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**Hearing Impairment and Correlations with Neuropsychological Function in
Alzheimer's Disease, Mild Cognitive Impairment and Older Adults with
Cognitive Complaints¹**

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Abstract. We examined hearing status in groups of participants diagnosed with Alzheimer's disease (AD), mild cognitive impairment (MCI), or presenting with subjective cognitive complaints (CC), as well as healthy elderly individuals (HE). Baseline hearing status differed across the groups, with AD individuals showing higher pure-tone thresholds than HE, CC and MCI groups. MCI individuals who went on to develop AD showed higher thresholds than those who remained stable, although this finding did not reach statistical significance. Hearing thresholds correlated significantly with verbal and non-verbal memory performance in HE participants as well as the patient groups.

Introduction

Communication impairments are well-documented in Alzheimer's disease (AD) and are a major source of stress for both caregivers and patients. While a good deal of research has focused on standardized language tests in this population, less work has been done examining low-level hearing performance in this population, and the links between hearing performance and cognitive decline.

A second patient group that is of major interest in delineating the factors contributing to cognitive decline in AD are individuals with mild cognitive impairment (MCI). Individuals diagnosed with MCI present with subjective and objective memory impairment in the absence of dementia (Petersen et al., 1999). Patients with MCI have a greatly elevated risk of developing AD, with a conversion rate of approximately 10-15% per annum, versus 1-2% in the general elderly population (Chertkow, 2002). This population thus represents pre-clinical AD in the majority of cases. Recent research has revealed the opportunity to study AD at an even earlier stage. Individuals presenting with subjective cognitive complaints (CC) but normal neuropsychological performance have been shown to exhibit similar patterns of cortical atrophy to those seen in MCI (Saykin et al., 2006), and thus may represent very early AD in many cases.

The present study investigates hearing and neuropsychological function in these populations using data from a five-year longitudinal study of healthy elderly adults, as well as groups with AD, MCI or CC. As part of the initial screening, patients underwent a pure-tone audiometric hearing assessment. Previous research has indicated that hearing loss is greater in AD patients than in healthy elderly (Weinstein & Amsel, 1987) and that this correlates with cognitive performance (Uhlmann et al., 1989). Thus, we examined correlations between neuropsychological performance and hearing thresholds in this population.

The aims of the present study were threefold. First, we wished to determine whether extent of cognitive decline was related to hearing performance; that is, whether differences in hearing thresholds would be observed across AD, MCI and CC groups. Second, we wanted to explore the relationship between hearing loss and longitudinal cognitive performance, with the goal of determining whether baseline hearing thresholds predicted cognitive decline. Finally, we examined correlations between hearing loss and performance on verbal and non-verbal memory tests, as well as several other neuropsychological measures. We predicted that verbal tasks, which rely heavily on auditory input, would correlate better than non-verbal tasks with hearing thresholds.

Methods

Participants

Four groups took part in the present study: participants with probable Alzheimer's disease (AD), mild cognitive impairment (MCI), or cognitive complaints (CC), and healthy elderly (HE). Classification of groups reflects initial diagnosis. All participants were aged ≥ 60 years, were right handed and were fluent speakers of English. Participant characteristics are presented in Table 1.

	Healthy Elderly - mean (SD)	CC ^a Participants - mean (SD)	MCI ^b Participants - mean (SD)	AD ^c Participants - mean (SD)
<i>N</i>	39	37	44	8
Age (years)	70.77 (5.34)	72.59 (6.19)	71.72 (8.51)	73.88 (6.33)
Education (years)	16.92 (2.60)	16.32 (2.92)	16.22 (3.06)	15.00 (3.59)
Sex	28F/11M	21F/16M	20F/23M ^e	4F/4M
MMSE (/30) ^d	29.05 (1.05)	29.03 (1.09)	26.91 (2.10)	24.38 (2.92)
Mother's Educational Level (years)	12.15 (3.13)	12.32 (3.21)	12.07 (3.49)	10.88 (3.48)
Father's Educational Level (years)	13.10 (4.46)	12.41 (4.08)	13.24 (5.12)	11.13 (3.80)
IQ	116.82 (4.34)	115.91 (5.61)	115.95 (5.87)	112.86 (9.61)

Table 1. Demographic characteristics of the 4 participant groups.

^aCC – cognitive complaints. ^bMCI – mild cognitive impairment. ^cAD – Alzheimer's disease. ^dHE = CC > MCI > AD. ^e One missing data point.

AD Participants. Eight AD patients took part in the study. The diagnosis of dementia was established by a neurologist or neuropsychologist according to standard diagnostic criteria (Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition; American Psychiatric Association, 1994), and the diagnosis of AD was established according to NINCDS-ADRDA criteria (McKhann et al., 1984).

MCI Participants. Forty-four MCI patients took part in the study. Individuals were classified on the basis of neuropsychological assessment, self and informant reports, and geropsychiatric and neurologic evaluation. Diagnosis of MCI was based on clinical consensus according to the following

criteria: (1) abnormal memory performance; (2) significant memory complaints, corroborated by an informant; (3) relatively preserved general cognitive functioning; (4) generally normal activities of daily living; (5) no dementia; (6) no depression or other major psychiatric disorder. The MCI participants performed 1.5 SDs below the adjusted mean of HEs on at least one verbal memory test score (CVLT Total 1-5, Short Delay, Long Delay, WMS-III LM I or LM-II).

CC Participants. Thirty-seven individuals with CC took part in the study. CC participants were also classified by consensus, fulfilling criteria (2)-(6) outline above but exhibiting normal performance on memory tests.

Healthy Elderly. Thirty-nine HE participants took part in the study. Healthy elderly fulfilled criteria (3)-(6) above but exhibited no subjective or objective memory impairment.

Neuropsychological Battery

Subjects underwent an extensive neuropsychological battery that examined general cognitive function, intelligence, memory, verbal learning, executive function and language. The following tests were included in the battery:

Mini-Mental State Examination (MMSE; Folstein et al., 1975). The MMSE is a brief test of cognitive function assessing orientation, registration, attention and calculation, recall, and language. It takes about 10 minutes and generally serves as a first measure in assessing cognitive decline. The MMSE is scored out of 30, with a score of 23 or below indicating cognitive impairment.

Mattis Dementia Rating Scale (DRS; Mattis, 1976). In order to obtain a more sensitive measure of dementia severity, participants completed this more extensive test that measures cognitive functioning across five subscales: attention, initiation-perseveration, construction, conceptualization, and memory. Scores range from 0 to 144, with higher scores representing better cognitive function.

Weschler Adult Intelligence Scale-III (WAIS-III; Wechsler, 1997a). The WAIS is a general test of intelligence that includes 14 measures of verbal and performance IQ. The verbal subtests include information, comprehension, arithmetic, similarities, vocabulary, digit span, and letter-number sequencing. The performance subtests include picture completion, digit symbol, block design, matrix reasoning, picture arrangement, symbol search, and object assembly. The battery of tests assesses verbal comprehension, perceptual organization, working memory, and processing speed.

Weschler Memory Scale-III (WMS-III; Wechsler, 1997b). The WMS-III includes eleven subtests assessing auditory immediate memory, auditory delayed memory, visual immediate memory, visual delayed memory delayed auditory recognition, and working memory.

California Verbal Learning Test (CVLT; Delis et al., 1987). The CVLT is a test that assesses verbal learning and memory. Participants listen to 16 words from 4 categories (4 items per category). They must then either repeat them or recognize them from a list of 44 items including distractors.

Delis Kaplan Executive Function System (DKEFS; Delis et al., 2001). The DKEFS is a set of standardized tests comprising nine subtests: trail making, verbal fluency, design fluency, color-word interference, sorting, twenty questions, word context, the Tower test, and a proverb test. These tests assess the integrity of executive functions and determine if deficits in abstract thinking impact the patient's daily life.

Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948). The WCST is a set-shifting test that evaluates participants' ability to adapt to constantly changing requirements. Participants must sort 64 cards according to criteria that switch periodically during testing. The WCST assesses executive functions.

Boston Naming Test (BNT; Kaplan et al., 1983). The BNT is a picture naming task in which participants name 60 line drawings of decreasing frequency.

Hearing Screen

Assessment of hearing ability was conducted using pure-tone audiometry. Each subject was tested separately in each ear at 500Hz, 1kHz, 2kHz, 3kHz, 4kHz, 6kHz, and 8kHz. A pure-tone average (PTA) for each ear was derived from averaging the audiogram data for 500Hz, 1kHz, and 2kHz.

Results

The data were analyzed to determine: (1) whether differences would be observed across the groups in baseline hearing status; (2) whether hearing status correlated with performance on verbal and non-verbal memory tests; and (3) whether baseline hearing status predicted cognitive decline. The results of each analysis are presented separately.

Group Differences in Baseline Hearing Status

Pure tone average thresholds in right and left ears for each group are presented in Figure 1. Visual inspection of the figures reveals increased hearing thresholds in both ears in the AD group relative to the CC and MCI groups, and in the CC and MCI groups relative to the HE group. A 4 (group) x 2 (left vs. right ear) ANOVA revealed a main effect of group ($F(3,124) = 3.02, p < 0.03$). LSD posthocs indicated a significant difference in both ears between AD participants and the remaining three groups ($p < 0.05$ in all cases), but no significant differences between HE, CC and MCI groups.

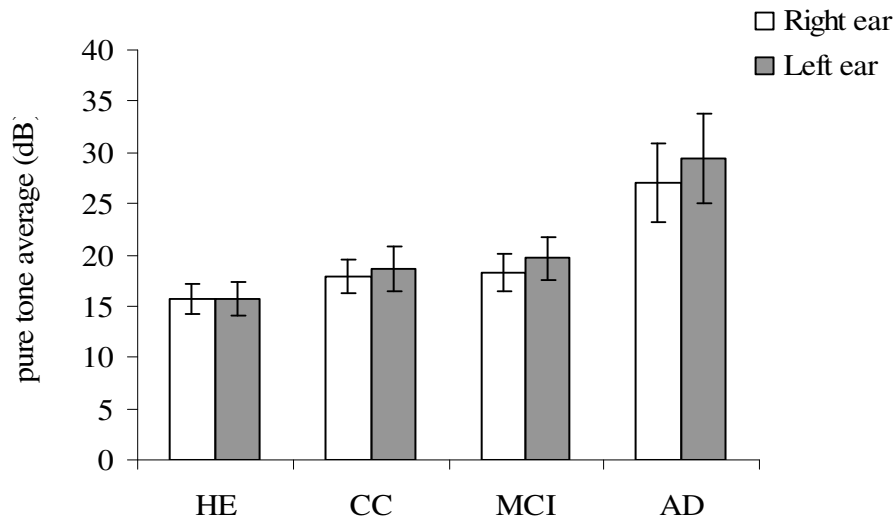


Figure 1. Pure tone average thresholds in the right and left ears for each participant group. Error bars represent standard error.

Correlations with Neuropsychological Function

A second issue of interest is whether hearing performance correlates with neuropsychological function in these populations. To address this question, we conducted Pearson correlations between hearing thresholds and scores on verbal (CVLT) and non-verbal (visual reproduction) memory tests. All participant groups were pooled for this analysis. Correlations were observed between CVLT scores in both ears (left ear: $r = -0.24$; $p < 0.005$; right ear: $r = -0.32$; $p < 0.001$), indicating lower performance on the CVLT with increasing hearing thresholds. The relationship between performance on non-verbal memory tests (the immediate and delayed visual reproduction subtests of the WMS) and hearing function was also assessed, with all participants pooled. Again, negative correlations were observed between performance on both measures and thresholds in both ears (immediate visual reproduction: right ear, $r = -0.34$ $p < 0.001$, left ear, $r = -0.30$, $p < 0.005$; delayed visual reproduction: right ear, $r = -0.22$ $p < 0.01$, left ear, $r = -0.25$, $p < 0.005$). A second set of correlation analyses including only HE participants found significant negative correlations between the CVLT and immediate visual reproduction and the right ear but not the left ear (CVLT: right ear, $r = 0.38$, $p < 0.02$, left ear: $r = 0.27$, $p < 0.09$; immediate visual reproduction: right ear, $r = -0.38$ $p < 0.02$, left ear, $r = -0.22$, $p < 0.18$; delayed visual reproduction: right ear, $r = -0.20$, $p > 0.23$, left ear, $r = -0.26$, $p > 0.11$).

Correlations were also performed for the remaining tests in the neuropsychological battery. Means across patient groups and correlations with hearing function are presented in Tables 2-4. When all participants are pooled, strong correlations are observed between hearing function and several neuropsychological measures, although these correlations do not remain significant when groups are analyzed separately.

	HE Participants	CC Participants	MCI Participants
MMSE (/30)	29.10 (1.09)	28.98 (1.09)	26.90 (1.86)
CVLT (50.13 (8.85)	46.95 (9.32)	31.22 (6.29)
VRI (%ile)	78.10 (10.90)	75.02 (13.06)	63.70 (18.60)
VRD (%ile)	52.85 (20.85)	43.36 (17.11)	29.82 (18.53)
BNT (/60)	57.9 (1.90)	56.7 (2.90)	55.7 (3.00)
WCST	3.804 (1.37)	3.523 (1.28)	2.816 (1.23)
DRS (/144)	141.00 (2.34)	141.15 (2.39)	136.14 (5.34)
DGSY	62.02 (14.47)	63.68 (13.17)	50.78 (12.28)
DGSP	16.87 (3.09)	17.59 (3.91)	16.37 (3.91)
DTR1sc	23.93 (4.72)	23.83 (6.75)	28.83 (7.50)
DTR1er	0.13 (0.35)	0.22 (0.53)	0.28 (0.51)

Table 2. Group performance on neuropsychological measures.

MMSE = Minimental State Examination; CVLT = California Verbal Learning Test; VRI = Visual Reproduction – Immediate; VRD = Visual Reproduction – Delayed; BNT = Boston Naming Test; WCST = Wisconsin Card Sorting Test; DRS = Mattis Dementia Rating Scale; WAIS-DS = WAIS – Digit Symbol; WAIS-DSP = WAIS – Digit Span; DTR1sc = DKEF visual scanning, seconds; DTR1er = DKEF visual scanning, errors.

* indicates significance at $p < 0.05$

	All Participants	HE Participants	CC Participants	MCI Participants
MMSE	-0.19*	-0.05	-0.10	-0.04
CVLT	-0.24*	-0.27	-0.06	-0.18
VRI	-0.30*	-0.22	-0.21	-0.26
VRD	-0.25*	-0.26	-0.11	-0.11
BNT	-0.10	-0.17	0.01	-0.04
WCST	-0.12	0.04	-0.11	0.05
DRS (/144)	-0.18*	-0.18	-0.14	-0.10
WAIS-DS	-0.22*	0.02	-0.31	-0.17
WAIS-DSP	-0.06	0.04	-0.22	0.08
DTR1sc	0.18	-0.08	0.28	0.38*
DTR1er	0.22*	0.49*	0.17	0.12

Table 3. Correlations between neuropsychological measures and left ear pure tone average threshold.

MMSE = Minimental State Examination; CVLT = California Verbal Learning Test; VRI = Visual Reproduction – Immediate; VRD = Visual Reproduction – Delayed; BNT = Boston Naming Test; WCST = Wisconsin Card Sorting Test; DRS = Mattis Dementia Rating Scale; WAIS-DS = WAIS – Digit Symbol; WAIS-DSP = WAIS – Digit Span; DTR1sc = DKEF visual scanning, seconds; DTR1er = DKEF visual scanning, errors.

* indicates significance at $p < 0.05$

	All Participants	HE Participants	CC Participants	MCI Participants
MMSE (/30)	-0.21*	-0.021	-0.14	-0.15
CVLT	-0.32*	-0.38	-0.28	-0.34*
VRI	-0.34*	-0.38	-0.23	-0.28
VRD	-0.22*	-0.20	-0.10	-0.10
BNT	-0.13	-0.13	0.04	-0.01
WCST	-0.12	0.03	-0.19	0.09
DRS (/144)	-0.22*	-0.23	-0.06	-0.17
DGSY	-0.22*	-0.05	-0.30	-0.09
DGSP	-0.05	0.08	-0.18	0.06
DTR1sc	0.34*	0.11	0.36*	0.29
DTR1er	0.18*	0.49*	0.05	0.12

Table 4. Correlations between neuropsychological measures and right ear pure tone average threshold.

MMSE = Minimental State Examination; CVLT = California Verbal Learning Test; VRI = Visual Reproduction – Immediate; VRD = Visual Reproduction – Delayed; BNT = Boston Naming Test; WCST = Wisconsin Card Sorting Test; DRS = Mattis Dementia Rating Scale; WAIS-DS = WAIS – Digit Symbol; WAIS-DSP = WAIS – Digit Span; DTR1sc = DKEF visual scanning, seconds; DTR1er = DKEF visual scanning, errors.

* indicates significance at $p < 0.05$

Prediction of Conversion to AD

Seven of the 44 MCI participants converted to probable AD over the course of this study. Average pure tone thresholds of converters and non-converters are shown in Figures 2 (pure tone average) and 3 (averages from 500-4000 Hz).

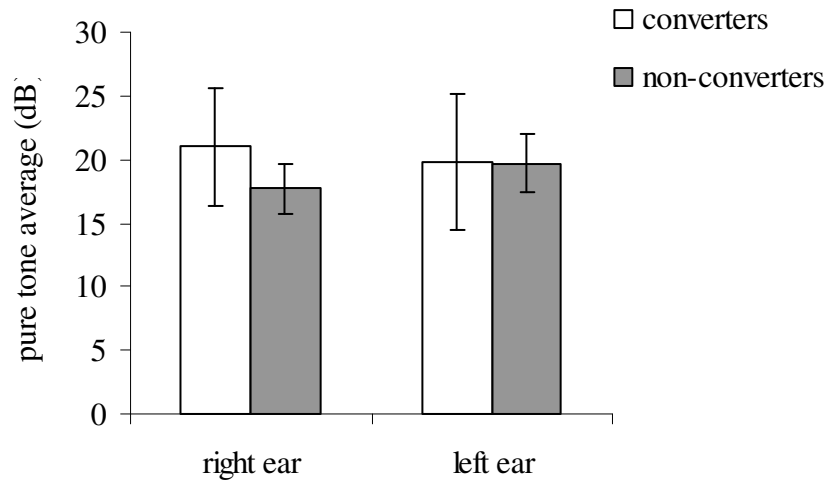


Figure 2. Pure tone average thresholds in the right and left ears for MCI participants who went on to develop probable AD (converters) and those who remained stable (non-converters). Error bars represent standard error.

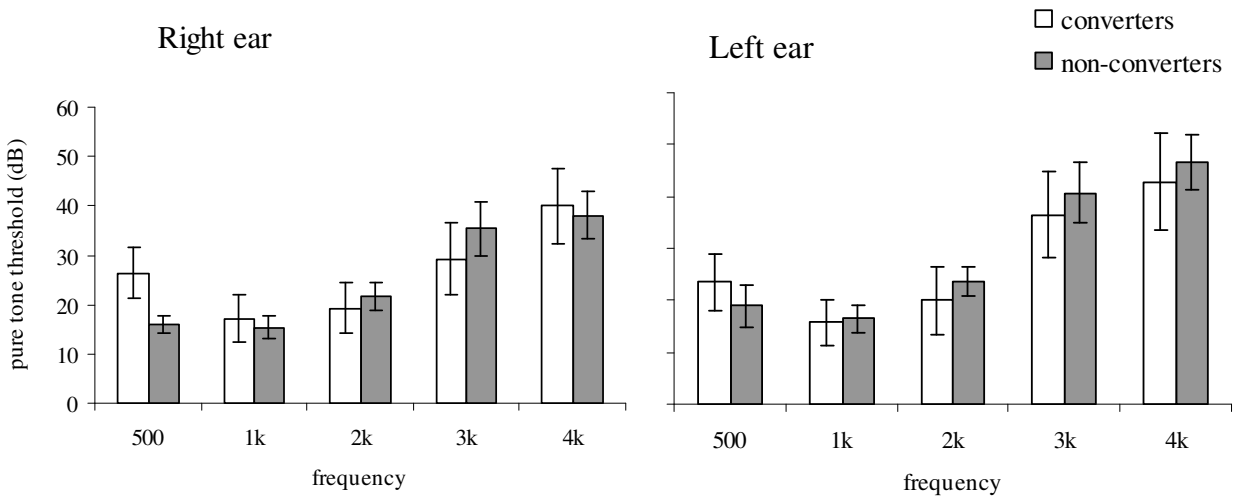


Figure 3. Pure tone average thresholds (500-4000 Hz) in the right and left ears for MCI participants who went on to develop probable AD (converters) and those who remained stable (non-converters). Error bars represent standard error.

While the figures demonstrate that the converter subgroup had higher thresholds than the non-converter subgroup in the pure tone average for the right ear and in lower frequencies (500 Hz), this comparison did not reach statistical significance.

Discussion

The present study demonstrated higher pure-tone hearing thresholds in AD participants than in HE, CC and MCI individuals. MCI and CC participants had higher thresholds than the healthy elderly, although this finding did not reach significance. Participants' thresholds were found to correlate with performance on verbal and non-verbal memory tests, in addition to a number of other cognitive functions. Moreover, hearing thresholds were higher in those MCI participants who went on to convert to AD, albeit not significantly so.

The finding that hearing loss is more severe in AD participants than in healthy elderly is consistent with a number of previous studies (e.g., Gates et al., 1995; Sinha et al., 1993; Uhlmann et al., 1989). Additionally, MCI and CC groups show a similar albeit statistically insignificant pattern, with hearing thresholds intermediate between those of AD and HE participants, suggesting that AD-related hearing loss may already be underway in this population. These data clearly indicate a relationship between hearing impairment and cognitive function.

A number of studies have found altered auditory evoked potentials in AD (Cancelli et al., 2006; Pekkonen et al., 1999) and MCI (Golob et al., 2007), reflecting deficits in sensory gating, which may be due to diminished hearing function in this population. It has been argued that these alterations in sensory gating may be related to dysfunction in the α -7 subunit of the cholinergic nicotinic receptor (Jessen et al., 2001), providing a possible neural substrate for the hearing impairment seen in this and other studies. Additionally, a recent study indicates alterations in dendritic arborization and loss of dendritic spines in the auditory cortex of early AD patients (Baloyannis et al., 2007); it is possible that the hearing impairments observed in our patients may be related to this auditory cortex pathology.

Correlations were also found with hearing function and a number of neuropsychological tests, including verbal and non-verbal memory. While it is possible that hearing impairment is compromising performance on these tasks, it is likely the case that AD-related hearing dysfunction is progressing in tandem with cognitive impairment but not influencing neuropsychological task performance, given that verbal and non-verbal memory are affected equally.

Interestingly, the HE group also showed a correlation between right-ear hearing loss and cognitive performance. This result was entirely unexpected, given the subclinical hearing loss seen in this population as well as the fact that cognition is not impaired in this group. Given that neither cognitive decline nor AD-related hearing decline is expected in this population, this finding suggests that hearing function may indeed impact upon neuropsychological performance. Another possibility is that the healthy elderly population contains individuals who will soon develop cognitive complaints or MCI, and these individuals are driving the correlations between hearing decline and cognitive performance. Future research should examine the possible causal link between hearing loss and neuropsychological performance in these populations.

Finally, we were interested in examining the possible predictive value of measures of hearing threshold in MCI. To this end, we compared the hearing thresholds of those MCI participants who converted to probable AD and those who did not. Converters had higher baseline thresholds, although

these differences did not reach significance, likely due to the small number of converters in the patient sample (7 of 44). Further research is clearly necessary to explore the question of whether hearing decline predicts conversion from MCI to AD.

In sum, the significantly higher hearing thresholds in AD compared to healthy elderly participants may be due to cortical pathology in AD. The finding that MCI and CC participants showed similarly elevated thresholds at baseline suggests that this auditory decline may be occurring even in very early AD, although these results did not reach significance. Additionally, the negative correlations between hearing thresholds and neuropsychological test performance may be due to concomitant decline in the two domains. However, the finding that this correlation also holds for healthy elderly opens the possibility that there may be a causal link, something that should be explored further. Additionally, our results point toward the possibility that auditory function is poorer in those MCI patients who will go on to develop AD, although this hypothesis should be tested with a larger sample.

Hearing declines in early AD have important implications at a number of levels, including neuropsychological assessment, as well as speech communication with these individuals. Communication impairments in AD are a major source of caregiver and patient stress, and contribute to increasing caregiver burden and breakdown of social relationships. As such, a better understanding of hearing impairment in this population is crucial to improve quality of life and care for this vulnerable population. Our results indicate that hearing thresholds are significantly higher in AD participants than in the healthy elderly, and suggest that impairments may be present even in very early AD. As such, a hearing screen should form part of any routine clinical examination for these patients.

References

- American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders* (4th Ed.). Washington, DC: Author.
- Baloyannis, S.J., Costa, V., Mauroudis, I., Psaroulis, D., Manolides, S.L., & Manolides, L.S. (2007). Dendritic and spinal pathology in the acoustic cortex in Alzheimer's disease: morphological and morphometric estimation by Golgi technique and electron microscopy. *Acta Oto-Laryngologica*, *127*, 351-354.
- Cancelli, I., Pittaro Cadore, I., Merlino, G., Valentini, L., Moratti, U., Bergonzi, P., et al. (2006). Sensory gating deficit assessed by P50/Pb middle latency event related potential in Alzheimer's disease. *Journal of Clinical Neurophysiology*, *23*, 421-425.
- Chertkow, H. (2002). Mild cognitive impairment. *Current Opinion in Neurobiology*, *15*, 401-407.
- Delis, D.C., Kaplan, E., & Kramer, J.H. (2001). *Delis-Kaplan Executive Function System (D-KEFS)*. San Antonio, TX: The Psychological Corporation.
- Delis, D.C., Kramer, J.H., Kaplan, E., & Ober, B.A. (1987). *California Verbal Learning Test*. San Antonio, TX: Psychological Corporation.
- Folstein, M.J., Folstein, S.E., & McHugh, P.R. (1975). Mini-mental state: a practical method for grading the cognitive state of the patients for the clinician. *Journal of Psychiatric Research*, *12*, 189-198.
- Gates, G.A., Karzon, R.K., Garcia, P., Peterein, J., Storandt, M., Morris, J.C., et al. (1995). Auditory dysfunction in aging and senile dementia of the Alzheimer's type. *Archives of Neurology*, *52*, 626-634.
- Golob, E.J., Irimajiri, R., & Starr, A. (2007). Auditory cortical activity in amnesic mild cognitive impairment: relationship to subtype and conversion to dementia. *Brain*, *130*, 740-752.
- Grant, D.A., & Berg, E.A. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card sorting problem. *Journal of Experimental Psychology*, *38*, 404-411.

- Jessen, F., Kucharski, C., Fries, T., Papassotiropoulos, A., Hoenig, K., Maier, W., et al. (2001). Sensory gating deficit expressed by a disturbed suppression of the P50 event-related potential in patients With Alzheimer's disease. *American Journal of Psychiatry*, *158*, 1319–1321.
- Kaplan, E.F., Goodglass, H., & Weintraub, S. (1983). *Boston Naming Test*. Philadelphia, PA: Lea & Febiger.
- Mattis, S. (1976). Mental status examination for organic mental syndrome in the elderly patient. In L.B.T.B Karasu (Ed), *Geriatric Psychiatry*, Pp. 77-121. New York: Grune & Stratton.
- McKhann, G., Drachman, D., Folstein, M., Katzman, R., Price, D., & Stadlan, E.M. (1984). Clinical diagnosis of Alzheimer's disease: Report of the NINCDS-ADRDA work group under the auspices of Health and Human Services Task Force on Alzheimer's Disease. *Neurology*, *34*, 939-944.
- Pekkonen, E., Jaaskelainen, I.P., Hietanena, M., Huotilainen, M., Naatanen, R., Ilmoniemi, R.J., et al. (1999). Impaired preconscious auditory processing and cognitive functions in Alzheimer's disease. *Clinical Neurophysiology*, *110*, 1942-1947.
- Petersen, R.C., Smith, G.E., Waring, S.C., Ivnik, R.J., Tangalos, E.G., & Kokmen, E. (1999). Mild cognitive impairment: Clinical characterization and outcome. *Archives of Neurology*, *56*, 303-308.
- Saykin, A.J., Wishart, H.A., Rabin, L.A., Santulli, R.B., Flashman, L.A., West, J.D., et al. (2006). Older adults with cognitive complaints show brain atrophy similar to that of amnesic MCI. *Neurology*, *67*, 834-842.
- Sinha, U.K., Hollen, K.M., Rodriguez, R., & Miller, C.A., (1993). Auditory system degeneration in Alzheimer's disease. *Neurology*, *43*, 779-785.
- Uhlmann, R.F., Larson, E.B., Rees, T.S., Koepsell, T.D., & Duckert, L.G. (1989). Relationship of hearing impairment to dementia and cognitive dysfunction in older adults. *Journal of the American Medical Association*, *261*, 1916-1919.
- Wechsler, D. (1997a). *Wechsler Adult Intelligence Scale—Third Edition*. San Antonio, TX: The Psychological Corporation.
- Wechsler, D. (1997b). *Wechsler Memory Scale (WMS-III)*. San Antonio, TX: The Psychological Corporation.
- Weinstein, B.E., & Amsel, L. (1987). Hearing impairment and cognitive function in Alzheimer's disease. *Journal of the American Geriatric Society*, *35*, 273-275.

