
PTA	-.0110	-.1940	-1.292	.0173
Age With Left Ear Variables Entered First				
Age	-.0001	-.4306	-2.947*	.0782

* $p < .05$

multiple regression analysis was completed including age as a predictor after the right ear auditory variables were included. This set of predictors accounted for 48.56 % of the variance. Age accounted for a significant portion of the variance (8.78%) after effects of right ear auditory variables were accounted for. A fourth multiple regression analysis was

complete including left ear auditory variables, which collectively accounted for 48.06% of the variance. Filtered Speech for the left ear was a significant predictor, accounting for 5.26 percent of unique variance. Low scores on Filtered Speech for the left ear were associated with poorer performance on delayed prose recall. When age was included as a predictor along with left ear auditory variables, age was a significant predictor, and accounted for 7.82 percent of the variance. That set of predictors accounted for 55.88% of the variance.

A memory retention score for the Logical Memory subtest was computed for each subject by subtracting the delayed recall score from the immediate recall score and dividing this difference by the immediate memory score. A series of multiple regression analyses was completed using this variable, and results are presented in Table 27. Age alone was a significant predictor, and accounted for 11.66 percent of the variance. Increased age was associated with better memory retention scores. A second multiple regression analysis was computed including right ear auditory variables. This set of predictors accounted for 23.02% of the variance. Pure tone average was a significant predictor, and accounted for 6.49 percent of unique variance. Higher sensory hearing thresholds were associated with poorer performance on the retention measure. When age was included in the equation which already included right ear variables, 24.03% of the variance was accounted for, and age no longer accounted for a significant portion (1.01%) of the variance. Next, a multiple regression analysis was completed using left ear auditory variables as predictor variables. That set of predictors accounted for 39.37% of variance. Filtered Speech for the left ear (8.84% of unique variance), the C-P ratio for the left ear

Table 27
Multiple Regression for Logical Memory Retention

Factor	Coefficient	Beta	t	r²
Age Alone	.1402	.3415	2.743*	.1166
Right Ear Auditory Variables Without Age				
FSR	-.0006	-.0539	-.308	.0015
C-P Ratio L	-.0017	-.2917	-1.920	.0687
C-P Ratio R	.0009	.0198	.113	.0002
SNR	-.0024	-.2307	-1.347	.0279
PTA	.0058	.3567	2.053*	.0649
TCR	.0012	.1102	.552	.0047
Age with Right Ear Variables Entered First				
Age	.0659	.1573	.806	.0101
Left Ear Auditory Variables Without Age				
FSL	-.0047	-.4371	-2.70*	.0884
C-P Ratio L	-.0019	-.3198	-2.497*	.0756
C-P Ratio R	-.0002	-.0352	-.261	.0008
SNL	-.0039	-.3414	-2.473*	.0741
TCL	.0019	.1762	1.097	.0146
PTA	.0022	.1381	.851	.0088
Age With Left Ear Variables Entered First				
Age	.0610	.1457	.8557	.0089

* $p < .05$

(7.56% of unique variance) and Speech in Noise for the left ear (7.41% of unique variance) were significant predictors. Low scores on the Filtered Speech test and Speech in Noise Test were associated with better prose memory retention; higher scores on the C-P ratio for the left ear were associated with poorer prose memory retention. When age

was added to the equation which already included left ear auditory variables, age was not a significant predictor, and accounted for only .89 percent of unique variance. That set of predictors accounted for 40.27% of the variance.

On the California Verbal Learning Test (CVLT), the slope of the learning curve from the 5 learning trials was calculated for each subject. This variable was subject to a series of multiple regression analyses (see Table 28). Age alone was not a significant predictor of the slope of the learning curve on the CVLT, and accounted for only 1.50 percent of the variance. This is consistent with the absence of an age by trials interaction previously reported for the ANOVA which was conducted in order to examine age differences in performance on the CVLT. When right ear variables without age were included as predictor variables, 10.66% of the variance was accounted for. The C-P ratio for the right ear accounted for a significant portion (7.88%) of unique variance. An examination of the beta weights revealed that higher scores on the C-P ratio for the right ear were associated with lower scores on the slope variable, indicating that poorer learning was associated with central auditory involvement. When age was stepped into the equation which already included right ear auditory variables, age was not a significant predictor, accounting for 5.05 percent of the variance. That set of predictors accounted for 15.71% of the variance. When left ear auditory variables were included in the equation without age, Speech in Noise for the left ear was a marginally significant predictor, accounting for 6.28 percent of unique variance. As performance on Speech in Noise left increased, the slope value increased. That set of predictors accounted for 12.64% of the variance. When age was added to the equation which already contained left ear auditory

Table 28

Multiple Regression for CVLT Slope of Learning Trials

Factor	Coefficient	Beta	t	r^2
Age Alone	.1582	.1223	.930	.0150
Right Ear Auditory Variables Without Age				
FSR	.0013	.0361	.193	.0007
C-P Ratio L	.0009	.0501	.308	.0017
C-P Ratio R	-.0059	-.3919	-2.100*	.0788
SNR	.0001	.0031	.017	.0005
PTA	.0008	.0151	.082	.0001
TCR	-.0113	-.3378	-1.579	.0446
Age with Right Ear Variables Entered First				
Age	.4455	.3387	1.714	.0505
Left Ear Auditory Variables Without Age				
FSL	-.0006	-.0164	-.086	.0001
C-P Ratio L	.0033	.1738	1.130	.0223
C-P Ratio R	-.0032	-.2154	-1.337	.0312
SNL	.0122	.3159	1.896	.0628
TCL	.0013	.0070	.0379	.0006
PTA	.0116	.2238	1.157	.0234
Age With Left Ear Variables Entered First				
Age	.4286	.3259	1.679	.0475

* $p < .05$

variables, age was not a significant predictor, and accounted for 4.75 percent of unique variance. That set of predictors collectively accounted for 17.40% of the variance.

A series of multiple regression analyses was then carried out for the intercept value of the learning curve of the CVLT learning trials (see Table 29). The intercept value

Table 29
Multiple Regression for CVLT Intercept for Learning Trials

Factor	Coefficient	Beta	t	r^2
Age Alone	-2.8914	-.5320	-4.743*	.2830
Right Ear Auditory Variables Without Age				
FSR	.0168	.1094	.662	.0061
C-P Ratio L	-.0234	-.2986	-2.075*	.0599
C-P Ratio R	.0113	.1801	1.094	.0167
SNR	-.0059	-.0405	-.256	.0009
PTA	-.0698	-.3206	-1.971	.0541
TCR	.0163	.1166	.617	.0053
Age with Right Ear Variables Entered First				
Age	-2.7661	-.5027	-3.055*	.1113
Left Ear Auditory Variables Without Age				
FSL	.0330	.2343	1.397	.0261
C-P Ratio L	-.0235	-.3000	-2.230*	.0665
C-P Ratio R	.0090	.1426	1.011	.0137
SNL	-.0332	-.2059	-1.412	.0267
TCL	.0097	.0675	.379	.0019
PTA	-.0697	-.3204	-1.893	.0480
Age With Left Ear Variables Entered First				
Age	-2.8118	-.5110	-3.221*	.1169

* $p < .05$

reflects level of memory performance, with higher values indicating that more words were recalled. Age alone was a significant predictor of the intercept, and accounted for 28.30 percent of the variance. An examination of the beta weights showed that as age increased, the intercept value decreased, so that older subjects recalled fewer words than younger

subjects. This is consistent with the significant main effect of age reported previously for our ANOVA. A second multiple regression was computed using right ear auditory variables as predictors, which accounted for 30.41% of the variance. The C-P ratio for the left ear was a significant predictor, and accounted for 5.99 percent of unique variance. Examination of the beta weights showed that higher scores on C-P ratio for the left ear were associated with lower intercept values on the CVLT learning trials, so that central auditory involvement was associated with poorer recall performance. When age was added to the equation which already contained right ear auditory variables, the set of predictors accounted for 41.55% of the variance, and age was a significant predictor, accounting for 11.13 percent of unique variance. Increasing age was associated with lower intercept values. Next, a multiple regression analysis was completed using left ear auditory variables as predictors. The C-P ratio for the left ear was a significant predictor, and accounted for 6.65 percent of unique variance. Higher scores on the C-P ratio for the left ear were associated with lower values on the intercept. Collectively, these variables accounted for 33.09% of the variance. When age was added to this equation which included left ear auditory variables, the set of predictors accounted for 44.78% of the variance, and age was a significant predictor, accounting for 11.69 percent of unique variance. Again, increased age was associated with lower intercept values.

For each subject, the scores on the five learning trials of the CVLT were averaged to create a new variable. This variable was subject to a series of multiple regression analyses (see Table 30). Age alone was a significant predictor of the mean performance across the 5 learning trials. Age accounted for 28.74 percent of the variance, and

Table 30

Multiple Regression for Average of CVLT Learning Trials

Factor	Coefficient	Beta	t	r^2
Age Alone	-.0002	-.5361	-4.795*	.2874
Right Ear Auditory Variables Without Age				
FSR	.0207	.1627	1.040	.0135
C-P Ratio L	-.0206	-.3160	-2.319*	.0671
C-P Ratio R	-.0063	-.1214	-.778	.0076
SNR	-.0056	-.0461	-.307	.0012
PTA	-.0674	-.3727	-2.419*	.0730
TCR	-.0176	-.1513	-.846	.0089
Age with Right Ear Variables Entered First				
Age	-.0001	-.3126	-1.905*	.0431
Left Ear Auditory Variables Without Age				
FSL	.0313	.0182	1.718	.0341
C-P Ratio L	-.0137	-.2111	-1.688	.0330
C-P Ratio R	-.0007	-.0143	-.109	.0001
SNL	.0033	.0249	.184	.0004
TCL	.0136	.1139	.687	.0055
PTA	-.0348	-.1924	-1.223	.0173
Age With Left Ear Variables Entered First				
Age	-.0002	-.3336	-2.150*	.0498

* $p < .05$

increased age was associated with lower average recall scores. Next, a multiple regression analyses was completed including only right ear auditory variables as predictors, and 37.58% of the variance was accounted for. The C-P ratio for the left ear was a significant predictor, with higher scores on the C-P ratio for the left ear associated with lower

average learning trial scores, associating central auditory involvement with poorer performance. The C-P ratio for the left ear accounted for 6.71 percent of the variance. The Pure Tone Average was also a significant predictor of average learning, and accounted for 7.30 percent of the variance. As hearing sensory thresholds increased, there was a decrease in average performance on the learning trials of the CVLT. When age was included after right ear auditory variables, age was a significant predictor, and accounted for 4.31 percent of the variance after the effects of right ear auditory variables had been accounted for. That set of variables accounted for 41.88% of the variance. When left ear auditory variables without age were included as predictors, no left ear auditory variables accounted for a significant portion of unique variability in average performance on the learning trials of the CVLT. Collectively, the left ear auditory variables accounted for 42.21% of the variance. When age was added to the equation which already contained the left ear auditory variables, 47.20% of the variance was accounted for, and age was a significant predictor, accounting for 4.98 percent of the variance.

The analysis of the short delayed free recall trial of the CVLT (see Table 31) revealed that age alone was a significant predictor, and accounted for 16.90 percent of the variance. Increased age was associated with decreased performance on the short delayed free recall trial. When right ear auditory variables were used as predictors, no right ear auditory variables accounted for significant portions of unique variance in short delayed free recall, and this set of variables together accounted for 23.63% of the variance. When age was stepped into the equation which already contained right ear auditory variables, age was a significant predictor, and accounted for 6.23 percent of unique variance. That

Table 31
Multiple Regression for CVLT Short Delay Correct

Factor	Coefficient	Beta	t	r^2
Age Alone	-3.9464	-.4111	-3.434*	.1690
Right Ear Auditory Variables Without Age				
FSR	.0584	.2137	1.248	.0233
C-P Ratio L	-.0348	-.2495	-1.673	.0419
C-P Ratio R	.0110	.1785	1.043	.0163
SNR	-.0474	-.1940	-1.167	.0204
PTA	-.1215	-.3194	-1.862	.0519
TCR	.0106	.0426	.218	.0007
Age with Right Ear Variables Entered First				
Age	-3.685	-.3778	-2.107*	.0623
Left Ear Auditory Variables Without Age				
FSL	.0362	.1456	.815	.0099
C-P Ratio L	-.0246	-.1764	-1.241	.0230
C-P Ratio R	.0239	.2136	1.429	.0305
SNL	-.0463	-.1739	-1.129	.0190
TCL	.0560	.2195	1.248	.0232
PTA	-.1015	-.2667	-1.483	.0328
Age With Left Ear Variables Entered First				
Age	-3.6007	-.3691	-2.072*	.0602

* $p < .05$

set of variables accounted for 29.85% of the variance. Next, a multiple regression analysis was completed with left ear auditory variables as predictors, and this set of predictors accounted for 23.91% of the variance. No left ear auditory variables were significant predictors. When age was added to the equation which already contained left ear auditory

variables, age was a significant predictor of short delayed free recall, and accounted for 6.02 percent of the variance. That set of predictors accounted for 29.93% of the variance.

Scores on the long delayed free recall trial of the CVLT were subject to the same series of multiple regression analyses. Results are presented in Table 32. The first

Table 32
Multiple Regression for CVLT Long Delay Correct

Factor	Coefficient	Beta	t	r^2
Age Alone	-3.4286	-.5305	-4.767*	.2815
Right Ear Auditory Variables Without Age				
FSR	.0235	.1281	.842	.0084
C-P Ratio L	-.0187	-.1995	-1.506	.0268
C-P Ratio R	-.0095	-.1259	-.828	.0081
SNR	-.0167	-.1016	-.688	.0056
PTA	-.1226	-.4797	-3.150*	.1172
TCR	-.0123	-.0736	-.423	.0021
Age with Right Ear Variables Entered First				
Age	-1.5039	-.2296	-1.409	.0230
Left Ear Auditory Variables Without Age				
FSL	-.0029	-.0176	-.115	.0001
C-P Ratio L	-.0082	-.0879	-.722	.0057
C-P Ratio R	-.0029	-.0389	-.304	.0010
SNL	.0064	.0356	.270	.0008
TCL	.0556	.3247	2.159*	.0509
PTA	-.0848	-.3320	-2.159*	.0509
Age With Left Ear Variables Entered First				
Age	-1.2956	-.1978	-1.266	.0173

* $p < .05$

analysis examined the effects of age alone in predicting long delayed free recall. Age alone was a significant predictor, and accounted for 28.15 percent of the variance. As age increased, long delayed recall decreased. Next, a multiple regression analysis was completed including right ear auditory variables without age, and the set of predictors accounted for 39.76% of the variance. The Pure Tone Average accounted for a significant portion of unique variance, with higher auditory sensory thresholds associated with poorer performance on the long delayed free recall trial. Pure Tone Average accounted for 11.72 percent of the variance. When age was stepped into the equation along with right ear auditory variables, age no longer was a significant predictor, accounting for only 2.30 percent of the variance, and the set of variables accounted for 42.06% of the variance. Next, an analysis was completed including left ear auditory variables without age, and these variables accounted for 44.35% of the variance. Time Compressed Speech for the left ear was a significant predictor, accounting for 5.09 percent of unique variance. Increased scores on Time Compressed Speech left were associated with better performance on long delayed free recall. Pure Tone Average was also a significant predictor, with lower hearing sensory thresholds associated with better performance on long delayed free recall. Pure Tone Average also accounted for 5.09 percent of unique variance. When age was added to the equation which contained left ear auditory variables, age was not a significant predictor, and accounted for only 1.73 percent of the variance. That set of predictors accounted for 46.08% of the variance.

A memory retention score was calculated for each subject on the CVLT. This score was calculated by subtracting long delayed recall from the short delayed recall and

dividing this difference by the short delayed recall score. This retention variable was subject to a series of multiple regression analyses, and results are presented in Table 33. No auditory variables were significant predictors, nor was age a significant predictor either alone or in combination with auditory variables. Age alone accounted for 0% of the

Table 33
Multiple Regression for CVLT Retention Ratio

Factor	Coefficient	Beta	t	r^2
Age Alone	.0347	.0720	.550	.0052
Right Ear Auditory Variables Without Age				
FSR	.0029	.2103	1.138	.0226
C-P Ratio L	3.2915	.0468	.291	.0015
C-P Ratio R	-2.0825	-.0370	-.200	.0007
SNR	-.0018	-.1489	-.830	.0120
PTA	.0057	.2958	1.598	.0046
TCR	-1.9520	-.0156	-.074	.0001
Age with Right Ear Variables Entered First				
Age	-.1104	-.2249	-1.128	.0221
Left Ear Auditory Variables Without Age				
FSL	.0021	.1703	.881	.0136
C-P Ratio L	6.7914	.0967	.628	.0069
C-P Ratio R	-3.7137	-.0066	-.041	.0000
SNL	-.0024	-.1763	-1.058	.0196
TCL	.0011	.0879	.462	.0037
PTA	.0058	.3010	1.547	.0418
Age With Left Ear Variables Entered First				
Age	-.1205	-.2455	-1.241	.0266

* $p < .05$

variance, right ear auditory variables collectively accounted for 11.02% of the variance, right ear auditory variables along with age accounted for 13.23 % of the variance, left ear auditory variables accounted for 10.92% of the variance, and left ear auditory variables along with age accounted for 13.59% of the variance.

Next, a series of multiple regression analyses was completed for the recognition trial of the CVLT (see Table 34). The first analysis was computed for items correct on the recognition trial. Age alone was a significant predictor, and accounted for 11.06 percent of the variance. Examination of the beta weights revealed that as age increased, number of items correctly recognized decreased. Next, a multiple regression analysis was completed including right ear auditory variables, which accounted for 28.47% of the variance. The C-P ratio for the right ear was a significant predictor, and accounted for 14.40 percent of unique variance. Higher scores on C-P ratio for the right ear were associated with lower scores on the recognition trial. The Time Compressed Speech Test for the right ear was also a significant predictor and accounted for 9.39 percent of unique variance. Examination of the beta weights showed that increased scores on the Time Compressed Speech Test right were associated with a lower number of items correctly recognized. Next, age was stepped into the equation which already contained right ear auditory variables. Age was no longer a significant predictor, and accounted for only .05 percent of the variance. That set of predictors accounted for 28.52% of the variance. Another multiple regression analysis was completed including left ear auditory variables without age. This set of variables accounted for 21.74% of the variance, and the C-P ratio for the right ear was a significant predictor, accounting for 7.40 percent of unique

Table 34

Multiple Regression for CVLT Recognition

Factor	Coefficient	Beta	t	r^2
Age Alone	-.9643	-.3325	-2.685*	.1106
Right Ear Auditory Variables Without Age				
FSR	.0123	.1515	.914	.0117
C-P Ratio L	.0015	.0366	.254	.0009
C-P Ratio R	-.0177	-.5307	-3.204*	.1440
SNR	-.0062	-.0848	-.527	.0039
PTA	-.0339	-.2986	-1.800	.0454
TCR	-.0364	-.4901	-2.587*	.0939
Age with Right Ear Variables Entered First				
Age	-.1001	-.0344	-.190	.0005
Left Ear Auditory Variables Without Age				
FSL	-.0056	-.0758	-.418	.0027
C-P Ratio L	.0065	.1552	1.076	.0178
C-P Ratio R	-.0111	-.3328	-2.195*	.0740
SNL	.0154	.1938	1.241	.0236
TCL	-.0068	-.0894	-.501	.0039
PTA	-.0242	-.2132	-1.169	.0210
Age With Left Ear Variables Entered First				
Age	-.2752	-.0945	-.503	.0039

* $p < .05$

variance. Higher scores on the C-P ratio were associated with lower recognition performance. When age was added to this equation, age no longer was a significant

predictor, and accounted for only .39 percent of the variance. That set of predictors accounted for 22.13% of the variance.

Next, a series of multiple regression analyses was completed on the errors on the recognition trial of the CVLT. The first series of analyses was conducted for the incorrect stimuli which were from the B list and shared categories with the A list (List B, Shared). Age alone was not a significant predictor of this type of error, and accounted for none of the variance. Neither was age a significant predictor in combination with right or left ear auditory variables; age and right ear variables together accounted for 5.18% of the variance, while age and left ear variables together accounted for 10.51% of the variance. No auditory variables significantly predicted this type of error; right ear variables alone accounted for 5% of the variance, and left ear variables accounted for 10.48% of the variance. Results are presented in Table 35.

A series of multiple regression analyses was than carried out for the error type which contained words from List B which did not share categories with words from List A (List B, Nonshared). Age was a significant predictor and accounted for 10.39 percent of the variance. As age increased, the number of errors increased. Next, a multiple regression analysis was completed including right ear auditory variables. The Filtered Speech Test for the right ear was a significant predictor and accounted for 8.30 percent of unique variance. As performance on the Filtered Speech Test increased, the number of this type of error decreased. That set of predictors accounted for 30.08% of the variance. When age was stepped into the equation along with right ear auditory variables, 32.76% of the variance was accounted for. Age no longer was a significant predictor and

Table 35
Multiple Regression for CVLT Recognition Error Type List B Shared

Factor	Coefficient	Beta	t	r^2
Age Alone	.2143	.1315	1.010	.0173
Right Ear Auditory Variables Without Age				
FSR	.0013	.0279	.146	.0001
C-P Ratio L	-.0013	-.0563	-.339	.0021
C-P Ratio R	.0026	.1393	.730	.0099
SNR	-.0073	-.1766	-.953	.0169
PTA	-.0037	-.0571	-.298	.0017
TCR	-.0006	-.0143	-.065	.0001
Age with Right Ear Variables Entered First				
Age	.1054	.0641	.307	.0018
Left Ear Auditory Variables Without Age				
FSL	.0015	.0364	.188	.0006
C-P Ratio L	-.0019	-.0809	-.524	.0048
C-P Ratio R	.0025	.1323	.816	.0117
SNL	-.0134	-.2987	-1.788	.0561
TCL	-.0059	-.1378	-.722	.0092
PTA	-.0114	-.1781	-.913	.0121
Age With Left Ear Variables Entered First				
Age	.0481	.0293	.145	.0004

* $p < .05$

accounted for only 2.67 percent of unique variance. Next, a multiple regression analysis was completed including left ear auditory variables as predictors. This set of predictors accounted for 21.92% of the variance. The C-P ratio for the left ear was a significant predictor, and accounted for 3.90 percent of unique variance. Lower scores on C-P ratio

for the left ear were associated with an increased number of errors of this type, indicating that peripheral auditory involvement increased errors of this type. When age was stepped into the equation along with the left ear auditory variables, age no longer was a significant predictor, and accounted for 2.12 percent of the variance. That set of predictors collectively accounted for 24.04% of the variance. Results are presented in Table 36.

The next error type examined consisted of words which were from neither List A nor List B, but were from one on the categories of List A (Neither list, same category). Results are presented in Table 37. Age alone was a significant predictor and accounted for 7.96 percent of the variance. Examination of the beta weights showed that as age increased, the number of this type of error also increased. Next, a multiple regression analysis was completed including right ear auditory variables, and these variables accounted for 5% of the variance. The C-P ratio for the right ear was a significant predictor and accounted for 6.61 percent of unique variance. Low scores on the C-P ratio for the right ear were associated with increased errors of this type, suggesting peripheral auditory involvement being associated with errors of this type. When age was added to the equation which already contained right ear auditory variables, the set of predictors accounted for 5.18% of the variance. Age was no longer a significant predictor, and accounted for only 2.22 percent of unique variance. Next, a multiple regression analysis was completed including left ear auditory variables. This set of variables accounted for 10.47% of the variance. Again, the C-P ratio for the right ear was a significant predictor which accounted for 6.43% of unique variance. Low scores on C-P ratio for the right ear were associated with increased numbers of this type of error. The Time Compressed

Table 36
<u>Multiple Regression for CVLT Recognition Error Type List B Nonshared</u>

Factor	Coefficient	Beta	t	r^2
Age Alone	.1786	.3223	2.593*	.1039
Right Ear Auditory Variables Without Age				
FSR	-.0064	-.4030	-2.461*	.0830
C-P Ratio L	-.0021	-.2590	-1.815	.0452
C-P Ratio R	.0012	.1851	1.131	.0175
SNR	.0014	.0955	.600	.0049
PTA	.0002	.0093	.056	.0000
TCR	-.0023	-.1564	-.835	.0096
Age with Right Ear Variables Entered First				
Age	.1397	.0991	1.410	.0267
Left Ear Auditory Variables Without Age				
FSL	.0008	.0533	.295	.0013
C-P Ratio L	-.0025	-.3055	-2.120*	.0039
C-P Ratio R	.0015	.2335	1.542	.0364
SNL	.0010	.0677	.434	.0029
TCL	-.0056	-.3789	-2.126*	.0692
PTA	.0022	.1019	.559	.0048
Age With Left Ear Variables Entered First				
Age	.1238	.2193	1.182	.0212

* $p < .05$

Speech Test for the left ear was also a significant predictor which accounted for 6.10% of unique variance. Examination of the beta weights revealed that as Time Compressed Speech performance increased, this type of error decreased. When age was added to the

Table 37
Multiple Regression for CVLT Recognition Error Type Nonshared, Same Category

Factor	Coefficient	Beta	t	r^2
Age Alone	.3705	.2823	2.241*	.0796
Right Ear Auditory Variables Without Age				
FSR	.0014	.0387	.228	.0008
C-P Ratio L	.0048	.2523	1.704	.0428
C-P Ratio R	-.0055	-.3595	-2.116*	.0661
SNR	-.0052	-.1555	-.942	.0131
PTA	.0113	.2172	1.276	.0242
TCR	-.0084	-.2475	-1.274	.0240
Age with Right Ear Variables Entered First				
Age	.3011	.2254	1.232	.0222
Left Ear Auditory Variables Without Age				
FSL	-.0049	-.1431	-.854	.0096
C-P Ratio L	.0043	.2260	1.693	.0376
C-P Ratio R	-.0048	-.3102	-2.212*	.0643
SNL	-.0039	-.1079	-.747	.0073
TCL	-.0124	-.3555	-2.154*	.0610
PTA	.0016	.0309	.183	.0004
Age With Left Ear Variables Entered First				
Age	.2048	.1534	.888	.0104

* $p < .05$ level

equation, age was no longer a significant predictor and accounted for 1.04% of the variance, and the predictor variables together accounted for 10.52% of the variance.

The next error type examined consisted of words which were from neither list but were phonetically similar to words from List A (see Table 38). Age did not significantly

Table 38

Multiple Regression for CVLT Recognition Errors of the Phonetically Similar Type

Factor	Coefficient	Beta	t	r^2
Age Alone	.0804	.1336	1.027	.0178
Right Ear Auditory Variables Without Age				
FSR	.0028	.1755	.933	.0158
C-P Ratio L	.0005	.0666	.407	.0230
C-P Ratio R	.0008	.0117	.062	.0001
SNR	.0022	.1526	.836	.0126
PTA	.0074	.0041	.3368	.0578
TCR	-.53714	-.0372	-.173	.0005
Age with Right Ear Variables Entered First				
Age	-.0459	-.0813	-.396	.0029
Left Ear Auditory Variables Without Age				
FSL	-.0021	-.1467	-.741	.0101
C-P Ratio L	.0006	.0681	.432	.0034
C-P Ratio R	-.0001	-.0110	-.121	.0003
SNL	.0021	.1358	.796	.0116
TCL	.0019	.1317	.676	.0084
PTA	.0055	.2483	1.246	.0285
Age With Left Ear Variables Entered First				
Age	-.0465	-.0824	-.401	.0030

* $p < .05$

predict this type of error, neither alone nor in combination with auditory variables. In addition, none of the auditory variables significantly predicted this type of error. Age alone accounted for 1.78% of the variance, the right ear auditory variables accounted for 7.85% of the variance, age and right ear variables together accounted for 8.14% of the

variance, left ear variables accounted for 6.60% of the variance, and age and left ear variables accounted for 6.90% of the variance.

The final error type consisted of words which were semantically and phonetically unrelated to words from List A. No subject made an error of this type. Therefore, age did not significantly predict this type of error, nor did any combination of auditory variables with or without age.

Because the older subjects had higher WAIS-R Vocabulary scores than the younger subjects, the analyses were repeated for each dependent variable including Vocabulary as a predictor along with age and the auditory variables. Results are presented in Table 39. For each depdendent variable, the amount of variance uniquely

Table 39
Age Effects After Contolling for Vocabulary Effects

	Age	Age after Voc	Age after Right	Age after R.& V	Age after Left	Age af. L.& V
DSF	.1939*	.2163*	.0413	.0388	.0598	.0733*
	.1939***	.1938	.2870	.2851	.2256	.2391
DSB	.1062*	.1693*	.0250	.0608	.0270	.0650*
	.1062	.1870	.2487	.2995	.1980	.2585
VPA						
Imm	.2646*	.2599*	.0431	.0321	.0421	.0412
	.2646	.2734	.4002	.4002	.4377	.4394
VPA						
Del	.0703*	.0606*	.0023	.0014	.0000	.0001
	.0703	.0703	.2488	.2489	.2787	.2797
VPA						
Ret	.1387*	.1473*	.0419	.0312	.0619	.0614
	.1387	.1498	.2648	.2649	.2862	.2892
LM						
Imm	.2787*	.3426*	.0979*	.1475*	.0850*	.1238*
	.2787	.3432	.4872	.5394	.4786	.5208

Table 39 continued

LM Del	.3843*	.4416*	.0878*	.1351*	.0782*	.1180*
	.3843	.4422	.4856	.5347	.5588	.6023
LM Ret	.1166*	.1187*	.0101	.0163	.0089	.0165
	.1166	.1228	.2403	.2468	.4027	.4123
CVLT Ave	.2874*	.2984	.0431*	.0396	.0498*	.0559*
	.2874	.3053	.4188	.4201	.4720	.4787
CVLT SD	.1690	.1304*	.0623*	.0401	.0602*	.0416
	.1690	.1708	.2985	.3001	.2993	.3009
CVLT LD	.2815*	.2903*	.0230	.0219	.0173	.0237
	.2815	.2984	.4206	.4215	.4608	.4675
CVLT Ret	.0052	.0156	.0221	.0095	.0266	.0342
	.0052	.0275	.1323	.1370	.1354	.1411
CVLT Rec	.1106*	.1719*	.0005	.0080	.0039	.0242
	.1106	.1871	.2852	.3064	.2213	.2738

*$p<.05$; **Multiple R squared values appear under individual r squared values

attributable to age is presented when age alone has been included in the equation, as well as after age and Vocabulary have been included. Next is presented the amount of variance uniquely attributable to age after right ear auditory variables have been included in the analysis, with and without Vocabulary. Underneath the r squared values is presented the Mutiple R squared values for each equation. As can be seen in the table, the pattern of significance was similar with and without the inclusion of Vocabulary.

CHAPTER IV

DISCUSSION

The purpose of the present study was to explore the degree to which peripheral and central auditory processing variables contributed to age-associated decline in auditory memory performance on several memory measures which are widely included in neuropsychological assessment batteries. While most explanations for age-associated decline on such measures have primarily focused on cognitive processing variables, another possible contributing factor is auditory processing efficacy. Previous exploratory studies in this area have been limited by a number of factors, including reliance on self-report measures of auditory processing, addressing peripheral but not central auditory functioning, and examining the relationship between auditory processing and cognitive functioning only within a restricted age range without including a comparison group of younger adults. The present study attempted to address these issues by assessing auditory performance using standard audiological evaluation procedures, by addressing central as well as peripheral auditory functioning, and by including a comparison group of young adults.

In examining auditory processing deficits associated with aging, it is important to consider central as well as peripheral auditory functioning. Peripheral hearing loss is a loss of hearing sensitivity, which affects hearing for sounds of low intensities. The degree of

peripheral hearing loss may vary across sound frequencies. This type of hearing loss reflects primarily cochlear involvement. Conversely, central auditory functioning involves speech discrimination skill, and deficits affect speech intelligibility. Central auditory processing deficits reflect primarily central nervous system involvement. Central auditory processing is assessed by examining word discrimination skill for stimuli whose speech signals have been degraded in a number of ways, for example, through the use of temporal alteration, spectral distortion, amplitude distortion, or through the addition of a competing signal.

The auditory assessment battery selected for use in the present study measured both types of auditory functioning. Peripheral auditory measures included: 1) the Pure Tone Average (PTA), which is the mean of the hearing sensitivity thresholds for each ear at 3 frequencies which are consistent with the frequency of typical speech sounds; and 2) the Speech in Quiet Test, which measures speech discrimination under optimal listening conditions. Central auditory measures included: 1) the Speech in Noise Test, which measures speech discrimination with the addition of a competing signal; 2) the Time Compressed Speech Test, which measures the perception of speech which has been temporally altered; and 3) the Filtered Speech Test, which measures the perception of speech which has been subjected to spectral distortion. The Central-Peripheral Ratio (C-P Ratio) was also calculated using the Speech in Quiet Test and the Synthetic Sentence Sentence Identification Test. Low scores on the C-P Ratio are indicative of primarily peripheral involvement, while high scores on this measure are indicative of primarily central involvement.

Previous research has demonstrated that all of the auditory measures which were included in the present study are sensitive to age-associated decline in auditory performance (Marshall, 1981; Thompson, 1987). Consistent with past research, younger subjects showed better performance on all auditory processing measures included in the study. Older subjects performed more poorly than their younger counterparts on measures of both peripheral and central auditory functioning.

Consistent with previous research, age associated performance declines were also observed on the memory measures included in the present study. One memory measure was the California Verbal Learning Test (CVLT). On this measure, older subjects evidenced poorer performance than younger subjects on the encoding/ acquisition phases of memory processing; older subjects showed poorer recall across all 5 learning trials, as well as poorer immediate recall of the distracter list. Older subjects were observed to have a similar learning curve to that of younger subjects, indicating that their ability to benefit from repeated presentations was not impaired; they simply recalled fewer words on each trial than their younger counterparts.

Older subjects also made more intrusive errors (producing extra-list words) on the 5 learning trials and on immediate recall of the distracter list as compared to the younger subjects. On the delayed recall trials, older subjects made a greater number of intrusive errors compared to the younger subjects, and this was more marked on the long delayed recall versus the short delayed recall. Thus, older subjects produced a greater number of extra-list words under all test conditions, and this trend was especially evident after a long delay.

There were no age differences in perseverative errors (repeating the same item 1 or more times within a recall trial) across the 5 learning trials, on the distracter list, nor on the delayed recall trials. More perseverative errors were made on later learning trials as compared to initial learning trials, presumably because as subjects recalled more items, it became more difficult to remember which words had already been produced. In addition, both groups made more perseverative errors during the free recall condition as compared to the more structured cued recall condition.

Age differences were not observed in the number of semantically clustered responses produced during free recall across the 5 learning trials. Therefore, the poorer recall performance of the older subjects on these trials cannot be explained by a failure to efficiently utilize an effective memory strategy. However, there were age differences in the use of semantic clustering on immediate recall of the interference list, and on the delayed recall trials. Older subjects produced fewer semantically clustered responses than younger subjects in the latter test conditions, indicating that they did not utilize semantic clustering as a memory strategy to the same degree as the younger subjects did in these test conditions. It was observed that both groups, but especially the younger group, made better use of this organization strategy after the long delay than after the short delay. Decreased use of this strategy on the short delayed recall trial was perhaps due to interference effects created by having completed the distracter list trial immediately prior to the short delayed recall trial. Thus, both groups made less efficient use of this organization strategy after a distracter trial, and this adverse effect tended to be more long-lasting in older as compared to younger subjects.

On the delayed recall trials, the younger subjects showed better performance than the older subjects for both free and cued recall, with the older subjects benefiting more than younger subjects from the additional structure inherent in the cued recall task. The proportion of items retained on long delayed recall as compared to the number of items learned on the highest learning trial was calculated to examine memory retention. It was observed that older subjects retained a proportion of previously learned items that was nearly similar to that retained by younger subjects over the long delay period. Therefore, age differences were less evident in the retention stage than in the acquisition stage of memory operations. Both groups had better memory retention on cued as compared to free recall, and this was especially true of older subjects, suggesting that the retrieval stage of memory operations may also be implicated in age differences in memory processing.

Recognition memory was found to be stronger for younger adults as compared to older adults. Younger subjects obtained more correct responses on the recognition trial. Older subjects, in addition to missing more items which had been included on the learning list, made more false positive errors than younger subjects on distracter words which were from neither List A nor the distracter list, but which belonged to one of the semantic categories represented in List A; and on words which were from List B but did not belong to one of the semantic categories represented in List A.

Three subtests from the Wechsler Memory Scale-Revised (WMS-R) were also administered. These subtests all measure auditory memory. On the Digit Span subtest, younger subjects performed better than older subjects on both Digits Forward and Digits Backward.

On the Verbal Paired Associates (VPA) subtest, younger subjects recalled a greater number of word associations than the older subjects. Older subjects had disproportionately greater difficulty on the difficult word associations relative to the easy word associations, and on immediate recall relative to delayed recall. Thus, VPA results provided evidence for age-associated declines which were especially evident in the encoding and acquisition phase of memory processing, particularly for more difficult material.

On the Logical Memory subtest, younger subjects showed stronger memory performance, on both immediate and delayed recall. Both groups showed sensitivity to the semantic structure of the text, as evidenced by the presence of the levels effect (Brown & Smiley, 1977). In other words, main ideas were more frequently recalled than less essential details. Both age groups had better recall of the stories immediately after presentation than after a 30 minute delay interval. Because older subjects did not show a disproportionate decline on the delayed recall trial as compared to younger subjects, impaired memory retention over time was not a significant contributing factor to the age differences observed on this measure. Rather, results suggested that age differences on this measure were apparent on the initial encoding phase.

Thus, age associated performance decline was demonstrated on both auditory and memory measures. It was therefore considered appropriate to complete a series of multiple regression analyses for the purpose of exploring the degree to which age deficits in auditory processing efficacy mediated the observed age associated decline in memory performance. Results of the present study suggested that in some instances, age no longer

accounted for a significant portion of the variance in memory performance when auditory variables were factored into the equation. In other instances, auditory variables greatly reduced the portion of the variance uniquely accounted for by age.

On both Digit Span Forward and Digit Span Backward, age alone accounted for significant portions of variance. When auditory variables were entered into the equations, age no longer accounted for significant portions of the variance in performance on either of these measures.

On the Verbal Paired Associates test, age was a significant predictor of performance on the measures of immediate recall, delayed recall, and memory retention. Right ear auditory variables accounted for a significant portion of the variance for the memory retention measure, while left ear auditory measures accounted for significant portions of the variance for immediate and delayed recall. When auditory measures were included along with age as predictor variables, age no longer accounted for a significant portion of variability in performance on immediate or delayed recall. With the addition of auditory variables as predictors, age continued to be a significant predictor of memory retention, although the amount of variance uniquely accounted for by age was greatly reduced.

On the Logical Memory Test, age accounted for a significant portion of the variance for immediate recall, delayed recall, and memory retention. Both right and left ear auditory variables were significant predictors in all of these conditions. The amount of variance uniquely accounted for by age was greatly reduced by the addition of auditory variables as predictors. After the addition of auditory variables as predictors, age

continued to be a significant predictor of immediate and delayed recall, although the amount of variance accounted for by age was much reduced by the addition of the auditory variables. On the memory retention measure, age no longer accounted for a significant portion of the variance after the addition of the auditory predictor variables.

On the California Verbal Learning Test (CVLT), age was not a significant predictor of the slope of the learning curve; in other words, the older subjects did not differ from the younger subjects in terms of rate of learning. However, right and left ear central auditory measures did emerge as significant predictors of the slope of the learning curve, suggesting that efficacy of the central auditory system was related to rate of learning over successive presentation. Age was a significant predictor of the number of words recalled on the learning trials. Right and left ear auditory variables were also significant predictors of performance on the learning trials, and the addition of the auditory measures as predictor variables greatly reduced the amount of variance uniquely accounted for by age.

Age was a significant predictor of performance on short delayed recall on the CVLT. While auditory variables alone did not account for a significant portion of the variability in this measure, the addition of the auditory measures as predictor variables did reduce the amount of variance accounted for by age. Age was also a significant predictor of performance on long delayed recall, as were both right and left ear auditory measures. When auditory measures were included along with age as predictor variables, age no longer accounted for a significant amount of variance in long delayed recall.

On the recognition trial of the CVLT, age alone was a significant predictor of the number of items correctly identified, as were right and left ear auditory measures alone. When auditory variables were included along with age in the analysis, age no longer accounted for a significant portion of the variance in word recognition. Similarly, age alone and right and left ear auditory measures alone were predictive of 2 types of recognition errors, namely, errors which consisted of those distracter words which were from List B but did not belong to any of the categories included in List A; and those distracter words which were from neither List A nor List B, but belonged to one of the semantic categories from List A. When auditory measures were included as predictor variables along with age, age no longer accounted for a significant portion of the variance on these measures.

Several auditory variables consistently emerged as significant predictors of memory performance, and these variables included both central and peripheral auditory measures for both right and left ears. The Central-Peripheral Ratio and the Pure Tone Average most often emerged as significant predictor variables. Time Compressed Speech was also an important predictor variable, followed by Speech in Noise and Filtered Speech. Interestingly, the auditory processes reflected by the most predictive measures appeared to coincide with several complaints commonly made by older individuals regarding their hearing, namely, that others often do not speak loudly enough, that others often seem to mumble, and that others often speak too quickly (Weinstein & Ventry, 1983). The frequency with which older adults cite these hearing related complaints, along with the correlation of decline in memory functioning and measures sensitive to these

auditory complaints underscore the importance of the relationship between these variables.

It may be noted that several times, and more specifically when peripheral auditory sensitivity was a factor, central auditory measures entered into the same equation predicted recall in the reverse direction of what might have been expected. For example, better performance on the Speech in Noise Test was predictive of poorer performance on Digits Backward. This may be more readily understood by considering a phenomenon commonly associated with peripheral, or cochlear hearing loss. Individuals with this type of hearing loss, which affects hearing sensitivity, have a reduced ability to perceive low intensity sounds. Therefore, sounds must be louder before they are perceived by these individuals. However, these individuals perceive increases in sound volume as becoming disproportionately louder than they would be perceived by individuals without cochlear hearing loss. Standard audiological testing procedures involve presenting central auditory tests such as the Speech in Noise Test at a presentation level which is 40dB above the subject's sensory hearing threshold in order to minimize effects of their sensory hearing loss on their central auditory performance. For the same reason, memory tests were also presented to these individuals at this same increased presentation level. Therefore, these individuals may have received a significant advantage on a given memory task, and subsequently performed better on that measure.

It was noteworthy that age differences in memory performance were particularly apparent during the encoding phase of memory operations. This is supportive of the hypothesis that auditory processing efficacy plays an important role in memory performance. Results provided evidence for the hypothesis that a degraded auditory signal

demands more working memory processing capacity during the encoding phase of memory operations, and that this increased demand reduces memory processing efficiency. Increased processing demands may reduce encoding efficiency, and result in less information being encoding into the memory system during the initial acquisition phase. Older adults consistently evidenced reduced auditory processing efficacy, indicating that they required more processing capacity to simply perceive the stimulus words as compared to younger adults. Auditory processing variables therefore played an important role in mediating age differences in memory encoding. Also, compared to younger adults, older adults were not observed to have poorer memory retention relative to the amount of information which was initially encoded. This pattern is consistent with the auditory processing hypothesis, as auditory processing would affect primarily the initial encoding phase of memory processing.

In contrast to the present findings, it has been reported (Tun & Wingfield, 1993) that on dichotic listening tasks using limited auditory materials such as digit lists, there are age differences in performance which cannot easily be attributed to peripheral auditory deficits. For example, following the simultaneous presentation of different material to each ear, older adults often show poorer recall for auditory stimuli presented to the second ear to be reported. Tun and Wingfield pointed out that recall of material presented to the second ear is poorer than recall of material presented to the first ear, while a decline in auditory sensitivitiy would affect recall for both ears. However, in the present study, age differences in Digit Span performance were completely eliminated after auditory variables had been accounted for. It appeared that a combination of peripheral and central auditory

variables were important predictors of performance on Digit Span, both Forward and Backward.

Results of the present study have several implications. It has been pointed out that while individuals with impaired hearing may be aware that they do not always accurately interpret auditorially presented information, they may attribute these lapses to impaired cognitive functioning rather than to a form of sensory dysfunction (Colsher & Wallace, 1990). It was observed in the present study that measures which are sensitive to complaints commonly made by older individuals regarding their ability to process auditory information (i.e. that others mumble, do not speak loudly enough, or speak too quickly; Weinstein & Ventry, 1983), often emerged as significant predictors of memory performance, and more specifically, of performance in the encoding phase of memory operations. Results suggest that as older individuals present with memory complaints, it is important to consider not only the possibility of memory impairment, but also the possibility of an age associated impairment in auditory functioning. Results also underscore the importance of screening for central auditory functioning as well as for peripheral auditory functioning. Older individuals with this constellation of presenting complaints may well benefit from compensatory strategies appropriate for individuals with auditory dysfunction, such as lip reading, training in how to use contextual information, or hearing aids (Colsher, 1990).

One limitation of the present study was the somewhat limited sample size. Tabachnick and Fidell (1989) recommended that a minimum ratio of five cases to each independent variable be included in any multiple regression analysis. This requirement was

met. However, Tabachnick and Fidell (1989) point out that because of the width of the errors in estimating correlations within small samples, it would be ideal to have as many as 20 times more cases than independent variables. Another limitation was that the older subjects had completed more years of education and had higher vocabulary scores than the younger subjects. Previous studies have demonstrated that age associated decline in text processing and memory performance is smaller in highly educated individuals with high verbal ability as compared to the declines observed in more representative samples of older adults (Taub, 1979; Daneman & Carpenter, 1980; Bolla-Wilson & Bleecker, 1986; Petros et. al, 1989). While an attempt was made to match older and younger subjects on variables including level of education and verbal ability in order to ensure that age differences would be observed on memory measures, the older adults included in the present study had completed more years of education and had stronger vocabulary knowledge than their younger counterparts on these measures. Because age differences were observed on measures of memory and auditory functioning, it was considered appropriate to complete subsequent analyses exploring the role of auditory processing in accounting for variability in memory performance using data from the present sample. Further, it has been pointed out (Wingfield et al.,1992; Riggs, Wingfield, & Tun, 1993) that it is not uncommon in aging research for the older adults to have superior vocabulary ability when compared to the younger subjects, and that because stronger vocabulary ability is generally associated with better performance on verbal memory measures, that stronger vocabulary ability in the older subjects allows more confidence in findings when age differences are found. However, it will be important for the present work to be

replicated using a larger sample of older adults who are more representative of the general population in educational attainment and vocabulary ability. It is possible that vocabulary ability or level of education affect the relationship between memory and auditory processing efficacy.

The auditory processing hypothesis could also be extended to other populations of individuals who experience more severe memory deficits than those associated with normal aging, such as those that occur with head injury or dementia. It may also be useful to study the role of auditory compensatory strategies in improving memory performance in groups of individuals who commonly experience deficits in the encoding phase of memory processing.

The present study examined the relationship between auditory processing efficacy and auditory memory. It would be interesting to extend this work by exploring the relationship between cognitive functioning and other sensory systems, such as the visual system. Perhaps subtle decline in functioning of the visual system is correlated with reduced performance on visual memory measures. It is also possible that sensory functioning in the auditory and visual systems may impact cognitive functioning in an interactive manner, perhaps by way of one system compensating for weaknesses in the other system.

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