Improving the Efficiency of Speech-In-Noise Hearing Screening Tests

Cas Smits

**Objective:** Speech-in-noise hearing screening tests have become increasingly popular. These tests follow an adaptive procedure with a fixed number of presentations to estimate the speech reception threshold. The speech reception threshold is compared with an established cutoff signal to noise ratio (SNR) for a pass result or refer result. A fixed SNR procedure was developed to improve the efficiency of speech-in-noise hearing screening tests.

**Design:** The cutoff SNR is used for all presentations in the fixed-SNR procedure. After each response a reliable test result is given (pass/refer) or an extra stimulus is presented. The efficiency and pass/refer rates between the adaptive procedure and the fixed-SNR procedure were compared.

**Results:** An average reduction of 67% in the number of presentations can be achieved (from 25 to an average of 8.3 presentations per test).

**Conclusions:** The fixed-SNR procedure is superior in efficiency to the adaptive procedure while having nearly equal refer and pass rates.

**Key words:** Adaptive, Efficiency, Hearing screening test, Speech-in-noise test, SRT.

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**INTRODUCTION**

Hearing loss is common in older adults and increases in prevalence and severity as a function of age. The majority of older adults do not seek professional help for hearing loss. Screening could identify individuals with hearing loss and promote help-seeking. Smits et al. (2004) developed a low-cost functional telephone-based hearing screening test. The test consists of a fixed number of spoken three-digit sequences (digit triplets) presented in a noise background. The test follows an adaptive procedure to determine the speech to noise ratio (SNR) required to achieve 50% correct recognition, called the speech reception threshold (SRT). This type of hearing screening tests has become increasingly popular over the past decade for use over telephone (Jansen et al. 2010; Watson et al. 2012; Zokoll et al. 2013), internet (Smits et al. 2006), or smartphone (Potgieter et al. 2015). The hearing screening test estimates the SRT of the individual and compares the SRT with an established cutoff SNR for a test result. If the SRT is lower (better) than the cutoff SNR the test result is “pass;” if the SRT is higher (worse) than the cutoff SNR then the test results is “refer.” The aim of a screening test is to identify affected individuals. The screening test is very accurate for individuals with true SRT's that are much lower or much higher than the cutoff SNR. These individuals will be classified correctly (pass or refer) despite the measurement error associated with each SRT estimate. For individuals with SRT's near the cutoff SNR, the accuracy will decrease and will be lowest (i.e., 50% correct) for those with an SRT corresponding to the cutoff SNR. The dependence of test accuracy on the SRT suggests that using a fixed number of presentations is not efficient. This is illustrated by an example where the individual reaches an SNR well below the cutoff SNR very quickly during the adaptive test procedure such that the test result will be pass irrespective the correctness of the responses to the presentations that will follow.

The aim of this study is to present a method that improves the efficiency of hearing screening tests without decreasing the sensitivity or specificity of the test. Essential for the approach is the use of a fixed SNR and a variable number of presentations in the test.

**TEST PROCEDURES**

**Adaptive Procedure**

Most speech-in-noise hearing screening tests use a standard 1-up 1-down adaptive procedure to estimate the SRT. The SNR of a presentation is based on the correctness of the previous response. That is, if the stimulus is recognized correctly, the next stimulus is presented at a lower SNR, and if the response is incorrect, the next stimulus is presented at a higher SNR. The difference in SNR between two consecutive presentations is the step size of the procedure. Often the step size is constant during the task. A fixed number of n presentations is used and the SRT is determined by averaging the SNRs of the presentations including the virtual n + 1st presentation while omitting the first few presentations. A typical step size in speech-in-noise tests is 2 dB. The SRT is compared with the cutoff SNR to classify the test result as a pass or refer.

**Fixed-SNR Procedure**

The optimized test procedure uses a fixed SNR. That is, the same SNR is used for all the presentations. The result is expressed as the proportion of correctly recognized presentations. When k correct responses occur among n presentations, the proportion correct is k/n. The ratio k/n approaches p for large n, with p the true probability for a correct response of the individual at the fixed SNR. The ratio k/n is compared with a predefined proportion to classify the test result as a pass or refer. The optimal choice for a screening test is to use 0.5 for this predefined proportion, which corresponds to a fixed SNR equal to the cutoff SNR. This means...
that at a fixed SNR corresponding to the cutoff SNR is used for all the presentations, and the test gives a pass result when the proportion correct is >50% and the test gives a refer result when the proportion correct is <50%. When using the same number of presentations for the fixed-SNR procedure as for the adaptive procedure, the test characteristics (pass rate, refer rate etc.) are better for the fixed-SNR procedure but the difference is extremely small (Smits, Reference Note 1).

The efficiency of the fixed-SNR procedure can be improved largely by using the following procedure:

1. present a stimulus and judge the response
2. calculate: (a) k/n; (b) the probability that p > 0.5, that is, the cumulative probability P(p > 0.5); (c) the probability that p < 0.5, that is, P(p < 0.5)
3. repeat steps (1) and (2) until P(p > 0.5) or P(p < 0.5) reach a high value (typically a cumulative probability of more than 95% would satisfy for good test characteristics) or when the maximum number of presentations, n_{max}, is reached
4. determine the test result: the test result is pass when k/n > 0.5; the test result is refer when k/n < 0.5.

The cumulative probabilities P(p > 0.5) and P(p < 0.5) cannot be calculated directly, but the probability distribution of p can be estimated by using Bayes’ theorem (Koch 2007). The estimated probability distribution of p (i.e., the posterior distribution), f(p|n, k), depends on the number of correct responses k, the total number of presentations n and the prior distribution. Here, a uniform prior distribution is used that gives equal weight to all possible values of p. Then the posterior distribution is

\[ f(p|n, k) = \frac{(n+1)!}{k!(n-k)!} p^k(1-p)^{n-k} \]  

(1)

Note that for p = k/n, the posterior distribution f(p|n, k) becomes maximal. The cumulative probability that p > 0.5, P(p > 0.5) is

\[ P(p > 0.5) = \frac{1}{0.5} \int_{0.5}^{1} f(p|n, k) dp \]  

(2)

and P(p < 0.5) = 1 – P(p > 0.5).

To illustrate the use of these equations in a screening test, assume that 6 stimuli have been presented during the test and n_{max} = 6. Then, in step (2) of the procedure, the posterior distribution, f(p(6, k), is calculated with Eq. (1) for k = 0, 1,...,6 correct responses. Figure 1A shows the different distributions. The cumulative probabilities P(p > 0.5) and P(p < 0.5) can be calculated with Eq. (2) and represent the probabilities that the true SRT is higher or lower than the cutoff SNR, respectively. Figure 1B shows the results. When using a cumulative probability of at least 0.925 to terminate the test, the test may be ended with a pass result after five or six correct responses out of six, or after only zero or one correct responses out of six with a refer result. Step (1) and step (2) will be repeated and another stimulus will be presented if the number of correct responses is 2, 3, or 4. Thus, very good or very poor performers may need only six presentations for a reliable screening test result, whereas more presentations are used to get a reliable result for other listeners.

The calculations were performed for series up to 25 presentations. For each number of presentations, n, the minimal number of correct responses, k, for a pass result and the maximum number of correct responses for a refer result was determined. The k values where P(p > 0.5) and P(p < 0.5) are larger than 0.925 were chosen because they yield an average P(p > 0.5) and P(p < 0.5) of approximately 0.95. Thus, the test should classify 95% of the results correctly. Table 1 shows the results.

**A COMPARISON BETWEEN THE ADAPTIVE PROCEDURE AND THE FIXED-SNR PROCEDURE**

The efficiency and test characteristics (i.e., the pass rate and refer rate) of a typical adaptive speech-in-noise hearing screening test were compared with a fixed-SNR hearing screening test. Monte Carlo simulations with 10,000 runs per data point modeled an adaptive speech-in-noise test with a 2-dB step size and 25 presentations per test, or a fixed-SNR speech-in-noise test with a variable number of presentations per test and n_{max} = 25. The procedures as described above under “Adaptive Procedure” and “Fixed-SNR Procedure” were used. Each run of the simulated adaptive procedure started at the true SRT; the estimated SRT was calculated from the 25 SNRs in the run and the virtual 26th presentation. The estimated SRT was compared with the cutoff SNR to classify the...
Each run of the simulated fixed-SNR procedure yielded a classified test result and the number of presentations used in the simulation. The Monte Carlo simulations modeled SRTs from −10 dB SNR to +5 dB SNR in 0.1-dB steps, with a cutoff SNR of −7 dB SNR. The speech recognition function associated with the SRT of −10 dB SNR was a cumulative normal distribution with a maximum slope of 20%/dB. The maximum slope of the speech recognition function for higher SRTs was shallower and based on the SRT value (Smits & Festen 2011). Figure 2A shows the number of presentations, averaged over 10,000 runs, in the fixed-SNR procedure (represented by filled circles) and the number of presentations in the adaptive procedure (i.e., 25 presentations per test) represented by the solid line. The number of presentations in the fixed-SNR procedure, averaged over the range of SRTs, equals 8.3 which compares very favorably to the 25 presentations in the adaptive procedure. Histograms showing the distribution of the number of presentations for all integer SRTs from −10 to 5 dB SNR are available in Supplemental Digital Content 1 (http://links.lww.com/EANDH/A349). Figure 2B shows the pass and refer rate as a function of SRT. These rates are very similar for both procedures as demonstrated by the nearly identical functions. For reference, the pass and refer rates for a reference fixed-SNR procedure with 25 presentations per test were calculated and shown as solid lines in Figure 2B. The percentage of wrongly classified test results is 4.2% for the adaptive procedure, 4.8% for the fixed-SNR procedure, and 4.3% for the reference fixed-SNR procedure. Because a priori information about the true SRT was used in the Monte Carlo simulations of the adaptive procedure (i.e., each run started at the true SRT), the pass and refer rates are slightly better than the reference fixed-SNR procedure with an equal number of presentations as in the adaptive procedure. Note that the average number of presentations in the fixed-SNR procedure and the percentages of wrongly classified test results depend on the distribution of SRTs in the test population.

**DISCUSSION AND CONCLUSION**

The fixed-SNR procedure is superior in efficiency to the adaptive procedure while having nearly equal refer and pass rates. An average reduction of 67% in the number of presentations was achieved (from 25 to an average of 8.3 presentations per test) for the modeled speech-in-noise tests and SRT population. The reduction depends on the distribution of SRTs in the population (Fig. 2A), but for most populations a reduction of at least 50% in the average number of presentations can be achieved. These numbers should be interpreted with caution because they are only based on calculations and simulations. Listener-related factors could lead to differences in refer and pass rates between the procedures. It may be hypothesized that, for example, an adaptive procedure aiming at 50% correct is more encouraging than a fixed-SNR procedure with very easy- or very difficult-to-recognize stimuli for some listeners, which may have an effect on performance. The adaptive speech-in-noise screening tests use a few presentations (typically 4) to reach an SNR near the SRT. The responses to these presentations are omitted from the SRT calculation, which means that the total number of presentations

### Table 1. The minimal and maximal number of correct responses, k, out of n presentations for a pass or refer result

<table>
<thead>
<tr>
<th>n</th>
<th>Minimal k for pass</th>
<th>Maximal k for refer</th>
<th>P(p &gt; 0.5); P(p &lt; 0.5)</th>
</tr>
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<tbody>
<tr>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0.97; 0.98</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>1</td>
<td>0.98; 0.94</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>1</td>
<td>0.94; 0.96</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>1</td>
<td>0.96; 0.98</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>2</td>
<td>0.98; 0.95</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>2</td>
<td>0.95; 0.97</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>3</td>
<td>0.97; 0.94</td>
</tr>
<tr>
<td>11</td>
<td>10</td>
<td>3</td>
<td>0.97; 0.97</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>3</td>
<td>0.97; 0.94</td>
</tr>
<tr>
<td>13</td>
<td>10</td>
<td>4</td>
<td>0.97; 0.94</td>
</tr>
<tr>
<td>14</td>
<td>10</td>
<td>4</td>
<td>0.96; 0.95</td>
</tr>
</tbody>
</table>

The last row shows the corresponding cumulative probability that p is larger or smaller than 0.5.

Fig. 2. Results of Monte Carlo simulations. A. The average number of presentations in the fixed-SNR procedure (filled circles) and the number of presentations in the adaptive procedure (solid line). B. Pass and refer rates for both procedures. For reference, the pass and refer rates for a fixed-SNR procedure with 25 presentations per test are shown as solid lines. SNR, signal to noise ratio.
in the adaptive procedure modeled in this article would be higher than 25. For the fixed-SNR procedure the test could start immediately, which makes the test even more efficient compared with the adaptive test. However, a few trial presentations might be beneficial in the fixed-SNR procedure to make the listener familiar with the test and reduce a possible training effect. Experimental data are needed to verify whether these dummy presentations are necessary or not, and at which SNR they should be presented. An advantage of the adaptive procedure is that it provides more information than the fixed-SNR procedure. The SRT, for example, gives an estimate of the amount of hearing loss.

The applicability of the procedure is not limited to speech-in-noise screening tests but it can be applied to essentially all psychophysical screening tests. When the cutoff value corresponds to a proportion correct that is different from 50%, then the minimal number of correct responses needs to be determined for that specific percentage. Otherwise the values from Table 1 can be used.

In conclusion, this study shows a highly efficient procedure for speech-in-noise hearing screening tests which can be easily implemented in existing tests. The average number of presentations needed is only 30–50% of the number of presentations used in an adaptive speech-in-noise screening test.

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REFERENCES


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