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Sensitivity and specificity of hearing tests for screening hearing loss in older adults

Hsin-Chen Ting [a, b, *], Yung-Yao Huang [a]

[a] PSA Charitable Foundation, New Taipei City, Taiwan
[b] Department of Audiology and Speech-Language Pathology, MacKay Medical College, New Taipei City, Taiwan

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ABSTRACT

Objectives: The study aimed to determine the most appropriate hearing screening test to identify disabling hearing loss for adults aged 65 years or older.
Methods: This study included 577 older adults. Four hearing screening tests were considered in the study, including the Hearing Handicap Inventory for Elderly Screening (HHIE-s), three single question tests, the whisper test, and the finger rub test. The sensitivity and specificity of these tests referenced to the hearing threshold of disabling hearing loss were estimated.
Results: Among all tests, only the single self-perception question (0.7064 for sensitivity; 0.7225 for specificity) and whisper test (0.7833 for sensitivity; 0.7708 for specificity) could obtain both sensitivity and specificity higher than 70% for adults aged ≥65 years.
Conclusion: Overall, we suggest using the whisper test to identify disabling hearing loss (>40 dB HL at the better ear) for adults aged 65 years or older. However, if the conditions do not permit, the single self-perception question is also acceptable. Moreover, HHIE-s might not be a good test to detect disabling hearing loss for adults aged 80 years or older.

1. Introduction

The prevalence of hearing loss increases with age. The World Health Organization (World Health Organization, 2018) reported one-third of adults older than 65 years old have disabling hearing loss. Hearing loss is not only associated with communication difficulties but also with other negative effects, including falling (Lin and Ferrucci, 2012), social isolation (Mick et al., 2014), depression (Li et al., 2014), and cognitive decline (Lin et al., 2013). Moreover, Livingston et al. (2017) reported hearing loss is one risk factor of dementia. Therefore, unaddressed hearing loss can affect multiple aspects of an adult's life and lead to reduced quality of life. Elders might benefit from early intervention to limit the impact of hearing loss. Some studies reported positive effect of hearing aids (Dawes et al., 2015) and cochlear implant (Mertens et al., 2020) on cognition. In addition to the individual level, WHO estimates unaddressed hearing loss poses an annual global cost of US$ 980 billion (World Health Organization, 2021), and managing hearing loss in adults may help lessen the economic burden (Huddle et al., 2017). Hearing screening and assessment could reduce individual, family, and societal burden from hearing loss among older adults (Bettger et al., 2020). Hearing loss is an important issue, especially in the aging society, because hearing loss is a common problem linked to aging.

To improve knowledge of hearing ability among the public and decrease unaddressed hearing loss, hearing screening might be a good solution. Although the standard Pure-Tone Audiometry (PTA) is the gold standard for hearing evaluation, it may not be suitable for hearing screening in communities because of rigorous test conditions. To complete the standard PTA, many conditions must be met, including a soundproof chamber (ANSI, 1999) and instrument (ANSI, 2010), and it is time-consuming to obtain an effective result. Apart from the standard PTA, many different hearing tests can be used to complete the hearing screening. The screening test must be simple, effective, and efficient to increase the reach of hearing

* Corresponding author. Department of Audiology and Speech-Language Pathology, MacKay Medical College, No.46, Sec. 3, Zhongzheng Rd, Sanzhi Dist, New Taipei City, 252, Taiwan.
E-mail address: juliehcting@gmail.com (H.-C. Ting).

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screening. Some hearing tests just need an examiner, such as a questionnaire, whisper test, and finger rub test; some tests need specific equipment, such as automatic auditory brainstem response (aABR), otoacoustic emission (OAE), and PTA. Although the tests need specific equipment were applied widely to hearing screening for newborns (Kanji et al., 2018) or children (Prieve et al., 2015) and the accuracy of these screening tests was great, the equipment and trained workforce used in these tests were expensive. Therefore, to reduce the cost and increase accessibility, the tests not requiring additional tools might be the better choice for hearing screening in communities.

The U.S. Preventative Services Task Force (USPSTF) (Moyer, 2012) evaluated the accuracy of various tests for detecting hearing loss in adults aged 50 years or older. However, because of the different criteria for hearing loss, the sensitivity and specificity of these hearing screening tests are difficult to compare across different studies. Although USPSTF (Feltner et al., 2021) updated the evidence for screening hearing loss and declare several screening tests can detect hearing, they still did not provide a recommendation for the best method for hearing screening.

Since the meaning of disabling hearing loss is hearing ability might lead to some problems affecting an individual's daily life, these individuals might be more active in further intervention. In this study, the referral criterion for PTA is defined by disabling hearing loss (i.e., an average hearing threshold of 0.5−4 kHz greater than 40 dB HL at the better ear in adults) (World Health Organization, 2018).

We selected the tests not requiring additional equipment such as self-questionnaire, whisper test, or finger rub test, to evaluate in this study. Self-questionnaires were self-assessment tools which mean they could be used by people themselves. Guidance of Integrated care for older people (ICOPE) (World Health Organization, 2019) suggested three test to screen hearing capacity, and whisper test was the only one test not requiring additional equipment. Although speaking might be common skill that people used day-to-day, there were many factors might affect the result of speech test, such as volume, speed, and language. Finger rub test could be completed without additional equipment or speech. WHO World Hearing Report (World Health Organization, 2021a) proposes some questions for screening in step1, including the hearing handicap inventory for the elderly (HHIE). However, the effectiveness of HHIE to detect disabled hearing loss in older adults is unclear. Although Yang et al. (2021) reported HHIE-S can detect disabled hearing loss, Everett et al. (2020) indicated HHIE-S had poor performance to detect hearing loss in older adults. Moreover, Everett et al. (2020) also concluded self-perception question could be a more sensitive and specific tool than HHIE-S.

This study aims to determine the appropriate hearing screening test to identify disabling hearing loss for adults aged 65 years old or above. For this aim, common hearing screening tests were considered, including (a) the traditional Chinese version of the hearing handicap inventory for elderly screening (HHIE-S), (b) single question test, (c) whisper test, and (d) finger rub test. Sensitivity and specificity were estimated and compared across these tests.

2. Material and methods

The Institutional Review Board at National Taiwan University approved our research on July 15, 2021 (ethical number: 202106EM039).

2.1. Subjects

The subjects included in this study were enrolled in the hearing screening program by the PSA Charitable Foundation. The program was implemented at community care stations in different cities in Taiwan. The station administrators took the initiative to submit the hearing screening program for elder at their community care stations. Subjects completed the tests could obtain a small gift, such as tissue paper, earplugs. In this study, adults aged 65 years old or above were included, and all subjects were not hearing aid users. A total of 577 adults were tested, including 147 males and 430 females, with ages ranging from 65 to 96 years old (M = 77.77, SD = 7.29).

2.2. Equipment and test setting

2.2.1. Pure-Tone Audiometry

Portable audiometers (MAICO MA25 and Grason-Stadler GSI18) with supra-aural headphones were used to obtain the average of air conduction hearing thresholds at 0.5, 1, 2, and 4 kHz. PTA tests followed guidelines from American Speech-Language-Hearing Association (2005). Tests were completed in mobile audiometric soundproof chambers or quiet rooms by audiologists and trained undergraduate student in audiology supervised by the audiologist. Type 2 sound-level meters were used to monitor noise levels, and tests would not start when noise level measured above 50dBA. This study defined the average hearing threshold at 0.5k, 1k, 2k and 4 kHz greater than 40 dB HL in better ear as disabling hearing loss.

2.2.2. Traditional Chinese version of the hearing handicap inventory for elderly screening (TC-HHIE-S)

The hearing handicap inventory for elderly screening (HHIE-S) consists of ten 4-point questions about the emotional and social aspects of hearing loss. The traditional Chinese version was translated by Yang et al. (2021) and validated by Yang et al. (2021). The HHIE-s scores were classified into 3 groups: 0 to 8 indicated no self-perceived hearing disability; 9 to 24 indicated mild-to-moderate disability; 26 to 40 indicated severe disability (Ventry and Weinstein, 1983). HHIE-s scores of more than 8 were considered to have a hearing disability in this study. HHIE-s was administered by trained volunteer via a face-to-face interview.

2.2.3. Single question test

Three single question tests were considered in this study: (a) single question 1 "*Do you think you have hearing loss? Yes/No*", (b) single question 2 "*Do you find it challenging to communicate on the phone? Yes/No*", and (c) single question 3 "*Do your family or friends think the television volume is too loud when you are watching? Yes/No*". Each single question test was judged independently, and an answer "*Yes*" was considered a hearing disability in this study.

2.3. Whisper test

Target words in the whisper test were composed of three digits, and each subject completed three trials with three target words (i.e., 619, 257, and 834). The whisper stimuli were spoken live by an examiner and presented at subjects' ears simultaneously. The examiners stood in front of the subjects, at arm's length from the subjects, and a piece of paper was used to cover the mouth to avoid lip reading. Whisper test was completed in the same room as PTA test, and test would not start when noise level measured above 55 dBA. In the whisper test, if subjects couldn't repeat two out of three trials correctly, they were considered to have a hearing disability in this study.

2.4. Finger rub test

In the finger rub test, the examiners stood behind the subjects and rubbed their fingers beside the subjects' ear. The examiners

were told to be careful not to touch the subject or for their fingers to be seen. The subjects were instructed to close their eyes and raise their hand when they heard a subtle sound. The finger rub test was conducted at each ear, and each ear was judged independently. Finger rub test was completed in the same room as PTA test, and test would not start when noise level measured above 55 dBA. In the finger rub test, if subjects didn't hear subtle sounds in both ears, they were considered to have a hearing disability.

2.5. Statistical analysis

Independent t-tests were used to test if the means of continuous variables between the two genders were significantly different. Chi-square tests were used to test the relationship between categorical variables, such as pass or refer for PTA, single question test, whisper test, and finger rub test. The results of PTA were considered as the standard of disabling hearing loss. The sensitivity and specificity of four hearing screening tests were calculated. The level of significance was set at 0.05.

3. Results

3.1. Demographic data of subjects

We divided subjects into two age categories, 338 adults (77 males and 261 females) were in the 65- to 79-year-old age group, and 239 adults (70 males and 169 females) were in the ≥80-year-old age group (Table 1). The age of subjects showed no significant difference between male and female subjects in both the 65- to 79-year-old and ≥80-year-old groups. Hearing thresholds at the better ear of males were significantly higher than females in both the 65- to 79-year-old ($p < 0.05$) and ≥80-year-old groups ($p < 0.05$).

3.2. Pure-Tone Audiometry (PTA)

Fig. 1 shows the audiogram for the 1434 tested ears across gender and age. The configuration of audiograms showed a sloping graph in two age categories with gender. The percentage of subjects with disabling hearing loss in the 65- to 79-year-old group was 46.45% for males, and 27.20% for females and in the ≥80-year-old group was 78.57% for males and 62.13% for females. Chi-square tests were used to test whether the prevalence of disabling hearing loss differs from gender or age. A significant gender effect was shown in both the 65- to 79-year-old group ($X^2 = 10.50$, $p < 0.05$) and ≥80-year-old group ($X^2 = 6.05$, $p < 0.05$). A significant age effect was shown in both male ($X^2 = 15.74$, $p < 0.05$) and female subjects ($X^2 = 51.76$, $p < 0.05$).

3.3. Traditional Chinese version of the hearing handicap inventory for elderly screening (TC-HHIE-s)

In this study, 58.95% of subjects obtained more than eight scores for HHIE-s. Compared to the PTA result of disabling hearing loss, the sensitivities of HHIE-s were 0.5704/0.8049/0.5802 for subjects aged ≥65 years (all subjects), 65–79 years, and ≥80 years, respectively. The specificities of HHIE-s were 0.7414/0.8049/0.5882 for subjects aged ≥65 years (all subjects), 65–79 years, and ≥80 years, respectively.

Chi-square tests show a statistically significant relationship between disabling hearing loss and HHIE-s for subjects aged ≥65 years ($X^2 = 24.79$, $p < 0.05$) or 65–79 years ($X^2 = 18.90$, $p < 0.05$), but no statistically significant for subjects aged ≥80 years ($X^2 = 2.73$, $p > 0.05$).

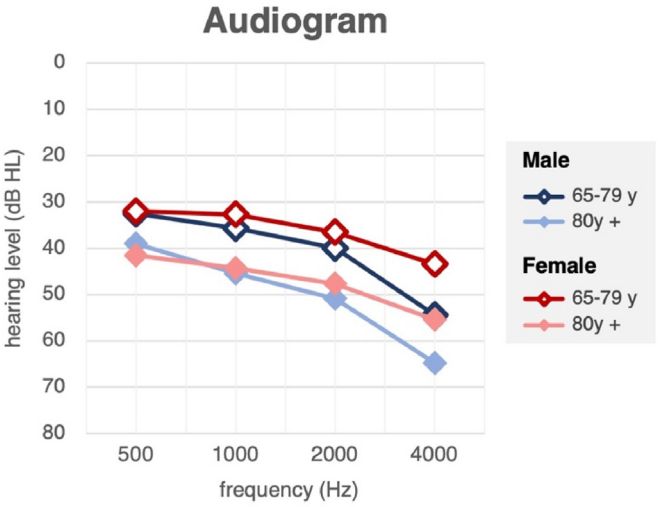

Fig. 1. Audiogram for the 1434 tested ears across gender and age.

3.4. Single question test

The percentage of the subjects who answered “yes” for the single question test was 44.33%/18.11%/26.89% for single question 1, single question 2, and single question 3, respectively.

Compared to the PTA result of disabling hearing loss, the sensitivities for subjects aged ≥65 years were 0.7064/0.3111/0.4348 for single question 1, single question 2, and single question 3, respectively. The specificities for subjects aged ≥65 years were 0.7225/0.8902/0.8356 for single question 1, single question 2, and single question 3, respectively (Table 2). Chi-square tests show a statistically significant relationship between disabling hearing loss and single question 1 ($X^2 = 49.86$, $p < 0.05$) or single question 2 ($X^2 = 7.93$, $p < 0.05$) or single question 3 ($X^2 = 10.49$, $p < 0.05$) for subjects aged ≥65 years.

The sensitivity and specificity of single question 1 for subjects aged ≥80 years were 0.7188 and 0.7027, respectively. There was a statistically significant relationship between disabling hearing loss

Table 1
Demographic Data of the subjects in the two age groups.

65–79 years			
	M	F	
Number of subjects	77	261	
Age	72.74 ± 3.75	72.71 ± 3.56	*p > 0.05*
PTA of the better ear	42.67 ± 10.26	36.13 ± 8.97	***p < 0.05***
≥ 80 years			
	M	F	
Number of subjects	70	169	
Age	85.21 ± 3.60	84.8 ± 3.12	*p > 0.05*
PTA of the better ear	50.86 ± 10.34	45.44 ± 9.0	***p < 0.05***

Table 2
The sensitivity and specificity of hearing screening tests for subjects aged ≥65 years.

Test	sensitivity	specificity
HHIE-s	0.5704	0.7414
Single Question 1	0.7064	0.7225
"*Do you think you have hearing loss?*		
Single Question 2	0.3111	0.8902
"*Do you think it is a challenge communicating on the phone?*"		
Single Question 3	0.4348	0.8356
"*Do your family or friends think the television volume is too loud when you are watching?*"		
finger rub test	0.5446	0.9364
whisper test	0.7833	0.7708
[a] screening criterion 1	0.8833	0.5069
[b] screening criterion 2	0.6167	0.9583

[a] The referral criteria for screening criterion 1 were the answer to single question 1 was "yes", or the result of the whisper test was "failed".
[b] The referral criteria for screening criterion 2 were the answer to single question 1 was "yes", and the result of the whisper test was "failed".

and single question 1 ($X^2 = 16.94$, $p < 0.05$) for subjects aged ≥80 years.

To determine what degree of hearing threshold could be identified by single question 1, we calculated the sensitivity and specificity of single question 1 referenced to different hearing thresholds. The sensitivity and specificity are shown in Table 3. There was a statistically significant relationship between single question 1 and the average threshold of 0.5–4 kHz (a) > 35 dB HL for the better ear ($X^2 = 19.23$, $p < 0.05$) or (b) > 40 dB HL for the better ear ($X^2 = 49.86$, $p < 0.05$) or (c) > 45 dB HL for the better ear ($X^2 = 50.78$, $p < 0.05$).

3.5. Whisper test

Based on this study's referral criterion for the whisper test, 39.22% of subjects failed the test. The sensitivity and specificity of the whisper test for disabling hearing loss were 0.7833 and 0.7708 for subjects aged ≥65 years, respectively, and 0.8235 and 0.7188 for subjects aged ≥80 years, respectively. Chi-square tests show a statistically significant relationship between disabling hearing loss and the whisper test for subjects aged ≥65 years ($X^2 = 84.18$, $p < 0.05$) or ≥80 years ($X^2 = 19.68$, $p < 0.05$), respectively.

To determine what degree of the hearing threshold could be identified by the whisper test, we also calculated the sensitivity and specificity of the whisper test referenced to different hearing thresholds. The sensitivity and specificity are shown in Table 3. There was a statistically significant relationship between the whisper test and the average threshold of 0.5–4 kHz (a) > 40 dB HL for the better ear ($X^2 = 54.57$, $p < 0.05$) or (b) > 45 dB HL for the better ear ($X^2 = 29.48$, $p < 0.05$).

3.6. Finger rub test

Based on this study's referral criterion for the finger rub test, 31.73% of subjects failed the test. The sensitivity and specificity of the finger rub test for disabling hearing loss were 0.5446 and 0.9364 for subjects aged ≥65 years, respectively, and 0.6441 and 0.8919 for subjects aged ≥80 years, respectively. Chi-square tests show a statistically significant relationship between disabling hearing loss and the finger rub test for subjects aged ≥65 years ($X^2 = 80.68$, $p < 0.05$) or ≥80 years ($X^2 = 26.54$, $p < 0.05$), respectively.

To determine what degree of hearing threshold could be identified by the finger rub test, we also calculated the sensitivity and specificity of the finger rub test referenced to different hearing thresholds. The sensitivity and specificity are shown in Table 3. There was a statistically significant relationship between the finger rub test and the average threshold of 0.5–4 kHz (a) > 35 dB HL for the better ear ($X^2 = 149.28$, $p < 0.05$) or (b) > 40 dB HL for the better ear ($X^2 = 144.01$, $p < 0.05$) or (c) > 45 dB HL for the better ear ($X^2 = 82.66$, $p < 0.05$).

4. Discussion

4.1. Comparison of different hearing screening tests for subjects aged ≥65 years

This study aimed to determine the appropriate tests to identify disabling hearing loss for adults aged 65 years or older. The sensitivity and specificity of all tests are shown in Table 2. Only two tests, single question 1 and the whisper test, could reach more than 70% sensitivity, and all tests could reach more than 70% specificity. Compared to the two tests that had sensitivity of more than 70%, the sensitivity and specificity of the whisper test were both higher than single question 1. The result indicated the whisper test might be the most appropriate test to identify disabling hearing loss for subjects aged ≥65 years. Different from our results, Boatman et al. (2007) reported the sensitivity of the whisper test was higher than self-assessment questionnaire and the finger rub test. Moreover, they showed the lower sensitivities of single question 1, finger rub test and the whisper test than our study. We speculated that the determining factor of the difference was the criterion of the hearing loss. Boatman et al. (2007) defined hearing threshold >40 dB HL at one or more frequency in either ear as hearing loss, and we defined an average hearing threshold of 0.5–4 kHz >40 dB HL at the better ear.

Table 3
The sensitivity and specificity of hearing screening test referenced different hearing thresholds.

	single question 1		whisper test		finger rub test	
[a]Hearing thresholds (dB HL)	sensitivity	specificity	sensitivity	specificity	sensitivity	specificity
>35	0.5509	0.7130	0.5545	0.7979	0.4706	0.9124
>40	0.7064	0.7225	0.7833	0.7708	0.6176	0.8786
>45	0.8209	0.6744	0.8	0.6923	0.7099	0.8201

[a] Hearing thresholds were calculated by an average threshold of 0.5–4 kHz for the better ear.

We wondered if combining single question 1 and the whisper test could lead to better performance. The sensitivity and specificity of the combination of the two tests are shown in Table 2. The result indicated if the referral criterion were "failed" in one of the two tests, the sensitivity would be higher than every single test, but the specificity would be lower than every single test. Further, if the referral criterion were "failed" in both two tests, the opposite result would occur, the sensitivity would be lower than every single test. However, the specificity would be higher than every single test. The result indicated combining the self-perception question and the whisper test might not lead to better performance than every single test.

4.2. Comparison of subjective questionnaires for subjects aged ≥65 years

Subjective questionnaires can be used by an ordinary person and have no restriction for a test environment. Therefore, if subjective questionnaires could obtain good performance, it would be advantageous to promote hearing screening. There were three single question tests and HHIE-s considered in the study. Comparing the sensitivity and specificity of each subjective questionnaire, single question 1 was the only test reaching 70% for both sensitivity and specificity. Since HHIE-s was considered by ten questions, HHIE-s was expected to achieve the best performance among the subjective questionnaires. However, the sensitivity of single question 1 was higher than HHIE-s, and the specificities of single question-1 and HHIE-s were similar. Everett et al. (2020) reported the same result that the self-perception question had better performance than HHIE-s, but different sensitivity and specificity were reported. A possible explanation for the difference might be that the criterion of hearing loss was more rigorous, and the age of the subjects was older in our study. Therefore, we showed the self-perception question still performed best compared to HHIE-s and other single questions to identify disabling hearing loss.

4.3. Comparison of different hearing screening tests for subjects aged ≥80 years

Cognitive ability might affect the hearing screening test because subjects with a cognitive problem might not be able to complete the tests. Older adults have a higher risk of suffering from cognitive decline. Therefore, to ensure the tests still performed well for subjects aged ≥80 years, we calculated the sensitivity and specificity for these subjects (Table 4). HHIE-s showed the lowest sensitivity and specificity among all tests, and it was the only test with no statistically significant PTA result of disabling hearing loss. The result indicated HHIE-s might not be appropriate to identify disabling hearing loss for subjects aged ≥80 years.

Two tests, single question 1 and the whisper test could reach 70% for both sensitivity and specificity. Further comparing these two tests, the sensitivity and specificity of whisper test were both higher than single question 1. The result indicated the whisper test might still be the most appropriate test to identify disabling hearing loss for subjects aged ≥80 years.

Table 4
Sensitivity and specificity of hearing screening tests for subjects aged ≥80 years.

	sensitivity	specificity
HHIE-s	0.5802	0.5882
single question 1	0.7188	0.7027
whisper test	0.8235	0.7188
finger rub test	0.6441	0.8919

Considered the cognitive condition of older adults, the tests should be simple enough to decrease effect of cognitive decline. According to the sensitivity and specificity of screen tests in the study for subjects aged ≥80 years, HHIE-s might slightly difficult than other tests for subjects aged ≥80 years. However, we did not conduct cognitive screening in the study, the correlation of cognition and hearing screening were not clear. There were many existing programs with integrated tests. For example, an examination capsule with screening tools was designed to test multisense (Skarzynski et al., 2021), and the ICOPE screening tool covered six relevant conditions of the intrinsic capacity (World Health Organization, 2019). On the basis of the existing programs with interred tests, we planned to append cognitive screening to the following program for the correlation of cognition and hearing screening.

4.4. Detecting different hearing thresholds for hearing screening tests

The performance of the hearing screening test was affected by the degree of the hearing loss we wanted to detect. The sensitivities of the hearing screening test increased when the hearing thresholds increased (Table 3). The results indicated these tests were more sensitive to detect subjects with more severe hearing loss. However, the specificities of the hearing screening test decrease when hearing thresholds increase (Table 3). The results indicated the false positive of the test increased, and subjects who had lower hearing thresholds than the criterion of hearing loss were erroneously labeled as having hearing loss. Low sensitivity and low specificity might cause different problems, but there is usually a trade-off between sensitivity and specificity. An efficient test should obtain both sensitivity and specificity higher than 70% at a minimum (Wietlisbach, 2020). Our findings demonstrated the self-perception question and the whisper test might be used to detect subjects with hearing thresholds>40 dB HL, and the finger rub test might be used to detect subjects with hearing thresholds>45 dB HL.

4.5. Limitations of the study

We only used supra-aural headphones as air-conducted transducers to obtain the air conduction hearing thresholds. We did not know the bone conduction hearing thresholds, and we could not distinguish conductive hearing loss, sensory neural hearing loss, or mixed type hearing loss. However, to determine disabling hearing loss might not need to distinguish different types of hearing loss. Considered the time and equipment limit, we did not use bone-conducted transducers in this study.

The whisper test and finger rub test might vary among different examiners, even if the examiners were trained before practice. The whisper test was spoken live by examiners; thus, the intensity of the whispering voice might vary across different examiners. Labanca et al. (2017) tested the reproducibility of the whisper test by the second examiner and found the whisper test was reproducible by a different examiner, but the inter-examiner reproducibility value varied. A possible solution was to prerecord the whisper target speech. However, it would lose the mobility of the whisper test (do not need an additional tool), and the device's volume control would be another issue. In addition to the whisper test, the finger rub test also had a problem with different intensities of sound. We found sweaty palms made less sound than dry palms. In other words, examiners with sweaty palms cannot make enough sound, increasing the false positives.

Another limitation of the study is other hearing screening tests were not considered in our study, such as words in the noise test. Considered the time limit of the screening test, we could not

examine every hearing screening test. Instead, we chose the more common and simple tests because these tests have greater potential for practical application. However, an inevitable consequence is we could not clarify if the most appropriate tests reported in our study were better than other tests, which were not considered in the study.

5. Conclusions

To identify disabling hearing loss (>40 dB HL at the better ear) for adults aged 65 years or older, we suggest using a whisper test, if time and space permits. However, if the conditions do not permit, the single self-perception question is also acceptable. Moreover, HHIE-s might not be a good test to detect disabling hearing loss for adults aged 80 years or older.

Declaration of competing interest

No conflicts of interest, financial or otherwise, are declared by the authors.

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