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**The Prevalence of Peripheral and Central Hearing Impairment and Its Relation to Cognition in Older Adults**

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**Key Words**

Ageing · Hearing loss · Central auditory processing disorders · Dementia · Mild cognitive impairment · Epidemiology

**Abstract**

Age-related hearing loss (ARHL) and dementia are two highly prevalent conditions in the adult population. Recent studies have suggested that hearing loss is independently associated with poorer cognitive functioning. The aim of this study was to evaluate the prevalence of ARHL and cognitive impairment in a large sample of subjects older than 65 years and to correlate hearing function with cognitive function. A total of 488 subjects older than 65 years (mean age 72.8 years) participating in the Great Age Study underwent a complete audiological, neurological and neuropsychological evaluation as part of a multidisciplinary assessment. The prevalence of a hearing loss greater than 25 dB HL was 64.1%, of Central Auditory Processing Disorder (CAPD) was 14.3 and 25.3% of the subjects reported a hearing handicap as reported on the Hearing Handicap Inventory for the Elderly Screening Version questionnaire. Multiple logistic regression analysis corrected for gender, age and education duration showed that mild cognitive impairment (MCI) was significantly associated with hearing impairment (CAPD and hearing threshold; odds ratio 1.6,  $p = 0.05$ ) and that Alzheimer’s disease (AD) was significantly associated with CAPD (odds ratio 4.2,  $p = 0.05$ ). Given that up to 80% of patients affected by MCI convert to AD, adding auditory tests to a screening cognitive battery might have value in the early diagnosis of cognitive decline.

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**Introduction**

Age-related hearing loss (ARHL) and dementia are two highly prevalent conditions in the adult population. The presence of

ARHL, both of peripheral [Lin et al., 2011c; Uhlmann et al., 1989] and central type [Gates et al., 2002], has been associated with incidental dementia and usually precedes the manifestation of the disease. ARHL, or presbycusis, is the most common sensory deficit in the elderly [Quaranta et al., 1996; Huang and Tang, 2010]. It is a multifactorial condition that involves a multitude of intrinsic and extrinsic factors [Van Eyken et al., 2007; Willot, 1991] acting on the inner ear over a lifetime that cumulatively lead to impairments in cochlear transduction of acoustic signals [Ohlenmiller, 2009]. Once hearing loss begins to occur in adulthood, it tends to become more pronounced and accelerated with each passing decade, with high-frequency loss developing more quickly than low-frequency losses, at all ages [Hinchcliffe, 1959]. ARHL is characterized by a loss of hearing sensitivity and a decreased ability to understand speech in the presence of background noise [Working Group on Speech Understanding and Aging, 1988]. Some subjects, even in the presence of normal hearing thresholds, present with impaired speech understanding. This phenomenon has been defined as central auditory processing disorder (CAPD) and refers to an impairment in the central auditory pathways, such as neural transmission, feature extraction deficit, or information processing problems that lead to impaired speech understanding [Humes et al., 1992]. Using the WHO (World Health Organization) definition of hearing loss (pure tone average, PTA, >25 dB for the frequencies 0.5–4 kHz), in the USA, the prevalence of hearing loss approximately doubles every decade of life from the second through seventh decades reaching the 45.6% in subjects aged 70–74 years, 67.6% in subjects aged 75–79, 78.2% in subjects aged 80–84 and 80.6% in subjects older than 85 [Lin et al., 2011c]. In Europe, roughly 30% of men and 20% of women have a hearing loss of 30 dB HL or more by age 70 years, and 55% of men and 45% of women by age 80 years [Roth et al., 2011]. According to the United Nations, the overall global population will grow from 6.9 billion in 2010 to 9.3 billion in 2050. The proportion of the population aged 60 or older will nearly double in the same period, reaching 21% of the total population or nearly 2 billion people in 2050. The 2008 data from the WHO estimated that over 360 million people (5.3% of the global population) had disabling hearing loss [Stevens et al., 2013]; in 2050, the number of hearing-impaired people will reach an impressive number. The prevalence of CAPD has been shown to increase with age, and Gates et al. [1990], in a sample of 1,026 elderly subjects, reported that the prevalence of CAPD was between 0.75 and 14.6% according to the tests used for diagnosis.

Alzheimer’s disease (AD) is the most common form of dementia. It is characterized by decline in cognition, memory and performance of activities in daily life. In 2005, 24.3 million people were estimated to have dementia, with 4.6 million new cases of dementia every year (one new case every 7 s). This number is expected to double every 20 years to 8.1 million people by 2040 [Ferri et al., 2005]. In Europe, the prevalence of AD increases exponentially with age [Wancata et al., 2003]. Subtle loss of cognitive function may be symptomatic of normal aging or a transition to early AD.

Mild cognitive impairment (MCI) is defined as a slight impairment in cognitive function with otherwise normal function in the activities of daily living [Levey et al., 2006]. MCI encompasses several types of cognitive dysfunction of varied etiologies none of which necessarily progress to AD [Petersen, 2004]; however, in a longitudinal study with a 6-year follow-up, 80% of patients affected by amnesic MCI converted to AD [Petersen et al., 2001].

The aim of this study was to evaluate the prevalence of ARHL and cognitive impairment in a large sample of subjects older than 65 years and to correlate hearing function with cognitive function.

## Materials and Methods

**Study Population.** Participants were enrolled in the Great Age Study, a prospective, observational study funded by the Italian Ministry of University and Research ('Impact of central and peripheral auditory dysfunction on risk of onset of subjective cognitive impairment, mild cognitive impairment, dementia, Alzheimer's disease, vascular dementia and late onset depression') in patients older than 65 years. All subjects aged >65 years living in Castellana Grotte, a small town 40 km from Bari, Italy, were recruited from a list of election voters and evaluated at the IRCSS 'De Bellis', Castellana Grotte, Bari, Italy. All 488 subjects underwent a complete audiological, neurological, neuropsychological, geriatric and psychiatric examination as part of a multidisciplinary assessment. For the purpose of this paper, only audiological, neurological and neuropsychological evaluations are considered.

**Audiological Examination.** All subjects underwent otoscopy and wax removal by an otolaryngologist, pure tone audiometry, speech audiometry, tympanometry, stapedia reflex recordings, and synthetic sentence identification with ipsilateral competing message (SSI-ICM) [Jerger et al., 1990] in a soundproof chamber. According to Gates et al. [1995], a central auditory speech-processing deficit was defined as a score of 50% or less at 0 dB SNR in the SSI-ICM test, with normal word recognition ability in both ears (>80%).

In addition, all subject were asked to complete the Italian version of the Hearing Handicap Inventory for the Elderly Screening Version questionnaire (HHIE-S) [Monzani et al., 2007; Ventry and Weinstein, 1983]. Results were classified into three categories by HHIE-S total scores: 0–8 (no self-perceived hearing handicap), 10–24 (mild-to-moderate handicap), and 26–40 (severe handicap) [American Speech-Language-Hearing Association Audiologic Assessment Panel 1997; Lichtenstein et al., 1988].

**Neurological and Neuropsychological Examination.** Neurological status was evaluated through a standard neurological exam, exploring awareness, gait, cranial nerves, motor function (muscle tone, straightness, and trophism) and presence of pathologic movements, sensory function, cerebellar and sphincter functions, deep tendon reflexes and signs of diffuse cerebral distress. Furthermore, several specific and validated clinical scales were administered to each subject: (1) Clinical Dementia Rating Scale, to evaluate cognitive functions; (2) Unified Parkinson Disease Rating Scale part III, to assess the presence of parkinsonian signs; (3) Epworth Sleepiness Scale-Italian version, to inquire the presence of daytime sleepiness; (4) Eating Assessment Tool-10, to screen the presence and the amount of swallowing disturbances.

Finally, a neuropsychological assessment through a standardized battery of tests to exclude impairment of global cognition with the Mini Mental State Examination and Frontal Assessment Bat-

tery. Further, specific cognitive domains were assessed; in particular, attention and executive functions were explored with Symbol Digit Modalities Test-oral version, the Trail Making Test and Controlled Oral Word Association; visuospatial abilities with Clock Drawing Test; language comprehension and naming with the Token Test and Boston Naming Test-short form, and memory with Rey's Verbal Learning Test. Dementia was diagnosed according to the *Diagnostic and Statistical Manual of Mental Disorders-V* [American Psychiatric Association, 2013] and MCI according to Petersen [Petersen, 2004].

**Statistical Methods.** Indices of centrality and dispersion of the distribution for the study subjects were reported as mean and standard deviation for continuous variables and relative frequency and percentages for categorical variables. Pearson product-moment correlation was used for the correlation analysis. The analysis of variance (ANOVA) was used to compare different groups, and the comparisons among their levels were evaluated with Bonferroni adjusted p values. The  $\chi^2$  test was used to compare different groups when only categorical variables were available. Logistic regression analysis was used to determine whether the possible associated factors for hearing loss remained significant after adjustment for other factors. The cutoff level for peripheral HL was set at 35 dB HL since only patients with a PTA better than this value underwent SSI-ICM. The statistical level of significance to reject  $H_0$ , the null hypothesis of no association or correlation, was set at  $p < 0.05$ , two tailed. Data were processed on a personal computer and analyzed using the STATA 10 statistical package for data management and analysis (release 10.0; STATA Corporation, College Station, Tex., USA).

## Results

The study group consisted of 488 subjects, 296 (60.7%) males and 192 (39.3%) females. The mean age at evaluation was  $72.8 \pm 6.2$  years with an average education interval of  $6.6 \pm 3.7$  years. The PTA in the poorer ear for frequencies 0.5–2 kHz was 35.2 dB HL ( $\pm 15.3$ ) in the right and 35.1 dB HL ( $\pm 14.8$ ) in the left ear; the average 4–8 kHz PTA was 60.7 dB HL ( $\pm 21.1$ ) in the right and 65.5 dB HL ( $\pm 19.9$ ) in the left ear. Considering the lower-frequency range of 0.5–2 kHz PTA in the better ear, 35.9% of the subjects presented with normal thresholds ( $\leq 25$  dB HL), 40.6% with mild hearing loss (PTA  $>25 \leq 40$  dB HL), 20.7% with moderate hearing loss (PTA  $>40 \leq 70$  dB HL), 2.2% with severe hearing loss (PTA  $>70 \leq 90$  dB HL) and 0.6% with profound hearing loss ( $>90$  dB HL). Average speech discrimination at 30 and 60 dB SPL were, respectively,  $87.9\% \pm 17$  and  $85\% \pm 17$  on the right side and  $89\% \pm 15$  and  $85.8 \pm 17$  on the left side. There were only 26 subjects who used hearing aids (5.3%, 26/488). The SSI-ICM was administered to 293 subjects; the test was normal in 251 subjects (85.7%), bilaterally abnormal in 22 subjects (7.5%) and unilaterally abnormal in 20 subjects (6.8%). The mean HHIEs scores were  $6 \pm 9$ : 74.7% of subjects reported no handicap; 18.6%, mild-to-moderate handicap, and 6.7%, severe handicap. The HHIE score was significantly correlated with the PTA for both low and high frequencies ( $p < 0.0001$ ), and subjects wearing hearing aids reported the highest HHIE-S score. Pearson product moment correlation coefficient was 0.44 on the right and 0.45 on the left side for PTA 0.5–2 kHz and 0.35 on both right and left sides for PTA (4–8 kHz). No significant differences in HHIE scores were found in subjects with and without CAPD.

According to the neurological and neuropsychological assessment, 259 (53.1%) were considered normal, 25 (5.1%) were af-

**Table 1.** Demographics and prevalence of hearing loss (PTA >35 dB HL 0.5–2 kHz) in the population studied

	Cognitive impairment								
	A			B			C		
	normal+MCI	AD	p	normal	MCI	p	normal	AD+MCI	p
Gender									
Males	279 (60.3)	17 (68.0)	0.44	162 (62.5)	117 (57.3)	0.26	162 (62.5)	134 (58.5)	0.36
Females	184 (39.7)	8 (32.0)		97 (37.2)	87 (42.7)		97 (37.4)	95 (41.5)	
Age, years	72.5 ± 6.0	78.7 ± 5.8	<0.0001	71.3 ± 5.6	73.9 ± 6.2	<0.0001	71.3 ± 5.6	74.5 ± 6.3	<0.0001
Education interval, years	6.8 ± 3.7	4.5 ± 2.0	0.003	8.1 ± 3.8	5.1 ± 2.8	<0.0001	8.1 ± 3.8	5.0 ± 2.7	<0.0001
CAPD									
Absent	242 (87.4)	5 (50.0)	0.001	156 (93.4)	86 (78.2)	<0.001	156 (93.4)	91 (75.8)	<0.001
Present	35 (12.6)	5 (50.0)		11 (6.6)	24 (21.8)		11 (6.6)	29 (24.2)	
Hearing loss >35 dB (0.5–2 kHz)									
Absent	242 (58.4)	5 (25.0)	0.003	156 (65.3)	86 (49.1)	0.001	156 (65.3)	91 (46.7)	<0.001
Present	172 (41.5)	15 (75.0)		83 (34.7)	89 (50.9)		83 (34.7)	104 (53.3)	
Hearing impairment (peripheral and CAPD)									
Absent	242 (53.9)	5 (20.0)	0.001	156 (62.4)	86 (43.2)	<0.001	156 (62.4)	91 (40.6)	<0.001
Present	207 (46.1)	20 (80.0)		94 (37.6)	113 (56.8)		94 (37.6)	133 (59.4)	

Figures in parentheses indicate percentages. Values for age and education are expressed as mean ± SD.

**Table 2.** Prevalence and significance of the different variables in three statistical models: model A (normal and MCI subjects vs. AD subjects), model B (normal subjects vs. MCI) and model C (AD and MCI vs. normal)

	Cognitive impairment								
	A			B			C		
	normal+MCI	AD	p	normal	MCI	p	normal	AD+MCI	p
Gender									
Males	279 (60.3)	17 (68.0)	0.44	162 (62.5)	117 (57.3)	0.26	162 (62.5)	134 (58.5)	0.36
Females	184 (39.7)	8 (32.0)		97 (37.2)	87 (42.7)		97 (37.4)	95 (41.5)	
Age, years	72.5 ± 6.0	78.7 ± 5.8	<0.0001	71.3 ± 5.6	73.9 ± 6.2	<0.0001	71.3 ± 5.6	74.5 ± 6.3	<0.0001
Education interval, years	6.8 ± 3.7	4.5 ± 2.0	0.003	8.1 ± 3.8	5.1 ± 2.8	<0.0001	8.1 ± 3.8	5.0 ± 2.7	<0.0001
CAPD									
Absent	242 (87.4)	5 (50.0)	0.001	156 (93.4)	86 (78.2)	<0.001	156 (93.4)	91 (75.8)	<0.001
Present	35 (12.6)	5 (50.0)		11 (6.6)	24 (21.8)		11 (6.6)	29 (24.2)	
Hearing loss >35 dB (0.5–2 kHz)									
Absent	242 (58.4)	5 (25.0)	0.003	156 (65.3)	86 (49.1)	0.001	156 (65.3)	91 (46.7)	<0.001
Present	172 (41.5)	15 (75.0)		83 (34.7)	89 (50.9)		83 (34.7)	104 (53.3)	
Hearing impairment (peripheral and CAPD)									
Absent	242 (53.9)	5 (20.0)	0.001	156 (62.4)	86 (43.2)	<0.001	156 (62.4)	91 (40.6)	<0.001
Present	207 (46.1)	20 (80.0)		94 (37.6)	113 (56.8)		94 (37.6)	133 (59.4)	

Figures in parentheses indicate percentages. Values for age and education are expressed as mean ± SD.

ected by AD, 189 (38.7%) by nonamnestic MCI and 15 (3.1%) by amnesic MCI. Table 1 describes the demographic characteristics and the prevalence of hearing loss (PTA 0.5–2 kHz >35 dB HL) and CAPD (abnormal SSI-ICM) in the subjects divided on the basis of the neuropsychological assessment (normal, MCI and AD).

In table 2, the prevalence and significance of different variables in three statistical models is reported: model A (normal and MCI subjects vs. AD subjects); model B (normal subjects vs. MCI), and model C (AD and MCI vs. normal). The AD patients were significantly older, had a shorter education interval and had a higher prevalence of peripheral HL (>35 dB HL) and CAPD compared to the rest of the population. Subjects affected by MCI were significantly older, had a shorter education interval and had a higher

prevalence of peripheral HL (>35 dB HL) and CAPD compared to subjects without cognitive impairment. Cognitively impaired (MCI and AD) subjects were significantly older, had a shorter education interval and had a higher prevalence of peripheral HL (>35 dB HL) and CAPD compared to subjects with normal cognition.

Multiple logistic regression analysis corrected for gender, age and education interval showed that

- MCI was significantly associated with hearing impairment (CAPD and hearing thresholds; odds ratio 1.6,  $p = 0.05$ ).
- AD was significantly associated with CAPD (odds ratio 4.2,  $p = 0.05$ ), but not with hearing thresholds (odds ratio 1.8,  $p = 0.31$ ).

- Cognitive impairment (dementia and MCI) was significantly associated with CAPD (odds ratio 2.4,  $p = 0.03$ ) and with hearing impairment (CAPD and peripheral HL) (odds ratio 1.6,  $p = 0.03$ ). The correlation with hearing thresholds was nearly significant (odds ratio 1.5,  $p = 0.08$ ).

### Discussion

In the present study, the prevalence of a hearing loss greater than 25 dB HL in a population with a mean age of 72.8 years was 64.1%. Similar prevalence has been reported in USA and in Europe. Lin et al. [2011] reported that 63.1% of the population aged over 70 years presented a hearing loss greater than 25 dB in the better ear; while in Italy, the percentage of subjects with hearing loss greater than 25 dB HL for the frequencies between 0.5 and 4 kHz was 69.4% in those aged between 71 and 80 years [Quaranta et al., 1996].

Of the population studied, 14.3% presented a pathological SSI-ICM test indicating the presence of a CAPD. This figure is also very similar to the prevalence of CAPD reported in the literature. Jergler et al. [1990] found a prevalence of about 20% using the Synthetic Sentence Identification (SSI) test for a group of 53 listeners with normal hearing (PTA <20 dB HL) who ranged in age from about 60 to 70 years. Gates et al. [1990], in a sample of 1,026 subjects in their 60–90s, showed that the prevalence of CAPD was between 0.75 and 14.6% according to a set of diagnostic tests, and when the SSI test was used the prevalence of CAPD was 9%.

The results of the HHIEs showed that although the prevalence of hearing loss in our population of 488 subjects was high, the associated handicap was low; 25.3% of the population reported a hearing handicap. Furthermore, while the HHIE score was shown to correlate significantly with PTA for both low and high frequencies, the correlation was weak (0.44 on the right and 0.45 on the left side for PTA 0.5–2 kHz). Similar results were reported by Chang et al. [2009] in a cross-sectional survey of 1,220 community-dwelling elderly individuals aged 65 years and older. In their series, 21.4% of subjects with a moderate-to-profound hearing impairment reported a hearing handicap, and the correlation coefficient between HHIE-S and threshold for frequencies 0.5–4 kHz was 0.52. The finding of only a moderate correlation between hearing impairment and hearing handicap in elderly persons implies that although hearing impairment is quite common among elderly people, not all are disturbed by the impairment. It is interesting to note that the highest HHIE scores in the present series were reported by subjects using hearing aids. This reflects the fact that self-perception of a hearing handicap is an important reason to seek consultation for hearing impairment or for using hearing aids [Chang et al., 2009; Swan and Gatehouse, 1990].

With respect to the main aim of this study, which was to evaluate the prevalence of presbycusis and of CAPD in an elderly population and examine the correlation between these issues with the cognitive status, our findings confirm the high correlation between CAPD and AD, as previously reported [Gates et al., 1995].

An interesting outcome of the present study was that MCI, a condition characterized by a slight impairment in cognitive function with otherwise normal function in performance of activities of daily living [Levey et al., 2006] that can progress to dementia in up to 80% of cases [Petersen et al., 2001], was associated with a higher risk of hearing impairment when both increased hearing threshold and a pathologic SSI-ICM were considered. After cor-

rection for age, gender and education (all factors associated with an increased risk of MCI), the odds ratio for hearing impairment in our study remained at 1.6. These results are consistent with previous studies demonstrating a significant independent association between hearing loss and cognition. A significant association between ARHL and poor scores in memory and executive functions in subjects older than 55 years of age participating at the large scale, Baltimore Longitudinal Study on Aging has been reported [Lin et al., 2011]. The authors proposed that hearing loss might be informally associated with cognitive decline through social isolation, cognitive load or a combination of these pathways, and that its treatment may potentially have an effect on the cognitive status of the individual [Lin et al., 2011].

In the present study, logistic regression analysis corrected for age, gender and education showed a strong trend for an association between MCI and CAPD (odds ratio 2,  $p = 0.09$ ). Other authors have previously reported a significant association between MCI and CAPD in smaller numbers of subjects [Idrizbegovic et al., 2011; Rahman et al., 2011]. Gates et al. [2008] demonstrated that central auditory tests are frequently abnormal in memory-impaired, nondemented older individuals, as well as in subjects with 'probable Alzheimer's disease' [Gates et al., 2002]. Given that about half of older adults with isolated memory loss progress to dementia [Bowen et al., 1997] and 80% of patients affected by amnesic MCI convert to AD ultimately [Petersen et al., 2001], inclusion of auditory tests to the routine screening cognitive test battery may have value in the early diagnosis of cognitive decline.

### Conclusions

The prevalence of ARHL and CAPD in a population older than 65 years was 64.1 and 14.3%, respectively. With the aging population and subsequent rising prevalence of dementia, there is widespread interest in the identification and use of markers of early signs of dementia and the associated tests to help distinguish which patients with MCI may progress to dementia. The use of hearing tests and the early diagnosis and treatment of ARHL may potentially represent a way to slow cognitive impairment and deserves further research.

### Disclosure Statement

The authors state that there is no conflict of interest to be disclosed.

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