Comparison of Speech Intelligibility by EAS, Bimodal, Uni- and Bilateral Cochlear Implant Patients in a 'Multi-Source Noise Field' (MSNF)

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Introduction

Speech perception in noise is one of the most difficult tasks for people suffering from hearing impairment. The Oldenburg Sentence Test (OLSA) is a useful tool to investigate speech intelligibility threshold in a noise environment. In the present study, a multi-source noise field (MSNF), introduced by Rader et al. (DAGA2008), consisting of a four-loudspeaker array with independent noise sources was combined with the OLSA. The MSNF enables the presentation of a more realistic noise environment and allows to measure a higher effect of binaural interaction regarding the separation of signal and noise from different directions.

Material and Methods

Subjects

Four different groups of cochlear implant patients - separated into listening conditions unilateral (deaf-CI), bimodal (hearing aid-CI), bilateral (CI-CI) and bimodal EAS (electric-acoustic stimulation-hearing aid) - served as subjects in the present study.

Experimental set-up

Speech intelligibility experiments and data collection were conducted by a personal computer with a high quality 24-bit 8-channel AD-DA converter (RME Digiface). The noise field was presented via a four-loudspeaker array (JBL Control One) as shown in Figure 1b. A Matlab GUI including the SoundMex toolbox (HörTech GmbH, Oldenburg) simultaneously drives four independent channels, which are amplified by an Ecler MPA 6-80R, of the RME-Digiface for noise presentation. Speech signal presentation was realized with a Tannoy VNet300 active speaker at 0° azimuth direction.

Loudspeaker placement

a) S0N0: The S0N0 noise condition presents speech and noise from 0° azimuth direction with one single speaker for both speech and noise signal. In this case, speech intelligibility performances of the subjects are not influenced by any localization effects.

b) Multi-Source Noise Field: In contrast to the S0N0 condition, four speakers, each set up in a corner of a sound-proofed room and directed to the subjects, sitting in the centre of the room, are used for noise presentation. The MSNF set-up allows the presentation of an pseudo-diffuse noise source field at the subjects' ears. It is supposed that the MSNF setup allows the subject to take advantages provided by localization cues and other binaural effects.

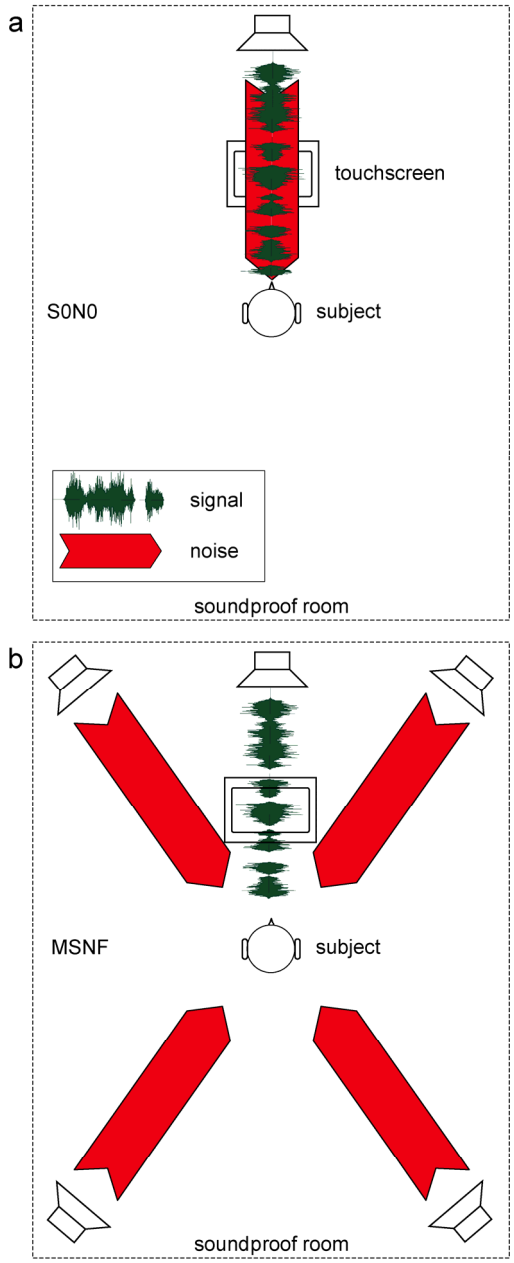

Figure 1: Schematic of sound proof room with two different noise conditions: a) S0N0: Signal and noise are presented from the same loudspeaker at 0° azimuth. b) Multi-Source Noise Field (MSNF): Signal is presented from 0° azimuth and noise is presented from four independent speakers in the corners.

Noise characteristics

In combination with the Oldenburg Sentence Test, different kinds of noise were compared with each other in regard to the usability for speech testing in noise:

a) OLnoise: The noise signal applied in the OLSA is synthesized by a mixture of time-shifted utterances derived from the test sentences. Therefore, OLnoise is nearly unmodulated and the long-term spectrum is equal to sentences of the OLSA. The frequency range of the noise starts at 150 Hz and ends at 12.6 kHz.

b) CCITT-noise was developed by the Comité Consultatif International Télégraphique et Téléphonique (according to ITU-T Rec. G.227 (11/88) Conventional telephone signal) and renamed in ITU Telecommunication Standardization Sector. Features of this noise are to contain almost no temporal fluctuation and to have no informational masking property. In contrast to OLnoise, the spectrum comprises frequencies up to 22 kHz.

c) Fastl-noise (Fastl 1987): In order to represent the temporal characteristics of speech, CCITT-noise is amplitude modulated with randomized modulation frequency. The spectral distribution of modulation signal of Fastl-noise shows a maximum at 4 Hz, which correlates with the amplitude-modulation statistics of German language. It serves as a single competing speaker simulation without any informational masking. The listener has the opportunity of gap listening.

The sound level of the noise was fixed to 75 dB SPL (normal hearing subject group) and 65 dB SPL (implanted subject group) during the presentation. In a pilot study, the sound level of noise presentation was investigated, which resulted in an optimal loudness of speech at the SRT after the adaptive procedure of adjusted loudness (approximately 65 dB).

Each of the four channels of the MSNF was calibrated separately to 75 dB. Afterwards all pre-equalized channels were combined to the target level of 75 dB in position of the subjects' ears. Calibration was accomplished in reference to dB SPL with a B&K 0.5 inch microphone 4155, a B&K preamplifier 2669, a B&K measuring amplifier 2690, and a NTI AL1 sound level meter.

Speech test

The Oldenburg Sentence Test (Hörtech GmbH, Oldenburg) was used to investigate the subjects' speech intelligibility in noise (Wagener 1999). Each test list comprises 20 sentences composed of a first name, verb, numeral, adjective and object.

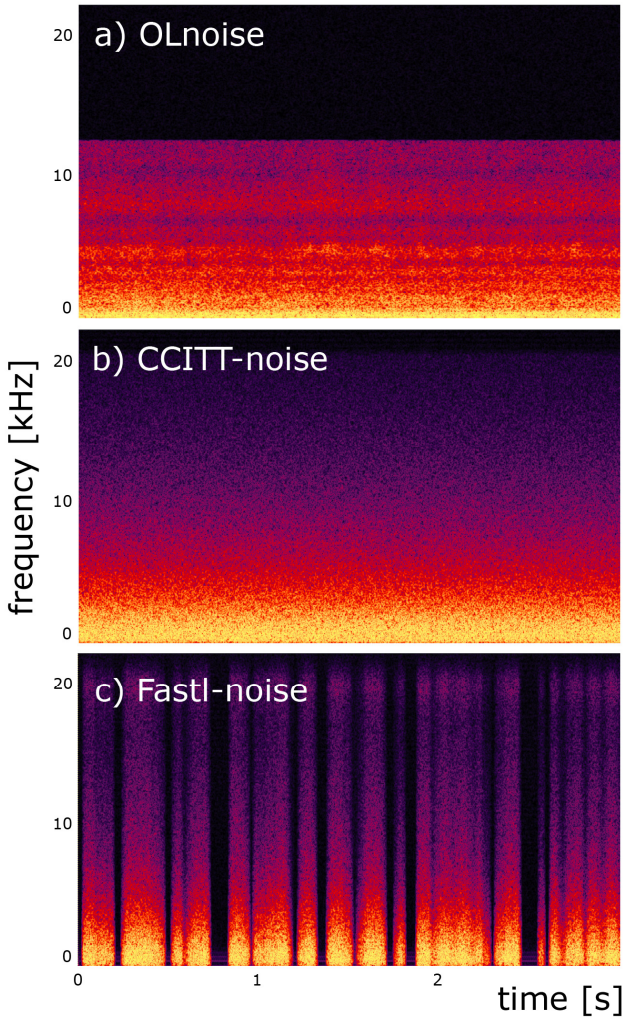

Figure 2: Spectrograms of presented noises: a) OLnoise included in the Oldenburg Sentence Test, b) CCITT-noise according to ITU-T Rec. G.227 and c) Speech simulating Fastl-noise with maxima of modulation frequency at ~4 Hz.

The sentences are built out of a ten-word-group for every word of the sentence. Based on the randomized selection of words, the sentences patterned seem to be senseless in most cases. However, this results in an enormous advantage: the subjects are unable to complete the sentence with logical syntax or to remember sentences.

The subjects' responses were analyzed using correct word-scoring. The result of the OLSA is given by the speech reception threshold (SRT) L50 and is defined by a signal-noise ratio (SNR). Therefore, the subjects can perceive correct 50 % of the presented sentence.

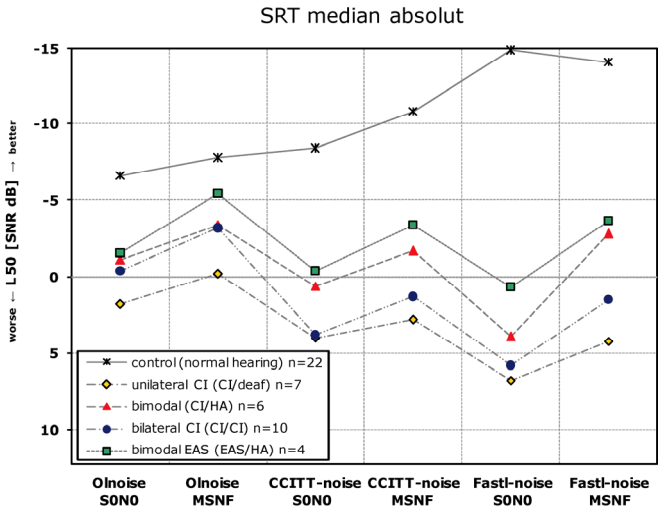

Figure 3: Median-values of speech reception thresholds (L50) for groups of normal hearing (control), unilateral CI, bimodal CI (CI and contralateral hearing aid), bilateral CI and EAS subjects in different noise conditions (S0N0 vs. MSNF) and different noise types.

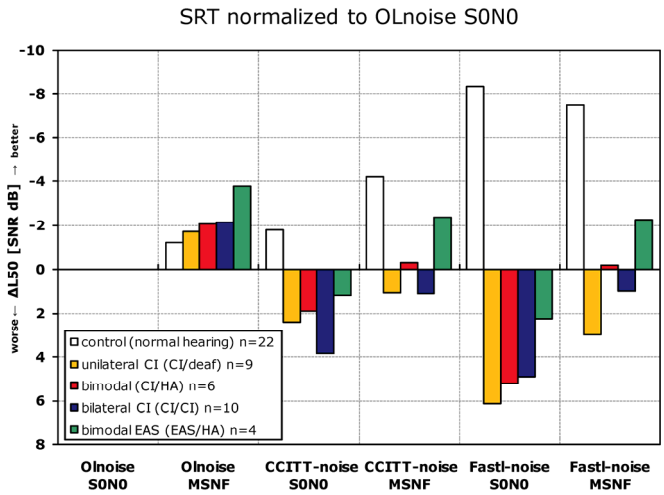

Figure 4: Relative changes of speech reception thresholds (L50) normalized to OInoise S0N0 condition for groups of normal hearing (control), unilateral CI, bimodal CI (CI and contralateral hearing aid), bilateral CI and EAS subjects in different noise conditions (S0N0 vs. MSNF) and different noise types.

Results

The results are compared with mean data obtained from a group of normal hearing subjects serving as control (Rader 2008). Figure 3 shows median values of the different subject groups in all noise conditions tested. Compared to the normal hearing group, deteriorated performance can be figured out for all noise conditions in the different cochlear implant groups, whereby the EAS group shows the best performance compared to all other implant .listening conditions.

Obviously, normal hearing subjects are able to make use of temporal gaps occurring in the Fastl-noise signal in order to improve speech intelligibility. This effect is slightly higher in the S0N0 condition compared to the MSNF condition and can be explained by a blending of noise signal energy radiated by four independent speakers in the MSNF condition. This effect is not present in cochlear implanted subjects and is independent of additional supply by a hearing aid, bilateral CI or EAS.

Obviously, speech recognition is severely compromised in all CI subject groups in the amplitude modulated noise condition. The differences in SNR for the examined patient groups show a clear discrepancy between Fastl-noise in the MSNF (ΔSNR=7.9dB) and OLnoise in the S0N0 condition (ΔSNR=3.4dB).

In order to visualize the impact of the different noise conditions on speech recognition, normalization was carried out with the OLnoise S0N0 condition serving as reference. The medians of normalized results are shown in Figure 4.[1] It is visible that the EAS subject group displays the highest benefit in all noise conditions compared to the other listening conditions.

[1] This condition was chosen by reason of best masking properties of speech (noise is based on overlaid OLSA-sentences, which results in the same spectrum).

Discussion

The MSNF with Fastl-noise is particularly suitable to measure the performance of various aided CI-patients in realistic sound environments. A better sensitivity to point out the speech intelligibility skills in realistic noise can be found for Fastl-noise in MSNF-condition compared to the OInoise in S0N0 condition as commonly used in hospitals.

The more the acoustic contribution to the hearing the merrier is the speech intelligibility in a multi talker noise condition (Fastl-noise in MSNF). The greatest differences of the SRT-values between the CI groups can be found for Fastl-noise conditions.

Fastl-noise in combination with a multi-source noise field is a qualified tool to evaluate the intelligibility of speech in realistic noise scenery for cochlear implanted patients.

References

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