Global cognitive function is associated with sex, educational level, occupation type, and speech recognition rate in older Chinese adults: a single-center, prospective, cross-sectional study

Hailing Gu1†, Xinyi Yao1†, Cong Diao1, Min Liu1, Weili Kong2, Haotian Liu1, Yu Zhao2 and Zhaoli Meng1*

Abstract

Background: The development of cognitive impairment may be delayed if its risk factors are identified and detected, if its developmental trend can be predicted, and if early intervention can be performed. This study primarily aimed to investigate the association between global cognitive function and hearing loss, educational level, and occupation type and to determine any differences in such associations according to sex among older Chinese adults.

Methods: In this cross-sectional study, we prospectively recruited 219 individuals above 55 years old in an otolaryngology outpatient clinic who could write independently and had no severe vision impairment. Audiometric examinations included otoscopy, acoustic immittance, pure-tone audiometry, and speech audiometry for each ear. Cognitive function was evaluated by using the Chinese version of the Mini-Mental State Examination (MMSE). Multivariable linear regression analyses were performed to evaluate the relationship between variables and MMSE scores after adjusting for independent variables that were statistically significant in the univariable analyses.

Results: We enrolled 219 individuals: 98 men (mean ± standard deviation age, 63.08 ± 6.64 years) and 121 women (62.64 ± 7.17 years). The overall MMSE scores of the normal hearing group and the mild, moderate, and severe-to-profound hearing loss groups were 24.00 (5.00), 24.00 (5.00), 23.00 (5.00), and 23.00 (13.00), respectively. MMSE scores were higher among participants with higher educational levels (p < 0.001) and were significantly correlated with occupation type (p < 0.001). MMSE scores were significantly higher in men than in women (p < 0.001). However, after the analysis of the five subdomains, significant differences were only observed for attention and calculation (p < 0.001) and language (p = 0.011). We further compared the distribution of educational levels between men and women by using the chi-square test; there was no significant difference in educational level between the sexes (p = 0.070).

†Hailing Gu and Xinyi Yao co-first authors.
*Correspondence: lucy-mengzhaoli@163.com

1 Department of Otolaryngology-Head and Neck Surgery, Hearing Center/Hearing and Speech Science Laboratory, West China Hospital of Sichuan University, 37 Guo Xue Lane, Chengdu 610041, Sichuan, People’s Republic of China

Full list of author information is available at the end of the article

© The Author(s) 2022. Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/. The Creative Commons Public Domain Dedication waiver (http://creativecommons.org/publicdomain/zero/1.0/) applies to the data made available in this article, unless otherwise stated in a credit line to the data.
Background
Cognitive impairment (CI) affects the quality of life, social functioning, and well-being of older adults. Given that the number of older adults is increasing with the increase in average life expectancy, CI is becoming a severe social and public health problem. The prevalence of mild CI (MCI) reported in population-based epidemiological studies ranges from 3 to 19% in adults older than 65 years [1]. MCI can act as a transitional stage in the development of dementia with a range of severity, ARHL seems to play a significant role in cognitive decline, which states that reduced cognitive capacity places a heavier load on perception, thus affecting sensory processing. Langa and Levine [5] identified the risk factors for cognitive decline, which include aerobic exercise, mental activity, and cardiovascular risk factors. Other studies indicated that age-related hearing loss (ARHL) is an independent risk factor [6, 7]. Depending on its severity, ARHL seems to play a significant role in cognitive decline, but the underlying mechanism of the relationship remains an open question. The type of hearing loss (HL) most commonly encountered in older adults is ARHL [8], and its clinical manifestation is speech perception difficulty in a noisy environment. Speech perception is a process in which people hear, interpret, and understand the sounds of language [9]. Instinctively, cognitive functions are involved in speech perception, but few studies have investigated their link.

A higher educational level and/or a complex occupational role is generally considered to protect against cognitive decline [10, 11] and to contribute to cognitive reserve, which helps the brain to actively cope with age-related changes and diseases via the flexibility and plasticity of cognitive networks [12]. Other putative protective factors may also be caused by a higher educational level and occupational complexity [13]. Dekhtyar et al. [14] indicated that a higher educational level decreased the risk of dementia, whereas occupational complexity was not associated with dementia. Furthermore, Dekhtyar et al. [14] and Jones et al. [15] revealed that the cut-off point at which educational level is protective against dementia may vary depending on the age composition of the cohort in question. Therefore, the influence of education and occupation type on cognitive performance in older adults is unclear.

Livingston et al. [16] reported that the prevalence of CI in China was 62.7% in women and 45.4% in men over 75 years of age. However, there are differences in hypotheses and results between studies regarding factors related to cognitive decline between the sexes among older individuals. Chou et al. [17] and Szeoeke et al. [18] provided an explanation for the better cognitive performance of men than that of women, namely, the effects of endogenous estrogen decline at older age. Older women are more likely to develop dementia than men of the same age probably in part because, on average, older women have had less education than older men [5]. When adjusting for educational status, it seems that women typically have better verbal memory than men, and this is consistent with the cognitive reserve hypothesis [19]. However, the difference in cognitive performance between the sexes after adjusting for age remains unknown.

The development of CI may be delayed if its risk factors are identified and detected, if its developmental trend can be predicted, and if early intervention can be performed. The main aim of this study was to investigate the associations between global cognitive function (as defined by using Mini-Mental State Examination [MMSE] scores) and HL, educational level, and occupation type and to explore whether there are any differences in such associations according to sex among older Chinese adults.

Methods
Study population
In this cross-sectional study, we prospectively recruited individuals in the otolaryngology outpatient clinic of West China Hospital from June 2020 to February 2021. Individuals were included in this study if they were aged 55 years or older [20], could write independently, and had no diagnosis of severe vision impairment. Participants were excluded if they were living alone [5]; had a history of more than 30 min of unconsciousness due to trauma [21]; had first-degree relatives who had been...
diagnosed with dementia; or had hypertension (systolic blood pressure ≥ 140 mmHg and/or diastolic blood pressure ≥ 90 mmHg) [22], diabetes mellitus (glycated hemoglobin > 6.5%) [23], hemorrhaging, cerebral infarction, cerebrovascular disease diagnosed with magnetic resonance imaging, body mass index > 24 or < 18.2 kg/m², thyroid dysfunction, abnormal electrocardiogram characteristics, chronic obstructive pulmonary disease (COPD Assessment Test score ≥ 11) [24], syphilis, or unilateral/bilateral conductive/mixed HL. The aim of this criteria was to avoid confounding factors, obtain relatively rigorous results, and provide strong evidence of the scientific association between HL and cognitive function. Individual medical history (dementia, hypertension, hemorrhaging, cerebral infarction, cerebrovascular disease, etc.) was collected by using a pre-designed questionnaire, which was used to select eligible participants.

This study was approved by the Biomedical Research Ethics Committee of West China Hospital (no. 2020285). All participants voluntarily signed an informed consent form.

After strict observance of the inclusion and exclusion criterion, a total of 219 individuals were enrolled in this study.

Audiometric examinations
A combination of otoscopy, acoustic immittance, pure-tone audiometry, and speech audiometry was conducted for each ear in a soundproof room with ambient noise < 30 dBA (A-weighted sound pressure level). Bilateral pure-tone hearing thresholds at frequencies of 0.25, 0.5, 1, 2, 4, and 8 kHz were measured at 5 dB increments in dB hearing level. Pure-tone threshold average (PTA) of the better ear for four frequencies (0.5, 1, 2, and 4 kHz) were adopted to define the participants’ degree of hearing according to guidelines published by the World Health Organization in 1997 [25]. The cut-off values for mild, moderate, severe, and profound HL were 25, 40, 60, and 80 dB hearing level, respectively. Speech recognition rate was determined using speech audiometry. The acoustic immittance test consisted of tympanometry and the acoustic reflex decay test and was used to measure the state of the middle ear and the function of the cochlear and facial nerves.

Cognitive assessment
Cognitive function was evaluated using the Chinese version of the MMSE. The MMSE has a 30-point scale and is commonly used to screen individuals for CI, with high sensitivity and specificity [26]. It covers five cognitive domains: orientation, registration, attention and calculation, recall, and language. The diagnostic criteria for CI varied with the participant’s educational level. CI was defined as an MMSE score > 17 in the illiterate group, > 20 in the primary school group, and > 24 in the middle school level and above group [27].

Covariate
The selected covariates included age, sex, occupation type, educational level, and HL duration. The specific occupation of the participants was acquired in face-to-face interviews and classified into mental labor, physical labor, retired, or none by researchers on the basis of the Professional Classification Dictionary of The People's Republic of China [28]. Mental labor refers to professional, managerial, or administrative work that is usually performed in an office or other administrative environment. Physical labor refers to strenuous physical work or other types of work that demand physical exertion. Educational level was categorized as illiteracy, primary, junior, high school, senior, undergraduate, master, and PhD on the basis of the self-report.

Statistical analysis
Continuous variables (age, HL duration, PTA, and speech recognition rate) are described as means and standard deviations. Categorical variables (binary variable: sex; multi-categorical variables: educational level and occupation type) are presented as numbers with percentages. Student’s t-test, one-way analysis of variance, the Mann–Whitney U test, and the Kruskal–Wallis test were used for the comparison of continuous variables among groups, and the chi-squared test or Fisher’s exact test was used for the comparison of categorical variables among groups. Univariable linear regression analyses were conducted to assess the relationship between each variable and the MMSE score. Multivariable linear regression analyses were performed to evaluate the relationship between variables and the MMSE score after adjusting for independent variables that were statistically significant in the univariable analyses.

All statistical analyses were performed with IBM SPSS Statistics for Windows version 25.0 (IBM Corp., Armonk, NY, USA) and GraphPad Prism 9.0 software (GraphPad Software, Inc., San Diego, CA, USA), and a two-sided P-value ≤ 0.05 was considered statistically significant.

Results
Demographic characteristics
Among the 219 individuals enrolled in this study, 98 were men (44.7%; mean age, 63.08 ± 6.64 years) and 121 were women (55.3%; mean age, 62.64 ± 7.17 years). With regard to HL, 64 (29.2%) participants had normal hearing, 70 (32.0%) had mild HL, 73 (33.3%) had moderate HL, and 12 (5.5%) had severe–profound HL (severe and profound HL groups were combined because of the small
sample size). Participant age, HL duration, PTA, and speech recognition rate differed among the four groups. Individuals with worse hearing were typically older, had had HL for a longer time, had a higher PTA, and had a worse speech recognition rate than those with better hearing. However, there were no differences in sex, educational level, or occupation type among the groups. The specific sociodemographic and hearing characteristics of the participants are summarized in Table 1.

Primary outcome: association between cognition and hearing
The overall MMSE scores of the normal hearing group and the mild, moderate, and severe–profound HL groups were 24.00 (5.00), 24.00 (5.00), 23.00 (5.00), and 23.00 (13.00), respectively. There was no significant association between MMSE score and the degree of HL ($p = 0.097$). Linear regression analysis revealed that the MMSE score was negatively correlated with PTA ($R^2 = 0.07, p < 0.001$, Fig. 1) and positively related to speech recognition rate ($R^2 = 0.09, p < 0.001$, Fig. 2).

Secondary outcome: association between cognition and other covariates
Association between cognition and educational level
MMSE scores were higher among participants with higher educational levels ($p < 0.001$). The overall MMSE scores of the illiterate, primary school, junior/high school, and undergraduate/master's/PhD groups were 17.50 (6.00), 20.50 (5.00), 24.00 (5.00), and 27.00 (4.00), respectively. The above trend among the four education levels was also present in the MMSE subdomains of orientation ($p < 0.001$), attention and calculation ($p < 0.001$), recall ($p < 0.001$), and language ($p < 0.001$) but not in registration ($p = 0.142$, Table 2).

Association between cognition and occupation
MMSE scores were significantly correlated with occupation type ($p < 0.001$). The overall MMSE scores of the unemployed, retired, mental labor, and physical labor

| Table 1 | Sociodemographic characteristics of all participants by degree of HL |
|---------|-------------------------------------------------------------|
| Characteristic | Normal ($n = 64$) | Mild ($n = 70$) | Moderate ($n = 73$) | Severe–profound ($n = 12$) | $p$ Value |
| Age, mean (SD), years | 59.92 (4.62) | 63.23 (6.83) | 64.42 (7.51) | 66.42 (9.22) | 0.001 |
| Sex, n (%) | | | | | | |
| Male | 23 (23.47) | 33 (33.67) | 37 (37.75) | 5 (5.10) | 0.146 |
| Female | 41 (33.88) | 37 (30.58) | 36 (29.75) | 7 (5.79) | |
| Education, n (%) | | | | | | |
| Illiteracy | 2 (16.67) | 3 (25.00) | 5 (41.67) | 2 (16.67) | | |
| Primary school | 6 (23.08) | 9 (34.62) | 11 (42.31) | 0 (0.00) | 0.249 |
| Junior/ high school | 36 (29.51) | 36 (29.51) | 42 (34.43) | 8 (6.56) | | |
| Undergraduate/ master/ PhD | 20 (33.90) | 22 (37.29) | 15 (25.42) | 2 (3.39) | | |
| Occupation type | | | | | | |
| None | 18 (29.03) | 18 (29.03) | 20 (32.26) | 6 (9.68) | 0.668 |
| Retired | 35 (32.71) | 33 (30.84) | 36 (33.64) | 3 (2.80) | | |
| Physical labor | 6 (24.00) | 9 (36.00) | 8 (32.00) | 2 (8.00) | | |
| Mental labor | 5 (20.00) | 10 (40.00) | 9 (36.00) | 1 (4.00) | | |
| Duration of HL, mean (SD), years | 0.33 (1.37) | 1.87 (4.47) | 5.91 (11.23) | 13.21 (15.15) | 0.000 |
| PTA, mean (SD), dB HL | 15.94 (4.71) | 31.18 (5.40) | 49.38 (5.78) | 66.88 (10.92) | 0.000 |
| Speech recognition rate, mean (SD), % | 98.56 (2.61) | 94.57 (10.64) | 49.38 (5.78) | 66.88 (10.92) | 0.000 |

HL hearing loss, SD standard deviation, PTA pure-tone threshold average
groups were 23.00 (6.00), 25.00 (5.00), 27.00 (4.00), and 22.00 (7.00), respectively. The distribution of the overall MMSE score and those for different occupation type is illustrated in Table 2.

**Association between cognition and sex**

MMSE scores were significantly higher in men than in women \((p<0.001)\). However, upon analysis of the five subdomains, significant differences were only observed for attention and calculation \((p<0.001)\) and language \((p=0.011)\). Scores did not differ between sexes in terms of orientation \((p=0.091)\), registration \((p=0.985)\), or recall \((p=0.128)\) (Table 2). We further explored whether the educational level is related to the cognitive differences between the sexes by comparing the distribution of educational levels between men and women by using the chi-squared test. This analysis revealed that there was no significant difference in the educational level between the sexes \((p=0.070)\, Table 3\).

**Tertiary outcome: association of MMSE score with all measured characteristics**

Table 4 summarizes the results of the linear regression analyses. In the univariable analysis, the MMSE score was significantly associated with sex, educational level, occupation type, HL duration, PTA, and speech recognition rate \((all\ p<0.05)\). In the multivariable analysis, the HL duration \((p=0.794)\) and PTA \((p=0.212)\) were excluded from the model. The MMSE scores of retired participants and those with a physical job did not differ from those of unemployed participants \((p=0.872)\ and \(p=0.239)\, respectively)\.

**Discussion**

Our study aimed to investigate the relationship between HL, educational level, occupation type, and cognition function among older Chinese adults and whether such associations differ according to sex. By using univariate analysis, we identified six factors associated with CI: sex, educational level, occupation type, HL duration, PTA, and speech recognition rate. After adjusting for covariates, we found that the MMSE score was lower among female participants, those with a lower educational level, those with mental labor occupations, and those with a higher speech recognition rate than among other groups.

We have demonstrated that severe HL is associated with an increased risk of developing CI, which manifests as a lower MMSE score. Fetoni et al. [29] compared patients with and without cognitive dysfunction by using MMSE and discovered a higher hearing threshold in those with cognitive dysfunction \((p=0.049)\). In Guglielmi et al. [30], HL affected episodic memory and attentional functions rather than executive functions. In fact, there is a large consensus that ARHL is an independent and modifiable risk factor for cognitive decline [31, 32]. Excessive cognitive load dedicated to auditory perceptual processing in everyday life causes structural changes in the brain and neurodegeneration, which are detrimental to other cognitive processes [35, 36]. We combined subjective measures and objective audiometry in the current study and discovered that an increase in HL severity and a poorer speech recognition rate were associated with a lower total MMSE score. Difficulties in understanding language in older adults result from age-related defects in peripheral and central auditory pathways because they are more likely to have decreased cochlear blood supply and loss of outer hair cells at the cochlear basal [37].

Our research also revealed a statistically significant correlation between educational level and cognitive function in four of the five MMSE subdomains (all except registration) even after adjusting for confounding factors. In the registration subdomain, participants are scored on the repetition of three words (namely, “tree,” “clock,” and “car”) on the first attempt after the words were read out to them. When sufficient auditory stimuli were presented, all three words were typically repeated correctly irrespective of the participant’s educational level. Consistent with a Brazilian community sample, education also did not have an important effect on memory registration [38]. However, overall MMSE scores are highly dependent on educational level: low education levels may affect the understanding of MMSE tests [39–41]. Furthermore,
Table 2: The difference in MMSE scores under the stratification of covariates

| Characteristics       | MMSE Score, median (interquartile range) | Total | Orientation | P    | Registration | P    | Attention and calculation | P    | Recall | P    | Language | P    |
|-----------------------|------------------------------------------|-------|-------------|------|--------------|------|--------------------------|------|--------|------|----------|------|
|                       |                                          |       |             |      |              |      |                          |      |         |      |          |      |
| **Age**               |                                          |       |             |      |              |      |                          |      |         |      |          |      |
| 55 – 59 years         | 24.00(5.00)                              | 0.495 | 8.00(2.00)  | 0.255| 3.00(0.00)   | 0.673| 5.00(4.00)               | 0.991| 2.00(3.00) | 0.481| 9.00(1.00) | 0.345|
| 60 – 64 years         | 24.00(5.00)                              | 8.00(2.00) | 3.00(0.00) | 5.00(3.00) | 2.00(3.00) | 9.00(1.00) |
| 65 – 69 years         | 25.00(4.00)                              | 8.00(2.00) | 3.00(0.00) | 5.00(3.00) | 2.00(3.00) | 9.00(1.00) |
| ≥ 70 years            | 24.00(6.00)                              | 7.00(2.00) | 3.00(0.00) | 5.00(4.00) | 2.00(3.00) | 9.00(2.00) |
| **Sex**               |                                          |       |             |      |              |      |                          |      |         |      |          |      |
| Male                  | 25.50(5.00)                              | < 0.001| 8.00(2.00)  | 0.091| 3.00(0.00)   | 0.985| 5.00(2.00)               | < 0.001| 2.00(2.00) | 0.128| 9.00(1.00) | 0.011|
| Female                | 23.00(5.00)                              | 8.00(1.00) | 3.00(0.00) | 3.00(4.00) | 2.00(2.00) | 9.00(1.00) |
| **Education**         |                                          |       |             |      |              |      |                          |      |         |      |          |      |
| Illiteracy            | 17.50(6.00)                              | < 0.001| 6.50(3.00)  | < 0.001| 3.00(0.00)   | 0.142| 1.50(2.00)               | < 0.001| 0.00(0.00) | < 0.001| 6.00(2.00) | < 0.001|
| Primary school        | 20.50(5.00)                              | 6.50(2.00) | 3.00(0.00) | 2.00(3.00) | 0.00(2.00) | 8.00(3.00) |
| Junior/ high school   | 24.00(5.00)                              | 8.00(1.00) | 3.00(0.00) | 5.00(3.00) | 2.00(1.00) | 9.00(1.00) |
| Undergraduate/master/ PhD | 27.00(4.00)                  | 8.00(1.00) | 3.00(0.00) | 5.00(1.00) | 2.00(2.00) | 9.00(0.00) |
| **Occupation type**   |                                          |       |             |      |              |      |                          |      |         |      |          |      |
| None                  | 23.00(6.00)                              | < 0.001| 7.00(2.00)  | < 0.001| 3.00(0.00)   | 0.374| 4.50(4.00)               | 0.003| 1.00(2.00) | 0.001| 8.00(2.00) | < 0.001|
| Retired               | 25.00(5.00)                              | 8.00(2.00) | 3.00(0.00) | 5.00(3.00) | 2.00(2.00) | 9.00(1.00) |
| Mental labor          | 27.00(4.00)                              | 8.00(1.00) | 3.00(0.00) | 5.00(3.00) | 2.00(2.00) | 9.00(1.00) |
| Physical labor        | 22.00(7.00)                              | 7.00(3.00) | 3.00(0.00) | 3.00(4.00) | 1.00(2.00) | 8.00(2.00) |
| **Hearing Loss degree** |                                          |       |             |      |              |      |                          |      |         |      |          |      |
| Normal                | 25.00(5.00)                              | 0.097 | 8.00(1.00)  | 0.130| 3.00(0.00)   |       | 4.00(3.00)               | 0.700| 2.00(2.00) | 0.175| 9.00(1.00) | 0.080|
| Mild                  | 25.00(5.00)                              | 8.00(2.00) | 3.00(0.00) | 5.00(3.00) | 2.00(3.00) | 9.00(1.00) |
| Moderate              | 23.00(5.00)                              | 8.00(1.00) | 3.00(0.00) | 5.00(4.00) | 2.00(3.00) | 9.00(1.00) |
| Severe-profound       | 23.00(13.00)                             | 7.50(2.00) | 3.00(3.00) | 5.00(4.00) | 1.00(2.00) | 8.50(2.00) |
with increasing educational duration, the levels of MMSE scores increase. In a study of community-dwelling older adults aged 60 years or older, a higher educational level was associated with better cognitive function [42]. Individuals with hearing impairment need to devote greater resources to understanding poor-quality auditory signals, thus leaving insufficient resources available for other cognitive activities; a higher educational level may provide sufficient cognitive reserve to counteract the effects of mild hearing impairment [43].

Our results support the findings of Stern et al. [10], who indicated that occupation type was related to cognitive function and may influence cognitive health via physiological and psychological pathways. Job stress may be a potential modifiable risk factor for adverse cognitive outcomes. In an epidemiological catchment area study in Baltimore, low-strain jobs were associated with statistically significantly lower decreases in cognitive scores than other job groups over an approximately 11-year period [44]. Normally, stress responses help individuals deal with urgent situations by activating the hypothalamus–pituitary–adrenal axis and increasing cortisol levels [45]. Given that a sense of low control is associated with high psychological stress, people with low job control bear higher risks of cognitive decline when facing higher job demands [46]. Furthermore, a higher educational level, higher cognitive level of a person’s occupation (white collar jobs, e.g., clerical work, medical practice, and other occupations requiring a university degree), and greater engagement in cognitive leisure activities were reportedly related to higher MMSE scores [47]. These results support the view that cognitive stimulation throughout the course of a person’s life may contribute to cognitive reserve, thereby protecting that person against cognitive decline [48–50].

Across our cohorts, men generally performed better than women for the MMSE subdomain of attention and calculation (but not the other subdomains) after adjusting for educational level. This result complements that of a report by the Lancet Commission [5]. However, only a
few studies [51, 52] have demonstrated the presence of sex differences in MCI. Better attention and calculation performance in men than in women could arise from the effect of estrogen [53] or sex-specific cognitive reserve [5]. An eight-year longitudinal study revealed that cognitive deterioration in women with MCI was twice as fast as that in their male counterparts [54]. Even with the same degrees of hippocampal atrophy and the same rates of glucose metabolism in the temporal lobe, verbal memory performance reportedly differs between male and female patients with MCI [55]. The brain atrophy rate of female patients with MCI is reportedly higher than that of male patients, with an additional decrease of 1.0–1.5% per year [56]. A possible explanation is that men may have higher resilience to MCI-related pathological damage to the brain [51] and better executive function than women; this finding is supported by cognitive reserve theory. However, this is different from the results of a previous study [57]. The reason for this difference may be due to population heterogeneity because the relationship between ARHL and CI was stronger in the population of the current study. Furthermore, another possible explanation is the different cognitive function assessment tools used and the different definitions of HL. This study identifies the need for sex-specific strategies in the risk factor modification and healthcare prevention policies of MCI in adults above 55 years. Beyond traditional risk factors, gender-related characteristics, such as psychological stressors, also play a sizable role in MCI risk; hence, a multifaceted approach targeted to these risk factors is important to improve sex-based differences in patient outcomes.

The main strength of our study is the strictness of the inclusion and exclusion criteria, which may have reduced potential confounders. Another major strength was our ability to adjust for educational level to allow the comparison of sex differences among older adults because educational level is highly correlated with MCI. However, there were also several limitations to our study. First, our results were based on cross-sectional data rather than longitudinal trajectories of HL and cognitive function. Second, this study was only a single-center study; therefore, the results had limited reproducibility for older individuals. Third, we assessed cognitive function mainly with the MMSE. Future research should be focused on a more comprehensive approach for the assessment of cognition, and longitudinal studies are needed to better explore the possible causal relationships between HL and cognitive function.

Conclusions
In this study, we reported statistically significant relationships between global cognitive function as defined via the MMSE score, sex, educational level, occupation type, and speech recognition rate. Sex-specific strategies may be required to improve healthcare policies. These results indicate that speech recognition rate may be associated with CI among older Chinese individuals, who should be screened routinely for the early identification of the risk of cognitive decline. Our results need to be confirmed with prospective, longitudinal cohort studies.

Abbreviations
ARHL: Age-related hearing loss; CI: Cognitive impairment; HL: Hearing loss; MCI: Mild cognitive impairment; MMSE: Mini-Mental State Examination; PTA: Pure-tone threshold average.

Acknowledgments
This research was supported by the Hearing Center/Hearing and Speech Science Laboratory, West China Hospital of Sichuan University, Chengdu, China. We wish to gratefully acknowledge Zhao Shi and Lingping Ding for data collection in this study.

Authors’ contributions
HG: Concept, design, literature search, and manuscript editing. XY: Data analysis, statistical analysis, and manuscript editing. CD, ML, WK, and HL: Data collection. ZM: Manuscript review. All authors read and approved the final manuscript.

Funding
This work was supported by the 1-3-5 project for disciplines of excellence–Clinical Research Incubation Project, West China Hospital, Sichuan University (No. 2020HXFH025). The funder played no role in the design, collection, analysis, and interpretation of data of this study.

Availability of data and materials
The datasets generated and/or analyzed during the study are not publicly available to protect patient privacy but are available from the corresponding author upon reasonable request.

Declarations
Ethics approval and consent to participate
This study involved human participants were performed in accordance with the Declaration of Helsinki and approved by the Biomedical Research Ethics Committee of West China Hospital (No. 20200285). All participants voluntarily signed an informed consent form for participation in this study.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
1 Department of Otolaryngology-Head and Neck Surgery, Hearing Center/ Hearing and Speech Science Laboratory, West China Hospital of Sichuan University, 37 Guo Xue Lane, Chengdu 610041, Sichuan, People’s Republic of China.
2 Department of Otolaryngology, Head and Neck Surgery, West China Hospital, Sichuan University, Chengdu, China.

Received: 8 February 2022    Accepted: 9 November 2022
Published online: 08 December 2022

References
1. Gauthier S, Reisberg B, Zaudig M, Petersen RC, Ritchie K, Broich K, et al. Mild cognitive impairment. Lancet. 2006;367:1262–70.
23. d’Emden MC, Shaw JE, Jones GR, Cheung NW. Guidance concerning the
study of cognitive aging? Psychol Aging. 1997;12:12–21.

24. Chinese Medical Association, Chinese Medical Journals Publishing House, Chinese Society of General Practice, Chronic Obstructive Pulmonology Group of Chinese Thoracic Society, Editorial Board of Chinese Journal of General Practitioners of Chinese Medical Association, Expert Group of Guidelines for Primary Care of Respiratory System Disease. Ren R, Sun Y. Guidance for primary care of chronic obstructive pulmonary disease (2018). Chin J Gen Pract. 2018;17:856–70.

25. World Health Organization. Programme for the Prevention of Deafness and Hearing Impairment. Future programme developments for prevention of deafness and hearing impairments: report of the first informal consultation. Geneva: World Health Organization; 1997.

26. Li G, Shen Y, Chen C, Li S, Zhang W, Liu M. Experimental study on simple mental state checklist in different populations. Chin Ment Health J. 1989;03:148–51.

27. Jaeger D. Digit symbol substitution test: the case for sensitivity over specificity in neuropsychological testing. J Clin Psychopharmacol. 2018;38:513–9.

28. National Committee for the Revision of Occupational Classifications. Occupational classification system of the People’s republic of China: China Labour & Social Security Publishing House; 2015.

29. Uhlmann RF, Larson EB, Rees TS, Koeppe TL, Duckert LG. Relationship of hearing impairment to dementia and cognitive dysfunction in older adults. JAMA. 1989;261:1916–9.

30. Boots EA, Schultz SA, Almeida RP, Oh JM, Koscik RL, Dowling MN, et al. Gender-specific associations of speech-frequency hearing loss, high-frequency hearing loss, and cognitive impairment among older community dwellers in China. Aging Clin Exp Res. 2022;34:857–68.

31. Anzivino R, Conti G, Di Nardo W, Fetoni AR, Picciotti PM, Marra C, et al. The assessment of cognitive reserve: a systematic review of the most used quantitative measurement methods of cognitive Reserve for Aging. Front Psychol. 2022;13:847186.

32. Fields TN, Mueller KD, Kosic RL, Johnson SC, Okonkwo OC, Litovszy RY. Self-reported hearing loss and longitudinal cognitive function in a cohort enriched with risk for Alzheimer’s disease. J Alzheimer Dis. 2020;78:1109–17.

33. Fortunato S, Forlli F, Guglielmi V, De Corsia E, Paludetti G, Berrettini S, et al. A review of new insights on the association between hearing loss and cognitive decline in ageing. Acta Oto-Hrolingualynzol Ital. 2016;36:155–66.

34. Strutt PA, Barnier AJ, Savage G, Picard G, Kocan NA, Sachdev P, et al. Hearing loss, cognition, and risk of neurocognitive disorder: evidence from a longitudinal cohort study of older adult Australians. Neuropsychol Dev Cogn B Aging Neuropsychol Cogn. 2022;29:121–38.

35. Uchida Y, Sugiyura S, Nishitaya Y, Saji N, Sone M, Ueda H. Age-related hearing loss and cognitive decline - the potential mechanisms linking the two. Auris Nasus Larynx. 2019;46:1–9.

36. Kraus KS, Mitra S, Jimenez H, Hinduja S, Ding D, Jiang H, et al. Noise trauma impairs neurogenesis in the rat hippocampus. Neuroscience. 2010;167:1216–26.

37. Peelle JE, Wingfield A. The neural consequences of age-related hearing loss. Trends Neurosci. 2016;39:486–97.

38. Laks J, Coutinho ESF, Junger W, Silveira H, Mouta R, Baptista EM, et al. Education does not equally influence all the Mini mental state examination subscales and items: findings from a Brazilian community sample. Braz J Psychiatry. 2010;32:223–30.

39. Spering CC, Hobson V, Lucas JA, Menon CV, Hall JR, O’Bryant SE. Diagnostic accuracy of the MMS in detecting probable and possible Alzheimer’s disease in ethnically diverse highly educated individuals: an analysis of the NACC database. J Gerontol A Biol Sci Med Sci. 2012;67:890–6.

40. O’Bryant SE, Humphreys JD, Smith GE, Invik RJ, Graff-Radford NR, Petersen RC, et al. Detecting dementia with the mini-mental state examination in highly educated individuals. Arch Neurol. 2008;65:963–7.

41. Nakahata N, Nakamura T, Kavarabavasya T, Seino Y, Ichi S, Ikeda Y, et al. Age-related cognitive decline and prevalence of mild cognitive impairment in the Iwaki health promotion project. J Alzheimers Dis. 2021;84:1233–45.

42. Harithasan D, Mukairi SZ-MS, Ishak WS, Shahar S, Yeong WL. The impact of sensory impairment on cognitive performance, quality of life, depression, and loneliness in older adults. J Geriatr Psychiatr Neurol. 2020;33:358–64.

43. Alattar AA, Bergstrom J, Laughlin GA, Kritz-Silverstein D, Richard EL, Reas ET, et al. Hearing impairment and cognitive decline in older, community-dwelling adults. J Gerontol A Biol Sci Med Sci. 2020;75:567–73.
44. Dong L, Eaton WW, Spira AP, Agnew J, Surkan PJ, Mojtabai R. Job strain and cognitive change: the Baltimore epidemiologic catchment area follow-up study. Occup Environ Med. 2018;75:856–62.
45. Lupien SJ, McGrew BS, Gunnar MR, Heim C. Effects of stress throughout the lifespan on the brain, behaviour and cognition. Nat Rev Neurosci. 2009;10:434–45.
46. Agrigoroaei S, Lachman ME. Cognitive functioning in midlife and old age: combined effects of psychosocial and behavioral factors. J Gerontol B Psychol Sci Soc Sci. 2011;66(Suppl 1):S130–40.
47. Ihle A, Gouveia ER, Gouveia BR, Freitas DL, Jurema J, Odim AP, et al. The relation of education, occupation, and cognitive activity to cognitive status in old age: the role of physical frailty. Int Psychogeriatr. 2017;29:1469–74 Cambridge University Press.
48. Darwish H, Farran N, Issaad S, Chaaya M. Cognitive reserve factors in a developing country: education and occupational attainment lower the risk of dementia in a sample of Lebanese older adults. Front Aging Neurosci. 2018;10:277.
49. Vance DE, Eagerton G, Hamish B, Mckie-Bell P, Fazeli PL. Cognitive prescriptions: a nursing approach to increasing cognitive reserve. J Gerontol Nurs. 2011;37:22–31.
50. Zhu W, Li X, Li X, Wang H, Li M, Gao Z, et al. The protective impact of education on brain structure and function in Alzheimer’s disease. BMC Neurol. 2021;21:423.
51. Li X, Zhou S, Zhu W, Li X, Gao Z, Li M, et al. Sex difference in network topology and education correlated with sex difference in cognition during the disease process of Alzheimer. Front Aging Neurosci. 2021;13:639529.
52. Narbutas J, Chyllinski D, Van Egroo M, Bahri MA, Koshmanova E, Besson G, et al. Positive effect of cognitive reserve on episodic memory, executive and Attentional functions taking into account amyloid-Beta, tau, and Apolipoprotein E status. Front Aging Neurosci. 2021;13:666181.
53. Ancelin ML, Ritchie K. Lifelong endocrine fluctuations and related cognitive disorders. Curr Pharm Des. 2005;11:4229–52.
54. Lin KA, Choudhury KR, Rathakrishnan BG, Marks DM, Petrella JR, Doraiswamy PM, et al. Marked gender differences in progression of mild cognitive impairment over 8 years. Alzheimers Dement (N Y). 2015;1:103–10.
55. Sundermann EE, Biegon A, Rubin LH, Lipton RB, Mowrey W, Landau S, et al. Better verbal memory in women than men in MCI despite similar levels of hippocampal atrophy. Neurology. 2016;86:1368–76.
56. Ardekani BA, Convit A, Bachman AH. Analysis of the MIRIAD data shows sex differences in hippocampal atrophy progression. J Alzheimers Dis. 2016;50:847–57.
57. Wu Y, Jia M, Xiang C, Lin S, Jiang Z, Fang Y. Predicting the long-term cognitive trajectories using machine learning approaches: a Chinese nationwide longitudinal database. Psychiatry Res. 2022;310:114434.

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Ready to submit your research? Choose BMC and benefit from:
- fast, convenient online submission
- thorough peer review by experienced researchers in your field
- rapid publication on acceptance
- support for research data, including large and complex data types
- gold Open Access which fosters wider collaboration and increased citations
- maximum visibility for your research: over 100M website views per year

At BMC, research is always in progress.
Learn more biomedcentral.com/submissions