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OTOLOGY

Contribution of noise reduction pre-processing and microphone directionality strategies in the speech recognition in noise in adult cochlear implant users

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Abstract

Purpose Refinement currently offered in new sound processors may improve noise listening capability reducing constant background noise and enhancing listening in challenging signal-to-noise conditions. This study aimed to identify whether the new version of speech processor preprocessing strategy contributes to speech recognition in background noise compared to the previous generation processor.

Methods This was a multicentric prospective cross-sectional study. Post-lingually deaf adult patients, with at least 1 year of device use and speech recognition scores above 60% on HINT sentences in quiet were invited. Speech recognition performance in quiet and in noise with sound processors with previous and recent technologies was assessed under four conditions with speech coming from the front: (a) quiet (b) fixed noise coming from the front, (c) fixed noise coming from the back, and (d) adaptive noise ratios with noise coming from the front.

Results Forty-seven cochlear implant users were included. No significant difference was found in quiet condition. Performance with the new processor was statistically better than the previous sound processor in all three noisy conditions ($p < 0.05$). With fixed noise coming from the back condition, speech recognition was 62.9% with the previous technology and 73.5% on the new one ($p < 0.05$). The mean speech recognition in noise was also statistically higher, with 5.8 dB and 7.1 dB for the newer and older technologies ($p < 0.05$), respectively.

Conclusion New technology has shown to provide benefits regarding speech recognition in noise. In addition, the new background noise reduction technology, has shown to be effective and improves speech recognition in situations of more intense noise coming from behind.

Keywords Cochlear implant · Speech recognition · Noise reduction · Directional microphones

Introduction

Cochlear implant is an outstanding device that offers the opportunity to hear for those who cannot benefit from conventional hearing aids, although it still does not mimic natural auditory system. The normal functions of the peripheral auditory system beyond the ganglion cells should ideally be represented by speech processor features to mimic natural events as much as possible. As compared with what happens in normal listeners, each structure of the outer and middle ear should ideally be able to contribute to the cochlear implant users' ability to separate from the background noise what they want to hear and focus their attention on. Similarly, the controlling role of the outer hair cells and the olivo-cochlear system seemingly so

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effective in normal-hearing individuals should be represented as much as possible in the cochlear implant signal.

Several approaches to signal management have previously been implemented in Nucleus cochlear implant systems, ranging from speech coding strategies development to new microphone features that represent expressive improvement to CI recipients' outcomes. Furthermore, technologies like Automatic Sensitivity Control (ASC) and adaptive dynamic range optimization (ADRO) are available to automatically improve the input signals received at the microphone [1–3]. These initiatives reflect the attempt to provide the profoundly hearing-impaired individuals with better filtering of sound, getting them thus closer to the performance of listeners with healthy peripheral auditory system.

Nevertheless, technology is moving at a fast pace and refinement currently offered in new sound processors, may allow not only device connectivity, but improved noise listening features. These improvements target to reduce constant background noise and enhance listening in challenging signal-to-noise conditions, with intelligent signal processing technology that allows automatic adaptation. Automatic scene classification aims to automatically deliver a selection of appropriate input processing technology to the user at each specific listening environment [4]. Signal management with the use of directional microphones with two microphones acting together and blocking sounds that are captured behind the head of the user, enables the listener to have a better configuration of speech information arriving from the front, while attenuating noise arriving from other directions [5]. ForwardFocus (FF), is a new background noise reduction technology introduced into the Nucleus 7® speech processor, which aims to reduce constant background noise and enhance listening in challenging signal-to-noise conditions [6]. FF was developed to provide additional benefits over directional microphones, as a spatial post-filter technology and is implemented on unilateral conventional behind the ear sound processors (SP) [6].

Another issue to be considered is that sound processors have a finite life and require periodic replacement after several years of use. In such cases, if the benefits derived from a new SP are significant, it could be interesting for users to opt for the most up-to-date device expecting not only a replacement, but a true upgrade. However, SP upgrade usually comes with significant cost implications. It is therefore important that potential real-life benefits of a new SP model over the previous version are objectively demonstrated to users, clinicians and stakeholders [5].

Objective

This research aims to evaluate whether there is a contribution of combining automatic noise reduction pre-processing strategies with fixed microphone directionality in the speech recognition in adult cochlear implant users.

Methods

This study was a multicentric, prospective and cross-sectional study, approved by all individual Ethics Review Boards (main protocol no 3.118.749), in which each subject served as their own control. Assessments were carried out at six different Cochlear Implants centers.

Patients

Selection criteria included adult CI users of both genders, 18 or more years of age with post-lingual deafness, users of at least an unilateral cochlear implant with Nucleus 5® (CP 810) speech processor for at least 1 year, with a minimum score of 60% in HINT in quiet condition with their own SP, native speakers of the local language, with no cognitive, neurological or other alterations that would prevent to carry out the procedures involved in the investigation. Participants were invited and selected after signing the informed consent.

A total of forty-seven subjects meeting the selection criteria were recruited, with ages ranging from 19 to 70 years. Demographical data are shown in Table 1. Among the participants, seven were bilateral CI users and four were bimodal users. However, during test sessions, all participants were tested unilaterally with the CI side or, in the case of bilateral users, the ear with the best outcome was considered in this evaluation.

Subjective listening benefits and satisfaction with their cochlear implants assessed by the SSQ[12]. Considering the maximum expected score in the SSQ for each of the subscales is ten, median results of 5.4, 5.7 and 6.5 revealed the difficulty in challenging situations for most of the patients, reinforcing the need of improvements in their quality of hearing.

Materials and procedures

Evaluation involved the HINT Test—Hearing in Noise Test (HINT) in the local language [8] presented from one or two loudspeakers positioned at zero azimuth and 180°,

Table 1 Demographical data of the studied sample

Sex (*N*)	
Female	29
Male	18
Age (in years)	
Median	43
Min–max	19–70
Time of CI use (in years)	
Median	6
Min–max	2–16
CI use (*N*)	
Unilateral	36
Bimodal	4
Bilateral	7
Etiology	
CMV	1
EVAS	1
Genetic	2
Meniere	1
Infectious/Meningitis	8
Otosclerosis/Osteogenesis	5
Unknown/Progressive	26
Trauma	3
SSQ[12]	
Speech	
Median	5.4
Min–max	1.4–9.4
Spatial	
Median	5.67
Min–max	0.67–10
Quality	
Median	6.5
Min–max	1.5–9.5

CMV Citomegalovirs, *EVAS* Enlarged vestibular aqueduct syndrome

1 m from the patient in a sound attenuated booth, in four conditions (Fig. 1).

- Quiet: speech presented at 0° azimuth at 65 dBSPL
- In noise
    - o Fixed noise S_0N_0: speech presented at 65 dBSPL with SNR = + 10 dB
    - o Adaptive noise S_0N_0: noise presented at 55 dBSPL with variable speech presentation levels with SNR targeted to 75% correct words
    - o Fixed noise S_0N_{180}: speech presented at 65 dBSPL with SNR = 0 dB. In this situation, to assess the contribution of the forward focus (FF) feature, it was enabled in the N7®

Both processors were evaluated in all conditions. Bilateral CI patients were assessed in unilateral fitting with both Nucleus 5® (N5®) and Nucleus 7® (CP1000) (N7®) processors. Test order with N5® and N7® was randomized (www.randomizer.org).

Subjective listening benefits and satisfaction with their cochlear implants were assessed using the SSQ-12 questionnaire (Speech, Spacial and Qualities) in the local language [7] in their daily life situations with their regular sound processor (CP 810).

In order to perform the evaluations with functioning speech processors, the patient´s regular routine maps (maps in use) were copied to a new N5® speech processor, and also converted to a new processor N7® (Fig. 2). The subjects were fitted with the N7® sound processor using the same settings and same program of the map in use with N5®. No home experience was provided since evaluations were all conducted in the same session. Clinicians also enabled Forward Focus option on N7® speech processors.

Statistical analysis

Collected variables involved the percentage of speech recognition in quiet and in noise and the SRT (in dB) for the adaptive noise situation. The SRT was collected in dB of the signal to noise ratio (SNR) to achieve 75% correct words on sentences at S_0N_0. Statistical analysis included the mean values comparison with two-tailed paired *t* test.

Results

Speech recognition mean scores data for N5® and N7® speech processors in quiet and noise conditions are shown in Fig. 3.

Two-tailed paired *t* test showed no significant difference between N5® and N7® in quiet conditions (Table 2), however, for speech in noise significant difference were observed for all conditions. Results indicate significant improvements in the percentage of correct words and also in the mean SNR with N7® when compared with N5® on a two-tailed paired *t* test ($p < 0.05$). In the condition that the speech comes from the front and noise from the back, performance with N7® with ForwardFocus enabled was significantly better than with N5® with Beam ($p < 0.05$).

Discussion

Since the introduction of the first cochlear implants (ICs) in the 1980s, manufacturers have been refining and upgrading internal components, particularly with regard to electrode design, and signal pre-processing algorithm [4, 5]. Although

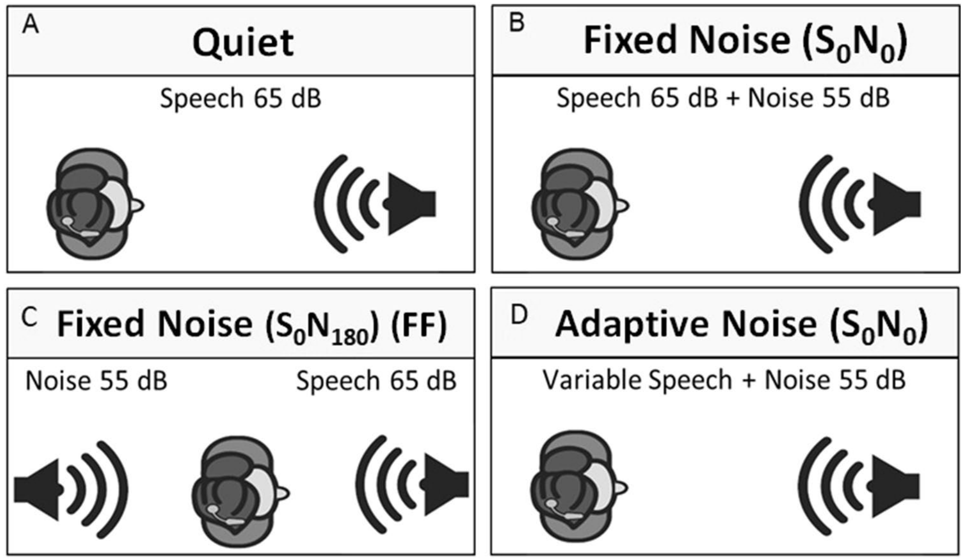

Fig. 1 **a**, **b**, **c** and **d** represent test conditions used with the N5® and N7® speech processor. (**a**) Quiet with speech coming from the front (S_0); (**b**) Fixed noise with speech and noise coming from the front (S_0N_0); (**c**) Fixed noise to test the Forward Focus contribution, with speech coming from the front and noise coming from the back (S_0N_{180}) (dB read dBSPL); (**d**) Adaptive noise with speech and noise coming from the front (S_0N_0)

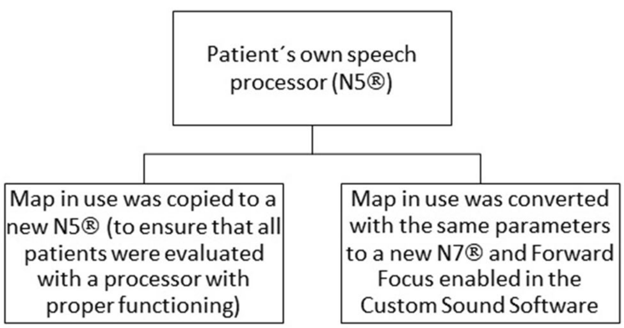

Fig. 2 Processors fitting procedure. Two new N5® and N7® speech processors were used during the study. The N5® to ensure the proper fitting of the speech processor, and the N7® as the study technology

the IC provides excellent quality of hearing, facilitating communication and speech recognition for its users, speech comprehension remains a challenge in complex real-world acoustic environments. In these situations, background noise can negatively interfere with the understanding of a conversation, as reported by the results from the SSQ in our sample, revealing low scores especially in the speech and quality domains. This study aimed to determine whether technology can improve listening in these challenging situations.

Our results showed significant improvements with no interference in quiet. Indeed, De Ceulaer et al. [9] in a study with adults verified that the average speech recognition in silence was not significantly different among the processors. In fact, the idea is to offer in noise a similar performance to silence.

On the other hand, there was a significant contribution in noise, either in the fixed noise condition (10%) and the adaptive noise mean SRT (1.3 dB) with N7®. In this situation, the automatic scene classifier (SCAN) includes SNR-NR (signal to noise ration noise reduction) technology over the ADRO and ASC (autosensitivity control) used by N5® processor.

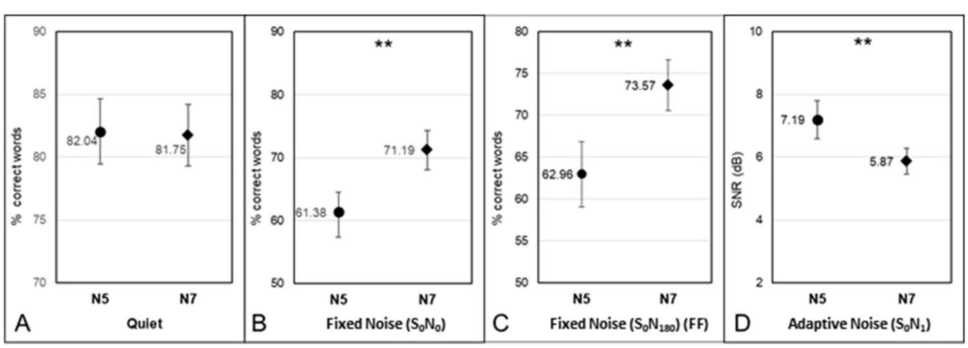

Fig. 3 Speech recognition mean scores (%) for both processors in quiet (**a**), fixed noise (**b**) and fixed noise coming from the back to evaluate forward focus (FF) with the N7® (**c**) and mean SNR (signal to noise ratios) (**d**) for the adaptative noise speech recognition. Bars represent the standard errors and **represent statistically significant difference ($p < 0.05$). Contribution of noise-reduction pre-processing and microphone directionality in the speech recognition in noise in adult cochlear implant users

Table 2 Speech recognition results in quiet and in noise with both technologies, Nucleus 5® (N5®) and Nucleus 7® (N7®) with two-tailed paired t test analysis

	N5®	N7®	*P*
Quiet (%)	82.04	81.75	0.8127
SE	2.61	2.44	
Fixed noise (S_0N_0) (%)	61.38	71.19	0.0034*
SE	3.98	3.15	
Adaptive noise (S_0N_0) (SNR in dB)	7.19	5.87	0.0027*
SE	0.60	0.41	
Fixed noise (S_0N_{180}) (%) (FF)	62.96	73.57	0.0009*
SE	3.91	3.04	

SNR signal to noise ratio to achieve 75% correct words on sentences. *S0N0* speech and noise at 0o azimuth; *SE* Standard error

*Statistically significant value ($p < 0.05$). FF. forward focus enabled in the N7® speech processor

The SNR-NR is designed to attenuate constant type of signals such as noise, which mask the low energy cues of speech, maintaining the transient information of acoustic signals. Mauger et al. [4] and Plasmans et al. [10] in studies in adults and children using N6 with the automatic algorithm provided (SCAN), showed an improvement of 1.2–1.7 dB in SRT, which would be equivalent to approximately 10–20% increase in speech recognition scores for adults. Although the speech reception threshold (SRT), defined as the signal-to-noise ratio (SNR) at which 50% of the speech is correctly understood has been proposed as a common measure of the ability of a listener to understand speech in noise, in the present study we intended to raise the difficulty and assess the SNR with adaptive noise where 75% of the speech was correctly understood. Even in this more challenging condition, the contribution of the noise reduction capability of the new technology (SNR-NR) could be evidenced. Moreover, the adaptive directional microphone (BEAM) is able to enhance the attenuation of noise by steering its null towards a dominant noise location, while Forward Focus is superior to attenuate noise locations coming from behind Hey et al. [6].

The present study compared speech recognition obtained using the N7® Sound Processor (CP 1000) and N5® (CP 800 series), which incorporates the new single integrated processing chip, enabling further miniaturization, but its basic signal processing is equivalent to that in the predicate Nucleus six series sound processors. The main innovation in quality sound is the incorporation of FowardFocus, which enhances hearing in noise environments with fixed directionality that can be used in combination with automatic input processing technology of ASC, ADRO, SNR/NR.

Our results may be applicable to all CI users, regardless of the speech recognition scores. Nevertheless, based on results of the study from Nascimento and Bevilacqua [10], we predicted that patients with 60% of speech recognition in quiet situations might decline to around 30% at SNR + 10 dB. Thus, we preferred not to recruit patients with less than 60% to avoid the risk of 0% scores during the assessment.

Comparisons of new CI sound processors (SPs) with their old versions have been made in a number of previous studies [9, 11–13]. Such studies are important as a means of confirming that the technological development results in measurable clinical benefits. This information may be useful for reimbursement purposes as well as providing evidence to clinical professionals and stakeholders.

Conclusion

Cochlear implant users showed significant improvements in speech perception in noise from the use of noise reduction technologies implemented in the Nucleus 7® sound processor, even without going through home experience with the new technology.

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Author contributions MVSGG and BC conceived the research idea and design. MVSGG and BC performed interpretation and analysis. All authors participated in data collection, preparing and reviewing the manuscript content.

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Code availability Not applicable.

Compliance with ethical standards

Conflict of interest All authors have no conflict of interest to declare related to the scope of this manuscript, except BC who is a Research Manager for Cochlear Latin America.

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