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The Impact of Hearing Impairment on Health Indicators in a Multiethnic Population of Older Adults in Singapore

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Abstract

Background and Objectives: To determine the impact of hearing impairment (HI) on health indicators in a multiethnic Singaporean population of older adults.

Research Design and Methods: In this cross-sectional, population-based study, pure-tone averages of air-conduction thresholds at 500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz were calculated for each ear. Eight categories of HI were defined ranging from: 1: No HI to 8: Bilateral severe HI. Health indicators included hearing-related quality of life (H-QoL), depressive symptoms, frailty, gait speed, instrumental activities of daily living, sarcopenia, and cognitive impairment. Multivariable regression models determined the independent associations between HI and outcomes.

Results: A total of 2,503 older adults (mean age ± *SD* 73.4 ± 8.4; 55.2% female participants) were enrolled. Of these, 289 (11.6%), 259 (10.4%), 798 (31.9%), 303 (12.1%), 515 (20.6%), 52 (2.1%), 155 (6.2%), and 115 (4.6%) had hearing levels in Cats 1 to 8, respectively; and 20 (0.8%) used a hearing aid. Compared to those with no HI, participants with unilateral mild HI (Cat 2) had a 107% reduction in H-QoL (β: 0.63; CI: 0.18, 1.09, p = .006), increasing to a 2,816% reduction (β: 16.78; CI: 13.25, 20.31, p < .001) in those with bilateral severe HI-Cat 8 (p-trend < .001). Those with Cat 8 also had lower gait speed and we observed a nonsignificant increase in odds of frailty as HI worsened.

Discussion and Implications: H-QoL is affected across the spectrum of severity and laterality of HI. Interventions to alleviate the effects of HI and provision of QoL support are warranted. Other health indicators were only affected in late stages, suggesting that slowing disease progression is crucial in clinical management.

Translational Significance: Studies exploring the impact of hearing impairment (HI) severity *and* laterality on health indicators, especially in Asia, are lacking. In our population-based study, we found a substantial impact on hearing-related quality of life (QoL) across the spectrum of HI, particularly bilateral severe HI. We also found adverse effects on gait speed in those with bilateral severe HI, and a trend for increased odds of frailty as HI worsened. Interventions to alleviate the effects of HI and provision of QoL support are warranted. As other health indicators were only affected in late stages, slowing disease progression is crucial in clinical management.

Keywords: Frailty, Functioning, Hearing impairment, Population-based, Quality of life

Background and Objectives

Hearing impairment (HI) is a chronic age-related condition that affects one in five people globally (GBD 2019 Hearing Loss Collaborators, 2021), with >100 million people estimated to have moderate-to-complete HI in the Southeast Asia region alone. With the population aging, the prevalence of HI has increased by 79% since 1990, with 430.4 million people having hearing loss that was moderate or higher in severity in 2019. The number of people with any hearing loss is projected to increase to 2.45 billion people by 2050 (GBD 2019 Hearing Loss Collaborators, 2021).

HI can substantially affect patients' hearing-related quality of life (H-QoL; Ciorba et al., 2012; Tseng et al., 2018). In the Blue Mountains Hearing Study, Gopinath and

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colleagues demonstrated that Australian adults aged ≥ 55 years with HI had a more than threefold higher risk of developing poor H-QoL (measured using the Hearing Handicap Inventory [HHIE-S]) at the 5-year follow-up compared with their nonhearing-impaired counterparts (Gopinath et al., 2012). HI also has a detrimental impact on depressive symptoms, physical function (including instrumental activities of daily living [IADLs], gait speed, and frailty); and cognitive impairment (Chen et al., 2015; Dalton et al., 2003; Lawrence et al., 2020; Lin et al., 2019; Tian et al., 2021; Utoomprurkporn et al., 2020). However, results are equivocal, with some studies also reporting no or limited relationship between HI and some of the previously mentioned health indicators (Amieva et al., 2018; Bouscaren et al., 2019; Harithasan et al., 2020; Sardone et al., 2021). These results discrepancies could be due to differences in assessment methods (e.g., measurement of HI by self-report vs objective assessment, and different pure-tone average thresholds to define HI), study type (e.g., clinic vs community-based) and size, and demographic characteristics of the study sample (e.g., ethnicity, age, and socioeconomic status).

Although there have been many large, community-based studies in older adult Western populations investigating the relationship between HI and health indicators (Amieva et al., 2018; Dalton et al., 2003; Gopinath et al., 2012; Kamil et al., 2016; Li et al., 2013; Maharani et al., 2019; Marrone et al., 2019; Mener et al., 2013; Sardone et al., 2021; Tsimpida et al., 2022), some have been limited to only men (Liljas et al., 2016; Tian et al., 2022) or women (Amieva et al., 2018; Bouscaren et al., 2019); and comparatively few have been in Asian populations (Jiang et al., 2022; Nicholas et al., 2021; Ning et al., 2022; Sakurai et al., 2022; Tseng et al., 2023; Yamada et al., 2012). In addition, very few studies have explored a comprehensive range of health indicators (Amieva et al., 2018; Harithasan et al., 2020; Sardone et al., 2021), with most focusing on only one or two outcomes. Importantly, many studies have assessed HI via self-report using unvalidated questionnaires comprising one to two items (Amieva et al., 2018; Bouscaren et al., 2019; Liljas et al., 2016, 2017; Maharani et al., 2019; Marrone et al., 2019; Shakarchi et al., 2021; Tian et al., 2022; Tsimpida et al., 2022; Yamada et al., 2012), limiting the accuracy of their results. Similarly, while most studies using clinically assessed HI took into account disease severity, none have explored the impact of HI severity *and* laterality on health indicators; as such, a detailed understanding of how HI affects people across the spectrum of the condition is lacking. Finally, no studies have explored the relationship between HI and sarcopenia (Cruz-Jentoft et al., 2019), a disease with a substantial health-related and economic burden (Bruyère et al., 2019).

We aimed to determine the impact of the laterality and severity of HI on several health indicators, including H-QoL (primary outcome), and psychosocial, physical and cognitive health outcomes, in a multiethnic population of older adults in Singapore participating in The PopulatION HEalth and Eye Disease PRofilE in Elderly Singaporeans (PIONEER) Study. We hypothesized that HI has a considerable impact on patients' health outcomes and participants with late-stage HI (i.e., bilateral moderate–severe HI) would report greater decrements compared to those with no HI.

Research Design and Methods

Study Design and Population

PIONEER is a population-based study conducted between 2017 and 2023 among Chinese, Malay, and Indian Singaporean adults aged ≥60 years living in Singapore (Gupta et al., 2020). Study invitation letters were sent out in batches to 6,377 individuals selected using an age-, gender-, and ethnicity-stratified sampling framework from a national database. These individuals were followed up by study recruitment officers in a home visit to ascertain eligibility and agreement to participate. Of the 6,377 invited, 1,015 (15.9%) were classified as "uncontactable" because of invalid address(s); or unresponsive to ≥3 home visit attempts, and/or our recruitment officers were unable to access the residence because of security restrictions. In addition, 648 (10.2%) individuals were excluded because they were incarcerated, residing in nursing homes or outside Singapore, or were deceased; while a further 994 (15.6%) were deemed ineligible because they were terminally ill, bedridden or otherwise unable to give informed consent due to severe cognitive or HI or muteness. Of the remaining 3,720 (69.4%) eligible individuals, 2,643 (71.1%) took part in the study, 1,054 (28.3%) refused, and 23 (0.6%) were undecided (71.5% response rate). Reasons for refusal included lack of interest (n = 895, 84.9%) or time needed to participate in the study (n = 159, 15.1%). Compared to participants (n = 2,644), nonparticipants (n = 1,054) were older ($p < .001$), more likely to be female ($p < .001$), and more likely to be Chinese ($p < .001$). Participants ranged from 60 to 100 years of age. About 54.8% of the sample was female participants, and 49.8%, 25.1%, 25.0% were Chinese, Indians, and Malays, respectively.

All study procedures were approved by the SingHealth Centralized Institutional Review Board (Reference #2016/3089), and written consent was obtained from all participants.

Assessment of Functional Hearing

Hearing was quantified by a trained study coordinator in a room with minimal background noise interference using a Portable pure-tone audiometer (SHOEBOX). Pure-tone averages (PTA) of air-conduction thresholds at 500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz were recorded and calculated for each ear without the use of hearing aids. Presence of HI was defined by the PTA > 25 dB in accordance with WHO guidelines (Humes, 2019), and severity of HI was further defined as average PTA ≤ 25 db (none); >25 dB to ≤40 dB (mild); >40 dB to ≤60 dB (moderate); and >60 dB (severe). Ten categories of HI were subsequently created: 1: No HI in either ear; 2: Unilateral mild HI; 3: Bilateral mild HI; 4: Unilateral moderate HI; 5: Mild HI in one ear, moderate in the other; 6: Bilateral moderate HI; 7: Unilateral severe HI; 8: Mild HI in one ear, severe in the other; 9: Moderate HI in one ear, severe in the other; 10: Bilateral severe HI. With only 17 (0.7%) participants in Group 4, we excluded it from our analyses. Additionally, due to the small number of participants in group 7 (n = 4, 0.8%), we merged Groups 7 and 8 into: "No/mild HI in one ear, severe in the other," leaving a total of eight groups.

Assessment of Psychosocial and Cognitive Health Outcomes

Face-to-face interviews with trained interviewers fluent in English, Malay, Tamil, and Mandarin were conducted in the participant's preferred language to collect the following questionnaire data. Validated non–English-language versions of each questionnaire were used when available. When not available, English-language questionnaires were professionally forward and back-translated and internally reviewed by a bilingual study team member before use. Hearing aid use was encouraged. If participants had difficulty hearing, interviewers repeated the questions in a louder voice while also presenting the questionnaires in large print until they were sure the participant had understood.

H-QoL

H-QoL was assessed using the HHIE-S (Jupiter & Palagonia, 2001), a 10-item questionnaire developed to assess how an individual perceives the social and emotional effects of hearing loss. The questionnaire consists of five social or situational items and five emotional response items; and the higher the HHIE-S score, the greater the detrimental effect of HI on H-QoL (scores range from 0 to 40).

Depressive symptoms

The nine-item Patient Health Questionnaire (Yu et al., 2012) was used to assess the presence of depressive symptoms, with a locally validated cut-off score of ≥6 indicating its presence (Sung et al., 2013).

Cognitive impairment

The Montreal Cognitive Assessment—Basic (Chen et al., 2016) was used to assess cognitive function, with the best possible score being 30 points. Cognitive impairment was defined as a score of <19 for individuals with education lower or equal to primary school, <22 for secondary or A levels, and <24 for tertiary education.

Assessment of Physical Outcomes

Instrumental activities of daily living

Participants' functional status was assessed using the eight-item Lawton IADL Scale (Lawton & Brody, 1969), which assesses eight different domains (e.g., shopping and handling finances). Items were recoded to reflect the increasing independence of the individual, with a score of 0 being the least independent and 2 being the most independent. "Dependent, low function" is defined as a total Lawton score of <16.

Gait speed

Gait speed was determined by a habitual gait speed test, where participants were instructed to walk 4 m (15 ft) at their usual speed, and timing was stopped when the first foot completely crossed the 4 m mark. Time taken to cross 4 m was recorded in seconds. Low gait speed was defined based on the latest Asian Working Group of Sarcopenia (AWGS) consensus update (2019) as a gait speed score of <1.0 m/s (Chen et al., 2020).

Frailty

Frailty was defined as presence of ≥3 conditions (body mass index [BMI] < 18.5 kg/m^2, low gait speed, low grip strength (men < 26 kg and women < 18 kg), exhaustion (score of <10 for three questions from the vitality domain of the 12-item Short-form survey), low moderate to vigorous physical activity (<150 min of moderate–vigorous physical activity per week) according to the Fried phenotype (Ng et al., 2014).

Sarcopenia

Body composition was measured using dual-energy X-ray absorptiometry (Hologic Discovery-W; Hologic Inc., Bedford, MA, USA). Based on the 2019 AWGS recommended cut-offs, sarcopenia was defined as having low muscle mass (men <7 kg/m^2 and women <5.4 kg/m^2) in the presence of either low grip strength or low gait speed (Chen et al., 2014).

Other Covariables

Data on sociodemographic characteristics (e.g., age, gender, income, and education), lifestyle factors (e.g., smoking, alcohol use, total caloric intake, and physical activity level), and medical history (e.g., previous diagnosis of ischemic heart disease and stroke) were collected using an in-house questionnaire. Total caloric intake and physical activity level were measured using an electronic Singapore Food Frequency Questionnaire (Neelakantan et al., 2016), and self-reported time (in hours) spent doing light (e.g., office work and strolling) and moderate–vigorous activities (e.g., gardening, brisk walking, and jogging), respectively. Clinical covariates were obtained via a standardized clinical examination (see Supplementary Material).

Statistical Analyses

Characteristics of the study population were examined using proportions, means, and standard deviation (*SD*). Key covariables included age (years), gender, ethnicity (Chinese, Malay, and Indian), low Socioeconomic status (SES), smoking status, alcohol use, physical activity, calorie intake, BMI, presence of diabetes, hypertension, and/or hyperlipidemia, and presenting visual impairment (except for the model with H-QoL as the outcome, as the HHIE-S item stems specifically refer to hearing, making adjustment for vision unnecessary). To determine if there were any univariable associations between the above covariates and H-QoL scores, *t* tests or analysis of variance were used as appropriate to determine if there were any mean differences in H-QoL scores between/among the groups of the respective covariate. Spearman correlation determined if there was any correlation between the corresponding continuous variables and H-QoL scores.

Linear or logistic multivariable models, adjusted for confounders, were then used to assess the independent impact of the eight groups of laterality and severity of HI on each continuous or categorical outcome, respectively, with no HI in either ear as the reference. To explore whether ethnicity was moderating the relationship between HI and H-QoL (test for interaction $p = .044$), we ran separate models in our Chinese, Malay, and Indian participants. Marginal absolute and relative (to the reference group) effect changes for each laterality and severity category of HI with reference to no HI in either ear were also determined. Bonferroni correction for multiple comparisons was applied (0.05/7 hypotheses) meaning we applied a p value of .007 to indicate statistical significance.

All statistical evaluations were made assuming a two-sided test at the 5% level of significance. Statistical analyses were conducted using STATA version 17.0.

Results

Sociodemographic and Clinical Characteristics of the Participants

Of the 2,503 PIONEER older adult participants (mean age ± *SD* 73.4 ± 8.4; 55.2% female participants), 289 (11.6%), 259 (10.4%), 798 (31.9%), 303 (12.1%), 515 (20.6%), 52 (2.1%), 155 (6.2%), and 115 (4.6%) had no, unilateral mild, bilateral mild, mild HI in one ear, moderate in the other, bilateral moderate, no/mild HI in one ear, severe in the other, moderate HI in one ear, severe in the other, and bilateral severe HI, respectively; and 20 (0.8%) used a hearing aid. Those with HI had substantially worse H-QoL compared to those without ($p < .05$, Table 1), and scores systematically increased (i.e., worsened) as laterality and severity of HI increased ($p < .05$). Older participants, males, Indians (compared to Chinese), and those with hyperlipidemia, ischemic heart disease, and low physical activity had significantly worse H-QoL compared to their counterparts (all $p < .05$, Table 1). There was also a significant difference in mean H-QoL scores across BMI categories.

Independent Association Between HI; and Psychosocial and Cognitive Health Outcomes

In our multivariable models adjusting for potential confounders, we observed a dose-response relationship between severity and laterality of HI, and H-QoL (Table 2; p-trend < .001). For example, compared to those with no HI, participants with unilateral mild HI had a 107% reduction in H-QoL (β: 0.63; confidence interval [CI]: 0.18, 1.09, $p = .006$); while those with bilateral severe HI reported a 2,816% reduction in H-QoL (β: 16.78; CI: 13.25, 20.31, $p < .001$). Although the pattern of the associations between severity and laterality of HI, and H-QoL were similar across all three ethnic groups (Supplementary Table 1), the magnitude of the associations (i.e., percentage change) was greater in Chinese people compared to Malays and Indians. Moreover, the association between unilateral mild HI, and H-QoL was not statistically significant in those of Malay and Indian ethnicity compared to the Chinese group (β: 1.12; CI: 0.41, 1.84, $p = .002$), and the association between bilateral mild HI and mild HI in one ear, moderate in the other, and H-QoL was not statistically significant in Malays.

No significant associations between HI, and depressive symptoms or cognitive impairment were observed.

Independent Association Between HI and Physical Outcomes

Compared to those with no HI, participants with bilateral severe HI had a 0.11 m/s lower gait speed (β: −0.11; CI: −0.19, −0.04, $p = .003$, −14.4% change; Table 2). No significant associations between the other severity and laterality levels and gait speed were observed, nor were significant associations found between severity and laterality of HI, and low IADL or sarcopenia. Although the associations between HI and frailty were also nonsignificant, there was a trend of increasing odds of frailty as severity and laterality categories increased (Table 2).

Discussion and Implications

In our large, contemporary, population-based study of older adults in Singapore, we found that HI had a substantial impact on H-QoL across the spectrum of severity and laterality, particularly in those with bilateral severe HI where nearly 3,000% reductions in H-QoL were observed, and in those of Chinese ethnicity. We found adverse effects on gait speed in those with bilateral severe HI but not in those with less severe HI, and a nonsignificant trend for increased odds of frailty as HI worsened. We report no significant associations between HI, and depressive symptoms, IADLs, sarcopenia, and cognitive impairment. Two key overall findings were evident from this work. First, our data reiterate the importance of screening for HI, as even individuals with unilateral HI (particularly those of Chinese ethnicity) may benefit from emotional and social support to improve H-QoL. Second, in the clinical management context, emphasis should be placed on preventing the progression from unilateral to late-stage bilateral HI or ameliorating the effects of hearing loss using interventions like hearing aids, to limit potentially debilitating functional impact. Longitudinal studies are needed to determine the effect of HI on incident health outcomes and to better understand the mechanisms underlying the HI–health indicators relationships.

Our finding that HI had a substantial, negative impact on H-QoL across the spectrum of laterality and severity is supported by other similar studies using the HHIE-S as an outcome measure (Dalton et al., 2003; Gopinath et al., 2012). For instance, in the Epidemiology of Hearing Loss Study, a large population-based longitudinal study of age-related HI conducted in U.S. adults aged >50 years, Dalton and colleagues found that participants with mild or moderate-severe hearing loss were 6 or 34 times as likely as participants without hearing loss to have poor H-QoL (score of >8 on the HHIE-S), respectively (Dalton et al., 2003). This suggests the provision of hearing aids or cochlear implantation to improve hearing is crucial, and indeed many studies have shown the positive effects of such interventions on H-QoL (Ferguson et al., 2017; Olsson et al., 2022). Importantly, despite 280 and 1,934 participants having unilateral and bilateral HI in our study, respectively, only 20 reported using a hearing aid. This low usage of hearing aids is concerning but not entirely unexpected, with other studies also showing low uptake of hearing aids in Singapore (Ho, Zhang, et al., 2018), despite the availability of subsidies for assistive devices (Chua Wei De, 2021), and elsewhere (Golub et al., 2018). More studies investigating the sociodemographic, clinical and patient-reported barriers to hearing aid usage (Ho, Ong, et al., 2018) are warranted to inform the development and evaluation of interventions to increase short and long-term uptake of hearing aids and assess associated efficacy on improving QoL outcomes (Barker et al., 2016).

Interestingly, we found that Chinese participants reported greater decrements in H-QoL compared to Indians and Malays, both in magnitude (percentage change) and scope (H-QoL affected even in mild and unilateral stages). To the best of our knowledge, no other studies have reported a differential impact of HI on H-QoL; however, several studies have reported ethnic differences in the association between vision impairment and vision-related functioning or QoL (Fenwick et al., 2017; Grisafe et al., 2022). Importantly, the association between HI and H-QoL in our study was independent of gender and low socioeconomic status, which often mediate the influence of ethnicity on outcomes. However, we did not collect data on other potentially mediating factors including coping skills, adaptation to hearing loss, social support, illness perceptions, and use of alternative medicine, which all vary

Table 1. Sociodemographic, Lifestyle, and Clinical Characteristics of Participants in the PIONEER Study

Variables[a]	*N*[e]	Overall (*N* = 2,503)	HHIE-S score
		Mean (*SD*) or %	Mean (*SD*)
Age group, years[b]			
60–69	939	37.5	1.79 (3.84)
70–79	816	32.6	2.89 (5.77)
≥80	748	29.9	4.56 (6.95)
Gender			
Female	1,381	55.2	2.32 (5.05)
Male	1,122	44.8	3.38 (5.91)
Race[b]			
Chinese	1,257	50.2	2.55 (5.35)
Malay	628	25.1	3.03 (5.60)
Indian	618	24.7	3.20 (5.70)
HI laterality and severity[c]			
No HI in either ear	289	11.6	0.45 (1.36)
Unilateral mild HI	259	10.4	1.21 (2.58)
Bilateral mild HI	798	31.9	1.38 (2.76)
Unilateral moderate HI	17	0.7	1.25 (1.61)
Mild HI in one ear, moderate in the other	303	12.1	2.36 (3.66)
Bilateral moderate HI	515	20.6	4.04 (5.77)
Unilateral severe HI	4	0.2	8.5 (5.97)
Mild HI in one ear, severe in the other	48	1.9	7.51 (8.49)
Moderate HI in on ear, severe in the other	155	6.2	9.68 (8.92)
Bilateral severe HI	115	4.6	16.45 (11.18)
Use of hearing aids			
No	2,483	99.2	2.77 (5.43)
Yes	20	0.8	10.7 (8.90)
Low socioeconomic status (SES)			
No	2,227	94.7	2.79 (5.44)
Yes	124	5.3	3.77 (7.00)
Diabetes			
No	1,389	61.9	2.85 (5.42)
Yes	855	38.1	2.88 (5.56)
Hypertension			
No	351	14.1	2.38 (4.45)
Yes	2,145	85.9	2.91 (5.67)
Hyperlipidaemia			
No	907	39.8	2.31 (4.52)
Yes	1,373	60.2	3.13 (5.92)
Stroke			
No	2,002	95.6	2.79 (5.47)
Yes	92	4.4	3.40 (5.57)
Ischemic heart disease			
No	1,694	82.8	2.56 (5.14)
Yes	353	17.2	3.97 (6.41)
Binocular presenting visual impairment (PVI)			
No	2,072	83.1	2.69 (5.26)
Yes	422	16.9	3.71 (6.81)
BMI[b]			
Underweight (BMI < 18.5)	132	5.3	3.39 (5.22)
Normal (18.5 ≤ BMI < 25)	1,172	47.0	2.65 (5.40)
Overweight (25 ≤ BMI < 30)	824	33.1	3.15 (5.99)
Obese (BMI ≥ 30)	364	14.6	2.48 (4.71)

Table 1. Continued

Variables[a]	N[e]	Overall (N = 2,503)	HHIE-S score
		Mean (SD) or %	Mean (SD)
Caloric intake (kcal) per day[d]		1,863.6 (621.7)	
Low physical activity			
No	814	36.8	2.49 (5.20)
Yes	1,400	63.2	3.02 (5.65)
Smoking			
Never smoked or past smoker	2,184	91.5	2.81 (5.51)
Current smoker	204	8.5	3.06 (5.45)
Alcohol status			
Never drank or past drinker	2,099	87.9	2.87 (5.59)
Current drinker	289	12.1	2.56 (4.91)

Notes: BMI = body mass index; HHIE-S = hearing handicap inventory for the elderly screening version; HI = hearing impairment; *SD* = standard deviation.
[a]Some variable totals may not add up to 100%.
[b]Pairwise comparisons were performed. Statistically significant mean differences of HHIE-S score were observed between: age group 60–69 and 70–79, 60–69 and ≥80, 70–79 and ≥80; Chinese and Malays, as well as Chinese and Indians; underweight and normal, underweight and obese, and overweight and obese.
[c]Pairwise comparisons not performed due to too many combinations.
[d]Spearman correlation was performed between caloric intake and HHIE-S score (p = .522).
[e]Missing low SES (n = 152), diabetes (n = 259), hypertension (n = 7), hyperlipidemia (n = 223), stroke (n = 409), ischemic heart disease (n = 456), binocular PVI (n = 9), BMI (n = 11), caloric intake (n = 638), low physical activity (n = 289), smoking status (n = 115), and alcohol status (n = 115).

according to cultural backgrounds. Future research could aim to untangle the underlying biological, behavioral, psychosocial, and cultural factors driving the ethnic differences found in our study. This could inform targeted health programs to improve H-QoL in the different ethnic groups in Singapore, particularly if modifiable factors such as health beliefs or barriers to accessing healthcare are uncovered.

Unlike other studies (Jiang et al., 2022; Tsimpida et al., 2022), including a recent systematic review and meta-analysis incorporating 147,148 older adult participants from 35 studies (Lawrence et al., 2020), we found no association between HI and depressive symptoms. This may be due to the very small number of participants reporting depressive symptoms in our study, which hampered our ability to properly explore this relationship. We also did not find an association between HI and cognitive impairment, which contrasts with other studies (Utoomprurkporn et al., 2020), including a recent report from the Singapore Longitudinal Ageing Study (Nicholas et al., 2021). Again, this is possibly because of a lack of statistical power related to the small number of people with cognitive impairment in our HI groups. Indeed, evidence suggests that provision of audiological rehabilitation to reduce hearing loss, especially as hearing aids (Bucholc et al., 2021; Jiang et al., 2023) and cochlear implants (Ohta et al., 2022) can improve cognition and reduce progression from mild cognitive impairment to dementia. Larger cohort studies are needed to elicit a better understanding of the HI–depression and HI–cognitive impairment relationships.

Similar to other studies (Chen et al., 2015; Li et al., 2013), we found that those with bilateral severe HI had a significantly slower walking speed (percentage change of −14%). However, we did not find an association between HI and sarcopenia, despite gait speed being a related component of sarcopenia and the fact that other related components of sarcopenia (e.g., hand grip strength) have also been found to be worse in those with HI (Vancampfort et al., 2019). Although our study is the first to report on the association between HI and sarcopenia (Ho et al., 2022), others have found that sarcopenia is associated with increased odds of age-related hearing loss (Kang et al., 2017; Lee et al., 2016), suggesting that longitudinal studies are needed to untangle the HI–sarcopenia relationship. Although we did not find a statistically significant association between HI and frailty, we do report a trend of increasing odds of frailty as severity and laterality of HI worsens, which is supported by findings from other studies (Tian et al., 2021). For example, in the Health, Aging, and Body Composition (Health ABC) study of 2,000 U.S. older adults aged 70–79 years, Kamil and colleagues found that those with moderate or greater HI had a 63% increased risk of developing frailty at the 5-year follow-up compared with normal-hearing individuals (Kamil et al., 2016). Interestingly, and contrary to other studies (Liljas et al., 2016; Yamada et al., 2012), we found no association between HI and IADLs, suggesting that performance of daily living tasks was not affected in our population. This could be due to the high rate of Singapore older adults (50% in those aged 75 years and over) employing live-in foreign domestic workers to assist with daily errands and self-care activities (Østbye et al., 2013). Collectively, our findings suggest that interventions to improve physical function in older adult individuals with HI may be warranted to reduce the debilitating impact of HI-related poor health outcomes like reduced gait speed, and frailty; indeed, pilot randomized controlled trials, such as the Walk, Talk, and Listen project, have shown that audiological rehabilitation along with a group exercise and socialization/health education intervention can improve functional fitness (i.e., gait speed and sit-to-stand; Jones et al., 2019).

Several pathways may explain our finding that HI is associated with adverse health outcomes (Fulton et al., 2015), namely the common-cause hypothesis, and the causal (direct and indirect hypotheses). The common-cause hypothesis suggests shared age-related degenerative changes (e.g., cellular aging, inflammation, and primitive neurodegeneration of the auditory cortex; Lawrence et al., 2020; Robertson et al., 2013) exist between HI and adverse health outcomes, such as frailty, depression, and cognitive impairment. The direct

Table 2. Multivariable Associations Between Laterality and Severity of Hearing Loss and Patient Health Indicators

Outcome	Exposure	Coefficient (95% CI)	*p* Value	Marginal effects (95% CI)	Change (%)
H-QoL	No HI in either ear	Reference		Reference	Reference
	Unilateral mild HI	β: 0.63 (0.18, 1.09)	**0.006**	0.63 (0.18, 1.09)	106.6
	Bilateral mild HI	β: 0.78 (0.44, 1.12)	**<0.001**	0.78 (0.44, 1.12)	130.8
	Mild HI in one ear, moderate in the other	β: 1.71 (1.10, 2.31)	**<0.001**	1.71 (1.10, 2.31)	286.2
	Bilateral moderate HI	β: 3.51 (2.75, 4.27)	**<0.001**	3.51 (2.75, 4.27)	589.6
	No/Mild HI in one ear, Severe in the other	β: 7.25 (4.49, 10.01)	**<0.001**	7.25 (4.49, 10.01)	1217.5
	Moderate HI in one ear, Severe in the other	β: 9.70 (7.42, 11.97)	**<0.001**	9.70 (7.42, 11.97)	1628.0
	Bilateral severe HI	β: 16.78 (13.25, 20.31)	**<0.001**	16.78 (13.25, 20.31)	2816.3
Depression (yes)	No HI in either ear	Reference		Reference	Reference
	Unilateral mild HI	OR: 4.18 (0.85, 20.56)	0.076	0.03 (−0.00, 0.05)	302.3
	Bilateral mild HI	OR: 3.44 (0.77, 15.37)	0.106	0.02 (0.00, 0.04)	233.7
	Mild HI in one ear, moderate in the other	OR: 5.34 (1.08, 26.35)	0.040[a]	0.03 (0.00, 0.07)	407.0
	Bilateral moderate HI	OR: 7.60 (1.60, 36.09)	0.011[a]	0.05 (0.02, 0.09)	603.5
	No/Mild HI in one ear, Severe in the other	OR: 3.83 (0.32, 45.49)	0.287	0.02 (−0.04, 0.09)	269.8
	Moderate HI in one ear, Severe in the other	OR: 3.72 (0.47, 29.22)	0.212	0.02 (−0.02, 0.07)	259.3
	Bilateral severe HI	OR: 6.68 (0.83, 53.73)	0.074	0.05 (−0.03, 0.12)	524.4
Cognitive impairment (yes)	No HI in either ear	Reference		Reference	Reference
	Unilateral mild HI	OR: 1.93 (0.61, 6.06)	0.261	0.04 (−0.03, 0.10)	69.7
	Bilateral mild HI	OR: 1.10 (0.40, 3.03)	0.861	0.00 (−0.04, 0.05)	7.9
	Mild HI in one ear, moderate in the other	OR: 1.14 (0.37, 3.49)	0.825	0.01 (−0.05, 0.06)	11.2
	Bilateral moderate HI	OR: 2.43 (0.88, 6.71)	0.088	0.06 (0.00, 0.11)	101.4
	No/Mild HI in one ear, Severe in the other	OR: 0.86 (0.15, 4.99)	0.862	−0.01 (−0.08, 0.07)	−12.5
	Moderate HI in one ear, Severe in the other	OR: 2.12 (0.65, 6.87)	0.213	0.05 (−0.08, 0.07)	81.9
	Bilateral severe HI	OR: 1.93 (0.50, 7.46)	0.342	0.04 (−0.04, 0.12)	69.7
Gait speed (m/s)	No HI in either ear	Reference		Reference	Reference
	Unilateral mild HI	β: −0.01 (−0.05, 0.03)	0.567	−0.01 (−0.05, 0.03)	−1.2
	Bilateral mild HI	β: −0.02 (−0.05, 0.02)	0.314	−0.02 (−0.05, 0.02)	−1.8
	Mild HI in one ear, moderate in the other	β: −0.03 (−0.07, 0.01)	0.116	−0.03 (−0.07, 0.01)	−3.5
	Bilateral moderate HI	β: −0.04 (−0.08, −0.00)	0.042[a]	−0.04 (−0.08, −0.00)	−4.4
	No/Mild HI in one ear, Severe in the other	β: −0.03 (−0.10, 0.04)	0.417	−0.03 (−0.10, 0.04)	−3.2
	Moderate HI in one ear, Severe in the other	β: −0.06 (−0.12, −0.00)	0.034	−0.06 (−0.12, −0.00)	−6.8
	Bilateral severe HI	β: −0.11 (−0.19, −0.04)	**0.003**	−0.11 (−0.19, −0.04)	−14.4
Frailty (yes)	No HI in either ear	Reference		Reference	Reference
	Unilateral mild HI	OR: 1.01 (0.61, 1.67)	0.973	0.00 (−0.08, 0.08)	0.3
	Bilateral mild HI	OR: 1.05 (0.69, 1.58)	0.829	0.01 (−0.06, 0.07)	1.7
	Mild HI in one ear, moderate in the other	OR: 1.24 (0.74, 2.05)	0.414	0.03 (−0.05, 0.11)	7.9
	Bilateral moderate HI	OR: 1.64 (1.00, 2.71)	0.052	0.08 (−0.00, 0.16)	18.4
	No/Mild HI in one ear, Severe in the other	OR: 1.29 (0.52, 3.20)	0.575	0.04 (−0.10, 0.18)	9.6
	Moderate HI in one ear, Severe in the other	OR: 2.01 (0.94, 4.32)	0.073	0.11 (−0.01, 0.23)	25.8
	Bilateral severe HI	OR: 2.45 (0.90, 6.69)	0.079	0.14 (−0.01, 0.29)	32.9

Table 2. Continued

Outcome	Exposure	Coefficient (95% CI)	*p* Value	Marginal effects (95% CI)	Change (%)
Dependent: low function (yes)	No HI in either ear	Reference		Reference	Reference
	Unilateral mild HI	OR: 1.00 (0.52, 1.95)	0.991	0.00 (−0.08, 0.08)	2.2
	Bilateral mild HI	OR: 1.35 (0.78, 2.31)	0.284	0.04 (−0.03, 0.10)	19.9
	Mild HI in one ear, moderate in the other	OR: 0.96 (0.51, 1.83)	0.902	−0.00 (−0.08, 0.07)	−2.5
	Bilateral moderate HI	OR: 1.06 (0.58, 1.95)	0.847	0.01 (−0.06, 0.08)	3.8
	No/Mild HI in one ear, severe in the other	OR: 0.99 (0.37, 2.66)	0.984	−0.00 (−0.12, 0.11)	0.7
	Moderate HI in one ear, severe in the other	OR: 1.75 (0.80, 3.82)	0.163	0.07 (−0.03, 0.18)	39.3
	Bilateral severe HI	OR: 2.14 (0.81, 5.67)	0.124	0.10 (−0.04, 0.24)	55.6
Sarcopenia (yes)	No HI in either ear	Reference		Reference	Reference
	Unilateral mild HI	OR: 0.70 (0.43, 1.15)	0.159	−0.06 (−0.14, 0.02)	−12.1
	Bilateral mild HI	OR: 0.76 (0.51, 1.13)	0.176	−0.05 (−0.11, 0.02)	−9.5
	Mild HI in one ear, moderate in the other	OR: 0.89 (0.54, 1.47)	0.643	−0.02 (−0.10, 0.06)	−4.1
	Bilateral moderate HI	OR: 1.12 (0.68, 1.85)	0.654	0.02 (−0.06, 0.10)	4.0
	No/Mild HI in one ear, Severe in the other	OR: 1.20 (0.48, 3.02)	0.695	0.03 (−0.12, 0.18)	6.4
	Moderate HI in one ear, Severe in the other	OR: 1.86 (0.85, 4.04)	0.119	0.10 (−0.03, 0.23)	21.4
	Bilateral severe HI	OR: 0.61 (0.24, 1.57)	0.306	0.08 (−0.23, 0.07)	−16.9

Notes: CI = confidence interval; HI = hearing impairment; H-QoL = hearing-related quality of life.
All models were adjusted for age, gender, ethnicity, low socioeconomic status, smoking status, alcohol status, total caloric intake per day, low physical activity, body mass index, diabetes, hypertension, hyperlipidemia, ischemic heart disease, stroke, and presenting binocular vision impairment. H-QoL was adjusted for all the above confounders except for presenting binocular vision impairment. Bolded values indicate statistically significant results, after Bonferroni correction.
[a]Not significant after Bonferroni correction.

causal pathway hypothesizes that the loss of auditory sensory information stemming from HI may lead to structural and functional cerebral changes that affect physical and mental functioning (Lawrence et al., 2020). Finally, the indirect causal pathway posits that HI may restrict individuals from social participation and subsequently forming or maintaining meaningful relationships, indirectly causing psychosocial, physical, and cognitive deficits (Chang et al., 2020). Being cross-sectional and epidemiological in design, our study is unable to provide supportive evidence for the common-cause or direct causal hypotheses. We also did not investigate factors that may be influencing the effect of HI on health indictors like QoL (Tseng et al., 2023), depression (Jiang et al., 2022), cognition (Maharani et al., 2019), and frailty (Ning et al., 2022), which have been shown previously to be mediated by physical function, loneliness, social participation, and depressive symptoms. Future research looking into the factors mediating the relationship between HI, and depressive symptoms, loneliness, frailty, sarcopenia, cognitive impairment, and poor mobility are warranted to untangle the complex relationships observed in this study.

Strengths of our study include its large, well-characterized, geographically representative study design; our clinical diagnosis of HI; and our use of valid objective and patient-reported outcome assessments. Finally, our novel assessment of both HI severity *and* laterality provided greater insight into our observed relationships, with our finding that H-QoL was negatively affected across all levels of HI whereas other health indicators (depressive symptoms, gait speed and frailty) were only affected at the more severe, bilateral stages. However, there are some limitations that must be acknowledged. First, as this was a cross-sectional analysis, we cannot make causal inferences. We are currently collecting 4-year follow-up data for the PIONEER study, which will allow us to ascertain whether baseline HI is linked with incident adverse outcomes. Second, audiometric testing was conducted in a nonsoundproof room meaning the sound level might be above the maximum recommended limit, despite best efforts to minimize external noise (Frank et al., 1993), which may mean our rates of HI are overestimated. Third, we employed grading guidelines for hearing loss from 2018 rather than using the updated system proposed in 2021 by the World Health Organisation (World Health Organisation, 2021), which may make our findings more difficult to compare to contemporary studies elsewhere. However, funding for hearing aids in Singapore is only available if the pure-tone average is poorer than 40 dB and most Singaporean hospitals continue to categorize hearing loss based on the 2018 criteria, meaning that our study findings are more clinically relevant than if we had used the updated criteria. Fourth, the very small number of cases for certain outcomes means some of our estimates may lack stability. Finally, although we adjusted for many relevant confounders, unmeasured confounding may still have affected our results.

In conclusion, HI has a substantial, independent impact on H-QoL across the spectrum of severity and laterality, particularly in those of Chinese ethnicity, whereas other health indicators are generally unaffected until hearing loss has reached the bilateral severe stages. Preventing progression from unilateral to bilateral disease, and/or ameliorating the effects of HI using interventions like hearing aids is crucial to reduce the debilitating psychosocial and functional impact of hearing loss. Additional studies are needed to determine the effect of HI on incident health outcomes and to better understand the mechanisms underlying the HI-health indicators relationships.

Supplementary Material

Supplementary data are available at *Innovation in Aging* online.

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Conflict of Interest

None.

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