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Original Article

The use of cochlear's SCAN and wireless microphones to improve speech understanding in noise with the Nucleus6® CP900 processor

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Abstract

Objectives: The newest Nucleus CI processor, the CP900, has two new options to improve speech-in-noise perception: (1) use of an adaptive directional microphone (SCAN mode) and (2) wireless connection to MiniMic1 and MiniMic2 wireless remote microphones. *Design:* An analysis was made of the absolute and relative benefits of these technologies in a real-world mimicking test situation. Speech perception was tested using an adaptive speech-in-noise test (sentences-in-babble noise). In session A, SRTs were measured in three conditions: (1) Clinical Map, (2) SCAN and (3) MiniMic1. Each was assessed for three distances between speakers and CI recipient: 1 m, 2 m and 3 m. In session B, the benefit of the use of MiniMic2 was compared to benefit of MiniMic1 at 3 m. *Study sample:* A group of 13 adult CP900 recipients participated. *Results:* SCAN and MiniMic1 improved performance compared to the standard microphone with a median improvement in SRT of 2.7–3.9 dB for SCAN at 1 m and 3 m, respectively, and 4.7–10.9 dB for the MiniMic1. MiniMic1 improvements were significant. MiniMic2 showed an improvement in SRT of 22.2 dB compared to 10.0 dB for MiniMic1 (3 m). *Conclusions:* Digital wireless transmission systems (i.e. MiniMic) offer a statistically and clinically significant improvement in speech perception in challenging, realistic listening conditions.

Key Words: Cochlear implant; wireless; directional microphone; speech perception; noise; assistive listening devices

Introduction

In everyday real-life conditions, sound reverberation and background noise can make it difficult to understand an individual speaker from a distance. As sound travels away from its source it reduces in intensity, while the background noise remains relatively constant. The ratio of the signal to noise thus decreases (Nabelek & Nabelek, 1994). The combination of reverberation, background noise and increased distance from the speaker results in poor listening conditions. This is true for persons with normal hearing, but the impact is even greater for persons with hearing loss (Nabelek & Pickett 1974).

Listeners with cochlear implants (CI) are known to have relative poor speech understanding in steady noise compared to their normal hearing peers but also relative to their own good speech understanding performance in quiet (Fu et al, 1998). This discrepancy becomes larger for competing noises in real environments that are modulated or fluctuating in level (Nelson et al, 2003). Sound processing technologies such as directional microphones and noise reduction algorithms as well as the use of remote microphones are applied in recent CI processors as an attempt to overcome this deficit.

Directional microphones in hearing aids, bone-anchored hearing aids (BAHA) and CI processors use dual-microphone technology to selectively attenuate sounds depending on their source location. Sounds from the front are less attenuated compared to sounds originating from sources behind or beside the hearing aid wearer. This is typically shown by directional sensitivity polar plots. Directional microphone technology has proven to be beneficial for speech-in-noise understanding in users wearing hearing aids (Walden et al, 2003), BAHA devices (Krempaska et al, 2014) and when implemented on CI processors (Wolfe et al, 2012). But for real-world situations, the benefit of directional microphones is

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Abbreviations

AD	analogue-to-digital
ALD	assistive listening device
BAHA	bone-anchored hearing aids
CI	cochlear implant
FM	frequency modulated
NR	noise reduction
SNR	signal-to-noise-ratio
SRT	speech reception threshold
WNR	wind noise reduction

known to decrease with increasing distance as well as with the mixing up of direct and indirect signals in everyday reverberating rooms (Walden et al, 2003).

The Nucleus CP900 processor (Nucleus 6 system) includes new sound processing algorithms for automated gain control, signal-to-noise ratio–based noise reduction (SNR-NR) and wind noise reduction (WNR) (Mauger et al, 2014; De Ceulaer et al, 2015). The automatic scene classifier called SCAN can activate the appropriate processing strategy in different listening environments. Moreover, SCAN can also switch between three microphone settings using the standard (slightly directional), the zoom (strongly fixed directional) or the beam microphone (adaptive directional). These fixed and adaptive directional microphone settings have proven their benefit over the standard microphone when mounted on CP900 and on former processor designs (N5 CP810 and Freedom) (Wolfe et al, 2012, 2015a). Most of these directionality studies in CI processors were performed in specific test set-ups with favourable relative orientation of speech and noise sources and executed in double-walled sound-treated room. These conditions are not representative for speech in noise performance in everyday challenging conditions.

Wireless microphones are assistive listening devices (ALDs) designed to help hearing impaired individuals in challenging listening conditions. The microphone is placed near the speaker's mouth and transmits the analogue-to-digital (AD)-converted signal wirelessly to a receiver worn by the listener. By acquiring the signal near its source, the negative effect of both the ambient noise and the distance is reduced, which results in an improved signal-to-noise ratio (SNR). In the past, these microphones were more commonly used in frequency-modulated (FM) and telecoil systems. Lately, new 2.4 GHz digital wireless transmission technology has been developed by ReSound (Jespersen & Laureyns, 2011). These wireless accessories enable the user to connect to a variety of wireless audio sources such as a remote microphone, a mobile phone or a television. Importantly, the use of the 2.4 GHz frequency spectrum omits the necessity to wear a large neck-loop receiver as an intermediate relay station between the accessory and the sound processor. One of these new wireless accessories is a small omnidirectional lightweight clip-on microphone called ''Unite'' (ReSound) or ''MiniMic1'' (Cochlear) remote microphone. A second generation of this clip-on microphone is called ''MultiMic'' (ReSound) or ''MiniMic2(+)'' (Cochlear) (Figure 1). This latter version incorporates a directional microphone that automatically activates when worn by a talker in noisy environments. The Nucleus 6 (CP900) processor has this wireless communication chip on-board and thus possesses the capacity for direct connectivity with these wireless accessories without the need for intermediate devices (Wolfe et al, 2015b). The MiniMic1 has been shown to improve speech in noise understanding by 11 dB SNR (SRT) in hearing aid recipients (Jespersen & Laureyns, 2011) and by 9 dB in BAHA wearers (Hoffmann et al, 2014). Wolfe et al. (2015c) obtained similar results and also showed equivalent benefit of MiniMic1compared to an adaptive remote microphone system (Roger, Phonak) for situations with low competing noise levels. Only at high competing noise levels (75 dBA), the adaptive remote system outperformed the MiniMic1. For the MiniMic2, an SNR benefit of 15 dB has been shown in hearing aid users when compared to a normal directional microphone in a sound-treated room (Jespersen & Kirkwood, 2016).

The objective of this study was to assess the absolute and relative advantage of the new technologies on speech perception in CI recipients. More specifically, the possible benefit of SCAN and MiniMic, on speech perception was assessed in realistic test conditions with the Nucleus 6 (CP900) speech processor.

Methods

An acute within-subjects repeated-measures study was carried out in post-lingually deafened adults with a Nucleus CP900 cochlear implant. Each participant underwent two test sessions.

Participants

Thirteen post-lingually deafened adults were recruited from the CI clinic at the Eargroup (Antwerp). Table 1 describes the participants' demographic data. All participants were experienced users of the Nucleus cochlear implant system (unilaterally or bilaterally implanted) with at least one month of CP900 experience at the time of testing. Concurrent participation in another study and difficulties additional to hearing impairment that would interfere with the study procedures were considered as exclusion criteria. Written informed consent was obtained from all participants. Prior to taking the tests in noise, participants were systematically assessed with their clinical map for speech in quiet at 70 dB SPL. Since multiple SRTs were measured in the study procedure, only patients with phoneme scores in quiet of 60% or more were included in the study.

For the sake of comparison, normative data were also obtained for the same test set-up with 3 m distance between speaker and recipient. These data were obtained from a group of 13 young adult participants (age range 16–30) with normal hearing.

Test set-up

A test situation was created to simulate a CI user having a conversation in a noisy room with a conversational partner located in front of the user at variable distances. The partner was mimicked by a Fostex 6301B Personal loudspeaker (Foster Electric Company, Limited, Tokyo, Japan) placed in front of the CI user at a distance of 1, 2 and 3 m, as shown in Figures 1 and 2. A multitalker babble noise, acquired by recording samples from 100 people speaking in a canteen (Signal Processing Information Base, 1990), was used to create a diffuse noise field by simultaneous but non-correlated presentation through six Alesis Elevate noise generating speakers (inMusicBrands LLC, Cumberland). All these speakers were connected to a PC using a Gigaport Soundcard (ESI Audiotechnik GmbH, Leonberg, Germany). The A§E software platform (Otoconsult nv, Antwerp, Belgium) (Govaerts et al, 2006) was used to generate and control the sounds presented.

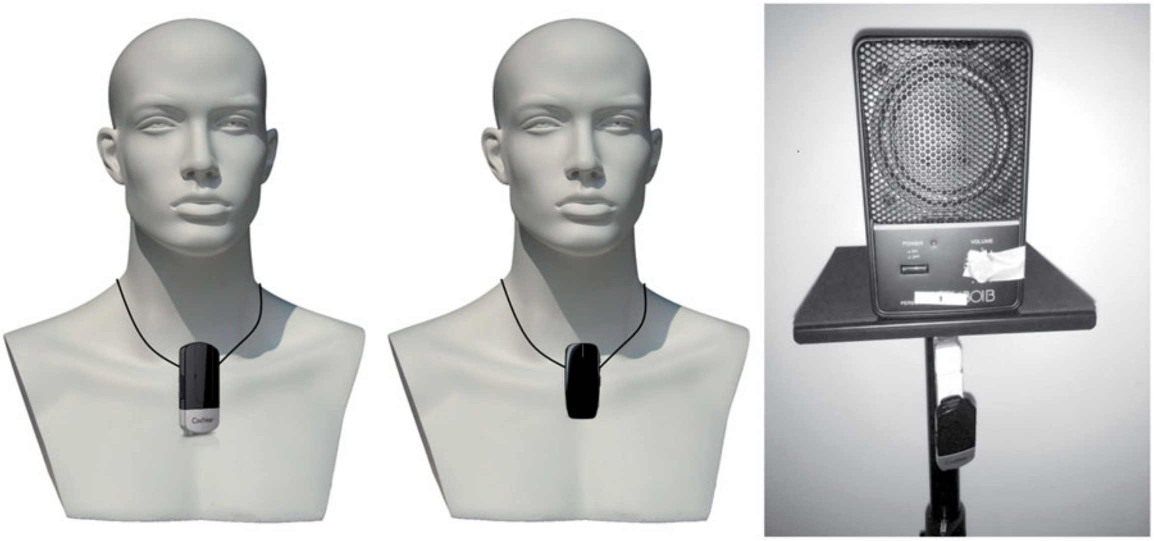

Figure 1. On the left and in the middle, schematic talker is wearing a MiniMic1 and MiniMic2 around the neck with the Lanyard adjusted so that the remote microphone is optimally placed (ideally 15 cm from the mouth). On the right how this was translated in the test set-up with the positioning of the remote microphone (MiniMic1) 15 cm down from the speech speaker.

Table 1. Reverberation times of the test room.

	125	*250*	*500*	*1000*	*2000*	*4000*
RT60	0.52	0.48	0.40	0.42	0.46	0.42

RT60 values: Time [seconds] it takes sound in the test room to decay 60dB in level; results are given for different frequencies from 125 to 4000Hz (column headers).

The test room was rectangular with dimensions 6.45 m by 3.55 m × 2.57 m high. The room reverberation time was measured using REW room acoustics analysis software (REW v5 software, 2015).The reverberation time (RT60) data of this test room are displayed in Table 1. The background noise level in the room was 37 dBA. The noise speakers were positioned throughout this test room ensuring a uniform noise field at any point of interest in the room.

Procedures and device fitting

During a first session (A), speech-in-noise testing was performed for three CI processor microphone settings: (1) using the standard microphone setting and the patients clinical map setting (condition ''Clinical''), (2) with the SCAN classifier (condition ''Scan'': ASC + ADRO and SNR-NR with SCAN) and (3) with the speech processor remotely connected to the MiniMic1 placed 15 cm from the speaker (condition ''MiniMic1''; Figure 1). All three CI microphone settings were evaluated for three distances between speech source and CI recipient, namely 1, 2 and 3 m (Figure 2). The total number of tests in one recipient in this first session was nine. The order was randomised for each test subject.

In the second session (B), the speech-in-noise testing for conditions ''Clinical'' and ''MiniMic1'' was re-assessed as in session A but only for the distance of 3 m. In addition, speech in noise performance at 3 m was tested with the speech processor remotely connected to the MiniMic2 (condition MiniMic2; Figure 1).

All CI processors had been fitted according to the FOX target-driven, computer-assisted approach as described in Govaerts et al (2010), Battmer et al (2014) and Buechner et al (2014). For this study, each subject was provided with a new Nucleus 6 (CP900) CI processor for the purposes of testing. No map changes were made to the everyday clinical map. The MiniMic microphones were coupled to the processor using the standard 2.4 GHz connection protocol. The mixing ratio of the MiniMic microphones to processor microphone was set to the default 2:1 mixing. The volume setting of the MiniMic microphones was always set to +6 dB. In case of bilateral (2 CIs) or bimodal stimulation (one CI and a contralateral hearing aid), the participants were instructed to switch off the contralateral device during the test.

Outcome measures

Speech perception was tested using the Flemish sentences-in-noise test (Van Wieringen & Wouters, 2008). This consists of 36 lists of 10 sentences each, characterised by a varying number of target words (between two and six per sentence). Scores were recorded as the percentage of the target words correctly repeated by the listener.

The presentation level of the speech was fixed at 65 dB SPL (always measured at 1 m distance from each of the individual speech speakers). Non-correlated multi-talker babble noise (Signal Processing Information Base, 1990) was presented simultaneously through the six noise speakers at different levels according to the adaptive algorithm and with a starting level of 55 dBSPL. To allow the SCAN classifier to switch on, the noise was activated 10 sec prior to the presentation of the first sentence in all conditions. The calibration and positioning of the six speakers was such that uniform noise levels were measured at all points of interest in the test room.

The adaptive SRT seeking algorithm in the A§E software used an initial signal-to-noise ratio of +10 dB, and an initial step size of 10 dB. The subsequent step sizes were determined by division of the initial 10 dB step by two raised to the power of the number of observed reversals. The minimal step size was set at 1 dB.

Figure 2. The test set-up of the room showing speaker locations. The CI user is seated at 1 m from the first speech speaker. The other two speech speakers are at 2 and 3 m in front of the CI user. Six noise speakers are positioned in the room to assure a uniform multitalker babble noise field. N: Noise presenting speakers; S: Speech presenting speakers.

Table 2. Subject demographic data including details of the implant type and SmartSound™ used in their Clinical map.

Subject ID	*Age (years)*	*CI side*	*CP900 Side*	*Duration of HL (yrs)*	*Duration CI use (yrs)*	*Implant type (R + L)*	***SmartSound™ Setting 'Clinical'***	***Speech in quiet @70 dBSPL****
S1	43	Right	Right	1	8	CI24RE(CA)	ASC	81
S2	65	Right	Right	2	15	CI24M	ASC	82
S3	20	Bilateral	Right	2	17	CI24RE(CA)+ CI24R(CS)	ADRO + ASC	72
S4	79	Left	Left	1	5	CI512(CA)	ASC + Less 60dB	85
S5	72	Left	Left	10	1	CI24RE(CA)	ASC	88
S6	47	Right	Right	1	13	CI24R(CS)	None	83
S7	49	Bilateral	Right	1	14	CI24R(CS)+ CI24R(CS)	ASC	90
S8	80	Right	Right	1	11	CI24R(CA)	ASC + Less 60dB	86
S9	56	Left	Left	1	12	CI24R(CS)	ASC	79
S10	18	Right	Right	1	11	CI24R(CA)	None	97
S11	52	Bilateral	Right	2	14	CI24R(CS)+ Digisonic SP	None	97
S12	41	Left	Left	3	15	CI24M	None	96
S13	29	Bilateral	Left	5	7	CI24RE(CA)+ CI24RE(CA)	None	77

*Phoneme score on a Flemish CVC word list (NVA).

The algorithm halted after eight reversals. The final SRT was calculated by averaging the SNRs from the last six reversals.

Statistics

Nonparametric methods were used for descriptive and analytical statistics. The distribution of the SRT results is presented as box-and-whisker plots representing the five parameter statistics (Tukey, 1977). A Friedman ANOVA test with *post hoc* Wilcoxon matched pairs tests were used for between-group differences. A Bonferroni adjustment was applied to set an overall level of significance at 5% (resulting an adjusted significance testing criterion used for these repeated measures at $p<.002$). All analyses were conducted using Statistica software (version 9.1, StatSoft Inc, Tulsa, OK).

Results

The median age of the participants was 49 years (range 18–80 years) with a median duration of pre-implant deafness of 1 year (range 1–10 years). The median duration of CI use was 12 years

Table 3. SRT-results (dB SNR) – and their median – for speech in noise as measured in session A and B for three test conditions (Clinical, Scan and MiniMic) and for 1 m, 2 m and 3 m distance between loudspeaker and subject.

	Session A Clinical			*Session A Scan*			*Session A MiniMic1*			*Session B Clinical*	*Session B MiniMic1*	*Session B MiniMic2*
	1 m	*2 m*	*3 m*	*1 m*	*2 m*	*3 m*	*1 m*	*2 m*	*3 m*	*3 m*	*3 m*	*3 m*
S1	−3.3	4.4	4.2	−5.9	2.2	1.1	−9.7	−5.3	−3.4	4.8	−3.3	−21.1
S2	−2.8	3.4	8.1	−7.7	2.7	4.2	−4.8	−3.4	3.3	6.4	−4.9	−21.1
S3	7.2	5.9	21.6	−5.9	3.0	8.3	2.5	−7.8	5.3	12.1	−2.0	−16.6
S4	5.0	0.6	8.8	−3.4	−1.6	2.7	−5.0	−5.3	−3.8	0.5	−7.0	−20.6
S5	0.8	2.2	2.9	−7.8	−0.2	4.7	−9.2	−7.8	−1.3	9.0	−7.3	−19.8
S6	1.3	7.2	17.7	−5.3	4.8	12.2	−7.0	−8.1	0.5	10.0	−1.3	−9.9
S7	−3.3	3.3	8.8	−4.1	2.2	6.6	−6.7	−3.0	−2.8	6.1	−4.1	−20.6
S8	−3.4	1.6	11.6	−4.1	−2.7	0.9	−4.8	−7.2	−1.6	7.6	−2.2	−18.9
S9	−0.8	4.1	9.1	−0.6	3.9	9.8	−4.5	−3.2	7.8	1.8	−3.6	−19.4
S10	−4.7	−0.9	3.1	−5.9	−3.1	−0.9	−8.9	−7.7	−7.8	0.4	−6.4	−20.0
S11	−6.1	−2.3	7.2	−7.8	1.6	−0.9	−11.9	−9.5	−5.9	1.9	−6.7	−17.9
S12	−9.7	−3.4	1.1	−3.4	−2.5	3.1	−9.4	−9.8	−8.6	2.5	−8.7	−19.5
S13	−3.4	6.6	4.5	−7.8	0.3	1.9	−9.4	−7.0	−2.3	4.5	−4.6	−16.0
Median	**−3.3**	**3.3**	**8.1**	**−5.9**	**1.6**	**3.1**	**−7.0**	**−7.2**	**−2.3**	**5.4**	**−4.3**	**−19.4**

A lower score indicates better performance.

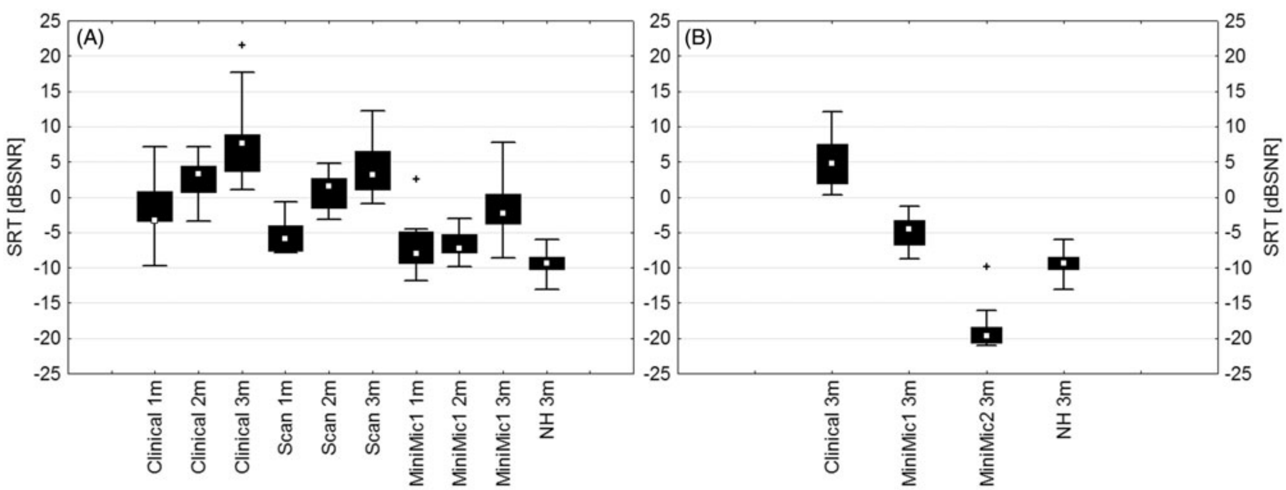

Figure 3. Left panel: Results of the session A shown as Box plots of the SRT distributions in the nine conditions, with Clinical Map settings, with use of default N6 SCAN settings and with use of MiniMic1 and this for the three test distances. Right panel: Results of session B shown as Box plots of the SRT distribution for Clinical, MiniMic1 and MiniMic2 condition at 3 m. In both panels also, the results for Normal Hearing persons at 3m are shown. Median values for SRT in dB are shown, with 25% and 75% quartiles and whiskers showing the minimum and maximum values for each condition. Outliers are labelled with crosses (+).

(range 1–17 years). All participants used the Nucleus ACE strategy in their map fitting.

The median speech-perception score in quiet, expressed as per cent correctly identified phonemes for Flemish monosyllables delivered at 70 dB SPL was 85% (range 72–97%).

All individual SRTs in noise are listed in Table 3 and their distributions are depicted in Figure 3. The distributions of the within-subject benefit of the Scan and MiniMic results are given in Figure 4.

Session A showed median SRTs in the Clinical condition of −3.3, 3.3 and 8.1 dB SNR for distances of 1, 2 and 3 m, respectively. For the Scan condition, these were −5.9, 1.6 and 3.1 dB SNR. The Scan settings outperformed the Clinical settings in 32 out of 39 paired results. The median within-subject SRT benefit of scan compared to Clinical was 2.7 dB SNR at 1 m, 2.2 dB at 2 m and 3.9 dB at 3 m. The within-subject differences between Scan and Clinical were not statistically significant ($p = 0.01$, $p = 0.03$ and $p = 0.005$ for the three respective distances). The median SRT in the MiniMic1 condition was −7.0, −7.2 and −2.3 dB SNR for the distances of 1, 2 and 3 m, respectively. The MiniMic1 settings outperformed the clinical settings in 38 out of 39 paired cases. The median within-subject SRT benefit of MiniMic1 compared to clinical was 4.7 dB SNR at 1 m, 7.3 dB at 2 m and 10.9 dB at 3 m. The within-subject differences between MiniMic1 and Clinical were statistically significant for all distances ($p < 0.002$ for the three distances), whereas between MiniMic1 and Scan they were only significant for the 3 m distance test ($p = 0.001$).

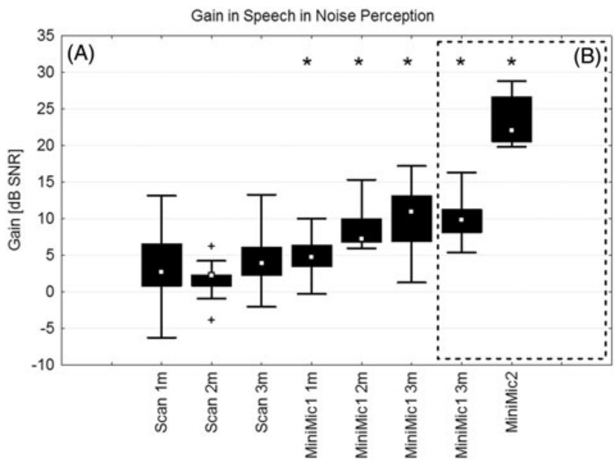

Figure 4. Left panel (A) Box plots show the SRT benefit for MiniMic1 over Clinical analogue for 1, 2 and 3 m of distance between speaker and CI recipient in session A and right panel (B) Box Plots of MiniMic1 and MiniMic2 benefit at 3 m found in session B. Median values for SRT in dB are shown, with 25% and 75% quartiles and whiskers showing the minimum and maximum values for each condition. Outliers are labelled with open dots (o) and significant benefits over the clinical analogues ($p < 0.002$) are marked by stars (*).

Session B showed a median SRT at 3 m distance of 5.4 dB SNR for the Clinical condition, −4.3 dB SNR for MiniMic1 and −19.4 dB SNR for the MiniMic2. Within-subject comparisons showed statistical significance for MiniMic2 being better than MiniMic1 ($p = 0.001$) which in its turn was significantly better than Clinical ($p = 0.001$).

The median SRT for normal-hearing participants for a distance of 3 m was −9.4 dB SNR (range −6.1 to −13.1 dB SNR). This SRT is statistically significant better than median SRT in CI participants in the Clinical condition ($p = 0.001$) but significant worse than median SRT in the CI participants in the MiniMic2 condition ($p = 0.001$). It is not significantly different from the MiniMic1 condition results ($p = 0.003$).

Discussion

This study shows that in a realistically mimicked everyday noisy listening condition, wireless remote microphones like the MiniMic1 and MiniMic2 offer a statistically and clinically significant benefit over the use of the standard clinical microphone setting. A smaller but not significant benefit is also observed for the use of the default SCAN microphone setting. This is the first study that assesses the relative benefit of both technologies in a realistic and challenging everyday situation.

Adaptive directional microphone benefit

Previous studies on directional microphones in cochlear implants have focussed on speech-in-noise assessments in less realistic test settings. For instance, such studies would use non-modulated speech-shaped noises that typically originate from one single or a limited number of sources located at favourable positions to maximally exploit the underlying technology (Wolfe et al, 2012, 2015a). Such test set-ups have demonstrated a 6 dB SNR benefit of SCAN compared to the standard Clinical microphone in Nucleus 5 (CP800) and Nucleus 6 (C900) CI processors. This is more than twice the 2.7 dB advantage of Scan condition (at 1 m) found in the current test set-up. The use of a realistically reverberating room as well as the use of a diffuse multi-talker babble noise in the current study probably resulted in lower but more realistic values. Previous work of Wolfe et al, (2015a) focussed on comparing the default Nucleus 6 settings (ADRO + ASC + SNR − NR + SCAN) to the default Nucleus 5 settings (ADRO + ASC). They found an overall improvement in the speech-in-noise intelligibility score of 27% and an isolated 9% improvement for the SNR-NR algorithm only. Considering a 9.3%-per-dB slope (for AzBio sentence lists in noise in adults (Spahr et al, 2012)), this would be in line with a benefit approximating 3 dB SNR when going from ADRO + ASC to ADRO + ASC + SNR − NR + SCAN, and a 1 dB SNR improvement attributable to the SNR-NR algorithm only. This figure is comparable to the isolated SNR-NR benefit of 1.2 dB SNR found by De Ceulaer et al (2015).

MiniMic1 benefit

Previous studies on the remote wireless mini-microphone MiniMic1 have shown improved speech-in-noise understanding in hearing aids. For a distance of two metres between recipient and speaker and an exclusive 100% input from the MiniMic1, Jespersen & Laureyns (2011) found SRT improvements for speech perception in noise of 10.6 dB SNR compared to the device's directional microphone. This benefit dropped to 8.6 dB SNR when mixing the inputs from MiniMic1 and the hearing aid microphone. In BAHA users, Hoffman et al (2014) showed a similar benefit of the MiniMic1 for listening in noise at a distance of 1.2 m. A 7.3 dB SNR difference was found with the directional microphone and an 8.8 dB SNR improvement compared to the omnidirectional microphone. Again, with a mixed input of MiniMic1 and the BAHA microphone this benefit dropped to 3.1 dB SNR. The current study shows similar benefits for CIs in realistically reverberating environment.

Comparing directional processor microphone versus omnidirectional wireless microphone, relative benefit

In contrast to other studies, the current study also allows within-subject comparison of two techniques. It is therefore possible to draw conclusions on the best use of each of both technologies. Up to a distance of 1 m, the speech-in-noise SRTs showed no significant difference between use of Scan and MiniMic. When the speaker became more distant to the CI recipient, the MiniMic1 significantly outperformed the SCAN technology. This comes as no surprise as speech will continue to reach the MiniMic1 with the same intensity because its relative distance to the speaker does not change. For the Scan, on the other hand, the speech must travel an increased distance to reach the processor microphone. It is noteworthy that on average for speech presented at 3 m distance in a noisy environment, a CI recipient using the MiniMic1 understood as much as a participant with normal hearing without any assistance.

MiniMic2 benefit

The only other study reporting on results with the same remote wireless remote microphone MultiMic/MiniMic2(+) is the white paper by Jespersen & Kirkwood (2016). They found an SRT improvement in speech-in-noise tests of 15 dB SNR for a 100% MiniMic2 input when compared to a 100% directional microphone input. Exact specification of noise and test condition is lacking in this report. Taking into consideration that the current study compared the MiniMic2 to an omnidirectional microphone in a 2:1 mixed input configuration, the observed benefit of 22 dB SNR is in line with Jespersen's findings. This means that for speech presented at 3 m distance in a noisy environment, a CI recipient using the MiniMic2 really outperforms a normal hearing listener without assistance.

Conclusions

For cochlear-implant users, both the SCAN function and the digital wireless remote microphone systems were found to improve speech perception in a challenging and realistic test set-up. When compared to clinical, scan yielded an SRT benefit of 2.7 and 3.9 dB SNR at 1 and 3 m, respectively. For the MiniMic1, this benefit was 4.7 and 10.9 dB SNR, respectively. Both technologies were rather comparable for distances up to 1 m. For larger distances, the MiniMic1 outperformed the scan technology. The benefit in noise of 22 dB SRT for the use of the MiniMic2 is impressive. In fact, with the aid of this remote microphone, the CI participant showed a better speech perception in noise compared to the normal-hearing participants who did not dispose of this remote microphone. These data should allow clinicians to counsel their patients when and how to use these technologies.

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