BILATERAL SIGNAL PREPROCESSING FOR COCHLEAR IMPLANT USERS

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Objectives: Speech understanding in real-life noisy environments represents a significant challenge to most CI-recipients. Bilateral signal preprocessing might improve auditory communication in these situations.

Study Design: A wearable, real-time signal preprocessing unit is connected to a standard speech processor via auxiliary input. The subject carries a two-microphone endfire-array on each ear. FIR-Filtering and summation of the signals from the front and back microphone elements creates restricted super-directive signals for the left and right ear. These signals are then routed into an adaptive spectral subtraction unit, which attenuates uncorrelated sound components. The resulting noise reduced two-channel output signal can be presented either to the two speech processors of a bilaterally implanted subject, or it can be summed and presented to the single speech processor of a monaurally implanted cochlear implant user.

Speech reception thresholds for 50% intelligibility were measured using sentences in noise (SN50), both with and without the processing scheme. Subjective impressions were also recorded.

Results: Our recent studies suggest an improvement of the SN50 due to the preprocessing scheme of up to 8dB in diffuse noise, i.e. perception of speech could be increased by 30 to 80%. In a busy cafeteria, all subjects noted a substantially reduced background-noise and an improved ability to communicate, as soon as the preprocessing was activated.

Conclusion: Bilateral signal preprocessing can improve auditory communication for cochlear implant users in challenging acoustic environments considerably and may be integrated in future advanced signal processing speech processors.

Bilateral Signal Preprocessing for Cochlear Implant Users

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Cochlear

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CRC for Cochlear Implant and Hearing Aid Innovation

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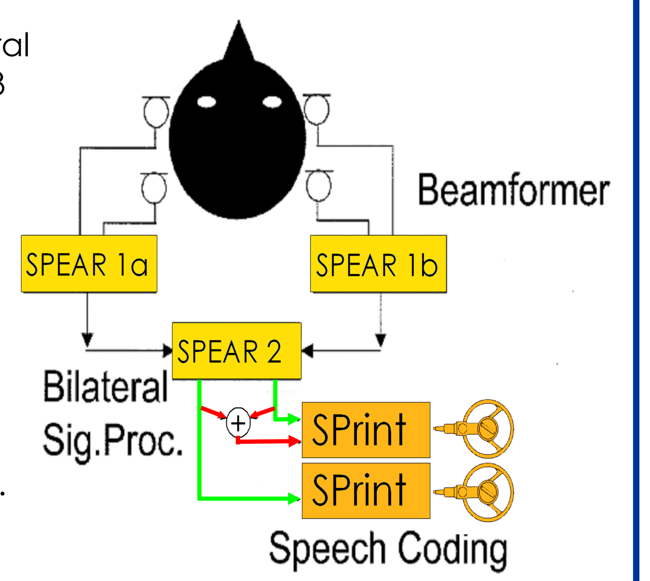
Objective:

Speech understanding in real-life noisy environments represents a significant challenge to most CI-recipients. Bilateral signal preprocessing might improve auditory communication in these situations. The poster demonstrates:

- effect of preprocessing on sentences recognition in mono- and binaural conditions
- user preferences in acoustically challenging environments
- effect of preprocessing on directional hearing.

System description

Based on a proposal from Dörbecker[1/2)], a two-staged bilateral signal processing scheme has been implemented in a set of 3 research body worn speech processors[3)] used for front end processing.



1. Stage I implements a fixed 2 microphone super directive endfire array beamformer (SPEAR 1a&b), capitalizing on the spatial distribution of the signal and the noise **(BeamForm).**
2. Stage II (SPEAR 2) uses an „Ephraim Malah"[4/5)], spectral subtraction technique which exploits the diffuse and left/right uncorrelated nature of the noise in contrast to the directional and correlated characteristic of the signal. This is followed by an adaptive Wiener Post-Filter which further reduces "musical tones" artifacts **(SpeSu).**

These 2 strategies can be combined in a pipeline fashion **(Combine).**
After preprocessing, the resulting stereo signal was either:

- presented to a left and right speech processor of a binaurally implanted CI recipient (green lines)
- summed, to be presented to a single speech processor (red line).

Subjects and Method

Monaurally implanted Subjects (total n=19):

- A preliminary implementation of the system was pilot tested in 5 CI-users in a sound field with 4 uncorrelated speech shaped noise sources placed in the corners of the room (T_{rev} ~1.6s) and a "HINT" sentences signal adaptively presented 80cm in front of the subject.
- A refined version of the system was tested in a "virtual acoustic" cafeteria environment:
  Using a KEMAR®, 4 microphone bilateral transfer functions were recorded in the empty cafeteria with the loudspeaker placed in front of the head. At a later stage, using the same set-up, ambient noise was recorded in the busy cafeteria.
  Hochmair-Schulz-Moser (HSM) sentences were convoluted with the transfer functions and mixed with the noise at various SNRs.
  The effect of the preprocessing was established by comparing the SNR [dB] at 50% speech understanding (SNR50) using an adaptive procedure (n=6), and by comparing scores [%], with and without preprocessing, at a fixed SNR (n=11).
- Preprocessing preference was established by having the subjects (n=14) listen to a recorded story in acoustic settings with different sound field characteristics.

Bilaterally implanted Subjects (total n=3):

- Performance with preprocessing was compared to performance with the bilateral clinical system in a standard and a more realistic sound field, using Oldenburg sentences (OLSA) presented from front (n=1):
  - audiometric booth using a directed sound field with a single speech shaped noise from 90°
  - reverberant room with a diffuse noise field with 3 uncorrelated noise sources (T_{rev} ~1.7 s.).
- The effect of presenting the preprocessed signal to the better ear and binaurally as compared to the better ear / bilateral situation without preprocessing was measured in terms of OLSA SNR50 in the reverberant room set-up (n=2).
- The directional hearing RMS error with and without preprocessing was recorded in fully binaural and monaural condition using 5 presentations each on 12 loudspeakers over 360° with the subject not moving the head (total n=2).

1) M.Dörbecker; Mehrkanalige Signalverarbeitung zur Verbesserung akustisch gestörter Sprachsignale am Beispiel elektronischer Hörhilfen; Aachen, Verlag der Augustinus Buchhandlung im Besitz des Verlages Mainz, 1998, ISBN 3-86073-439-3

2) 4) M.Dörbecker, S.Ernst; Combination of Two-Channel Spectral Subtraction and Adaptive Wiener Post-Filtering for Noise Reduction and Dereverberation; Proc. EUSIPCO, S.995-998, Sept.1996

3) Product Brief; SPEAR3 – 3rd generation „Speech Processor for Electrical and Acoustic Research"; CRC for Cochlear Implant and Hearing Aid Innovation, and HearWorks Pty Ltd, 384-388 Albert Street, East Melbourne, Vic, 3002, Australia

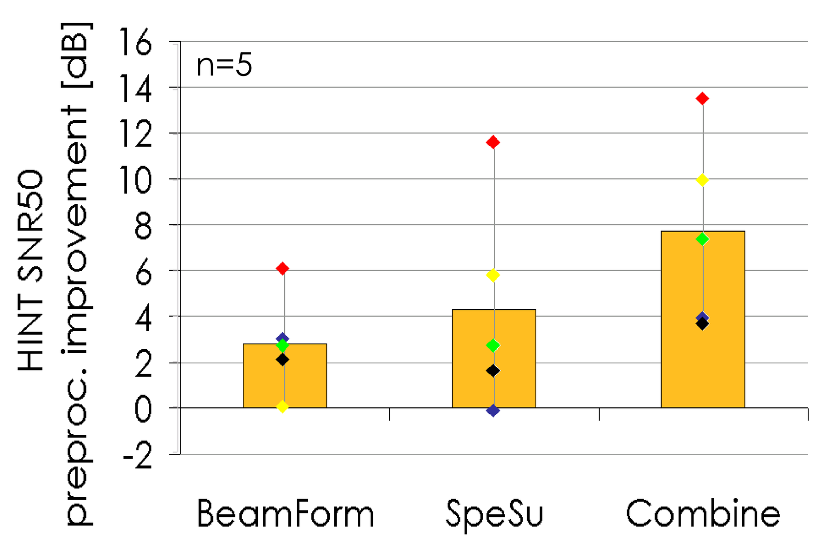
4) Y.Ephraim, D.Malah; Speech Enhancement Using a Minimum Mean-Square Error Lo-Spectral Amplitude Estimator; IEEE Transaction on Acoustics, Speech and Signal Processing, vol.ASSP-33, no.2, pp.443-445, Apr.1985

5) M.Marzinzik, B.Kollmeier; A review of the Ephraim-Malah noise reduction algorithm; Z Audiol 2001; 40(1)4-15

Results:

Monaurally implanted Subjects

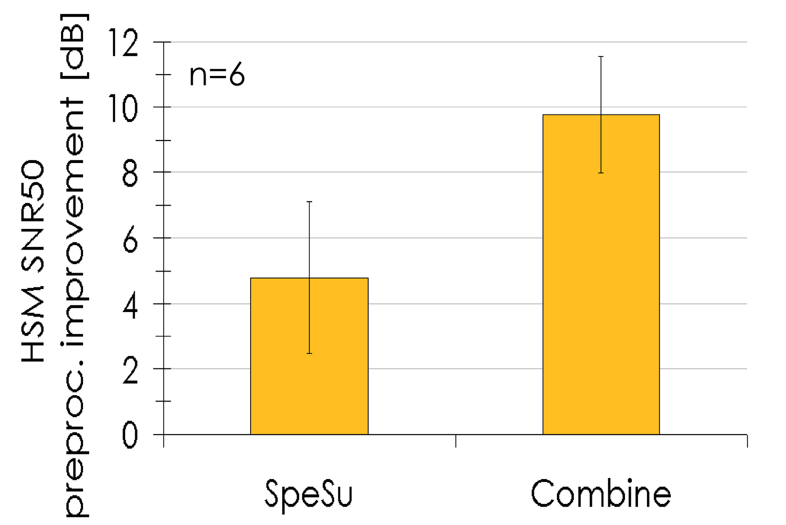
Four uncorrelated noise sources, T_{rev} ~1.6s
Effect of signal processing as compared to just summation of left and right microphone signal. Bars: mean across subjects; diamonds: individual data.



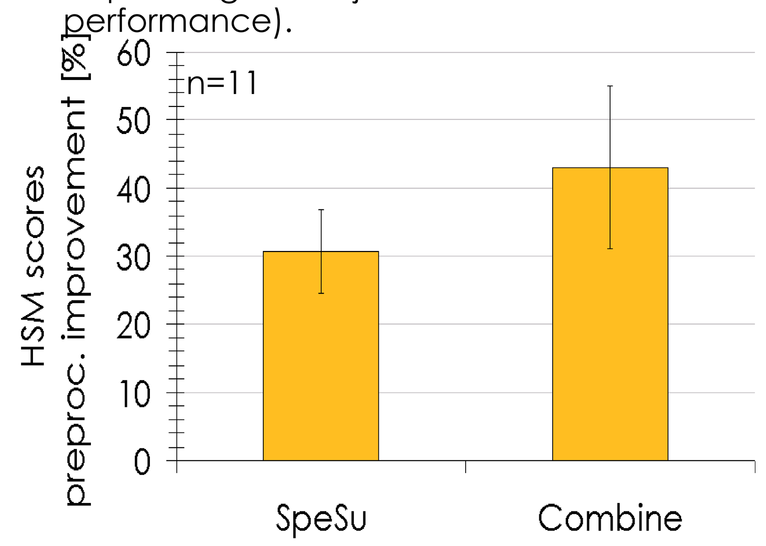
The average improvement with preprocessing is significant for all conditions. Using beamforming and spectral subtraction gives a significantly larger benefit compared to any single preprocessing stage.

Simulated Cafeteria
Effective Improvement with preprocessing system as compared to clinical monaural condition. Bars indicate the mean, error bars the confidence interval (p=0.05).

- SNR50 (adaptive presentation).

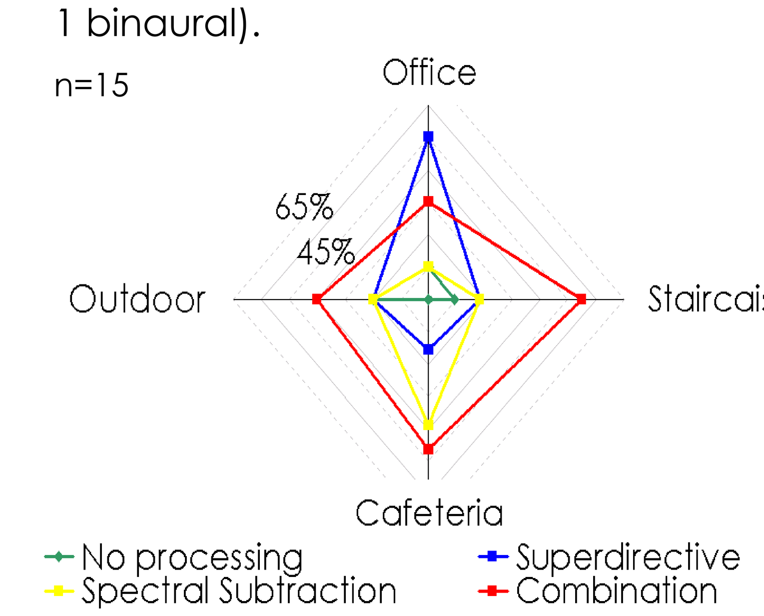


- Scores (presentation with fixed SNR in within a total range of –6 to 7.5 dB, depending on subject baseline performance).



The average improvement is significant for all conditions. For both recording methods, the improvement with the combined system is significantly larger than with spectral subtraction alone.

Preference
Percentage of subjects preferring a preprocessing strategy in different, real acoustic settings (14 monaural, 1 binaural).

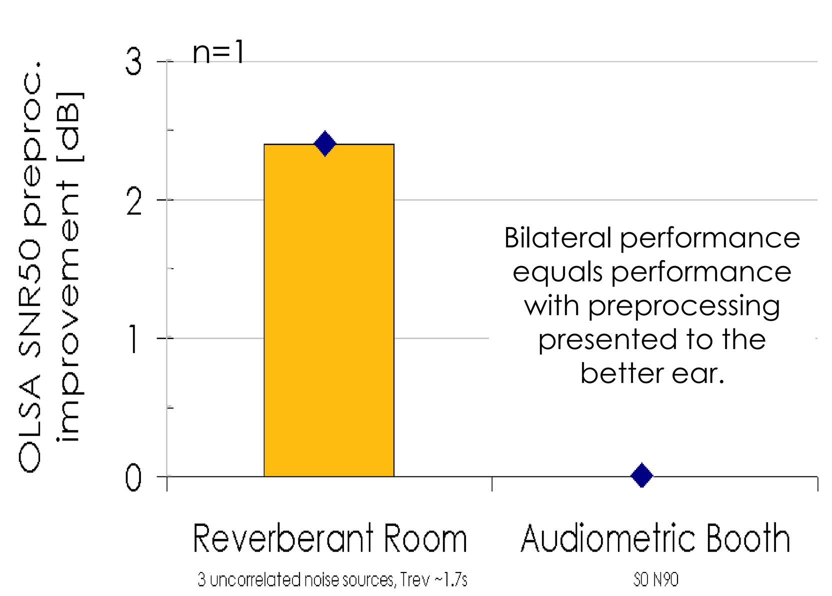


In reverberant / diffuse conditions (staircase, cafeteria, outdoor), subjects mainly preferred spectral subtraction or combined preprocessing.

Many subjects noted a change in sound quality with the (adaptive) spectral subtraction activated. Consequently, in the acoustically less complex office situation, mainly the (fixed) beamformer was preferred.

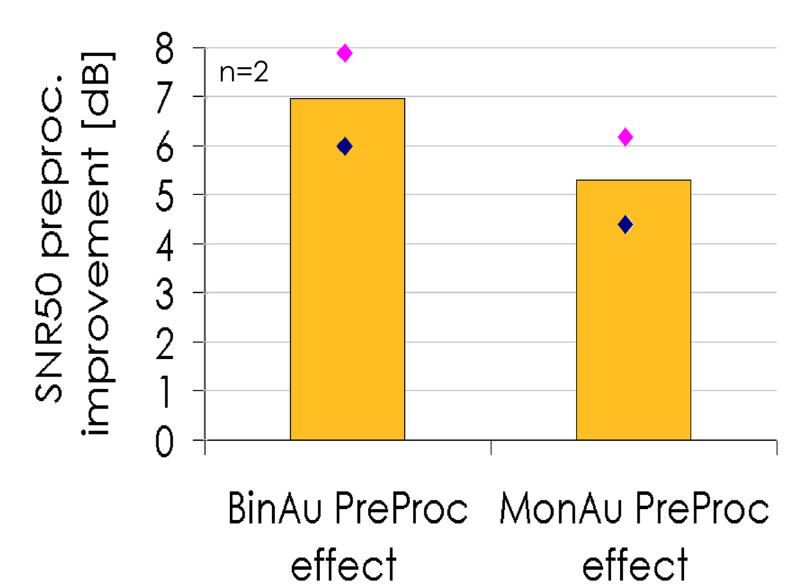
Bilaterally implanted Subjects

Comparison of different Sound Fields
Improvement with preprocessing presented monaurally to the better ear compared to clinical binaural CI situation.



In the especially challenging diffuse noise condition, the to the better ear only presented preprocessed signal allowed increased sentences understanding compared to the binaural CI without preprocessing.

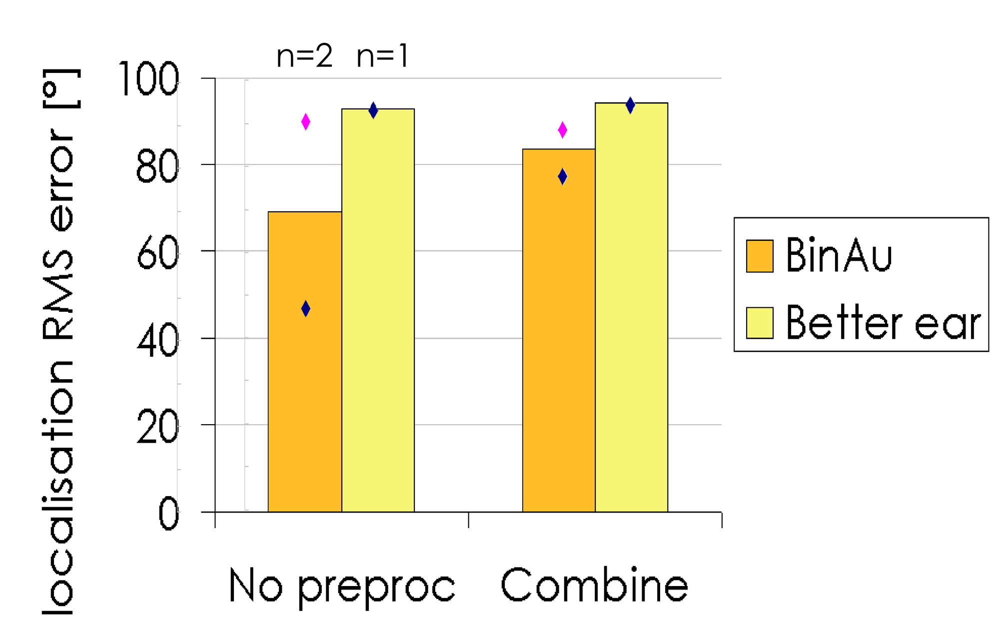
Preprocessing presented binaurally
Bars: mean combined preprocessing effect; diamonds: individual data. Magenta: HSM, simulated cafeteria; blue; OLSA, reverberant room condition.



Preprocessing improved sentences understanding in the binaural and monaural condition.

Trend: Slightly larger preprocessing effect in the binaural condition.

Localization
Bars: mean RMS error
Diamonds: individual data.



The better than chance performance of the subject with the better localization (blue diamonds) in the binaural condition with no preprocessing seems to be suffered after combined preprocessing activation. The other subject (magenta diamonds) does not show significant localization in any condition.
Monaural condition: Preprocessing did not have an effect on localization.

Some subjects noted a loss of orientation outdoors with the preprocessing turned on.

The binaurally implanted subject from which preference data is available preferred combined preprocessing in all 4 conditions.

Conclusion

Bilateral signal pre-processing can significantly improve and ease speech understanding in noisy real-life environment for monaurally implanted CI users. The presented technique seems to be especially efficient in reverberant / diffuse sound fields with multiple noise sources, which are typically challenging for many other noise reduction approaches (this is also confirmed by data from 2 monaurally implanted subjects not shown here)**.**

Initial findings suggest this effect might even be slightly enhanced in a true binaural condition.

The data is not yet conclusive to compare the preprocessing effect on the better ear to the benefit of bilateral implantation - this will be done in the future.

Directional hearing in binaurally implanted recipients – which is an important argument for binaural implantation - might be compromised by bilateral signal preprocessing.