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Peripheral Hearing Loss and Its Association with Cognition among Ethnic Chinese Older Adults

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Keywords
Hearing loss · Cognition · Older adults

Abstract
Introduction: Many studies on hearing loss (HL) and cognition are limited by subjective hearing assessments and verbally administered cognition tests, the majority of the document findings in Western populations. This study aimed to assess the association of HL with cognitive impairment among ethnic Chinese Singaporean older adults using visually presented cognitive tests. ***Methods:*** The hearing of community-dwelling older adults was assessed using pure tone audiometry. Cognitive function was assessed using the Computerized Cambridge Cognitive Test Battery (CANTAB). Multiple regression analyses examined the association between hearing and cognitive function, adjusted for age, education, and gender. ***Results:*** HL (pure-tone average [PTA] of thresholds at 0.5, 1, 2, and 4 kHz in the better ear, BE4PTA) was associated with reduced performance in delayed matching and multitasking tasks ($\beta = -0.25$, $p = 0.019$, and $\beta = 0.02$, $p = 0.023$, respectively). Moderate to severe HL was associated with reduced performance in delayed matching and verbal recall memory tasks ($\beta = -10.6$, $p = 0.019$, and $\beta = -0.28$, $p = 0.042$). High-frequency HL was associated with reduced performance in the spatial working memory task ($\beta = 0.004$, $p = 0.022$). All-frequency HL was associated with reduced performance in spatial working memory and multitasking ($\beta = 0.01$, $p = 0.040$, and $\beta = 0.02$, $p = 0.048$). ***Conclusion:*** Similar to Western populations, HL among tonal language-speaking ethnic Chinese was associated with worse performance in tasks requiring working memory and executive function.

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Introduction

A growing number of cross-sectional, longitudinal, and meta-analytical studies have demonstrated a relationship between peripheral HL and cognitive impairment among older adults [1–5]. Furthermore, HL has been associated with risk of incident dementia and Alzheimer's disease [6, 7]. The mechanism for this remains poorly understood [8, 9].

Much of the relevant research has methodological drawbacks in the testing of HL and cognition [8]. Self-reported HL and subjective hearing tests may not accurately characterize hearing status. Verbally administered cognitive tests could overestimate the strength of the association [10–12]. Researchers have attempted to overcome this with test batteries that are visually presented or have been adapted for use in hearing-impaired subjects [9, 13, 14]. Computerized test batteries have also been employed [15, 16].

The literature pertaining to Asian populations is sparse and documents conflicting results [17, 18]. The association of HL with cognition could vary in different populations depending on the mechanisms involved. Proposed pathways include impoverished sound input resulting in increased cognitive load, sensory decline causing increased brain atrophy, and social isolation [19]. Genetics and sociocultural contexts such as stigma associated with HL, resistance to seeking rehabilitation, and multigenerational households are some factors that may vary across populations and impact these pathways [20]. Tonal language may also play an important but previously under-investigated role. Understanding Mandarin, for example, depends less on hearing higher frequencies than English and may therefore be less sensitive to the effects of early age-related high-frequency hearing loss [21]. The aims of this study were to assess (i) the association of HL with cognitive impairment among ethnic Chinese Singaporean older adults using visually presented cognitive tests and (ii) how these observed associations compare to those in Western populations.

Methods

Participants

The Singapore Longitudinal Ageing Study (SLAS) is a population-based longitudinal study of ageing and health transition of community-dwelling older Singaporeans aged ≥55 years [22]. Around 6,000 participants have been followed up at 3–5 yearly intervals since 2004. SLAS participants who lived close to the study site were invited to participate in the current study.

Table 1. Sociodemographic characteristics of participants

Variable	Mean ± SD or *n* (%)	
Age, years	71.4±5.69	
Gender (female)	155 (65.1)	
Education		
Primary	97 (47.1)	
Post-primary	109 (52.9)	
Hearing levels		
Normal hearing	134 (56.8)	
Mild hearing loss	82 (34.7)	
Moderate to severe hearing loss	20 (8.5) (moderate, *n* = 18; severe, *n* = 2)	
Preferred language	**First language**	**Second language**
Mandarin	126 (52.9)	80 (33.6)
English	51 (21.4)	14 (5.9)
Hokkien	25 (10.5)	77 (32.4)
Cantonese	23 (9.7)	34 (14.3)
Teochew	8 (3.4)	18 (7.6)
Hakka	4 (1.7)	9 (3.8)
Malay	1 (0.4)	2 (0.8)
Hainanese	0	4 (1.6)

Participants were recruited only if they had no known dementia diagnosis and could communicate fluently in English or Mandarin. Subjects who wore hearing aids were excluded as their effect on cognitive performance is unknown.

Measures

Hearing Assessment

Pure tone audiometry was conducted using a fully automated audiometer (KUDUwave™; eMoyo, Johannesburg, South Africa) [23]. Air conduction thresholds from 0.25 to 8 kHz were measured. HL was defined by a BE4PTA (normal ≤25 dB; mild 26–40 dB; moderate 41–60 dB; severe 61–80 dB; profound ≥81 dB) [24]. Moderate HL and severe HL were grouped together due to the small numbers of subjects. A PTA of high frequencies (4 and 8 kHz; BEHPTA) and all frequencies (0.25–8 kHz; BEallPTA) in the better ear was computed to examine the relationship of other measures of peripheral hearing with cognition.

Cognitive Assessment

CANTAB was utilized because it has previously been found to be sensitive to age-related cognitive decline in the local Chinese population, can be presented in languages spoken locally, and is visually presented [25, 26]. CANTAB was administered using an Apple iPad Air 1. Participants were able to select either English or Mandarin as the test medium. Participants completed the following CANTAB subtests.

Motor Screening Task. It is a brief task to familiarize participants with the touch screen interface. The task tests participants' sensorimotor and comprehension abilities to ensure accurate data

Table 2. Association of hearing (measured with the better ear 4 frequency PTA [0.5, 1, 2, and 4 kHz]) and demographic factors with the CANTAB subtest scores

Subtest	*N*	BE4PTA		Age		Education		Gender	
		β	*p* value	β	*p* value	B	*p* value	β	*p* value
Memory									
PALTEA	206	–0.000	0.967	0.009	0.156	–0.029	0.715	–0.051	0.515
PALFAMS	204	–0.000	0.996	–0.186	0.001*	0.302	0.622	0.524	0.345
VRMFRDS	183	–0.002	0.449	–0.016	0.014*	–0.002	0.973	0.057	0.457
VRMIRTC	183	0.000	0.977	–0.005	0.028*	0.013	0.484	0.002	0.936
VRMDRTC	183	–0.004	0.646	–0.004	0.057	0.011	0.525	0.000	0.991
DMSPCS	205	–0.005	0.753	–0.011	0.744	–0.164	0.646	–0.445	0.219
DMSPCAD	205	–0.250	0.019*	0.009	0.967	2.241	0.325	–3.116	0.168
SWMBE	186	0.004	0.131	0.001	0.895	–0.113	0.046*	0.087	0.184
Executive function									
MTTTIC	166	0.018	0.023*	0.032	0.041*	–0.292	0.076	0.252	0.241

PALTEA, PAL total errors (adjusted); PALFAMS, PAL first attempt memory score; VRMFRDS, VRM free recall; VRMIRTC, VRM immediate recall total correct; VRMDRTC, VRM delayed recall total correct; DMSPCS, DMS percent correct (simultaneous); DMSPCAD, DMS percent correct (all delays); SWMBE, SWM between errors; MTTTIC, MTT total incorrect. * Significance at $p < 0.05$.

collection. Participants who were not able to complete the Motor Screening Task due to problems such as visual impairment, inability to comprehend instructions, or dexterity problems were excluded from further participation.

Paired Associates Learning. Paired Associates Learning (PAL) assesses episodic visual memory and learning. Six white boxes change briefly to reveal a pattern which varies in shape and colour. A pattern is then revealed in the centre of the screen. Participants must remember the pattern and match that to a pattern in their memory by touching the box that contains the correct response. The task is made progressively more difficult by presenting 1, 2, 3, 6, and 8 patterns to the participant. The outcome measures are "PAL total errors (adjusted) (PALTEA)" and "PAL first attempt memory score (PALFAMS)." PALTEA is a measure of the total number of errors across all stages, adjusted for each stage not attempted due to previous failure. PALFAMS is the number of correct responses made on the first attempt across all trials.

Verbal Recognition Memory. Verbal Recognition Memory (VRM) assesses immediate and delayed recognition memory and recall. Participants are shown a list of 18 words one at a time and asked to (i) repeat aloud as many as they can immediately after (free recall), (ii) recognize the original words from a list of both new and original words immediately after (immediate), and (iii) recognize the original words from a list of different new and original words after 20-min delay (delayed). The outcome measures for VRM are "VRM free recall: distinct stimuli (VRMFRDS)," "VRM immediate: total correct (VRMIRTC)," and "VRM delayed: total correct (VRMDRTC)."

Multitasking Task. Multitasking Task (MTT) assesses EF and cued attentional set shifting. Participants must touch a box on the left or right of the screen, depending on which side of the screen the arrow appears, or which direction the arrow points at. The words "direction" or "side" will appear on the screen, informing participants which to look out for. The outcome measure is "MTT total incorrect (MTTTIC)."

Delayed Matching to Sample. Delayed Matching to Sample (DMS) tests attention and visual recognition. Participants are shown a complex visual graphic. Four other graphics are then either presented simultaneously with the original graphic or after a delay of 0, 4, or 12 s. Participants must choose the graphic that is identical to the original graphic. The outcome measures are "DMS percent correct (simultaneous) (DMSPCS)" and "DMS percent correct (all delays) (DMSPCAD)."

Spatial Working Memory. Spatial Working Memory (SWM) assesses non-verbal and visuospatial WM and EF. Participants are required to find tokens hidden in either 3, 4, 6, or 8 boxes. Participants are informed that there is only 1 token per box and hence should refrain from revisiting a box that was already found to have a token. The outcome measure is "SWM between errors (SWMBE)." SWMBE denotes the number of times a participant revisits a box in which a token has previously been found.

Participants who were not able to understand test instructions for the MTT and SWM subtests were excluded from the MTT and SWM analyses, as the instructions for these tests were more difficult to understand and could directly impact performance. Participants who self-reported reading difficulty were excluded from VRM analyses.

Procedure

A research assistant was present throughout the assessments for support and further explanation. Participants were randomized to complete the hearing or cognitive assessment first. A Williams Sound Pocketalker (Eden Prairie, MN, USA) personal amplifier was provided for participants with HL, adjusted to comfort level, during the cognition tests and general instructions.

Table 3. Association of hearing loss (mild, moderate, or greater) and covariates with CANTAB subtest scores

Subtest	Mild		Moderate to severe		Age		Education		Gender	
	β	*p* value	β	*p* value	β	*p* value	B	*p* value	β	*p* value
Memory										
PALTEA	0.004	0.958	−0.223	0.124	0.011	0.091	−0.041	0.612	−0.069	0.352
PALFAMS	−0.454	0.474	1.779	0.088	−0.200	<0.001*	0.291	0.633	0.632	0.250
VRMFRDS	−0.031	0.687	−0.275	0.042*	−0.014	0.038*	−0.008	0.906	0.053	0.465
VRMIRTC	0.000	0.990	0.005	0.909	−0.005	0.027*	0.013	0.474	0.002	0.929
VRMDRTC	0.007	0.738	−0.021	0.640	−0.004	0.057	0.013	0.455	0.002	0.909
DMSPCS	−0.275	0.456	0.069	0.918	−0.010	0.754	−0.183	0.608	−0.435	0.220
DMSPCAD	−2.700	0.242	−10.600	0.019*	−0.005	0.980	2.424	0.272	−2.677	0.230
SWMBE	0.107	0.051	−0.049	0.676	0.002	0.698	−0.108	0.065	0.062	0.333
Executive function										
MTTTIC	0.064	0.716	0.432	0.168	0.036	0.020*	−0.349	0.043*	0.174	0.334

N similar to Table 2. Normal hearing is used as the reference category. PAL total errors (adjusted). PALFAMS, PAL first attempt memory score; VRMFRDS, VRM free recall; VRMIRTC, VRM immediate recall total correct; VRMDRTC, VRM delayed recall total correct; DMSPCS, DMS percent correct (simultaneous); DMSPCAD, DMS percent correct (all delays); SWMBE, SWM between errors; MTTTIC, MTT total incorrect. * Significance at $p<0.05$.

Statistical Analysis

Statistical analyses were performed using STATA version 14.0 [27]. Multiple regression analyses were performed to examine the association between peripheral hearing and cognitive function, adjusted for age, education, and gender. Education was measured categorically as primary of ≤6 years or post-primary of >6 years. Peripheral hearing was defined in 3 ways: (1) BE4PTA, (2) BEHPTA, and (3) BEallPTA. All 3 variables were entered as continuous independent variables in separate regression analyses. CANTAB subtest scores were entered as dependent variables. Negative binomial regression was used to model PALTEA, VRMIRTC, MTTTIC, and SWMBE. Poisson regression was used to model VRMFRDS and VRMDRTC. Linear regression was used to model PALFAMS and DMSPCAD. DMSPCS was modelled using logistic regression – due to the distribution of the data, DMSPCS was examined as a binary variable (100% correct responses or <100% correct responses). Multiple comparisons were not accounted for due to the exploratory nature of the analyses.

Results

The sociodemographic characteristics of the 238 older adults who participated in the study are shown in Table 1. Two participants did not complete audiometry. All participants spoke at least 1 Chinese tonal language (Table 1).

The significant associations are detailed in Tables 2–5. In brief, BE4PTA was associated with reduced performance in DMSPCAD ($\beta = -0.25$, $p = 0.019$) and MTTTIC ($\beta = 0.02$, $p = 0.023$). Moderate to severe HL was associated with reduced performance in DMSPCAD ($\beta = -10.6$, $p = 0.019$) and VRMFRDS ($\beta = -0.28$, $p = 0.042$). BEHPTA was associated with reduced performance in the SWMBE ($\beta = 0.004$, $p = 0.022$). All-frequency HL was associated with reduced performance in spatial WM and multitasking ($\beta = 0.01$, $p = 0.040$, and $\beta = 0.02$, $p = 0.048$).

Discussion

Our results contribute domain-specific data obtained using a non-verbally administered cognitive test battery in an ethnic Chinese population to the literature on the association between HL and cognitive function. New data are presented pertaining to how HL in different frequency ranges affects cognition in a tonal language-speaking population.

Hearing was a predictor of performance on VRM, SWM, MTT, and DMS tests that required verbal, nonverbal, and visuospatial WM, attention, and EF after adjusting for age, education, and gender. WM, EF, and attention are all important for speech comprehension and deteriorate with age [15, 28]. WM becomes increasingly important in difficult listening situations in older people, even when their peripheral hearing is normal [29]. Yet further demand is placed on WM, EF, and attention to aid speech perception in older people with HL, resulting in poorer performance in tests of these domains as resources become overwhelmed. It is notable that altered EF is found in early Alzheimer's disease [30].

Interethnic differences in dementia and HL have previously been identified, and this relationship therefore

Table 4. Association of hearing (measured with the better ear high-frequency PTA [4 and 8 kHz]) and demographic factors with CANTAB subtest scores

Subtest	BEHPTA		Age		Education		Gender	
	B	*p* value	β	*p* value	β	*p* value	β	*p* value
Memory								
PALTEA	0.002	0.452	0.007	0.288	−0.018	0.825	−0.026	0.744
PALFAMS	−0.010	0.584	−0.173	0.003*	0.261	0.664	0.409	0.471
VRMFRDS	−0.000	0.921	−0.017	0.005*	0.006	0.926	0.068	0.391
VRMIRTC	0.001	0.348	−0.005	0.007*	0.015	0.397	0.007	0.710
VRMDRTC	−0.000	0.951	−0.004	0.032*	0.013	0.463	0.002	0.927
DMSPCS	0.002	0.837	0.037	0.021*	−0.132	0.709	−0.388	0.292
DMSPCAD	−0.082	0.238	−0.017	0.601	2.855	0.205	−2.564	0.273
SWMBE	0.004	0.022*	−0.081	0.686	−0.109	0.059	0.103	0.124
Executive function								
MTTTIC	0.005	0.395	−0.007	0.009*	−0.341	0.045*	0.172	0.369

N similar to Table 2. PAL total errors (adjusted). PALFAMS, PAL first attempt memory score; VRMFRDS, VRM free recall; VRMIRTC, VRM immediate recall total correct; VRMDRTC, VRM delayed recall total correct; DMSPCS, DMS percent correct (simultaneous); DMSPCAD, DMS percent correct (all delays); SWMBE, SWM between errors; MTTTIC, MTT total incorrect. * Significance at $p < 0.05$.

Table 5. Association of hearing (measured with the better ear all-frequency PTA [0.25–8 kHz]) and demographic factors with CANTAB subtest scores

Subtest	BEallPTA		Age		Education		Gender	
	β	*p* value	β	*p* value	β	*p* value	β	*p* value
Memory								
PALTEA	0.003	0.541	0.007	0.271	−0.017	0.833	−0.031	0.692
PALFAMS	−0.011	0.722	−0.177	0.002*	0.265	0.664	0.450	0.425
VRMFRDS	−0.003	0.350	−0.015	0.019*	−0.004	0.954	0.051	0.513
VRMIRTC	0.000	0.783	−0.005	0.022*	0.014	0.452	0.003	0.874
VRMDRTC	0.000	0.718	−0.004	0.054	0.011	0.508	0.000	1.000
DMSPCS	0.000	0.987	−0.014	0.667	−0.144	0.686	−0.415	0.255
DMSPCAD	−0.190	0.077	−0.023	0.909	2.531	0.268	−2.892	0.214
SWMBE	0.006	0.040*	−0.001	0.883	−0.109	0.055	0.100	0.133
Executive function								
MTTTIC	0.017	0.048*	0.031	0.047*	−0.301	0.062	0.244	0.276

N similar to Table 2. PAL total errors (adjusted). PALFAMS, PAL first attempt memory score; VRMFRDS, VRM free recall; VRMIRTC, VRM immediate recall total correct; VRMDRTC, VRM delayed recall total correct; DMSPCS, DMS percent correct (simultaneous); DMSPCAD, DMS percent correct (all delays); SWMBE, SWM between errors; MTTTIC, MTT total incorrect. * Significance at $p < 0.05$.

warrants comprehensive study [31, 32]. Most of the published literature from Asia has used cognitive screening tools or mild cognitive impairment/dementia diagnosis, which provides little domain-specific information [17, 18, 33–35]. Furthermore, most Asian studies on cognitive impairment and HL are based in part on verbally loaded cognition tests. Deal et al. [3] found that the exclusion of cognitive tests that solely utilized auditory stimuli from domain summary scores resulted in a significant difference in memory performance. Our findings largely mirror the limited domain-specific data that are available in ethnic Chinese subjects. Ren et al. [36] found peripheral hearing to be associated with tests of EF, verbal learning and memory, psychomotor speed, and attention in a Han Chinese population. Our results are also similar to research done on Australian, European, and American participants [9, 15, 37]. Direct comparison can be made with an English-speaking Australian population, in whom similar CANTAB tests were utilized [16]. Spatial WM was also found to be significantly associated with worse HL. However, attention and non-verbal recall and recognition tasks were not affected. This may reflect the different frequency ranges that were used for analysis or represent real differences in the effect of HL on the two populations.

Differences in the acoustic properties of language could potentially impact this relationship. Variation in pitch serves to convey lexical meaning in tonal languages [38]. Many Mandarin speech sounds are clustered together in frequency and intensity between 0.5 and 2 kHz so may be easily confused in patients with HL; conversely, Mandarin speakers may be less affected by early age-related high-frequency hearing loss [21]. Our results suggest that in this mixed tonal language-speaking population, WM is the first cognitive domain to become overwhelmed, as evidenced by poorer performance on tests of WM in subjects with high-frequency HL. Further demand is placed on cognitive processes utilized for speech processing such as attention and EF when HL progresses to involve the middle and low frequencies, resulting in increasing difficulty discriminating Mandarin tones [21].

Education has been consistently shown to predict cognitive performance and dementia risk [39, 40]. Less education is also associated with worse performance in CANTAB tests of visual sustained attention, reaction time, and learning ability [41]. However, education did not predict performance on most CANTAB subtests in our study. Our results also indicate that age was a more consistent predictor of cognitive performance than hearing in this population. Age has previously been reported as a stronger predictor than hearing of some domains such as processing speed and inhibition [15]. In the present study, age could have been a more consistent predictor because participants needed to use an iPad. Nevertheless, the associations of HL with cognitive parameters reported are comparable to other risk factors for cognitive decline and dementia in the existing literature [5].

Our study has several limitations. Instructions for the CANTAB tests were presented in Taiwanese Mandarin, which is slightly different to the Standard Mandarin used locally in Singapore. This might have contributed to difficulty in understanding certain test instructions, thus reducing the power of some analyses. Second, the sample of all hearing-impaired individuals was small and precluded subgroup analyses on participants with moderate to severe HL. Third, the study subjects, despite being Chinese, were heterogeneous in that they spoke a mixture of several different Chinese dialects, all of which may have different acoustic properties. Finally, the study is cross-sectional in nature and provides only a static snapshot of Singaporean older adults. Objective hearing assessments and visually presented cognitive assessments should be administered longitudinally. Studies comparing homogeneous populations of tonal and non-tonal language speakers would also be of interest.

Conclusion

The present study is one of the few studies globally which uses non-hearing-dependent cognitive assessments to estimate the relationship between peripheral hearing and cognitive functioning among older adults. HL was associated with worse performance in tasks requiring WM and EF in this tonal language-speaking population, as in many Western populations.

Statement of Ethics

The study was approved by the National Healthcare Group Domain Specific Review Board (NHG DSRB Ref: 2016/00962). All participants gave written informed consent.

Conflict of Interest Statement

Ng Tze Pin is an Editorial Board member for *Dementia and Geriatric Cognitive Disorders*. The other authors have no conflicts of interest to declare.

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Author Contributions

S.L.W., T.P.N., and R.L.H. conceptualized and supervised the research, reviewed and edited the final draft, and acquired funding for the research. S.O.N. and E.J.K. curated data, analysed data, managed the project, prepared the original draft, and reviewed and edited the final draft. F.L., R.E., and D.J. provided external mentorship to the core team, contributed to study design and data interpretation, and reviewed and edited the final draft.

Data Availability Statement

The data that support the findings of this study are available upon written request to the corresponding author.

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