Central Auditory Dysfunction in Older Persons With Memory Impairment or Alzheimer Dementia

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Objective: To assess the effect of memory impairment on central auditory function.

Design: Case-control study.

Setting: The Virginia Merrill Bloedel Hearing Research Center, Seattle, Washington.

Participants: The study cohort of 313 volunteers from a dementia surveillance research program comprised 3 groups: (1) controls without memory loss (n=232); (2) memory-impaired participants with mild memory impairment but without dementia (n=64); and (3) memory-impaired participants with a dementia diagnosis (n=17).

Main Outcome Measures: Behavioral central auditory tests were the Synthetic Sentence Identification with Ipsilateral Competing Message test, the Dichotic Sentence Identification test, and the Dichotic Digits Test. Memory impairment was indicated by a total score on the Cognitive Ability Screening Instrument of 86 or less, or a total score of 90 or less with a memory subscale score of 10 or less.

Results: The mean score on each central auditory test worsened significantly across the 3 memory groups even after adjustment for age and peripheral hearing status (P<.05); it was poorest in the dementia group and moderately reduced in the memory-impaired group compared with the control group. Heterogeneity of results was noted in all 3 groups.

Conclusions: Central auditory function was affected by even mild memory impairment. The Dichotic Sentence Identification test in the free report mode was the most sensitive test for the presence of memory impairment. We recommend that central auditory testing be considered in the evaluation of older persons with hearing complaints as part of a comprehensive, individualized program to assist their needs in both the aural rehabilitative and the cognitive domains.


Behavioral auditory testing using standard test protocols provides a clinical opportunity to examine brain functions involved in understanding and interpreting speech. We previously demonstrated that central auditory processing (CAP) dysfunction in the presence of adequate peripheral auditory function, as judged by competing message testing, is highly prevalent in persons with a diagnosis of Alzheimer dementia (AD). The present report extends those observations and provides additional evidence about the possible mechanism(s) involved.

CAP dysfunction is a general term that is applied to persons whose hearing in quiet settings is normal or near normal yet who have substantial hearing difficulty in the presence of auditory stressors such as competing noise and other difficult listening situations. People with CAP dysfunction typically note difficulty in hearing a single conversation amid several competing conversations (“cocktail party effect”). Central auditory testing is important in evaluating individuals with hearing difficulty, because poor CAP ability, per se, is not helped by amplification and requires alternative rehabilitation strategies. The prevalence of CAP dysfunction increases with age. Because cochlear function also declines with age, CAP tests are often performed in the presence of reduced cochlear function due to age-related hearing loss (presbycusis), which requires care in interpretation.

Common causes of CAP dysfunction are aging, dementia, stroke, head injury, neoplasm, and developmental disturbances. CAP dysfunction may be suspected by below-normal responses on one or more of a heterogeneous group of au-
Cognitive impairment and to determine risk factors for these disorders. The details of the ACT study population have been previously described. A second type involves listening to 2 different signals (words [the Dichotic Sentence Identification (DSI) test] or numbers [the Dichotic Digits Test (DDT)]) presented simultaneously, one in each ear (dichotic presentation). These CAP test paradigms evaluate how well an individual manages competing signals, a task that requires adequate short-term memory and the ability to shift attention rapidly.

In the present study, we asked whether abnormal CAP results, which have been previously demonstrated in persons with Alzheimer-type dementia, could also be observed in persons with memory loss but with none of the other criteria for a diagnosis of AD. If CAP dysfunction should prove to be associated with early cognitive decline, then tests for CAP dysfunction, over and above their importance for auditory rehabilitation, might have value in identifying persons who are at risk for cognitive decline and dementia.

METHODS

OVERVIEW

We report the findings from 313 members of a dementia surveillance cohort aged 71 through 99 years (mean age, 80 years) obtained by comprehensive audiometry (behavioral thresholds and word recognition, central auditory tests, and electrophysiologic measures) to determine whether poor performance on central auditory tests was associated with memory deficits, auditory pathway deficits (as measured electrophysiologically), or both.

STUDY POPULATION

Participants were enrolled in the Adult Changes in Thought (ACT) study, a population-based longitudinal study of aging and dementia that began in 1994. The ACT study was designed to assess the incidence of AD, other types of dementia, and cognitive impairment and to determine risk factors for these conditions. The details of the ACT study population have been previously described. The ACT participants who volunteered were screened by the hearing study staff over the telephone to confirm eligibility, specifically that the participant’s hearing and functional status were good enough to complete the test protocol. After the step-by-step details of participation were explained, eligible participants were scheduled for a 3.5-hour test session or for 2 shorter sessions on separate days. At the end of the test session, participants received a copy of their hearing test, counseling about their test results, and information about assistive listening devices and local hearing resources as needed.

Informed consent was obtained from all participants using forms and procedures approved by the Human Studies Committee of the University of Washington and the institutional review board of the Group Health Cooperative, Seattle, Washington. For ACT subjects with an established diagnosis of cognitive impairment, proxy consent via a family member or friend was obtained in addition to the participant’s consent.

ELIGIBILITY CRITERIA

Of 445 persons who were evaluated on site and 90 persons who were telephone screened, 337 participants were enrolled in the hearing study. The 198 ACT participants who were not enrolled after initial contact either refused to participate or were ineligible. Enrolled participants were subsequently excluded from the present analysis if their peripheral auditory function was inadequate to perform central behavioral testing; ie, if they had (1) a pure-tone threshold average (PTA) of 0.5, 1.0, or 2.0 kHz that differed by more than 25 dB between ears; (2) a PTA greater than 48 dB HL (hearing level) in either ear; (3) a word recognition score of less than 70% in either ear; or (4) evidence of middle ear disease on examination. Twenty-four participants were excluded based on inadequate peripheral auditory function, resulting in a final sample size of 313 participants for analysis.

COGNITIVE ASSESSMENT

Cognitive function was evaluated using the Cognitive Ability Screening Instrument (CASI). The CASI consists of 25 items that cover 9 cognitive domains (attention, mental manipulation, orientation, short-term memory, long-term memory, language ability, visual construction, list-generating fluency, and abstraction and judgment). Total scores range from 0 to 100, with higher scores indicating better cognitive performance. Follow-up examinations, including CASI screening, are conducted biennially with the ACT cohort to identify incident cases of dementia and AD. Participants scoring 87 or higher on the CASI are considered dementia free. Those scoring 86 or below on the CASI undergo a standardized clinical and neuropsychological evaluation, which is reviewed at a consensus diagnosis meeting attended by a geriatric physician, neurologist, research nurse, and neuropsychologist. For this study, we considered that CASI scores of 90 or lower may be indicative of possible cognitive decline, although that score did not trigger the diagnostic evaluation for dementia in the parent study.

GROUP CLASSIFICATION

In the current hearing study, 2 groups of ACT participants were enrolled. The memory-impaired (target) group had a total CASI score of 86 or less or 90 or less with a CASI memory subscale score of 10 or less. Clinical Dementia Rating scores of 0.5 (questionable dementia) or 1.0 (mild dementia) also qualified participants for the target group. We refer to the target group as memory impaired throughout this report. Participants who did not show signs of memory impairment that were substantial enough to qualify for the target group were enrolled in the control (non–memory-impaired) group. The target group was further subdivided into no-AD and AD-positive subgroups. Participants who met the National Institute of Neurological and Communicative Diseases and Stroke–Alzheimer Disease and Related Disorders Association criteria for possible or probable AD at the consensus conference were considered incident AD cases.

OTHER MEASURES

Other variables collected from study participants included age, sex, years of education, apolipoprotein E genotype (APOE4), a risk factor for AD), depression, physical exercise, and self-reports of coronary heart disease and cerebrovascular disease. The latter was defined as a self-report of stroke, cerebral hemorrhage, and small strokes or transient ischemic attacks. Depression was measured by the 20-item Center for Epidemiological...
logic Studies Depression Scale, with scores above 16 indicating the presence of depressive symptoms. Age was noted at the time of the hearing testing. Sex, education, and APOE4 were noted on enrollment into the ACT study. All other variables were assessed at the ACT biennial visit that occurred closest in time to the hearing testing.

AUDITORY TESTING

Tympanometry and Pure-Tone Thresholds

Conventional 226-Hz probe-tone tympanometry was conducted to assess middle ear status after otoscopic clearance. Standard audiometric measures were obtained with the participant seated in a sound-treated room listening through insert earphones (ER-3A; Etymotic Research Inc, Elk Grove Village, Illinois) to signals generated by an audiometer (No. 16; Grason-Stadler Inc, Milford, New Hampshire) calibrated to American National Standards Institute S3.6-1996 specifications. Conventional pure-tone air conduction thresholds were obtained from 250 to 8000 Hz, and pure-tone bone conduction thresholds were obtained at 500 and 1000 Hz.

Word Recognition Testing

The Auditec (Auditec of St Louis, Maplewood, Missouri) compact disc recording of the Central Institute for the Deaf Auditory Test W-22 was used for word recognition testing at a presentation level of 90 dB HL or at the upper limit of comfortable loudness if this was less than 90 dB HL. Twenty-five words were presented to each ear, with speech-noise masking in the opposite ear at a presentation level 20 dB below the word recognition test level. A second 25-word list was presented at a level 10 dB lower if the participant scored less than 80% on the first trial to exclude auditory adaptation as a cause of the reduced word recognition.

Central Auditory Test Battery

Three behavioral central auditory tests were chosen for this study based on robustness, standardization, ease of use, likelihood of being affected by dementia, and testing of different central auditory skills. The tests were the SSI-ICM, a monaural speech test with competing message, and 2 dichotic tests involving speech: the DSI test and the DDT. The sequence of test presentation was randomized to prevent an order effect. Speech materials recorded by Auditec on compact disc were used for the 3 tests. Completion time was 30 minutes or less for facile subjects and up to 1 hour for those needing extra time.

The SSI-ICM Test

The SSI-ICM test requires the listener to select which 1 of 10 nonsense sentences was presented against a background of an interesting narrative presented by the same talker. The competing narrative is presented to the same ear as the sentence and is referred to as the SSI-ICM. A practice presentation of 1 to 3 lists was completed at 50 dB above the PTA with a +10-dB signal-to-noise ratio. Participants had to score at 80% or above to proceed. The actual test stimulus was at a 0-dB signal-to-noise ratio using the same presentation level. Although up to 30 presentations may be necessary to reach an asymptote, only 1 list of 10 sentences was presented for participants scoring 90% or better; 2 lists were presented if the score was 80% or better; otherwise, 3 lists were presented. Since raw SSI-ICM test scores decrease with age and hearing level (peripheral presbycusis), we used a presentation level 50 dB above the PTA and used insert earphones to enhance high-frequency audibility and to avoid collapsing ear canals. To obtain optimal performance from the participants, pauses between presentations were taken as needed for slow responders. Correct identification of 80% or more of 10 to 30 sentence presentations is considered normal performance. The SSI-ICM test is sensitive to cognitive decline and AD.

The DSI Test

The DSI test uses 6 of the same sentences as the SSI-ICM test but presents 1 sentence to each ear simultaneously at 50-dB sensation level, and the participant is asked to select from a printed list which 2 sentences were heard. Fifer et al showed that the test is resistant to the effects of sensorineural hearing loss below 50 dB HL. The DSI test is administered in both a free and a directed mode. In the directed mode, only the sentence heard in test ear is noted, whereas in the free mode, the sentences heard in both ears are reported. Five presentations are used if the score is 100%; otherwise, another 5 sentences per ear are administered. Scores are better in the directed mode than in the free mode, and the right ear scores are normally higher in adults than the left ear scores, presumably due to age-related corpus callosum dysfunction. Normal scores are 80% correct and above.

The DDT

The DDT is a widely used dichotic test to screen for central auditory dysfunction. In the present study, it was given at 50 dB above the PTA. Following the practice round, 40 numbers (1-10, excluding 7) were presented in pairs to each ear simultaneously. If all numbers were recognized correctly, a score of 100% (40 x 2.5) was given. The DDT is relatively easy to administer, is not greatly affected by moderate hearing loss, and commonly reveals abnormal results in persons with AD. Strouse et al demonstrated acceptable test-retest reliability of the DDT in 10 people with mild to moderate AD. Normal scores for adults are 90% and above.

Electrophysiologic Tests

A battery of electrophysiologic tests were administered to assess auditory-evoked potentials. The tests were used to evaluate the auditory brainstem responses, middle latency responses, and late latency responses. The results will be reported separately.

COGNITIVE TESTING

Additional neuropsychological tests, including the Trail-Making Test, the Stroop Color and Word Test, and the Clock-Drawing Test, were also conducted with enrolled subjects. The results of these tests will be reported separately.

STATISTICAL METHODS

The peripheral auditory function was assessed, and the behavioral CAP tests were scored on both the left and the right ear of each study participant. For each CAP test, the analysis used the poorer of the 2 scores from the left and right ears. In multivariate analyses, which adjusted for peripheral auditory function, we adjusted for the pure-tone threshold measured in the ear with the lower CAP score, even if that was not the ear with the lower peripheral auditory function.
We used χ² tests and analysis of variance models to assess differences in demographic characteristics and peripheral audiomeric measures between the 2 target groups. When the overall test for group differences was significant, post hoc analyses assessed differences between each of the target groups compared with the control group. Linear regression models were used to assess differences in mean CAP scores across target groups. Models were adjusted for age at hearing testing and for pure-tone threshold. To assess the ability of the CAP scores to identify participants with memory impairment, we computed the receiver operating characteristic (ROC) curve associated with each of the CAP tests. The ROC curve illustrates the trade-off between the sensitivity and the specificity of a test, as the test threshold is varied. CAP test scores of less than 80% are typically considered abnormal. However, ROC curve analysis allows us to consider other cut points and to examine the overall discriminative ability of the 3 CAP tests across all cut points. Also, we considered the ROC results for a composite test, defined as the lowest score on any of the 3 CAP tests, to see if this simple combination of test results would significantly increase the ability of the CAP tests to identify participants with memory impairment. A Stata statistical software package (Version 7.0; Stata Corp, College Station, Texas) was used for all data analyses.

**Table 1** summarizes the demographic characteristics and peripheral audiomeric measures of the study sample by memory impairment group. As expected, the mean age in the 2 target groups was greater than that of the control group. Also, the number of years of education was greater in the control group than in the target groups. There were no statistically significant differences between groups by sex, race, cardiovascular or cerebrovascular disease, or frequency of exercise. The results of the electrophysiologic tests (data not shown) did not vary by memory group. The target groups had significantly worse peripheral hearing than the control group, with the PTA significantly poorer in both the better and the worse ears, and the word recognition score was significantly poorer in the worse ears. Therefore, adjustment for pure-tone thresholds was used in evaluating group scores on the CAP tests. There were no ears with otoscopic or tympanometric evidence of middle ear effusion, perforation, or otitis media. The vast majority of audiograms displayed the typical presbycusis pattern with a gradually sloping, monotonic, high-frequency threshold elevation. **Table 2** illustrates the mean scores on each CAP test for the target groups. Differences in group means, both unadjusted and adjusted for age and pure-tone threshold, are also reported in Table 2. The mean CAP scores in both of the target groups were significantly lower than those in the control group on all CAP tests. The DSI test showed the largest difference between groups, with the adjusted mean 31.9 points lower in the target group without AD and 38.8 points lower in the AD group than the mean in the control group. The SSI-ICM test showed the largest difference in means between the 2 target groups (adjusted mean difference, 17.1), suggesting that the SSI-ICM may be the test most sensitive to change when memory impairment has progressed to a diagnosis of AD. Even though the group means showed a robust and consistent degradation of test scores across the 3 cognitive groups, there was considerable heterogeneity among the test results, with an overlap of outcomes among comparable participants: some targets had normal results on all tests; some had abnormal results on one test but not on the others; and some had abnormal results on all tests (data not shown). Scores below 80 are typically considered abnormal for the CAP tests. The percentages of target/control participants with abnormal test results (ie, <80%) were 79%/42%, 84%/42%, and 84%/47% on the SSI-ICM test, the DSI test, and the DDT, respectively. **Table 3** reports the sensitivity and specificity of each of the CAP tests and of the composite test (defined as the minimum of the 3 test scores) for discriminating between targets and controls using this threshold. The sensitivity of the DSI test was 83.8%, meaning that 83.8% of the target group scored below the 80% threshold. Of those in the control group, 58.6% scored above the 80% threshold (specificity, 58.6%). The results on the SSI-ICM and the DSI tests were similar to those on the DSI test. Table 3 also reports the sensitivity and specificity for each test using the cut point of 50% to define an unambiguously abnormal test result. At this threshold, the SSI-ICM and DSI tests had similar sensitivity (35.7% and 52.5%, respectively) and specificity (85.8% and 93.5%, respectively), whereas the DDT test had similar specificity (92.6%) but at the expense of greatly reduced sensitivity (25.9%). The **Figure** illustrates the ROC curves for the CAP tests and the composite test for differentiating between controls and targets. The ROC curve plots the sensitivity and specificity of each test for all possible choices for the threshold value. The ROC curve for the DSI test is...
Figure. The area under the curve is shown for each test: the Dichotic Sentence Identification (DSI) test (area 0.83), the Synthetic Sentence Identification with Ipsilateral Competing Message (SSI-ICM) test (area 0.78), the Dichotic Digits Test (DDT) (area 0.75), and the composite test (lowest score on any of the 3 tests) (area 0.86).

This study sought to evaluate whether abnormal central auditory processing test results, which have been previously demonstrated in persons with Alzheimer-type dementia, could also be observed in persons with memory loss but none of the other criteria for a diagnosis of AD. Our hypotheses were confirmed. Test performance was consistently the worst in the target group with dementia, but each of the 3 CAP tests also showed poorer performance in the target group without dementia than in the control group, even after adjustment for age, hearing threshold, and word recognition score. These findings illustrate the robust association of even early memory loss and tests of central auditory function.

The recent emergence of therapies aimed at delaying the progression of AD has generated interest in new methods for early diagnosis of AD, such as imaging and cognitive screening. Based on the observations from the Framingham Dementia Cohort, in which very poor performance on the SSI-ICM preceded the diagnosis of AD by several years, we suggested that central auditory testing might warrant consideration as a screening test. The present study showed that the results of central auditory tests are also frequently abnormal in memory-impaired nondemented older individuals. Given that about half of older adults with isolated memory loss progress to frank dementia, identifying early cases has considerable merit. While adding central auditory tests to a screening cognitive battery might have value, the logistical implications of such an approach have not been established or evaluated. However, the addition of central auditory tests to a cognitive screening battery might have value.
auditory testing to the initial evaluation of older individuals seeking hearing assistance is a simple supplement to existing services, one that also has value for auditory rehabilitation. Therefore, alerting audiologists, otologists, and geriatricians to the potential value of central auditory testing is one of the goals of this report.

Although memory decline and age-related hearing loss often coexist, a causal relationship was not established by our study. Our working hypothesis that memory impairment and central auditory dysfunction have a common cause—frontal lobe dysfunction—is supported but not proved by the present findings. We do not yet know whether the combined presence of memory impairment and central auditory dysfunction conveys a greater risk of dementia than either condition alone, even though a prudent interpretation of these findings would raise concern that such could be the case. The ACT study protocol includes serial cognitive testing of all participants. Comparing the future changes in the present participants in relation to CAP tests will shed light on these questions.

There are distinct advantages to bear in mind when the role of CAP testing is being considered as part of the health assessment of older adults. The CAP tests are relatively simple to administer because standardized, prerecorded materials are used. Unlike many cognitive tests, patients find the hearing tests pleasant and nonthreatening and are generally interested in knowing their individual results. The tests are given in training mode to familiarize the patient with the process and to ensure sufficient comprehension of the test paradigm. The resources and experience needed to administer these tests and to interpret their results are widely available in audiologic and otologic practices.

There are some limitations to the tests, however. Patients must have sufficient vision to read the number of the sentence that was heard and sufficient peripheral auditory function to understand speech at a comfortable loudness level. Because of the need to ensure adequate peripheral auditory function, CAP testing would not be suitable for widespread use. Nevertheless, adding these tests to conventional audiometric measures for the elderly is very feasible, and we recommend that they be considered and evaluated in the periodic health assessment of persons older than 65 years, particularly those in the 75-and-older group and those with a history of memory problems.

CAP testing is not routinely performed for individuals who are seeking assistance for failing hearing. We believe that CAP testing is warranted for 3 reasons: (1) CAP dysfunction contributes to difficulty of hearing in noise settings (a common reason hearing aids are not worn); (2) CAP dysfunction may be a sign of cognitive decline, which also affects auditory rehabilitation; and (3) early identification of persons at risk for dementia will assume greater importance as new therapies for AD emerge.

The results of CAP testing in the elderly may be influenced by the effects of age and acquired conditions on peripheral function, which may coexist with central auditory dysfunction. For that reason, we limited our testing to individuals with peripheral function that was deemed adequate for the central auditory tests presented, and we used other measures to optimize auditory performance of our participants, such as expanding the test time, to minimize test method artifacts. Therefore, we believe that our results truly reflect the impact of memory loss on central auditory function rather than peripheral hearing or test-taking ability.

Although the majority of poor CAP test results occurred in the target group, some individuals in the control group also demonstrated poor CAP test results. Whether these persons may have had central auditory difficulties independent of memory loss (pure CAP dysfunction) or whether these cognitively normal, audiatory- abnormal patients may represent occult cases of memory impairment or preclinical dementia cannot be determined as yet. If our hypothesis is correct that CAP is a sign of early cognitive decline, we would expect a higher proportion of the individuals with CAP dysfunction to show cognitive decline on serial testing than those without CAP dysfunction. We will be able to test this assumption over the next few years as part of the ACT study.

In conclusion, persons with memory impairment identified by low scores on the CASI perform more poorly on central auditory tests than do control subjects with normal CASI scores. The DSI test demonstrated the greatest sensitivity to memory loss followed by the SSI-ICM test and the DDT. The ease and availability of central auditory test materials in audiologic and otologic clinics make it readily possible to perform such testing as a baseline for older persons with possible memory loss. Patients seeking hearing assistance should also receive CAP tests because amplification does not improve poor hearing performance due to CAP dysfunction and because cognitive dysfunction adversely affects standard auditory rehabilitation strategies.

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