# Effects of hearing aid signal processing on cognitive outcome measurements

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## Introduction

It has been demonstrated that the benefit of signal processing intended for hearing aids is not limited to improvement in speech perception. Sarampalis et al. (2009) show that the Ephrahim-Mallah noise reduction algorithm improves cognitive performance and reduces listening effort for people with normal hearing. However, better performance on the word-memory task for hearing-impaired listeners has not been reported.

This study examines how signal processing intended for hearing aids affects the cognitive demands of speech recognition and the remaining cognitive capacity in people with a hearing impairment. Binary time-frequency masking (BM) (Wang et al., 2009), which is a noise-reducing signal processing technique, was employed.

## Method

### *Participants*

Twenty experienced hearing aid users of 32 to 65 years of age (mean=58, SD=8) with symmetrical sensorineural hearing loss of 43 to 60 dB HL (mean=48, SD=4.9) were tested.

### *Procedure*

A) Dual task – an assessment of cognitive demands
Each participant listened to 35 lists of 8 sentences in 7 background conditions and completed the dual task:

1) **Perceptual speech recognition task:** Repeat the final word immediately after listening to each sentence.
2) **Free recall memory task:** Report back, in any order and as many as possible, the final words that have previously repeated in a list.

B) Cognitive tests – assessing different cognitive abilities
Physical matching / Lexical / Rhyme / Reading span / Word span / Semantic / Non-word span

### *Test conditions*

- Seven conditions; 5 repetitions per condition

| | Linear amplif. + No processing (NoP) | Linear amplif. + Realistic BM (NR) | Linear amplif. + Ideal BM (IBM) |
|---|---|---|---|
| **Quiet** | Fixed at 65 dB A | | |
| **Unmodulated speech spectrum noise (SSN)** | Same individualized SNR across noise conditions | | |
| **4-talker babble (4T)** | | | |

**NB. Realistic BM (NR) = binary masking with errors in the mask**

- Presentation levels were individualized to optimize equality in listening effort across participants:

**All noise conditions**: SNR yielding 95% speech recognition + linear amplification with individually prescribed frequency response (VAC).
**Quiet:** Speech fixed at 65 dB A + linear amplification with individually prescribed frequency response (VAC).

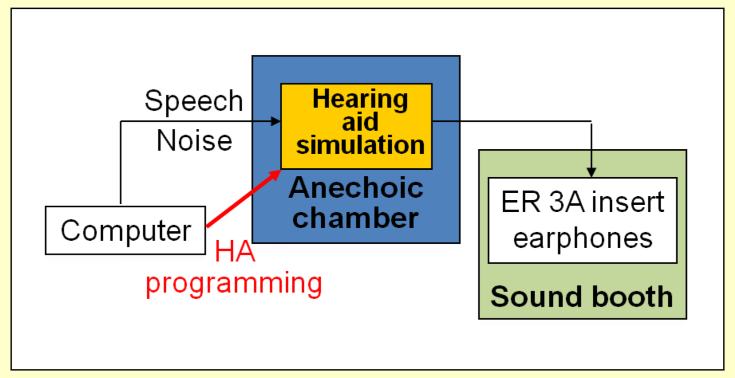
**References**
Sarampalis, A., Kalluri, S., Edwards, B. & Hafter, E. (2009). Objective measures of listening effort: Effects of background noise and noise reduction. *J Speech Lang Hear Res*, *52*(5), 1230-1240.
Wang, D., Kjems, U., Pedersen, M. S., Boldt, J. B., & Lunner, T. (2009). Speech intelligibility in background noise with ideal binary time-frequency masking. *J Acoust Soc Am*, *125*(4), 2336-2347.

### *Sentence material*

- Dual task: 35 lists of 8 Swedish HINT sentences

E.g. Pappa ska laga min fåtölj
Tanten handlar en gång i veckan
Rektorn tog fram kastrullen
Farmor åker till golfbanan
Golvet täcktes av en vit matta
Frukten packades i sex lådor
Plånboken låg kvar på isen
Farfar ska vaxa bilen

### *Test set-up*




## Preliminary results

Table 1 shows correlations between cognitive tests and the results of the memory task (in terms of percentage of words that were recalled correctly). Reading span test, which measures working memory capacity, correlates with memory performance in most of the background conditions.

| | Quiet | SSN: No processing (NoP) | SSN: Realistic processing (NR) | SSN: Ideal processing (IBM) | 4-talker: No processing (NoP) | 4-talker: Realistic processing (NR) | 4-talker: Ideal processing (IBM) | Age |
|---|---|---|---|---|---|---|---|---|
| Age | -0.20 | -0.18 | -0.41 | -0.26 | -0.19 | -0.16 | -0.32 | — — |
| Physical matching | ** 0.77 | ** 0.63 | ** 0.62 | ** 0.58 | * 0.50 | * 0.49 | ** 0.61 | -0.03 |
| Lexical | 0.41 | * 0.48 | 0.32 | 0.43 | 0.12 | 0.30 | 0.32 | -0.05 |
| Rhyme | * 0.45 | * 0.46 | 0.36 | 0.42 | 0.28 | 0.29 | 0.38 | 0.01 |
| Reading span | ** 0.65 | * 0.49 | ** 0.58 | ** 0.67 | 0.28 | * 0.52 | * 0.48 | -0.05 |
| Word span | 0.41 | 0.40 | 0.42 | 0.43 | 0.13 | 0.34 | 0.32 | -0.07 |
| Semantic | 0.41 | * 0.51 | 0.29 | 0.37 | -0.30 | 0.06 | -0.16 | -0.02 |
| Non-word span | 0.33 | 0.40 | 0.30 | 0.41 | 0.33 | 0.25 | 0.40 | 0.04 |

** $p < 0.01$; * $p < 0.05$

Table 1. Correlations between cognitive tests and the results of the free recall memory task (n=20).

The results of the memory task in all conditions are shown in Figure 1. Participants with higher reading span scores performed significantly better in the memory task than those with lower reading span scores.

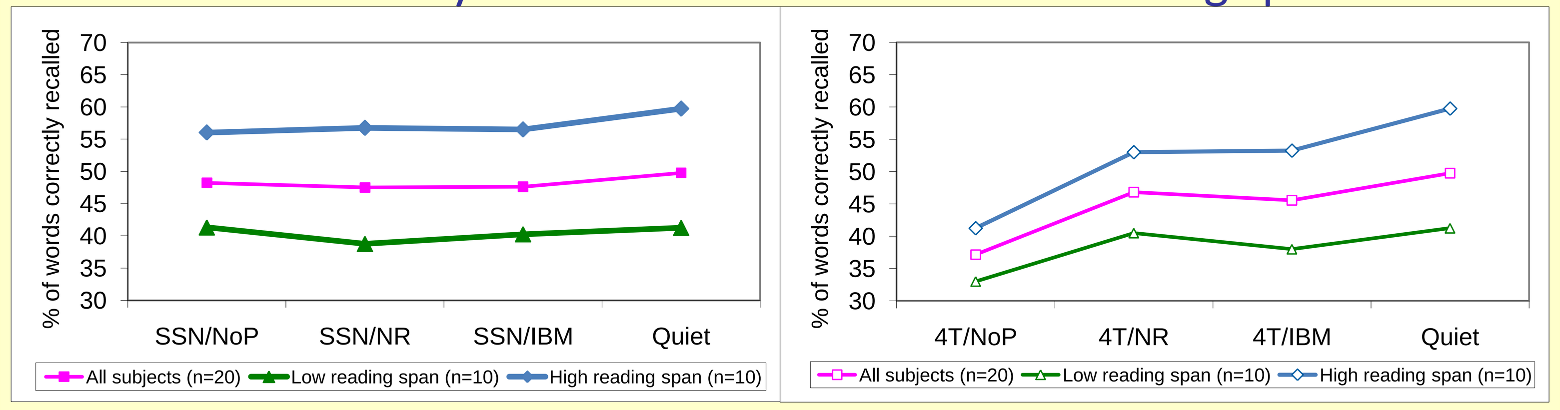



Fig 1. Percentage of words correctly recalled in quiet and in the SSN (left) and 4T background (right) in the memory task.

ANOVAs show significant main effects of noise type (SSN vs 4T) and noise reduction (NoP/NR/IBM). The 2-way interaction (noise type x noise reduction) indicates that in the 4T background, noise reduction improves memory performance; while in the SSN background, there is no improvement with the use of noise reduction (Figure 2).

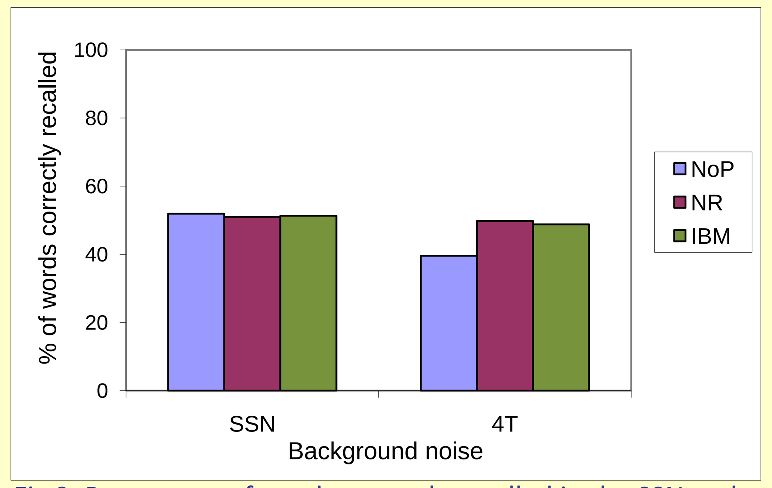



Fig 2. Percentage of words correctly recalled in the SSN and 4T background in the memory task (n=20).

The position of the final words in each of the 8-sentence lists in the memory task was also analyzed. Figure 3 shows mean memory performance as a function of position.

Low reading span group (n=10)

High reading span group (n=10)

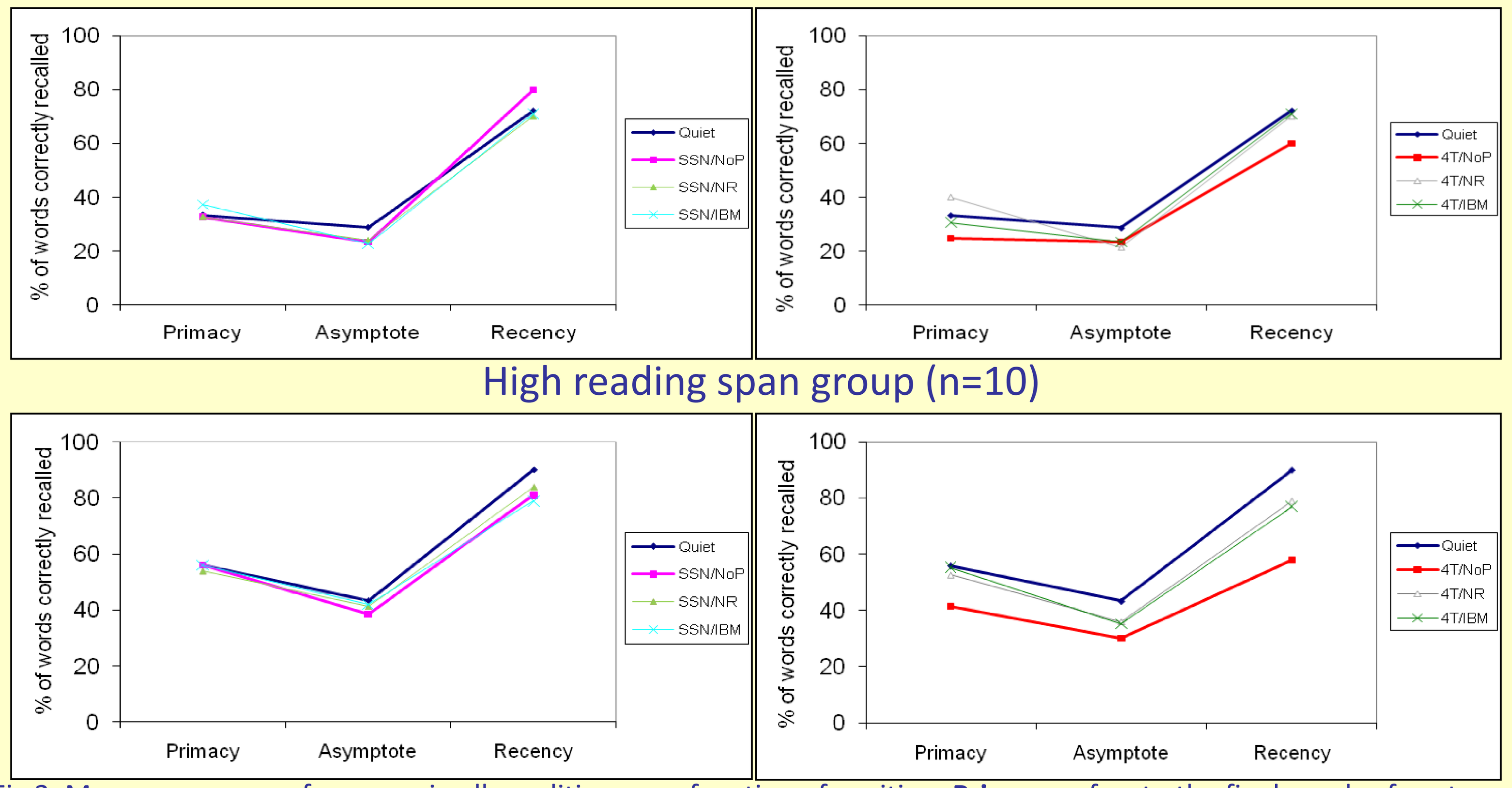



Fig 3. Mean memory performance in all conditions as a function of position. **Primacy** refers to the final words of sentences 1 to 3; **Asymptote** refers to the final words of sentences 4 to 6; and **Recency** refers to the final words of sentences 7 and 8. The upper and lower panels show performance for individuals with lower and higher reading span scores respectively.

The 3-way interaction (noise type x noise reduction x position) was significant, suggesting the memory performance, particularly for the initial (primacy) and terminal (recency) items, was relatively improved in the 4T background with noise reduction (Figure 4).

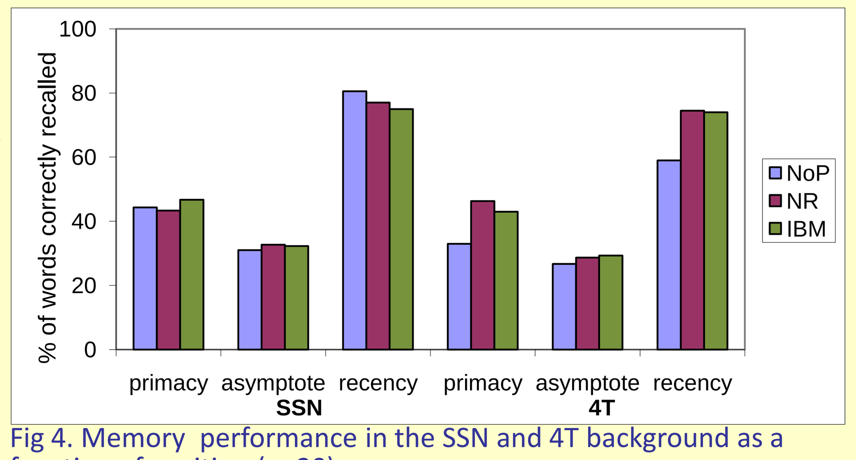



Fig 4. Memory performance in the SSN and 4T background as a function of position (n=20).

Memory performance in quiet and in the SSN and 4T backgrounds with no processing was compared (Figure 5). Reading span performance interacted with noise type when there was no noise reduction, indicating that the low reading span group performed equally in these three conditions, while the high reading span group performed significantly worse in the 4T background than in quiet and in the SSN background when there was no noise reduction.

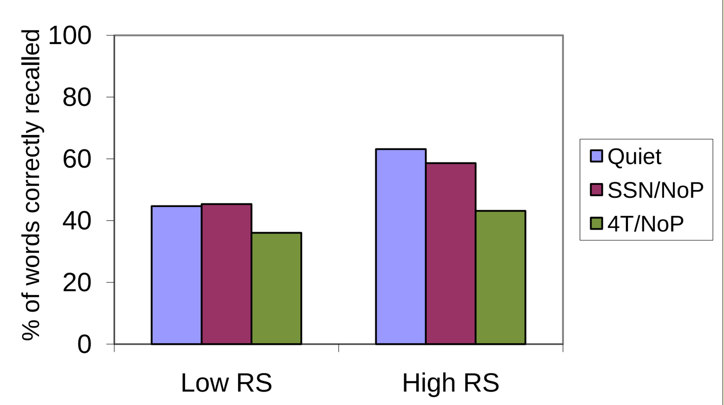



Fig 5. Mean memory performance in quiet and in the SSN and 4T background with no processing (n=20).

## Preliminary conclusions

- Binary masking noise reduction technique helped freeing up cognitive resources and hence enhanced memory task performance in the 4T background. Such enhancement occurred in both long-term storage (primacy) and short-term storage (recency).
- In individuals with better working memory capacity, memory performance was more disturbed in the competing background speech than steady-state noise when there was no noise reduction.

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