

# Internet-based hearing screening using speech-in-noise: validation and comparisons of self-reported hearing problems, quality of life and phonological representation

Peter Molander,<sup>1</sup> Peter Nordqvist,<sup>2</sup> Marie Öberg,<sup>1,3</sup> Thomas Lunner,<sup>1,4</sup> Björn Lyxell,<sup>1</sup> Gerhard Andersson<sup>1,5</sup>

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For numbered affiliations see end of article.

## Correspondence to

Peter Molander;  
[peter.molander@liu.se](mailto:peter.molander@liu.se)

## ABSTRACT

**Objectives:** For the last decade a host of different projects have been launched to allow persons who are concerned about their hearing status to quickly and at a low cost test their hearing ability. Most often, this is carried out without collecting complementary information that could be correlated with hearing impairment. In this two-part study we first, present the development and validation of a novel Internet-based hearing test, and second, report on the associations between this test and phonological representation, quality of life and self-reported hearing difficulties.

**Design:** Cross-sectional study.

**Setting:** An opportunity sample of participants was recruited at the Stockholm central station for the first study. All parts of the second study were conducted via the Internet, with testing and self-report forms adapted for online use.

**Participants:** The first part of the study was carried out in direct contact with the participants, and participants from the second study were recruited by means of advertisements in newspapers and on webpages. The only exclusion criterion was that participants had to be over 18 years old. Most participants were between 60 and 69 years old. There were almost an equal number of men and women (total n=316).

**Outcome measures:** 48 participants failed the Internet-based hearing screening test. The group failing the test reported more problems on the Amsterdam Inventory of Auditory Disability. In addition, they were found to have diminished phonological representational skills. However, no difference in quality of life was found.

**Conclusions:** Almost one in five participants was in need of contacting their local hearing clinic. This group had more complaints regarding tinnitus and hyperacusis, rated their own hearing as worse than those who passed, and had a poorer capability of generating accurate phonological representations. This study suggests that it is feasible to screen for hearing status online, and obtain valid data.

## ARTICLE SUMMARY

### Strengths and limitations of this study

- Internet-based hearing screening can be a useful and cost saving adjunct for early screening of hearing impairment.
- The study population was not representative in relation to the general population as they were twice as likely to have completed an academic degree.

## INTRODUCTION

Being one of the most prominent health burdens in the world, with over 360 million sufferers world-wide, hearing impairment is an important health problem to address.<sup>1</sup> Although different forms of rehabilitation are available for persons with hearing impairment, the time gap between when a problem arises and actual help seeking can in some cases be remarkably long,<sup>2</sup> in many cases up to 10 years before help seeking. In response to this, several research projects have been launched in recent years with the aim of facilitating the transition from initially noting a diminished hearing capacity, to seeking and obtaining rehabilitation. Southall *et al*<sup>3</sup> conducted interviews with people who were in the early stages of hearing disability, aiming to better understand this gap between identifying a problem and actually seeking help. Their findings indicated that a 'critical juncture' had to be reached, when a person moves from a stage of stigmatised equilibrium by re-appraising either what negative consequences they are currently suffering or the positive gains made possible by engaging more actively in solving their hearing problem. One way of making it easier to reach this 'critical juncture' could

be to lower the barriers for the public to evaluate their hearing status. To this end, several researchers have focused on making accessible screening tools available to the public.<sup>4-6</sup>

In one screening study, Yueh *et al*<sup>7</sup> compared outcomes in a randomised controlled trial for a veteran population for either screening with tone-emitting otoscope, questionnaires, a combination of both or no screening. One year later, the active groups showed superior outcomes with the tone-emitting otoscope being the option favoured by the authors. Thus, the authors did not consider that the addition of self-report forms would add sufficient value to the screening process. In contrast, self-reported hearing disability has been identified as the most important factor influencing aspects that are relevant with regard to positive outcomes.<sup>2</sup> However, few studies have focused on comparing objective and subjective measures potential for successful outcomes in the context of screening processes.

There is a lack of well controlled and randomised trials on the benefits of screening.<sup>2</sup> Although one study found that only 5% of the individuals who undergo a screening test resulted in successful hearing aid use as a consequence of that screening, there is still a case to be made for implementing such procedures as they are of some value to a small proportion of the participants with little cost to the others.<sup>8</sup> Indeed, publicly available screening test have been found to generate a substantial amount of interest when launched, as evidenced by the fact that during a single month in 2004 a total of 36 611 persons took the Dutch National Hearing test.<sup>4</sup> The research institute Hearing Bridge, governed by the Swedish Association of Hard of Hearing People, has developed a speech-in-noise test supporting multiple platforms. To date, over 71 000 Swedes have tested their hearing online (<http://www.horseltest.se>), and more than 23 000 installations have been made on iOS and Android devices.

In a review of the available literature on hearing aid uptake, Knudsen *et al*<sup>2</sup> concluded that self-reported hearing problems seemed to be the most important factor influencing help seeking, hearing aid uptake, use and satisfaction. Although self-report measures have been used in parallel with previous online screening studies, like the HearCom project,<sup>9</sup> self-reported hearing problems have not been measured in most studies. One exception is the study by Nachtegaal *et al*,<sup>10</sup> who used both data from a speech-in-noise test and questionnaires about the need for recovery after work and psychological work characteristics. Thus, the notion of combining both questionnaires and speech-in-noise test has previously been explored. Still, most studies rely on some variation of a triple-digit test where the participants are instructed to listen to numbers being read in varying amounts of background noise in order to assess their ability to perceive speech in noise, which is the area where most people with hearing difficulties experience problems.<sup>11</sup> Adopting established paper and pencil questionnaires to

online versions is relatively unproblematic and do not influence their psychometric properties.<sup>12</sup> Thus, there is a case to be made for including both some sort of self-report form and a speech-in-noise test.

Andersson<sup>13</sup> examined whether those with an acquired severe hearing loss differed in their phonological representation ability, operationalised as performance on a rhyme-judgement task, from their normal hearing counterparts. Results indicated that this indeed was the case, and that individuals with hearing losses performed worse on the rhyme-judgement task. A later review concluded that the decline of this domain of cognitive abilities was separate from the more basic working memory, that is, the ability to simultaneously store and process chunks of information.<sup>14</sup> However, although not of primary importance in rhyme judgement, it is important to stress that working memory, among other things, is of importance for language comprehension.<sup>15</sup> The importance of working memory increases in noisy environments, when interpretation of the limited signal requires the listener to make sense of the information by 'filling in the missing words'.<sup>16</sup> Thus, in order to be able to determine if words rhyme or not, an ability to compare and analyse the phonological representations of words is required that goes further than basic working memory capacity.<sup>14</sup> This acquired inability can be explained as a result of diminished functioning of a person's phonological representational skills stemming from a lack of relevant auditory stimulation. Thereby, poor rhyme judgement could serve as an indicator of declined hearing.

The concept of quality of life has received a wide range of criticism over the years, often pointing out the confusion regarding what the concept actually entails.<sup>17</sup> At the same time, the need to evaluate the impact of different states of health beyond range and severity of symptoms has long been established.<sup>18</sup> One way of looking at quality of life is to quantify it as the sum of one's satisfaction across all relevant domains of life.<sup>19</sup> The relevant strength of such a position stems from the move beyond a 'one size fits all' approach, and allowing the participant's final score to encompass only those domains that are of value to the individual. For example, if an individual is unhappy with the local neighbourhood, but at the same time indifferent to the neighbourhood as a factor influencing their overall quality of life, then that should also be reflected in the person's test result.

The study was divided into two parts. The aim of the first part was to validate an Internet-based hearing screening. The aim of the second part was to study the associations between hearing screening, phonological representation, quality of life and self-reported hearing difficulties. Furthermore, comparisons between those who failed and those who passed the Internet-based hearing screening were made in order to investigate whether the two groups differed in areas other than pure hearing screening performance.

It was hypothesised that poor results of the Internet-based hearing screening would be associated with worse performance on the test of phonological representation (a rhyming test), lower quality of life and more self-reported hearing problems.

### Part I: validation of internet-based hearing screening

#### Method: internet-based hearing screening

The speech-in-noise test consisted of 10 different words presented in background noise. The words were derived from an already established speech-in-noise test.<sup>20</sup> The original material was designed and validated for clinical use and needed to be adapted to better suit an internet screening solution. The modification from the original test was that only the last word in each sentence was used. The background noise was generated by mixing each word with multiple delayed copies of itself until a stationary noise was determined, having the same long-term spectrum as the speech material.

Participants were instructed to click on the icon representing the correct word that they just had heard. If the presented stimulus was unintelligible, an option to skip the word and move on to the next stimulus existed. Depending on if a correct answer was given or not, the following stimulus was adjusted by a simple up-and-down procedure (2 dB/step). The words were presented in a random order for a total of 20 times. The speech reception threshold (SRT), at which 50% intelligibility was achieved, was calculated as the average of the last 10 answers. Initial trials have shown this test to have satisfactory properties for screening purposes, as well as reasonable test-retest values of 1 dB difference between the first and second trial.<sup>21</sup> Using words as stimuli in internet-based hearing screening has also been adopted by other researchers.<sup>22</sup>

#### Participants

An opportunity sample of participants was recruited at the Stockholm central train station. People passing by were asked to participate in the study. Both people experiencing hearing problems and people without any hearing problems were included. In total, 223 participants were included in the evaluation (women,  $n=112$ , mean age 61 years,  $SD=14$  years, men,  $n=111$ , mean age 60.3 years,  $SD=14.5$  years). The internet-based hearing screening test was carried out with headphones (Sennheiser HD 428) connected to an ordinary PC, and no loudspeakers were used. Participants also took part in audiometric screening with standardised headphones (THD 39) at the frequencies 250, 500, 1k, 2k, 3k, 4k and 6k. The screening level was set to 20 dB HL. The audiometric screening was carried out in standard audiometric sound booths. Both the internet-based hearing screening and the audiometric screening were conducted directly after the recruitment within the same building as the central train station.

Pure-tone average (PTA) was calculated for each ear at the frequencies 250, 500, 1k, 2k, 3k, 4k, and 6k. For

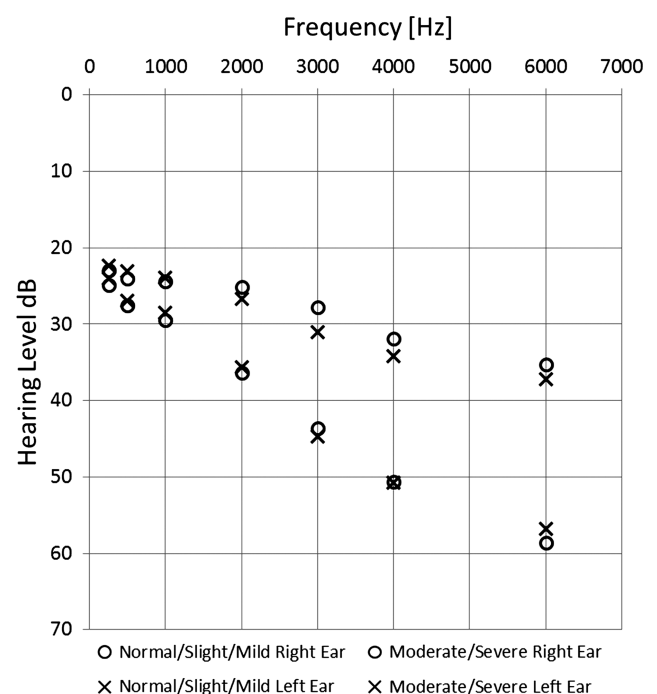
those with asymmetrical hearing loss, the PTA value for the better ear was used in the validation. A desired goal of internet-based hearing screening tests is to provide advice about getting hearing aids. The participants were divided into two groups. One group with normal or a slight impairment not needing a hearing aid and the other group with slight or moderate impairment needing a hearing aid. The WHO classification for recommending a hearing aid is a PTA value between 41 and 60 dB HL (moderate impairment).<sup>23</sup> We made a decision to include slight impairment (26–40 dB HL) as well, indicating that a hearing aid or further tests in a clinic might be needed. Thus, the PTA for separation of the two groups was set to 35 dB HL. The average left and right pure-tone audiograms for the two groups are illustrated in figure 1.

#### Statistical analyses

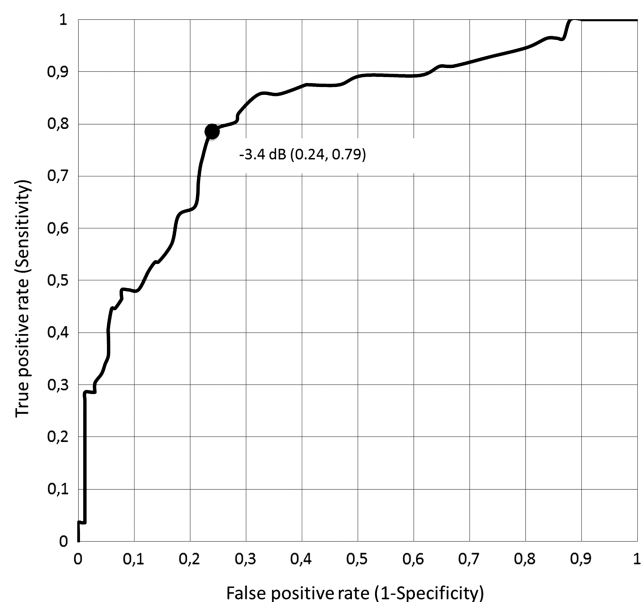
As a standard way to show the performance of screening methods we calculated the receiver operating characteristic (ROC) curve.

#### Results

The performance of the internet-based hearing screening is illustrated with the ROC curve in figure 2. The true positive rate (sensitivity) is displayed on the y axis and the false-positive rate (1-specificity) is displayed on the x axis. True positive corresponds to hearing impaired participants correctly classified as hearing impaired. False negative corresponds to normal hearing participants incorrectly classified as hearing impaired. An SRT value of  $-3.4$  dB corresponds to a true-positive



**Figure 1** Left and right ear pure-tone audiogram for the two groups.



**Figure 2** Receiver operating characteristic curve for the screening test. A  $-3.4$  dB speech reception threshold screening threshold corresponds to a true-positive rate of 79% and false-positive rate of 24% given a pure-tone average threshold of 35 dB HL.

rate of 79% and false-positive rate of 24% given a PTA threshold of 35 dB HL.

The threshold was set to be a compromise between high sensitivity and false-positive rate. An SRT value higher than  $-3.4$  dB gives a probability of 79% of classifying the user correctly as hearing impaired, given the used PTA threshold.

## Discussion

Several factors affect the outcome of the ROC curve when validating an internet-based hearing screening test, for example, speech material, recruitment of participants, definition of hearing impaired (PTA threshold) and noise type. Clearly it is difficult to compare one screening method with another.

**Table 1** Demographical characteristics of all included participants

Variable	Category	Frequency (%)
Age	18–29	9 (2.8)
	30–39	14 (4.4)
	40–49	22 (7)
	50–59	64 (20.3)
	60–69	124 (39.2)
	70–79	76 (24.1)
	80–89	7 (2.2)
Education	Elementary	38 (12)
	High school	78 (24.7)
	College/University	200 (63.3)
Marital Status	Married	223 (71)
	Not married	93 (29)

In one study the ROC was calculated for different types of noises.<sup>24</sup> The speech spectrum-shaped background noise (true-positive rate 51%, false-positive rate 10%) was compared with a low-pass filtered variant (true-positive rate 95%, false-positive rate 2%). Our result is comparable with the first version from this study; however, several factors differ between the studies. Clearly it seems advantageous to low-pass filter the noise to increase the sensitivity. However, this was not done in this study.

In another study the reported performance was 91% and 7% for the true-positive rate and the false-positive rate.<sup>25</sup> However, the previous studies used a different recruitment method compared with this study.

It is preferable to design the validation as close as possible to resemble realistic conditions. Therefore all participants were recruited directly from the community. Another alternative is to recruit the participants from two separate sources, for example, normal hearing participants recruited from universities or colleges and hearing impaired participants recruited from clinics. This method may result in a biased and sharper ROC curve since the representation of participants with ambiguous impairments between the two groups is not as well represented as in reality.

The performance of the internet-based hearing screening was satisfactory for our purposes. It was then used in the second part as an important component together with other measures.

## Part II: associations between internet-based hearing screening, phonological representation, quality of life and self-reported difficulties

### Participants

Following advertisements in the Swedish national press, a total of 596 individuals declared interest in participating in the study by signing up for an email with further instructions. Of those, 316 actually signed up and, at least partially, completed the screening. The study was conducted between 26 February and 6 March 2012. A total of 287 participants successfully completed the internet-based hearing screening described above. Adults over 18 years of age were invited to participate, regardless of auditory status, use of assisted hearing devices or any medical condition. Hearing aid ownership was not an exclusion criterion as the relationship between the internet-based hearing screening and the other variables was in focus. Hearing aid owners were instructed to take the test unaided. Participants from part I (eg, the validation study) were not included.

Information on age was collected by selecting predefined categories. As is obvious from the table, the age distribution was negatively skewed and centred on the 60–69 age strata, with the youngest participants being in the 18–29 age group while 80–89 was the oldest reported age range. There were 157 women, representing 49.7% of the total sample. Most participants had completed a university degree (63.3%). Although not shown in table 1,



information was collected regarding living arrangements and family situation. In essence, over 80% currently lived with their family in their own homes and 86% were parents. Of the 316 that actually started to take the test there were no drop outs meaning that all who answered the first question also gave an answer to the last question.

### Procedure

All data were collected through an internet-based hearing screening platform. This platform was based on the previously described speech-in-noise test, and even though headphones were recommended, the use of loudspeakers was allowed for this test. Following registration, participants were guided through a series of different tests and self-report measures. These were, in chronological order, questions on demographics (age, gender, educational level, living arrangements, number of children), the internet-based hearing screening, the rhyming test, the Amsterdam Inventory for Auditory Disability and Handicap (AIAD),<sup>11</sup> the Quality of Life Inventory (QOLI),<sup>19</sup> as well as questions regarding use of hearing aids, tinnitus and hyperacusis. When finished, participants were thanked for completing the tests and given a recommendation as to whether they should seek professional care or not depending on if the cut-off point at  $-3.4$  dB was reached on the internet-based hearing screening. Reminders were sent to the email addresses of those who had not completed the questionnaires after 1 week. The study was approved by the local ethics committee.

### Measures

Besides the internet-based hearing screening, already described in part I, the following measures were used.

#### Rhyming test

As previously noted, hearing impaired persons seem to experience diminished phonological representation skills.<sup>13 14 26</sup> In the present study, participants were presented with 20 different word pairs, and were to determine if the pair rhymed or not within two seconds from task presentation. If the participant did not answer within the fixed presentation time the stimuli was removed and a reminder of the 2 s rule was given. When the participant once again had acknowledged that they understood the procedure the next word pair was presented. This test mimicked a previously developed test, and contained the same word pairs as was used by Andersson.<sup>13</sup> Outcomes were coded as being a correct answer or not. The word pairs were distinctly separated in four classes; orthographically similar and rhyming (ie, SAL—BAL), orthographically similar but not rhyming (BACKE—BOCKA), orthographically dissimilar and rhyming (PLANSCH—ORANGE) or finally both orthographically dissimilar and not rhyming (PRICK—LÖK; for further test properties, see Lyxell *et al*<sup>27</sup>).

#### The Amsterdam Inventory for Auditory Disability

This self-report inventory consists of 30 questions that cover five different factors, each relating to different forms of hearing situations.<sup>11</sup> These factors are as follows: distinction of sounds, auditory localisation, intelligibility in noise, intelligibility in quiet and detection of sounds. These different factors have a fairly high internal consistency, with  $\alpha=0.88$ , 0.88, 0.91, 0.75 and 0.79, respectively.<sup>28</sup> The AIAD has been translated to Swedish and an initial validation of that version has been published.<sup>29</sup> In its original form, the questionnaire consists of three different parts per item, each assessing degree of disability, former hearing performance and how handicapped the respondent feels in that kind of situation. Drawing on experiences from previous work on the psychometric properties on the AIAD, only the first part dealing with degree of disability was included.<sup>28</sup> Items 18 and 30 were administered, but are not included in any subscale, as per instructions from the first author (Kramer SE. Personal communication, 2012 Nov 30) of the original version as these items did not fit within any of the five factors of the scale.

#### Quality of Life Inventory

The QOLI aims at measuring quality of life by averaging the satisfaction for 16 life domains, scoring on a 6-point scale for each area, from  $-3$  to  $+3$ . The total score is then calculated by multiplying the satisfaction score with the respondents' ranked importance of that area from 0 to 2, thereby eliminating all areas deemed unimportant by the individual from the total score.<sup>19</sup> The total score is then divided by the number of domains ranked with a higher importance than 0. This way of arriving at a total quality of life score means that the range of the inventory is between  $-6$  and  $+6$ . Internal consistency is high, ranging between  $\alpha=0.77$  and 0.89, with a test-retest reliability between  $r=0.80$  and 0.91.<sup>19</sup> Normative data for a normal group of Swedish adults showed a mean score of 2.76 (SD=2.29).<sup>30</sup> The QOLI has established psychometric properties for online administration.<sup>31</sup>

#### Statistical analyses

We used t tests to compare the groups, and Pearson correlations for associations. All variables were checked for normality assumptions. p Values  $<0.05$  were regarded as statistically significant.

## RESULTS

### Descriptive statistics

The mean signal to noise ratio for all participants was  $-5.92$  dB. Using a cut-off value of  $-3.4$  dB, meant that 48 (16.7%) of the 287 participants that completed the internet-based hearing screening were classified as hearing impaired, according to the investigation above (part I). As can be seen in box 1, in the 40–49 age strata and onwards, results on the hearing test tended to worsen with increasing age. The use of hearing aids also

### Box 1 Descriptive statistics for hearing status and covariates stratified by age group

Rhyming, hearing aid, tinnitus and hyperacusis are presented as percentages instead of means. The label hearing aid refers to proportion of the specified age strata that always or sometimes uses a hearing aid. Tinnitus and hyperacusis refers to participants who answered positively on questions regarding experiencing a tinnitus-like sound or oversensitivity to even low sounds, respectively.

increased with age. Being sensitive to everyday sounds (hyperacusis) was most prevalent in the group of 30-year-olds to 39-year-olds, with the following age groups reporting lower, or the same, rates of this kind of sensitivity. In total, 24.1% reported experiencing sensitivity to sounds. Tinnitus remained relatively stable across age groups, and was a more common complaint than hyperacusis with 39.6% of participants acknowledging such an experience. Performance on the rhyme-judgement task constantly decreased with increasing age, save for the small group of 80-year-olds to 89-year-olds. On the other hand, quality of life tended to increase with age, and only the youngest age group had a mean below that of the average population (2.76 vs 2.33).<sup>30</sup>

### Differences between the groups

The results in table 2 show that participants in the group that failed the internet-based hearing screening also perceived themselves as having difficulties in all of the subscales of the AIAD. Poor hearing was also significantly associated with lower scores on the rhyming test. However, no significant association between the internet-based hearing screening and quality of life was detected as the correlation coefficient was non-significant. While lower performance on the speech in noise test did not affect quality of life, tinnitus did ( $t(286)=2.19$ ,  $p=0.029$ ). Hyperacusis was not associated with lower levels of quality of life.

There was a difference in the results for the internet-based hearing screening between those who used headphones and those who listened to the sounds through

speakers ( $t(282)=-2.79$ ,  $p=0.006$ ). The difference was about 1 dB, with headphone users averaging  $-6.59$  dB while speaker usage produced  $-5.47$  dB average. When examining potential differences in hearing between the sexes, no such connection was found ( $t(285)=-1.63$ ,  $p=0.104$ ). However, women were more likely to experience an oversensitivity towards sounds ( $t(314)=-4.68$ ,  $p<0.001$ ) but at the same time enjoyed an overall higher quality of life ( $t(314)=-3.35$ ,  $p=0.001$ ).

As can be seen in table 3, those who failed the internet-based hearing screening scored quite similar on the AIAD as the hearing impaired participants in a previous study, especially regarding speech intelligibility in noise.<sup>29</sup>

When summarised, the AIAD showed a significant association with the SRT test ( $r=0.46$ ,  $p<0.001$ ). All of the subscales were also significantly associated with the SRT test (range between  $r=0.49$  for the speech in noise subscale and  $r=0.261$  for the auditory distinction scale). The screening procedure also contained a single question whether the participant had problems hearing or understanding speech. Answering yes to this question showed a positive correlation with the internet-based hearing screening test ( $r=0.23$ ,  $p<0.001$ ).

Twenty-seven (9%) participants stated that they did not think the questions in the modules were relevant to them, meaning that the majority (270 participants, representing 86% of the total sample) were positive and the remainder of 19 participants (6%) were uncertain.

### DISCUSSION

The present study adds to the growing body of research on different ways to use information technology to enhance and simplify the hearing screening process. Findings indicate that using the AIAD is superior to simply asking people if they have impaired hearing or not. The internet-based hearing screening test proved easy enough to use for most participants, and was also able to discriminate between different hearing abilities. The proportion of participants failing the test was similar to another study of a small group of Swedish hunters who screened their hearing through the internet (16.7% vs 20%).<sup>35</sup>

**Table 2** Difference between those who passed and those who failed the SRT test

Variable	Failed (n=48) M (SD)	Passed (n=239) M (SD)	t	df	p Value
Amsterdam total score	30.13 (13.52)	17.77 (10.61)	7.03	285	<0.001
Amsterdam—distinction of sound	6.29 (3.46)	4.7 (2.47)	3.8	285	<0.001
Amsterdam—localisation	11.05 (3.15)	12.65 (2.67)	4.39	285	<0.001
Amsterdam—intelligibility in noise	6.95 (3.34)	10.45 (3.03)	7.23	285	<0.001
Amsterdam—intelligibility in quiet	10.49 (2.47)	12.42 (1.96)	6.54	285	<0.001
Amsterdam—detection of sounds	11.08 (2.6)	13.37 (1.87)	6.7	285	<0.001
QOLI	3.34 (1.15)	3.12 (1.28)	-0.56	285	0.58
Rhyme judgment	79.45% (12.82%)	87.34% (11.04%)	2.84	265	0.005

QOLI, quality of life inventory; SRT, speech reception threshold.

**Table 3** Mean scores for the Amsterdam Inventory of Auditory Disability from different studies

Subscale	Average population*	Impaired hearing <sup>29</sup>	Failed the internet-based hearing screening (n=48)	Passed the internet-based hearing screening (n=268)
Speech intelligibility in noise	0.41	1.67	1.61	0.91
Detection of sounds	0.17	1.08	0.79	0.31
Localisation of sounds	0.23	1.11	0.79	0.46
Speech intelligibility in quiet	0.23	0.109	0.9	0.5
Distinction of sounds	0.16	0.73	0.75	0.59

\*From 58 normal hearing persons, obtained from Kramer.<sup>32</sup> These data does not differ significantly from normal hearing participants' average scores in other studies.<sup>33, 34</sup>

Tinnitus and hyperacusis, although usually comorbid conditions with poor hearing status, were reported to a remarkably high degree with 39.6% and 24.1%, respectively. This number is almost three times larger regarding tinnitus than has been previously been found in the general population; 14.2%.<sup>36</sup> However, this number was more in line with studies on hearing impaired populations, where the prevalence is roughly 60%.<sup>37</sup> Another study, aiming at collecting data about hyperacusis by invitation to a cross-sectional sample of the Swedish population as well as through an open recruitment for the same questionnaire through the internet, found a point prevalence of hyperacusis at 8.6%.<sup>38</sup> This number changed to 19.4% when examining a subsample of hearing impaired participants.

Previous studies, like the one by Demeester *et al.*,<sup>39</sup> have found that simply asking a single question regarding whether the person was suffering from hearing loss is inferior to using a questionnaire, much like the present study. Others have found the opposite result.<sup>40, 41</sup> In the present study the AIAD had a stronger association with the speech in noise test than the single question regarding hearing ability did. When compared with those already diagnosed in a clinic with impaired hearing, the group who failed the internet-based hearing screening in the present study scored quite similarly on all aspects of the AIAD.<sup>29</sup> The comparison between those who passed the internet-based hearing screening to the normal population was however quite dissimilar, with scores roughly twice as high as those in the present study. The reason for this is unknown, but could simply be an indication that those willing to participate in a screening study also in fact experience subjective hearing problems—albeit not always to a clinically significant degree.

Most often, using good-quality headphones is recommended when testing a person's hearing capability. In line with previous research on the difference between modes of sound delivery, a difference of 1.12 dB was detected between loudspeakers and headphones. As a point of reference, Arlinger and Billmark<sup>42</sup> found a difference of 1 dB in speech perception between classic headphones placed outside the ear and headphones

fitted inside the ear. This means that there is a risk in producing more false positives with loudspeakers if no arrangements are made to compensate for this dissimilarity. However, examining those who failed the internet-based hearing screening revealed that there was no significant difference between those who used headphones in comparison to those that used loudspeakers on any of the other included test modules (all  $p > 0.17$ , all  $t > 0.35$ ). Hence, the use of one cut-off irrespective of listening modality seemed reasonable.

A possible future option for online screenings would be to construct a battery composed of a number of relevant measures and then combine the information in order to better understand what, if any, further action is suitable for the individual. This would, of course, mean that there is a need to follow the participants for a longer period of time and, much like the study by Meyer *et al.*<sup>8</sup> follow the participants from screening to outcome as a means to estimate who actually benefited from the screening. Motivational efforts could also be of use to bridge the gap between those in need of rehabilitation and those who actually initialise appropriate health promoting behaviours.

In the screening study we added a rhyme-judgement task. As concluded by Andersson,<sup>13</sup> subpar performance on rhyme judgement is an indicator of lack of appropriate auditory stimulation. A probable explanation for this is that hearing loss leads to a loss of precision in phonological representations of words in long-term memory.<sup>13</sup> Thus poor performance indicates a longer time with a hearing problem. Therefore, this measure has the potential to discriminate between those in need of further clinic-based testing in addition to the internet-based hearing screening, in particular when there is a discrepancy between the test results. Further development of this test could benefit from some adjustments as we deliberately decided to have a fairly easy test which reduces variance in test scores. That is, by making the test harder the variance would increase and thus the risk of a ceiling effect is lowered. Furthermore, as this test does not depend on the working memory capability of the test participant, inclusion of some sort of working memory test could be beneficial as this factor also affects

a person's hearing ability.<sup>15</sup> Further testing in the cognitive domain could benefit from some sort of control of the participant's general reaction times and computer skills, as slowed psychomotor skills may influence the test results.

Previously, a number of studies had shown that hearing problems also affect quality of life.<sup>29 43 44</sup> Surprisingly, no such correlation was found in the present study using the internet-based hearing screening. The reason for this is unclear, but one possibility is that hearing problems had not yet influenced quality of life as much in this population that was screened through the internet. Another possible explanation lies in the kind of quality of life measure used as the QOLI contains quite different domains than most other similar inventories.<sup>30</sup> It is, for example, different from Short Form 36 (SF-36), which is probably the most commonly used quality of life measure.<sup>45</sup> The SF-36 can be conceptualised as measuring quality of life as achievements,<sup>46</sup> and lower scores in this questionnaire is sometimes associated with hearing loss.<sup>43 44</sup> Hearing interventions may have effect on quality of life, see for example, Swan *et al.*<sup>47</sup> The QOLI on the other hand seems to fit into the description of a scale that measures quality of life as subjective well-being,<sup>46</sup> and this probably accounts for the difference in findings. Even though the internet-based hearing screening did not show any significant association with quality of life, the AIAD indicated a weak but significant correlation ( $r=-0.14$ ,  $p=0.01$ ).

The procedure in itself seemed to be highly acceptable by the participants. No information on the characteristics of those who signed up with their email address but yet did not take the test was collected, rendering a drop-out analysis impossible.

## LIMITATIONS

As the currently used speech in noise test uses spoken words, and not digits, it is possible that correct word apprehension relies more heavily on the participant's command, of the language in which the stimulus is presented than would have been the case if the task merely was to distinguish between a small set of digits. Thus, participants who do not have Swedish as their native tongue may have difficulties with the test unrelated to hearing levels. Unfortunately, no data were collected that allowed control for this issue, but it is unlikely that this would have a substantial influence on the results as all information and instructions were in Swedish, including all self-report measures.

As participants were recruited from advertisements in newspapers, the results have to be interpreted with caution since it is possible that our study population differs from the general population. Indeed, the educational level of the participants (63.3% reporting a college/university degree) compared with that of the general population (36% of 20-year-olds to 64-year-olds having completed some form of education at a more

advanced level than high school equivalence) indicates that this was indeed the case.<sup>48</sup>

## CONCLUSIONS

In spite of the limitations, we believe that screening for hearing disability over the internet has the potential to become an attractive option for people who start to worry about their hearing. A major strength of the study is that the internet is now widely available and there is a low added cost for each person doing the test. Internet-based hearing screening has the potential to serve as a complement to other hearing healthcare services and in the less well-favoured regions of the world it can be the first available screening of hearing. The present study found that almost one in five participants were in need of contacting their local hearing clinic. This group had more complaints regarding tinnitus and hyperacusis, rated their own hearing as worse than those who passed the speech in noise test and also had a poorer capability of generating accurate phonological representations. However, results indicated that quality of life was largely unaffected. Further developments of quality of life measures in the context of hearing problems, and how to properly measure it, could be a fruitful further development.

### Author affiliations

<sup>1</sup>Department of Behavioural Sciences and Learning, Linnaeus Centre HEAD, Swedish Institute for Disability Research, Linköping University, Linköping, Sweden

<sup>2</sup>Division of Swedish Association of Hard of Hearing, Research Institute Hearing Bridge, Stockholm, Sweden

<sup>3</sup>Department of Clinical and Experimental Medicine, Division of Technical Audiology, Linköping University, Linköping, Sweden

<sup>4</sup>Eriksholm Research Centre, Snekersten, Denmark

<sup>5</sup>Department of Clinical Neuroscience, Karolinska Institute, Stockholm, Sweden

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