Towards a clinically viable spectro-temporal modulation test

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Introduction
The Spectro-Temporal Modulation (STM) test has shown good predictive power for speech-in-noise outcomes beyond the audiogram in several studies [1–3]. Thus, the STM test is a promising diagnostic value for hearing-aid fitting.

In the STM test, the depth of spectro-temporal modulations applied to a wide-band carrier is varied, and a threshold is determined at which the test subject can just detect the difference between the STM stimulus and a reference without modulations. A schematic example of an STM stimulus is shown in Figure 2.

Aims of this study
To modify the STM test in terms of stimulus parameters and procedure to make it sensitive within the target population of elderly people with hearing impairment. In particular, to carry out the STM test with full compensation for hearing loss.

To extend the earlier experiments towards more realistic speech-in-noise scenarios. Previous tests typically used headband presentation of target and maskers that were either co-located steady-state noise (SSN), modulated noise, or babble noise [3] at presented high levels but without frequency-specific compensation for audibility [1,2].

Method and material
Participants
N = 12, age 61-82 years, hearing-loss configurations with modulated audiograms. Audiograms in terms of left/right mean hearing levels at Hearing Threshold Levels (HTL) are shown in Figure 2.

STM conditions
STM stimulus parameters were chosen to make the test easier, so as to avoid the upper bound issue, and to make the modulation carry proper energy:

- Wide carrier bandwidth, 354 – 5650 Hz (except one condition with 354 – 2000 Hz bandwidth).
- Low center frequency ripple density for the 1, 2 and 4 Hz, and 4 Hz upward moving temporal ripple (main speech modulation frequency).
- Frequency-specific hearing loss compensation, starting at 65 dB broadband SNR and then ensuring at least 15 dB SL (sensation level) in all relevant 1/3 octave bands, according to the individual left/right mean audiograms (4).
- 3-AFC test paradigm with 1 stimulus duration, no level roving, and static presentation.
- In addition to using a noise carrier [1,2], two conditions with a tone-complex carrier (100 Hz spacing) were included. The 6 conditions selected and reflected in Figure 4 and Table 1. All reported STM thresholds were averaged across 3 test runs.

Speech-in-noise test
The speech-in-noise test was set up in an IC listening room (R1, 0 ± 0.5 dB). Targets were 20-item lists of Danish words presented with a male talker, presented at a nominal level of 70 dB-SPL. The four maskers presented from 200° and 213° (see Figure 3) were different running male speech signals with speech characteristics (steady-state noise (SSN) mixed in 6 dB below each speech signal. All speech signals and the SSN were shaped to have the same long-term spectrum.

Compensation for hearing loss was achieved by raising (where necessary) the hearing aid setting at 15% of all 1/3 octave bands of the target 15 dB SL (6), with a roll-off starting at 4.5 kHz at 8 kHz to avoid the low-frequency

temporal modulation (Hz)

Figure 2: (A) schematic presentation of the STM stimulus. Grey scale indicates modulation, (v) cycles per octave.

Figure 3: Sketch of the speech-in-noise test loudspeaker layout, showing (A) 2 targets in front and four maskers (M1–M4).

Results
The STM thresholds for each of the 6 different conditions are shown in Figure 4. Note that in all runs, including the training runs, all participants managed to produce a valid STM threshold. The results for the two speech-in-noise conditions are shown in Figure 5.

Analysis
First, the potential predictor variables were individually correlated with the STM to select the preferred ones. The correlated predictors were the 6 STM variables, Age, and three hearing-loss descriptors:

- 4PTA: mean of left and right HTL values across 500, 1000, 2000, and 4000 Hz.
- LNR: mean across 2000, 3000, and 4000 Hz.
- HFA: mean across 2000, 3000, 4000, and 6000 Hz, in (5).

All correlations are summarized in Table 1. For the Spatial SRTs, the preferred predictor was the tone2co condition, whereas for the co2kHz condition, the preferred predictor was the SRTs. In both cases, the HFA hearing loss predictors was selected. The correlations with Age were small and counter-intuitive (reverse), hence this was disregarded from further analyses.

Table 1: Individual predictor outcome correlations. N = 13. Preferred predictors are highlighted in bold. (p < 0.05).

<table>
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<th>Spatial SRT</th>
<th>age</th>
<th>4PTA</th>
<th>LNR</th>
<th>no2co</th>
<th>no2kHz</th>
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Notes for specific predictor variables:

- Age: The highest SRTs for the two speech-in-noise conditions are shown in Figure 5.

Discussion

The hearing-loss descriptors
The higher correlations observed for IPA compared with HFA in Table 1 are in good agreement with results from [7,8] obtained with similar speech-in-noise setups. In contrast, [3] found HFA to be the best hearing-loss descriptor in a much larger dataset (N = 154), based on Figure 7.

Note that table 1 and [7] gave preference to the IPA predictor for both spatially separated and co-located SRT outcomes, indicating that the different result found in [15] is due to a different between-predictor agreement with the HFA predictor in Figure 6 (right-most column).

As expected, this led to much more variance being explained by the STM predictor in our data, compared with the modest contribution from the STM test when used together with IPA. As two intermediate examples, results for the IPA hearing-loss predictor as well as a 20PTA predictor opening all 10 audometric outcomes in this study are also included in Figure 6 (middle column).

Spatial versus SSN SRTs
Figure 5 shows that the STM in noise averaged were higher than the SSN at the spread was wider. The higher mean SRT makes the Spatial condition more ecologically relevant [9] and the higher spread indicates that the Spatial STM test brought out more individual difference among the participants.

The higher spatial outcome showed greater individual variation and allowed more variance to be explained by the hearing-loss and STM predictors, compared with the co-located steady-state noise (SSN) condition. As an additional observation it was found that:

- Figure 6: SRT variance successively explained by the hearing-loss (HTL) descriptors and the preferred STM predictor. Whole-model significance (α = 0.05) is indicated by *.

Conclusions
Referring back to the study’s aims it can be concluded that:

1. The proposed modifications to the STM test appear to have solved the upper-bound issue reported in [3].
2. The preferred STM thresholds on their own have considerable predictive power for the SRT outcomes, and can explain additional variance in outcomes beyond the hearing-loss descriptors.
3. The actual amount depends on the degree to which the hearing-loss descriptor is tailored to the dataset.
4. The Spatial speech-in-noise outcome showed greater individual variation and allowed more variance to be explained by the hearing-loss and STM predictors, compared with the co-located steady-state noise (SSN) condition.

As an additional observation it was found that:

- Figure 6: SRT variance successively explained by auditory processing in this study, the hearing-loss descriptors have considerable predictive power for the supra-threshold SRT outcomes.

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