Online Hearing Screening using Logatomes in Fluctuating Noise

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Abstract

As older adults become more internet-savvy, there is an increasing demand for a quick and anonymous online hearing screening test to support the early detection and treatment of hearing loss. One primary challenge to an accurate online hearing screening, however, is the fact that the test design cannot control if the user calibrates the volume of the headphones or speakers appropriately. To overcome this limitation, an online hearing screening needs to assess the hearing threshold of the user without relying upon the user to calibrate the volume. The adaptive logatome hearing screening procedure described here determines the presence of hearing loss by measuring the speech reception threshold (SRT) of the user in fluctuating noise. Since it is well established that the SRT in fluctuating noise increases significantly for those with hearing loss, this information is compared against established norms to yield a screening test result. In this adaptive procedure, nine “a-consonant-a” logatomes are presented at various levels along with a fluctuating speech noise (“Fastl noise”) presented at a constant level. The test was first performed by normal hearing listeners to normalize the logatomes for equal intelligibility and to establish a baseline SRT. With those thresholds, a 4 minute screening test (per ear) was then performed by 20 individuals with confirmed hearing loss and 20 normal hearing individuals. Results show that this screening procedure has a sensitivity of 98% and a specificity of 95% when hearing loss is defined as having a PTA of more than 20 dB. Since the speech stimuli used are logatomes, this procedure can be adapted for use internationally. Preliminary data obtained with an internet implementation confirm the applicability of this logatome test as an online hearing screening test.

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An Online Hearing Screening Tool?

There are an increasing number of older adults who are internet-savvy. They use the internet to research health-related information (source: Pew Research [1]). Thus, an internet-based hearing screening may facilitate early identification and treatment of hearing loss, with the additional benefits of being quick, convenient and anonymous.

However, there are some possible stumbling blocks which must be considered: First, it is not possible to control the calibration of the headphones or speaker volume for the end user. Since the speech reception threshold in noise is largely robust against calibration errors, a speech-in-noise test is a better choice than a conventional pure tone listening test. Second, other confounding factors such as the end user’s mother tongue need to be eliminated. This can be ensured by using nonsense words, called logatomes, as test signals. Logatomes are nonsense combinations of vowel-consonant-vowel such as /asa/ or /afa/.

Experiment 1: Methods

An adaptive determination of the threshold was selected for the test procedure. As the threshold would be extracted from the signal-to-noise ratio, a suitable noise signal had to be added to the logatome. A ‘Fastl’ noise was specifically selected, representing a fluctuating speech noise which simulates average spectral and temporal features of fluent speech [2]. It has been shown that hearing impaired subjects have more difficulties than normal hearing subjects recognizing speech, especially in fluctuating noise [3]. The adaptive procedure to determine the user’s SNR threshold was designed as follows: The ‘Fastl’ noise signal remains constant while the signal adapts based on how the user responds, which is similar to the procedure used for the HINT (hearing in noise test). Pass / fail criteria are determined based on the SNR, which is necessary for a correct logatome identification of 71% [3].

As a next step, an appropriate set of logatomes had to be chosen according to the following criteria: The test items should all be equally intelligible in noise as well as equally identifiable by international subjects with different mother tongues. To achieve this, recordings of 16 logatomes were presented to native speakers of English, French, Spanish, Finnish, Czech, Croatian, Chinese and Swedish. Subjects were asked to assign correct spelling to the sounds heard. Nine logatomes were identified to match the selected criteria: /acka/, /adda/, /affa/, /ahha/, /alla/, /amma/, /assa/, /asha/, /atta/. During the test procedure, the selected logatomes were presented in ‘Fastl’ noise after two pure tones, functioning as alert beeps to catch the listeners’ attention before the presentation of the actual test item. To ensure equal intelligibility in noise, the necessary SNR level was separately measured for all test items. The thresholds were determined in an adaptive manner. Retest-reliability of the test results was confirmed by only small intra-individual variations. Consonant-specific thresholds varied by 16 dB (mean) from -33.15 dB for /affa/ to -49.15 dB for /alla/, with a standard deviation of 7 dB (3 - 10 dB).

For each logatome, the average SRT threshold across the 20 normal-hearing subjects was defined as 0 dB SNR to ensure the same intelligibility of each logatome. In the first experiment, the threshold (SNR), which differentiates normal hearing from hearing impaired, had to be defined in terms of pass / fail criteria.
This was carried out with the help of the following subjects:

- 20 normal-hearing (NH) native speakers of: English, Italian, Indian, Persian, Serbian, Finnish, Czech, Arabic, Swedish, French, Spanish, Russian, Chinese
- 20 hearing-impaired (HI) native speakers from Germany

Five normal hearing German native speakers served as control group. The test was carried out in a 1-up-1-down procedure determining the SRT necessary for a percentage of 50% correct answers, as well as a 1-up-2-down procedure (70.7%). The decision to go for the 1-up-2-down procedure was based on the fact that especially for hearing impaired subjects, it is less frustrating than determining the threshold for 50% correct answers. The individual SRT was averaged for the last nine trials. In the first place, the test was terminated after 27 trials. The items were presented in random order, but each once in first 9, second 9 and third 9 trials. For hearing impaired subjects, the logatomes were presented without background noise before the test started in order to enable a familiarization with the test materials (click on “alla” → hear “alla”). After that training phase, the actual test was started. With the option “I did not understand”, which is treated as a wrong answer, guessing is avoided. The additional option “repeat” should only be used in exceptional cases.

Because of the relatively long test duration, the question arose if valid data could be obtained after 18 trials. Based on a retrospective analysis of the results, it was concluded that 18 trials deliver the same validity as 27 and thus, the test could be shortened. The tests were repeated on different days to ensure test reliability. Each ear was tested separately with an initial SNR of 24 dB. During the adaptive test procedure, the noise level was kept constant while the speech material was changed automatically with an initial step size of 8 dB, which was halved after every turning point down to the smallest step size of 1 dB. In 18 trials, the items were presented in a random order; each one once during the first nine presentations as well as the second nine. The individual SRT was defined as the average across the last nine test items.

**Experiment 1: Results**

Both the 1up-1down as well as the 1up-2down procedure showed a high test-retest correlation, which was slightly higher in the 1up_2down procedure:

- 1up_1down = 0.90
- 1up_2down = 0.93

The test results enabled a clear difference between normal hearing and hearing impaired, see figure 1:

<table>
<thead>
<tr>
<th></th>
<th>1up_1down</th>
<th>1up_2down</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH: 6.89 dB</td>
<td>NH: 9.0 dB</td>
<td></td>
</tr>
<tr>
<td>HI: 25.98 dB</td>
<td>HI: 30.9 dB</td>
<td></td>
</tr>
<tr>
<td>DE: 3.26 dB</td>
<td>DE: 8.2 dB</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>1up_1down</th>
<th>1up_2down</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH: 5.98 dB</td>
<td>NH: 5.7 dB</td>
<td></td>
</tr>
<tr>
<td>HI: 9.84 dB</td>
<td>HI: 9.3 dB</td>
<td></td>
</tr>
<tr>
<td>DE: 3.37 dB</td>
<td>DE: 5.1 dB</td>
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The threshold to separate the results for hearing impaired from normal hearing was determined by a regression analysis. A PTA for 0.5, 1 and 2 kHz of $\geq 20$ dB HL was set as an indication for recommended hearing aid usage. The regression analysis showed a linear regression of $y=7.64+0.64\times x$ and a high correlation of 0.90 with PTA$_{0.5, 1, 2, 4}$ kHz. Based on these specifications, a resulting threshold of 20.51 dB SRT was derived to separate hearing impaired from normal hearing impaired subjects, see figure 2.
For this definition, results show a high sensitivity (rate of correctly identified hearing impaired) and specificity (rate of correctly identified normal hearing):

- sensitivity: 97.56%
- specificity: 94.87%
- false-positive rate: 5.13%
- false-negative rate: 2.44%
- relevance: 95.24%
- segregance: 97.37%
- correct-classification rate: 96.25%
- false-classification rate: 3.75%

Experiment 2: Method

A second experiment was conducted with international subjects to ensure that the test is also appropriate for global use. The test was performed with a larger pool of international users from 15 countries around the world. The test instructions and the user interface were translated into different languages, as indicated in figure 3. Subsequently, the reliability of the test was checked in an uncontrolled environment. The following questions were addressed: Is the user a normal hearing or hearing impaired subject? Does he or she use headphones or headsets?

Before starting with the actual test, the signal level was adjusted to a “normal” volume. After a short period of familiarization with the test material, the actual screening test started, always beginning with the right ear. After 18 trials, the test results and a recommendation were displayed.

Fig. 3: Different language versions of user Interface for online implementation
Experiment 2: Results and Conclusion

Preliminary results show sufficient accuracy compared to the internally gathered results. As well, there was no indication of language-specific differences. Accordingly, it can be stated that logatomes in fluctuating noise are internationally applicable. Therefore, it can be recommended as a valid method for online hearing screening in adults, in terms of identifying normal hearing and hearing impaired subjects.

The start screen with the final user interface of the logatome hearing screening test is shown in Figure 4.

Fig. 4: User Interface for online implementation of hearing screening with logatomes

References

[1] Pew Internet Research Center - Internet and American Life Project [http://www.pewinternet.org/]