Effects of minimum phase processing on binaural hearing in a spatial release from masking paradigm

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INTRODUCTION

- Open-fit hearing aids (HAs) provide a more natural and comfortable experience [1]. However, in addition to the processed sound, direct sound is transmitted to the ear canal through the open fitting. The delay in the processed sound (up to 12 ms) interferes with the direct sound leading to comb-filtering [2, 3], resulting in an altered sound quality perceived as tinny and artificial [4].
- **Minimum phase processing (MIN)** can provide much shorter processing delays and thus improve the perceived sound quality [5].
- With MIN, the group delay depends on the shape of the gain-frequency characteristic. This is different than linear phase processing (LIN), which provides a constant delay across frequency [5].
- In a binaural HA setting, gain differences between the ears can result in a different delay at each ear, potentially altering the interaural time difference (ITD) in the processed sound.
- Binaural cues are essential in complex listening situations since the brain uses the differences in time and level to separate the speech from interfering sounds [6].
- Main goal: Investigating the effects of MIN, relative to LIN, on speech intelligibility using broadband (BB) stimuli, where listeners have access to interaural level differences (ILDs) and ITDs, and using lowpass (LP) filtered stimuli, where listeners primarily have access to ITDs.

METHODS

- Spatial Release from Masking (SRM) paradigm with maskers being spatially co-located or spatially separated (±30°) (Fig. 1), elevation was 0° in all measurements.

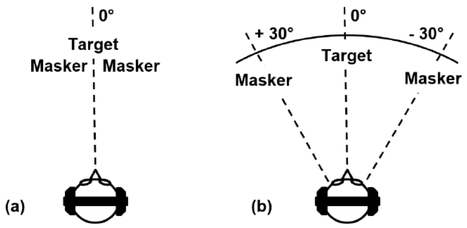

Figure 1. Masker and target configuration. (a) Maskers and target are co-located at 0°. (b) Maskers are spatially separated at ±30°.

- Target and maskers were female talkers uttering 5-word sentences (Danish Hagerman sentences: Dantale II [7]).
- Stimuli were either BB or LP filtered with a cut-off frequency at 1 kHz and were presented over Sennheiser HD-650 headphones.
- The stimuli were pre-processed with non-individualized head-related transfer functions from Oreinos et al. [8] and a simulated fast-acting HA-compressor [9] to introduce exaggerated gain differences between the ears.
- The level- and the frequency-dependent gain prescription was based on the N2 standard audiogram [10] and the NAL-NL2 rationale.
- 18 participants with normal hearing (NH) participated in the study.

HYPOTHESES

1. With BB stimuli, MIN and LIN will have similar effect on the SRM
2. With LP filtered stimuli, some listeners will have reduced SRM with **both** MIN **and** LIN
3. With LP filtered stimuli, the listeners with SRM with LIN will have less SRM with MIN when compared to LIN

RESULTS

The data was fitted to a linear mixed effects model. A type III analysis of variance (ANOVA) with repeated measures was conducted, as well as post hoc analyses.

BB vs. LP filtered stimuli

- The final model was reduced to only show a significant effect of stimulus type. Thus, interactions between stimulus type and processing type were removed as well as processing type. The post hoc comparisons are shown with asterisks for significant values and N/A for non-significant values.
- Due to the non-significant contribution of processing type, the data for MIN and LIN were combined for each stimulus type, and a two-sample t-test between stimulus types was performed.
- The mean of the BB stimulus was 15.52 dB and 8.37 dB with the LP filtered stimulus. The listeners achieved significantly better SRM with BB stimuli compared to LP filtered stimuli,

$$t(141.75) = 9.3986, p < 0.001.$$

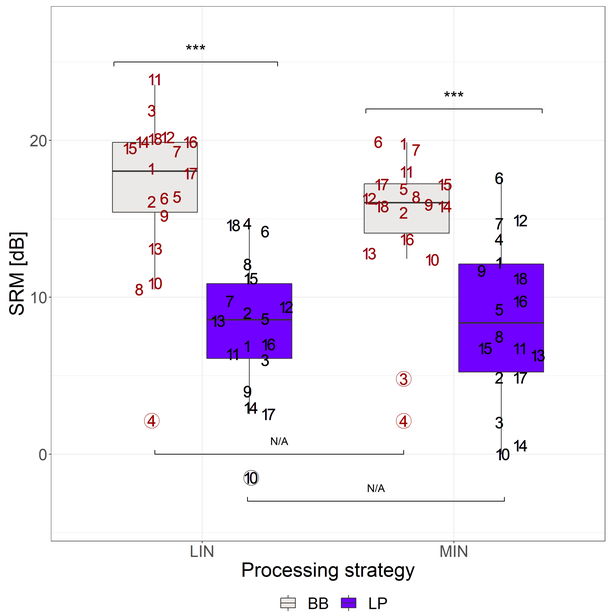

Figure 2. SRM for each processing condition, LIN and MIN, and stimulus type, BB and LP filtered. Individual datapoints for each processing type and stimulus type are plotted as well.

MIN vs. LIN phase processing

- There was no statistical difference found between MIN and LIN using LP filtered stimuli.
- Figure 3 shows the SRM obtained using MIN as a function of SRM obtained using LIN for each listener.
- Eight listeners (44%) gained an equal amount ($\pm 3\ dB$) of SRM in both processing conditions. Five listeners gained more using LIN, and the remaining five gained more with MIN.

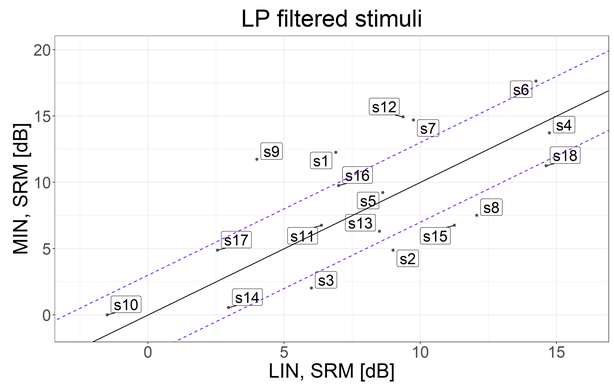

Figure 3. SRM in MIN condition as a function of SRM in LIN condition using LP filtered stimulus. Data points plotted between the dashed purple lines indicate listeners (n = 8) that gained an equal amount ($\pm 3\ dB$) of SRM in both processing conditions. Listeners who gained more SRM with MIN are plotted over the first dashed line (n = 5), and listeners who gained more SRM with LIN are plotted below the second dashed line (n=5).

DISCUSSION AND CONCLUSION

Main findings

- Hypothesis 1: Using BB stimuli, the same amount of SRM was gained in MIN and LIN.
- Hypothesis 2: LP filtering resulted in reduced SRM for nearly **all** listeners with both LIN and MIN.
- Hypothesis 3: In the LP filtered condition, MIN, compared to LIN, did not have detrimental effects on the SRM on the group level.
- The present study demonstrated that MIN did not negatively affect the SRM in listeners with NH, at least in the laboratory conditions tested.

Limitations

- Datapoints are based on a single measurement. The variation in the data could be reduced if several measurements were conducted and averaged.
- The purpose of LP filtering the stimuli was to make the listeners rely on ITD cues. However, LP filtering the stimuli distorts the phonemes, mainly consonants, above 1 kHz, leaving essential phonemes distorted or inaudible. Therefore, the reduced SRM fir the MIN processing is likely due to reduced speech intelligibility when using LP filtered stimuli, since the SRM was reduced to a similar extent with the LIN processing.

Future studies

- Employing an alternative method of investigating the effects of ITD distortion with MIN processing to understanding speech in noise.
- Include participants with hearing loss.

Abbreviations

ANOVA	Analysis of variance	ITD	Interaural time difference	NH	Normal hearing
BB	Broadband	LIN	Linear phase processing		
HA	Hearing aid	LP	Lowpass		
ILD	Interaural level difference	MIN	Minimum phase processing		

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