Auditory Processing Deficits in Alzheimer’s Disease

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Abstract

The purpose of the current study was to study auditory processing (monaural closure, monaural separation, binaural integration, and binaural separation) skills in subjects with- and without- Alzheimer’s disease. Ten individuals with Alzheimer’s disease and seven individuals without Alzheimer’s disease participated in central auditory processing tasks (degraded speech and dichotic speech). Reduced auditory processing skills were found for the Alzheimer’s group and a pronounced left ear deficit was found for this group (re: control group without Alzheimer’s disease). Results support models that postulate breakdown in information processing mechanisms in the central auditory nervous system in individuals with cognitive decline.

Keywords: Alzheimer’s disease; Auditory processing; Central auditory dysfunction

1. Introduction

Alzheimer's disease (AD) is the most common cause of mental decline in the elderly population and the most common form of dementia. Alzheimer's disease is defined by the National Institute on Aging (NIA) as an irreversible, progressive brain disease that slowly destroys memory and thinking skills and eventually, the ability to carry out the simplest tasks of daily living. AD affects 4.5 million Americans and nearly half the population over the age of 85 years old has some of the common characteristics of AD. Histopathological landmarks of AD are described as neurofibrillary tangles and neuritic ß-amyloid plaques, which are found most abundantly in the auditory association cortex and subcortical nuclei, with fewer plaques in the primary auditory cortical areas located in the temporal lobes (Esiri, Pearson, & Powell, 1986; Lewis, Campbell, Terry, & Morrison, 1987). Given this histopathological evidence of temporal lobe involvement, breakdown is expected in the auditory system in individuals with AD but is a largely understudied issue. This problem needs particular attention since prevalence figures for AD are expected to triple by the year 2050 and costs projected to be as much as $1.1 trillion (Alzheimer’s Association).
According to recently published findings from a working group of the National Institute of Aging and Alzheimer's Association, new diagnostic criteria have been identified for individuals with dementia related to AD (McKhann et al., 2011). Individuals with AD dementia can be classified into three categories: 1) probable AD dementia, 2) possible AD dementia, and 3) probable or possible AD dementia with pathophysiological evidence. The first two types are intended for use in a clinical setting and can be diagnosed on the basis of specific clinical criteria (e.g., onset, amnestic and non-amnestic deficits, progression of disease etc.) while the third type is intended for use in a research setting only and is based on pathophysiologic evidence (biomarkers, neuropathology etc.).

The relationship between peripheral (sensorineural) hearing loss and AD has been studied previously and the interaction of these two medical conditions has been found to interact with each other to cause greater disability than either one alone. While it is accepted that the strong interaction between these conditions can be devastating to communication and somewhat attributed to age-related decline of the cochlea/auditory nerve, it appears that individuals with AD have a greater probability of peripheral hearing loss. Palmer et al. (1999) showed that the incidence of hearing loss among individuals with a mental disorder is almost two times the number of persons with normal mental capacity. Lin et al. (2011) compared with normal hearing, the hazard ratio for dementia was 1.89 for mild hearing loss, 3.00 for moderate hearing loss, and 4.94 for severe hearing loss.

To compound the problems of peripheral hearing loss and AD-related dementia, central auditory deficits have also been found and attributed to decline of neural function associated with changes in the central auditory nervous system (brainstem nuclei, corpus callosum, cerebral cortex). Strouse, Hall, & Berger (1995) found dichotic listening deficits consistent with diffuse cortical involvement associated with Alzheimer's disease. Gates et al. (2008) performed central auditory tests in three groups of individuals with: 1) no memory loss, 2) mild memory loss and 3) dementia. They found central auditory dysfunction to be the highest in dementia group followed by mild memory loss group, even after adjusting for peripheral hearing loss and age. Gates et al. (2011) found that persons diagnosed with Alzheimer's disease performed the poorest on APD tests, indicating that: 1) there is a robust association between early memory loss and tests of central auditory function and 2) central auditory speech-processing deficits may be an early manifestation of probable Alzheimer's disease and possibly a harbinger of the onset of clinical dementia. While central auditory function declines in individuals with AD, they tend to show intact sustained auditory attention skills needed for most central auditory tests (Krishnamurti, Drake, & King, 2011).

The current study was completed to study the relation between central auditory dysfunction and cognitive decline in a group of individuals with AD dementia (re: a control group without AD dementia) on two types of speech intelligibility tasks (degraded speech and dichotic speech). Degraded speech tests (Filtered Words and Auditory Figure Ground) that force the listener to understand speech in unfavorable listening conditions. Two types of degraded speech tasks were utilized for speech intelligibility testing in the current study. The first degraded task used in the current study used Low Pass Filtered Speech testing to evaluate monaural auditory closure (ability to fill in missing sound elements). The second degraded speech test used Auditory Figure Ground testing to evaluate monaural separation (speech in noise) skills. Two types of dichotic speech tasks were utilized in the current study to force the listener into divided- and directed-listening attention modes demanding higher order auditory processing (interhemispheric interaction). The first
dichotic speech test used a Competing Words task to evaluate binaural integration (divide attention to identify messages in both ears) skills. The second dichotic speech test used a Competing Sentences task to evaluate binaural separation (ability to direct attention to one ear while ignoring the message in the opposite ear) skills.

Two hypotheses relating to aging, auditory function, and cognition were evaluated in the current study. One hypothesis is based on the Cognitive Load Theory and postulates that the older listener’s difficulty in speech intelligibility can be attributed primarily to a cognitive slowing of information processing (Pichora-Fuller, 2003). If indeed cognitive overload drives auditory dysfunction in individuals with AD dementia, then the decline in cognitive processing is expected to influence performance similarly on all of the monaural (degraded speech) and binaural (dichotic speech) tasks in the current study. The alternative hypothesis is that individuals with AD dementia experience perceptually-related information processing difficulties even before cognitive decline plays a significant role (information degradation hypothesis). If this perceptual decline drives auditory dysfunction in individuals with AD dementia, then task-related differences in degraded and dichotic speech conditions in the current study would be expected.

Three questions related to central auditory dysfunction were addressed in the current study: 1) Do auditory processing skills in a group of individuals with AD dementia differ from an elderly listener group without AD; 2) Are there differences in monaural versus binaural processing skills; and 3) Are there ear differences across auditory processing skills (Monaural closure, Monaural separation, Binaural integration, and Binaural separation).

2. Method

2.1 Subjects
The Institutional Review Board at Auburn University approved the current study for human subject research. All subjects signed informed consent prior to participation in the study. Subjects were assigned to two groups: 1) a cognitive deficit group with AD dementia comprised of a group of ten individuals with AD (recruited from a local nursing home) and 2) a control group comprised of seven individuals without AD dementia (recruited from a local healthy aging institute). The Mini Mental State Exam (MMSE), a screening tool for assessing cognitive mental status (Folstein, 1975) was used with a cut-off criterion score of 23 or less for presence of cognitive impairment. An MMSE score of 24 to 30 indicates no cognitive impairment while scores of 17 to 23 indicate mild cognitive impairment and scores of 0 to 17 indicate severe cognitive impairment (Tombaugh & McIntyre, 1992). Auditory working memory for words was evaluated by Woodcock-Johnson III test of cognitive abilities. The mean characteristics of subjects from both groups are shown in Table 1 and indicate that the cognitive deficit group with AD dementia showed a severe cognitive impairment and decline in auditory working memory (re: control group).

The participants in the cognitive deficit category were: a) in the age range of 78-85 years, b) previously diagnosed with probable very mild to moderate Alzheimer’s disease based on the clinical diagnosis criteria provided by the Alzheimer’s disease task force (McKhann et al., 1984; McKhann et al., 2011) and c) showed Mini Mental State Exam (MMSE) scores of 23 or lower. The control group consisted of seven individuals in the age range of 62-82 years with: a) no evidence of Alzheimer’s disease based on the clinical diagnosis criteria provided by the Alzheimer’s disease
task force (McKhann et al., 1984; McKhann et al., 2011) and b) Mini Mental State Exam (MMSE) scores of greater than 23. Otoscopy was conducted first to ensure that there was normal outer and middle ear integrity and no earwax impaction in both ears. Air conduction audiometry (500-8000Hz) was completed for each subject and Pure Tone Average (PTA) was computed by averaging the air conduction thresholds at frequencies 500 Hz, 1000 Hz, 2000 Hz. Based on the most accepted audiological classification of hearing loss proposed by Goodman (1965), a PTA value lower than 25 dB indicates normal hearing sensitivity and PTA values greater than 25 dB indicate hearing loss of mild (26-40 dB), moderate (41-55 dB), moderately severe (56-70 dB), severe (71-90 dB), and profound (>90 dB). Based on this classification of hearing loss, the mean degrees of sensorineural hearing loss in the group with AD dementia were of moderate degree in both ears. The control group without AD dementia showed moderate and mild degrees of sensorineural hearing loss respectively in the right and left ears. The sensorineural loss observed in both groups is expected because auditory thresholds increase with advancing age in elderly listeners at a rate of approximately 6.32 dB/decade (Divenyi, Starks, & Haupt, 2005).

Table 1 Comparison of subject-related characteristics across Alzheimer’s disease and control groups

<table>
<thead>
<tr>
<th></th>
<th>Avg. Age</th>
<th>Avg. MMSE score</th>
<th>Avg. Working Memory score</th>
<th>Avg. Right ear PTA</th>
<th>Avg. Left ear PTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>69 years, 2 months</td>
<td>27.42</td>
<td>17</td>
<td>43 dB</td>
<td>37 dB</td>
</tr>
<tr>
<td>Alzheimer’s</td>
<td>82 years, 6 months</td>
<td>12.5</td>
<td>1.67</td>
<td>47 dB</td>
<td>50 dB</td>
</tr>
</tbody>
</table>

2.2 Auditory tests

Evaluation of auditory performance on degraded and dichotic speech tasks for each participant was completed using the SCAN-A, a standardized test for auditory processing disorders in adults (Keith, 1995). The SCAN-A test battery consists of four subtests: Filtered Words, Auditory Figure Ground, Competing Words, and Competing Sentences.

The monaural degraded speech tasks of the SCAN-A are the filtered words and auditory figure ground subtests. Filtered words subtest is a degraded speech task designed to evaluate monaural auditory closure skills. Monaural closure refers to the ability to fill in missing elements of an auditory message and involves listening to low-pass filtered speech. The test consists of monosyllabic words, which are low-pass filtered at 500Hz, in which the listener is asked to repeat the twenty “muffled” words that are presented to each ear. Auditory figure ground subtest evaluates the subject’s monaural separation skills by determining their ability to understand monosyllabic test words that are recorded in the presence of multi-talker speech babble noise at a 0dB signal-to-noise ratio. Two practice words and twenty test words are presented to each ear.

The dichotic speech tasks of the SCAN-A are the competing words and competing sentences subtests. Competing words subtest, which evaluates binaural integration skills, consists of monosyllabic word pairs presented simultaneously to both ears. First, two practice word pairs and fifteen word pairs are presented. The subject is instructed to repeat the words presented in each ear, repeating the word heard in the right ear first. Then, a second set of two practice word pairs and fifteen word pairs are presented, with the subject asked to repeat the word hearing in the left
ear first. Competing sentences subtest consists of ten pairs of sentences unrelated in topic, presented to the right and left ear simultaneously. This subtest evaluates binaural separation skills by using a directed ear task, whereby the subject is asked to repeat the sentence heard in one ear while ignoring the sentence in the other ear.

3. Results

Raw scores for speech intelligibility accuracy on SCAN-A test items were obtained in number correct form (e.g., 16 of 20) and these were converted to percent correct speech intelligibility scores. Because SCAN-A is normed for adults between 12-50 years of age, we collected SCAN-A data from an elderly control group of individuals without AD to compare with the experimental elderly group of individuals with AD. For normal distribution purposes, all percentage correct scores were arcsine transformed.

Statistical analyses were completed on a SPSS version 20 software package available to the researchers. ANCOVA analyses were conducted on the dependent variable (arcsine-transformed scores described above). The three independent variables were: group (Alzheimer’s versus control), ear (right versus left), and auditory processing skill (monaural closure, monaural separation, binaural integration, binaural separation, temporal processing). To adjust for the differences across-groups in terms of age and degree of loss, pure tone average and age were treated as covariates. Results of ANCOVA analyses are shown in Table 2 and after adjusting for age and pure tone average, there were significant differences (p<0.01) across groups, ears, and skills. Based on the ANCOVA model used, the differences related to group, ear, and skills accounted for more than 50% of the variance in speech intelligibility scores (Total R²=0.596; Adjusted R²=0.538).

Table 2 Analysis of variance results for speech intelligibility scores on central auditory tests for factors (cognitive status, auditory processing skills, ears)

<table>
<thead>
<tr>
<th>Factor</th>
<th>df</th>
<th>Sum of Squares (SS)</th>
<th>Mean Square (ms)</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Status</td>
<td>1</td>
<td>9694.97</td>
<td>9694.97</td>
<td>18.71</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>AP Skill</td>
<td>3</td>
<td>11519.67</td>
<td>3839.89</td>
<td>7.41</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Ear</td>
<td>1</td>
<td>7939.99</td>
<td>7939.99</td>
<td>15.32</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Cognitive Status * AP Skill</td>
<td>3</td>
<td>1568.58</td>
<td>522.86</td>
<td>1.01</td>
<td>0.39</td>
</tr>
<tr>
<td>Cognitive Status * Ear</td>
<td>1</td>
<td>2512.70</td>
<td>2512.70</td>
<td>4.85</td>
<td>0.03</td>
</tr>
<tr>
<td>AP Skill * Ear</td>
<td>3</td>
<td>2038.40</td>
<td>679.47</td>
<td>1.31</td>
<td>0.27</td>
</tr>
<tr>
<td>Cognitive Status * AP Skill * Ear</td>
<td>3</td>
<td>2214.31</td>
<td>738.10</td>
<td>1.43</td>
<td>0.24</td>
</tr>
<tr>
<td>Error</td>
<td>118</td>
<td>61140.20</td>
<td>518.14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3 shows the descriptive statistics for the auditory processing skills demonstrated on the degraded and dichotic speech tasks in the current study.

**Table 3** Descriptive statistics for arcsine transformed speech intelligibility scores are shown in the form of means and standard deviations (shown in parentheses)

<table>
<thead>
<tr>
<th></th>
<th>Monaural closure</th>
<th>Monaural separation</th>
<th>Binaural integration</th>
<th>Binaural separation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>Mean = 63.64 (13.77)</td>
<td>Mean = 58.30 (11.95)</td>
<td>Mean = 61.57 (19.62)</td>
<td>Mean = 89.83 (19.11)</td>
</tr>
<tr>
<td>Alzheimer’s</td>
<td>Mean RAU 26.29 (20.2)</td>
<td>Mean RAU 28.29 (18.24)</td>
<td>Mean RAU 26.07 (15.5)</td>
<td>Mean RAU 41.12 (34.13)</td>
</tr>
</tbody>
</table>

**Fig 1.** Total RAU scores combined from right and left ears for Alzheimer’s and control groups

Fig. 1 shows a graphical representation of the mean arcsine transformed scores (total RAU) that included scores from both ears. As shown in Fig. 1, total RAU scores differed significantly (p<0.05) across groups for the monaural closure skills but not for the other (monaural separation, binaural separation, binaural integration) skills. Figs. 2 and 3 illustrate RAU mean scores for the right and left ear respectively across the Alzheimer’s and control groups. Results in Fig. 2 indicate that RAU scores in the right ear did not differ significantly (p>0.05) across groups for any of the auditory processing skills (monaural closure, monaural separation, binaural separation, binaural integration).
Fig 2. Right ear RAU scores on central auditory tests for Alzheimer's and control groups

Fig 3. Left ear RAU scores on central auditory tests for Alzheimer's and control groups
However, results in Fig. 3 show that there was a significant decline in performance in the left ear for the group with AD dementia (re: controls) on both the monaural (closure and separation) and binaural (integration and separation) tasks. These results alert us to the auditory processing deficits in the left ear as an important indicator of central auditory dysfunction in subjects with AD dementia.

4. Discussion

4.1 Interaction of dementia and hearing loss
Memory impairment is the key descriptor of early dementia/AD. Gates et al. (2008) have shown previously that frontal lobe dysfunction may be a common dominator in memory loss and CAPD, and hence there is a need for serial testing of auditory and cognitive function in individuals with dementia and hearing loss. Lin et. al (2011) proposed that in individuals with AD, there is a need to accommodate for the complex processing of speech and as a consequence, working memory is sacrificed to allow for more cognitive reserve. If there is a peripheral hearing loss in individuals with AD, difficulties are expected in detection and discrimination of signals. A central auditory deficit relating to degraded or dichotic listeners can compound this and make processing more difficult. Finally, poor peripheral and central auditory deficits can occupy and exhaust information processing resources in the central neuron systems and not allow working memory to reach its capacity and the information to be stored correctly for cognitive purposes. Results of our study show that there are significant differences in performance between individuals with- and without-AD on various auditory processing skills. Results of the current study highlight the importance of APD testing when evaluating any elderly individual with declining cognitive skills, especially those with Alzheimer’s disease.

4.2 Effects of peripheral hearing loss
It is now well recognized that in elderly individuals with AD, an expected decrease in cognition comes with a concomitant decrease in the ability to correctly process the auditory information they receive. Although aging individuals are susceptible to hearing loss caused by aging (presbycusis), a mild to moderate hearing loss can be more devastating for those with AD than for aging individual with normal cognition. When Alzheimer’s patients hearing thresholds are compared to their peers, their thresholds are poorer than their peers. Lin et. al (2011) stated hearing loss greater than 25dB only increased the probability of early onset dementia, due to a decrease in communication success and in turn social interactions. Use of amplification in individuals who have both hearing impairment and AD is a high priority and must receive attention of both clinicians and researchers in the area of audition. This may decrease the impairment imposed by concurrent cognitive and auditory deficits in AD. Implementing APD screening into a routine audiological evaluation could be the first step in identifying a cognitive deficit by identifying at risk persons, generating appropriate referrals for these at risk patients and determining the need for a modified aural rehabilitation program. Auditory dysfunction in older adults with AD can be easily identified and subsequently treated with a combination of amplification and auditory rehabilitation. Patients with AD and hearing impairment should be informed of the importance of auditory stimulation.

4.3 Central auditory dysfunction in Alzheimer’s disease
Results from this study are supported by previous studies indicating poorer auditory processing skills in individuals with AD dementia. Results from the Gates et al. (2008) showed that that the
individuals with incident dementia scored extremely poor on the DSI when compared to their non-demented peers and they speculated that APD may even be a harbinger of dementia. Similar results were found in this current study, showing a significantly decreased score on the competing dichotic word and sentence subtests of the SCAN-A. Gates concluded, the poor scores on the DSI “strongly and significantly predicted the risk of a subsequent diagnosis of AD up to 3 years later.” Gates et al. (2008; 2011) found that persons diagnosed with Alzheimer’s disease perform the poorest on APD tests and reported a robust association of even early memory loss and tests of central auditory function. They concluded that central auditory speech-processing deficits may be an early manifestation of probable Alzheimer’s disease and may precede the onset of clinical dementia.

In addition to the greater degree of central auditory dysfunction found in AD dementia, findings from our study showed a greater weakness in the form of a left ear deficit in dichotic speech testing in group with AD dementia (re: controls). While the underlying mechanism for this left ear weakness is not clear; the pathophysiology suggests cortical involvement in AD dementia. Strouse, Hall, & Berger (1995) found a strong positive relationship between the degree of hearing impairment and cognitive status of the individuals. They found a left ear deficit in individuals with Alzheimer's disease (compared with control group who did not show an ear effect). They reported that their results were consistent with diffuse cortical involvement associated with Alzheimer's disease. Another underlying mechanism to explain this dichotic deficit may be related to degenerative changes in AD associated with a decline in the efficiency of the information transfer across the corpus callosum to the opposite hemisphere (Rahman et al, 2011). Future fMRI studies may provide a neurophysiological view into such phenomena and need to be conducted in these groups.

4.4 Relationship between cognitive decline and auditory processing skills

The relationship between auditory and cognitive abilities in aging individuals has been explained on basis of the Berlin model (Pichora-Fuller, 2003). The Berlin model proposed four hypotheses which are as follows: 1) declines are symptomatic of widespread neural degeneration (common cause hypothesis), 2) cognitive decline results in perceptual decline (cognitive load on perception hypothesis), 3) perceptual decline results in permanent cognitive decline (deprivation hypothesis), and 4) impoverished perceptual inputs results in compromised cognitive performance (information degradation hypothesis).

None of the hypotheses above are mutually exclusive but the evidence from our study supports hypotheses 2 and 4. Due to the poorer scores of patients with AD (re: their peers with normal cognition), it seems plausible that the interaction of cognitive decline and peripheral hearing loss results in perceptual decline (cognitive load on perception hypothesis). This hypothesis supports a top-down model of information processing. If cognitive overload drives central auditory dysfunction in individuals with AD dementia, then the decline in cognitive processing would be expected to influence total RAU scores for the group with AD dementia to a similar extent on all of the monaural (degraded speech) and binaural (dichotic speech) tasks. While this was indeed the case for total RAU scores (Fig. 1) in our study, it is also important to note the lack of statistically significant differences across groups for right ear performance, implying cognitive load may not have a dominant effect on auditory perception in central auditory tasks.
Alternatively, it is also plausible that individuals with AD dementia experience perceptually-related decline in information processing even before cognitive decline plays a significant role (information degradation hypothesis). If this perceptual decline drives central auditory dysfunction in individuals with AD dementia, then task-related differences across ears in performance under degraded and dichotic speech conditions in the current study are expected. This was indeed reflected for the group with AD dementia by asymmetry in performance across right and left ears (see Figs. 2 and 3). Specifically the dichotic conditions (Fig. 3) appeared to be more affected than monotic conditions, probably due to the greater cognitive demand for these tasks. Perceptual decline appears to be greater in the left ear (re: right ear) and this left ear deficit may be an important indicator of central auditory dysfunction in subjects with AD dementia.

Future studies must address this relationship between cognitive decline and left ear deficits on central auditory tasks further in elderly listeners. We realize that sample size limitations in our study make it difficult to provide a clear basis for auditory dysfunction in the elderly individuals with AD dementia. However, if the information degradation hypothesis supported by our study were to be further validated, the growing need for amplification technology and communication effectiveness strategies for this population becomes a critical issue for consideration by healthcare systems, particularly as they are increasingly admitted as inpatients in many of the skilled nursing homes in the United States.

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