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AUDITORY IMPLANTS

The effectiveness of a weighted prediction error algorithm for dereverberation in cochlear implants

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Introduction

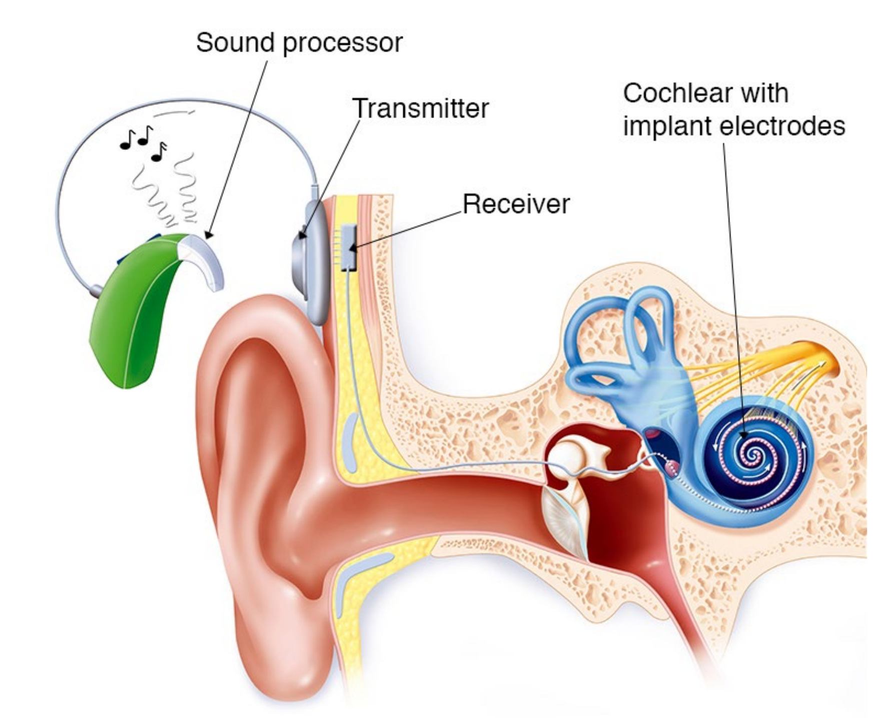


Fig. 1 An overview of the external and internal parts of a cochlear implant

Reverberations are time-delayed reflections of the original signal and cause temporal smearing and blurring of spectral cues [1,2]. Reverberation is a form of noise that is experienced as the most detrimental by CI users and consists of early and late reflections. Early reflections are combined with the direct sound for typical hearing listeners and hearing aid users. However, for CI users these early reflections can already be detrimental. Late reflections are perceived as reverberations for all listeners. Figure 2 illustrates the direct sound, early reflections and late reflections. To increase speech intelligibility for CI users, a reduction of reverberation (dereverberation) can be highly beneficial. The signal processing group of the University of Hamburg designed a novel WPE algorithm, with an optional post-filter (PF) for CI users [3,4]. Their method is based on a deep neural network which was trained to model the power spectral density (PSD) of the non-reverberant signal. This PSD is used by the weighted prediction error (WPE) method to minimalize late reverberations. A PF was designed for CI users to also minimalize the early reverberations.

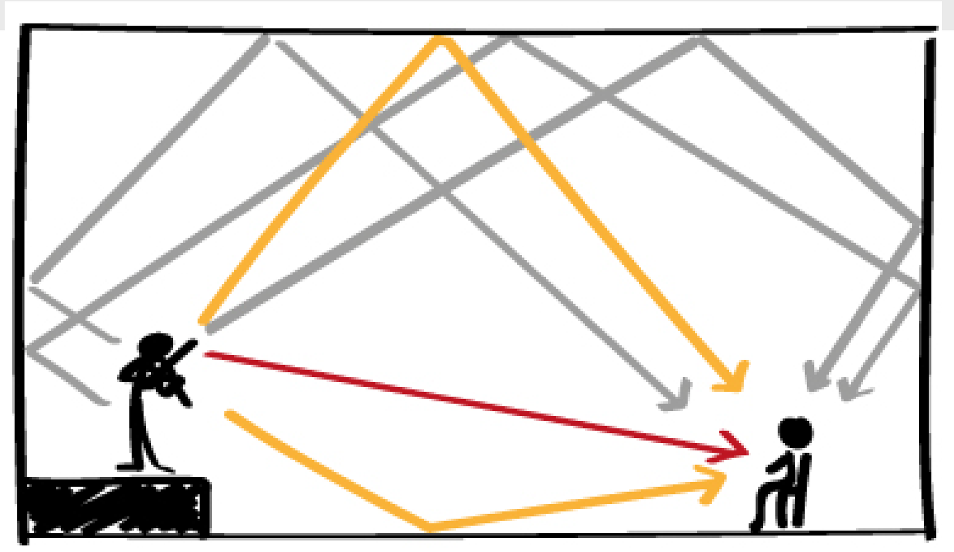


Fig. 2 Graphical presentation of reverberation. The red arrow presenting the direct sound, the yellow arrows the early reflections and the grey arrows the late reflections.

Study Objective

In this study we tested sentence understanding with the WPE algorithm with and without an additional PF in unilateral CI users. Study participants also indicated their preference via subjective ratings.

Methods and Materials

15 unilateral CI users (Advanced Bionics, Marvel™ 90 processor) were included. All participants had experience with their CI for more than six months, were fluent in Dutch and had a consonant-vowel-consonant phoneme score in quiet of at least 75% at 65 dB SPL. We performed speech intelligibility tests for six different conditions: clean speech, clean speech with algorithms, reverberated speech and reverberated speech with both algorithms. The participants also indicated their preference via subjective ratings presented by a graphical interface (fig. 3). The participants compared two fragments to each other and indicated their preference on a continuous VAS scale with 'No preference', 'a little bit better', 'better' and 'the best' as scale. Afterwards this scale was converted to a score between 1 and 100.

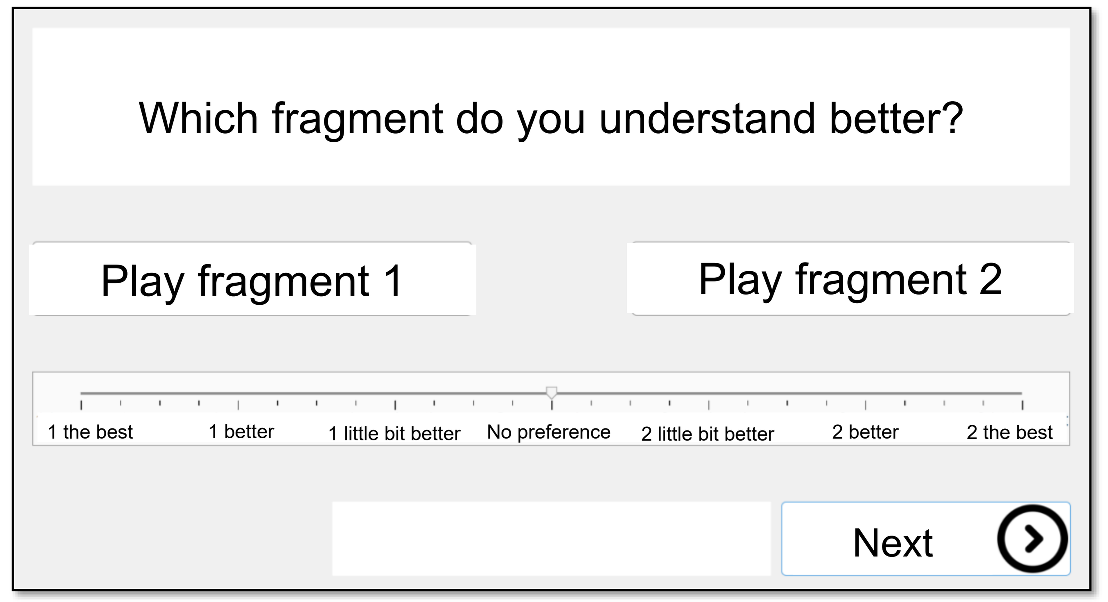


Fig. 3 The graphical interface where the study subjects could indicate their preference for one of both fragments.

Speech intelligibility

To create different measurement conditions, reverberation was added via a computer model of room acoustics to the Dutch/Flemish Matrix sentences [3,4].

Subsequently, the sentences were presented to the algorithms and preprocessed sound fragments were created to present to the participants via Bluetooth (fig. 4). Per test condition ten sentences were presented. The average percentage correct score per condition of these sentences was used as the outcome.

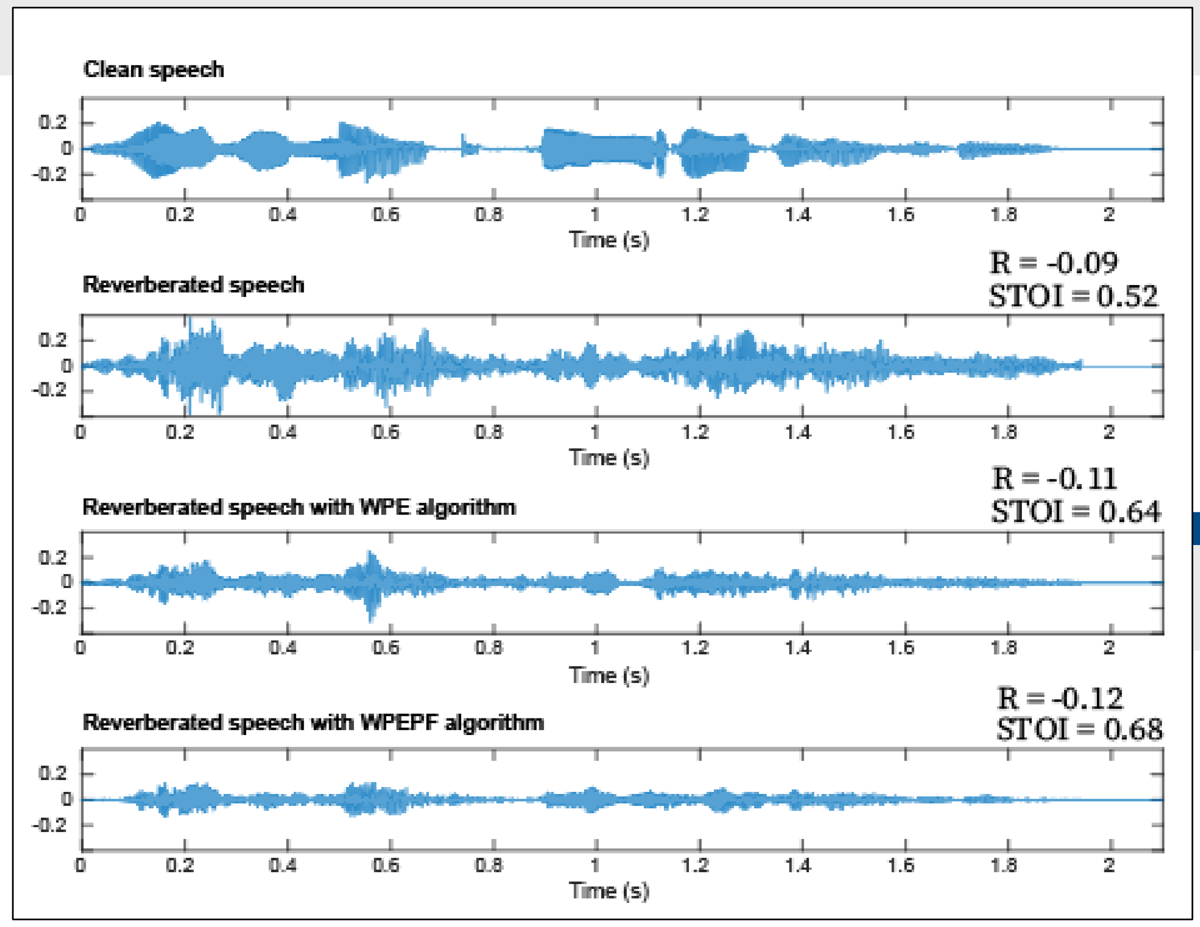
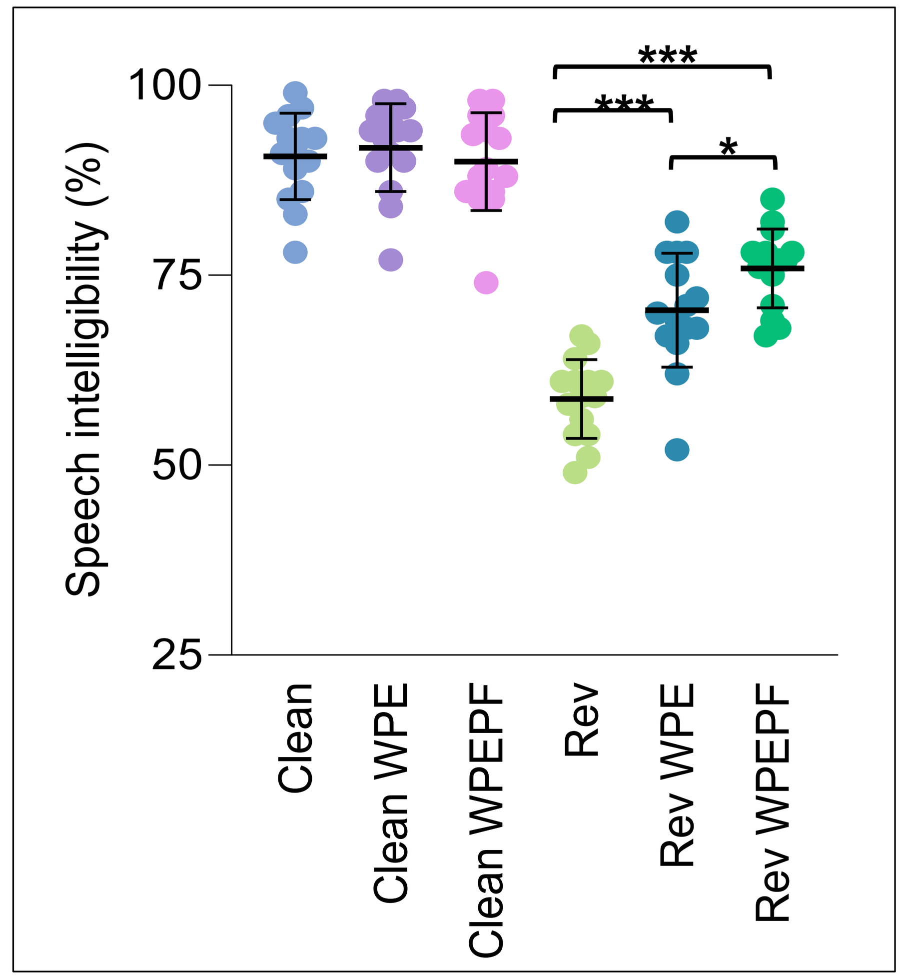


Fig. 4 The raw signals for clean speech, reverberated speech and reverberated speech with both algorithms.

Results

Figure 4, on the right, shows the results of the speech intelligibility test of CI users. With minimal reverberation added to the speech, the speech understanding scores already decrease dramatically (>30%). The algorithm does not have any significant impact on clean speech but does show a statistically significant improvement of the speech intelligibility scores when reverberation is present. WPE resulted in a benefit of 11% and WPE with PF resulted in a benefit of 17% and this benefit was statistically significantly higher than without PF.



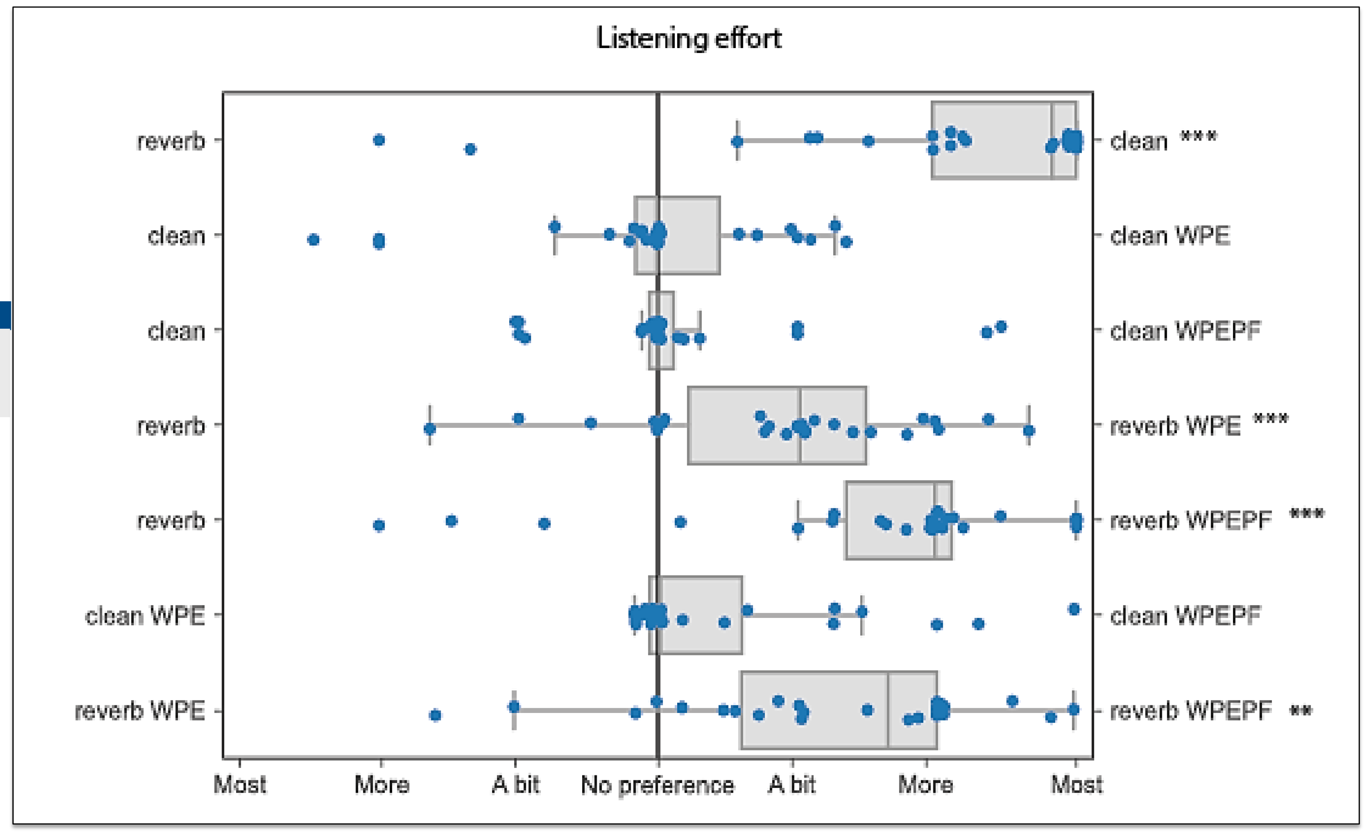


Figure 5, on the left, shows the results of the subjective ratings on listening effort. For reverberated speech there is a statistically significant preference for the algorithms. The algorithm with PF requires slightly less listening effort than WPE alone.

Conclusion

We conclude that the WPE(PF) algorithm can be highly beneficial for CI users when reverberation is present in a room. And the algorithm does not show to have an influence on speech perception when no reverberation is present, meaning that the algorithm can be turned on even when no reverberation is present.

References

[1] Hu, Y., & Kokkinakis, K. (2014). Effects of early and late reflections on intelligibility of reverberated speech by cochlear implant listeners. *J Acoust Soc Am, 135*(1), EI22-28. https://doi.org/10.1121/1.4834455; [2] Hazrati, O., & Loizou, P. C. (2012). The combined effects of reverberation and noise on speech intelligibility by cochlear implant listeners. *International Journal of Audiology, 51*(6), 437-443. https://doi.org/10.3109/14992027.2012.658972 ; [3] Lemercier, J. M., Thiemann, J., Koning, R. and Gerkmann, T. (2022). Customizable end-to-end optimization of online neural network-supported dereverberation for hearing devices. *Proceedings of the ICASSP 2022.* ; [4] Lemercier, J.-M., Thiemann, J., Koning, R., & Gerkmann, T. (2023). A neural network-supported two-stage algorithm for lightweight dereverberation on hearing devices. *EURASIP Journal on Audio, Speech, and Music Processing, 2023*(1), 18. https://doi.org/10.1186/s13636-023-00285-8

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