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Objectives: Cochlear implants (CIs) usually provide severe to profoundly deaf recipients with speech intelligibility in quiet. In difficult listening situations such as background noise however, communication often remains challenging. For unilateral CI recipients with a bilateral hearing loss, speech intelligibility for speech sources on the non-implanted side is further impaired by the head-shadow effect. One possibility to overcome this impairment is the use of Contralateral Routing of Signal (CROS) systems, which capture sounds from the non-implanted side and (wirelessly) transmit them to the implant processor, therefore increasing audibility. Such a CROS system was evaluated in this study.

Methods: Speech intelligibility in noise was measured in several spatial listening setups using the Oldenburg matrix sentence test in ten cochlear implant users. Performance was compared between listening with the CI alone and listening with the CI in combination with a wireless CROS device. Following an extended trial phase, subjective feedback regarding the device benefit in everyday life was collected via the Bern Benefit in Single Sided Deafness (BBSS) questionnaire.

Results: The addition of the wireless CROS device significantly improved speech intelligibility by 7.2 dB (median) in spatial noise. Using advanced directional microphones, a statistically significant benefit of 4.4 dB (median) could be shown in a diffuse noise field. Responses to the BBSS questionnaire revealed that subjects perceived benefit in their everyday lives when using the CROS device with their CI.

Conclusion: The investigated CROS system presents a valuable addition to a unilateral CI in cases where bilateral implantation is not an option.

Keywords: Unilateral cochlear implant, Contralateral routing of signal, Speech intelligibility, Interfering noise

Introduction

In individuals with bilateral severe-to-profound hearing loss, a single cochlear implant usually provides substantial speech intelligibility benefits. In quiet listening situations, scores for the perception of sentences typically exhibit strong ceiling effects (Brendel *et al.*, 2008; Buechner *et al.*, 2010; Frijns *et al.*, 2003; Wilson and Dorman, 2008). However, in even moderately challenging listening situations, speech perception scores drop below the level required to support practical communication (Buechner *et al.*, 2006).

Bilateral cochlear implantation has been shown to provide several advantages when compared to unilateral implantation. These benefits include the ability to localize sounds and ensuring that the better ear is implanted. The primary benefit is providing improved speech intelligibility in noise, which has consistently been demonstrated (Litovsky *et al.*, 2009; Tyler *et al.*, 2007; van Hoesel and Tyler, 2003). The main contribution of bilateral CIs to improved speech intelligibility in noise has been shown to occur due to relief of the head shadow (Litovsky *et al.*, 2006; van Hoesel *et al.*, 2008), which refers to the difference in signal strength between the two ears for sound sources located towards one ear, caused by attenuation of the head. Bilateral implantation ensures access to the ear/signal with the better signal to noise ratio (SNR) in such asymmetric listening conditions. True binaural hearing advantages on the other hand have been shown to only play a secondary role. Bilateral cochlear implantation however, is expensive and only in a few countries is a second implant reimbursed by health insurances or national institutions, especially for adult recipients (Vickers *et al.*, 2016). Even in these countries, not all bilateral candidates will pursue a second device. Some

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individuals will be excluded due to medical indications and others may not elect to undergo a second surgery. These bilaterally deaf unilaterally implanted subjects will continue to experience limitations due to the head shadow, similar to single-sided deaf (SSD) individuals. This puts them at a significant disadvantage in situations where speech is presented away from the implanted ear (e.g. car, meetings, classrooms, social groups). In the treatment of individuals with SSD, one option is contralateral routing of signal (CROS) devices. In the case of bilateral deafness, such devices present a non-surgical intervention for the second ear and have been investigated in combination with a unilateral CI (Arora *et al.*, 2013; Dwyer *et al.*, 2018, Grewal *et al.*, 2015; Guevara *et al.*, 2015; Taal *et al.*, 2016; van Loon *et al.*, 2014; Weder *et al.*, 2015; Wimmer *et al.*, 2017; Mosnier *et al.*, submitted; Snapp *et al.*, 2018), however with inconsistent results. In quiet, some studies reported speech intelligibility not to be significantly changed by the addition of a CROS device (Grewal *et al.*, 2015; Taal *et al.*, 2016), while others reported significantly improved speech intelligibility (Arora *et al.*, 2013; Guevara *et al.*, 2015). In noise, speech intelligibility changes due to the additional CROS device depend strongly on the locations of the target speaker and interfering noise source. When target speech is presented from the non-implanted (CROS) side, significant improvements in speech intelligibility are reported by all studies, regardless of the tested noise environment. For speech presented from the front, some studies found no significant change in speech intelligibility (Taal *et al.*, 2016; Weder *et al.*, 2015), while van Loon *et al.* (2014) discovered a small but statistically significant deterioration, Snapp *et al.* (2018) showed a statistically significant improvement for speech and noise presented from the front () and Wimmer *et al.* (2017) showed improved speech intelligibility for a speech source located at 0° in diffuse noise using a directional microphone as the CROS device.

Some of the studies cited here did not employ actual CROS systems in combination with a CI but rather used a combination of commercially available CI accessory microphones to recreate a CROS system (Taal *et al.*, 2016; van Loon *et al.*, 2014; Wimmer *et al.*, 2017) or provided the input of a HA-based CROS system to CI users (Taal *et al.*, 2016). Due to the amount of cable connections necessary, these systems only had limited practical usability, and as a consequence these studies only included acute speech intelligibility tests and sometimes short (approx. 15 min) everyday listening experiences, but no chronic trials. Guevara *et al.* (2015) and Weder *et al.* (2015) used a CROS accessory designed for hearing aids (HAs) and a contralateral microphone designed for use with the Digisonic SP binaural implant (Neurelec, Vallauris, France) respectively. Both solutions allowed for longer chronic trials (several weeks), however the connection between the contralateral microphone and the speech processor was accomplished via a cable, impacting on wearing comfort. Snapp *et al.* (2018) investigated a wireless CROS prototype designed for use with a CI processor but did not include a chronic trial phase.

While all studies agree that a CROS device used in combination with a unilateral CI is not an alternative to bilateral implantation, several studies suggest that, in case the second implant is not available, a CROS device presents a useful addition to a unilateral CI. Based on the experiences using investigational devices, several improvements were suggested for a CROS device to be clinically beneficial: instead of wired solutions, such as tested by Guevara *et al.* (2015) and Weder *et al.* (2015), wireless transmission of the signal has been suggested to improve wearing comfort and aesthetic appeal. Most studies tested omnidirectional CROS microphones and additional signal processing features such as beamformers were proposed to add value (van Loon *et al.*, 2014; Weder *et al.*, 2015). Van Loon *et al.* (2014) also indicated the possibility to mute the CROS device in unfavourable listening conditions (i.e. noise on the CROS side) to be beneficial.

In this study, a wireless CROS solution, designed to work with the Naída CI Q70 and Q90 (Advanced Bionics LLC, Valencia, USA) processors was investigated. Speech intelligibility in noise was evaluated with and without the CROS device in test setups where a speech intelligibility benefit of the CROS device can be expected based on previous research. The potential benefit provided by a binaural beamformer made available by the CROS device was investigated. During a 4-week chronic take-home phase, feedback regarding the practical usability and perceived, subjective benefit in everyday listening environments was gathered.

Materials and methods

Subjects

Ten experienced cochlear implant (CI) users participated in the study. Three subjects were male, seven female. The mean age at testing was 63 ± 16 years. Nine subjects were implanted with a HiRes90k™, one subject with a HiRes™ Ultra implant (Advanced Bionics LLC, Valencia, USA). On average, the subjects had 4.5 ± 3 years of experience with their CI. All subjects clinically used a Naída CI Q70 or Q90 speech processor and had a severe-to-profound hearing loss in the contralateral ear. Clinical use of a contralateral hearing instrument (HI) was not an exclusion criterion if the subject derived no or only minimal benefit from that device. Four of ten subjects regularly used a HA contralaterally, one subject clinically used a Vibrant Soundbridge (VBS) and one subject clinically wore a CI. Contralateral devices were switched off during the study. Detailed subject information can be found in Table 1.

Devices

The Advanced Bionics Naída CI Q70 and Q90 sound processors have the ability to communicate wirelessly with another Naída CI processor and with several Phonak HI models, including the Phonak Naída™ Link CROS device (Phonak AG, Stäfa, Switzerland), based on established Phonak wireless CROS technology. It receives sounds at the non-implanted ear and transmits them wirelessly to the CI sound processor. In omnidirectional microphone mode, the omnidirectional CROS signal is mixed 50:50 with sounds picked up by the omnidirectional microphone of the sound processor. The CROS device used in combination with the Naída CI Q90 sound processor also enables the use of the binaural beamformer StereoZoom (Buechner *et al.* 2014, Omisore 2015). In StereoZoom mode, a time-domain beamformer (TDBF) signal is transmitted from the CROS device to the sound processor, where a directional microphone characteristic focusing to the front is calculated, based on the CROS TDBF signal and the signal of the sound processor's directional microphones. For the duration of the study, all subjects were provided a loaner Naída CI Q90 processor and a loaner prototype CROS device.

For the study, three programs were provided:

- CI only, omnidirectional microphone mode (CROS deactivated)
- CI + CROS (CROS activated), omnidirectional
- CI + CROS (CROS activated), StereoZoom mode

All programs were based on each subject's clinical everyday program. No changes were made beyond the activation of CROS and StereoZoom.

Test material and procedure

Speech tests were performed in an acoustically treated measurement room with low reverberation (T_{60} = 0.2 s). Speech reception thresholds (SRTs) were determined using the Oldenburg matrix sentence test (Wagener, Kühnel, and Kollmeier 1999) in stationary speech-shaped-noise (SSN). The noise level was fixed at 65 dB SPL and the speech level was varied adaptively to determine the signal-to-noise ratio (SNR) at which 50% of the speech material was intelligible. At the beginning of each appointment, at least one list of 20 sentences was measured with speech and noise presented from the front as training. For each test condition, two lists of 20 sentences were measured and the resulting SRTs averaged to yield one data point per subject and condition.

Subjective feedback regarding the practical usability of the CROS device and the perceived benefit in everyday listening environments was collected using questionnaires. The Bern Benefit in Single Sided deafness (BBSS, Kompis *et al.* 2011) questionnaire was collected from eight of the 10 subjects; the remaining two subjects failed to return the questionnaire Subjects were asked to rate whether ten different everyday listening situations were easier with or without the CROS device on a visual analog scale of −5–5 where −5 corresponds to 'Much easier without the aid' and 5 corresponds to 'Much easier with the aid'.

Test setups and measurement schedule

Speech intelligibility tests were performed in three spatial setups. Twelve loudspeakers (Genelec 8010AP; Genelec Oy, Iisalmi, Finland) were positioned at 30° intervals at a distance of 1 m from the subject in an acoustically treated measurement room with low reverberation (T_{60} = 0.2 s). Target speech was presented from one loudspeaker located either on the non-implanted (CROS) side of the subject or at the front, while noise was presented from one or more loudspeakers as indicated in Fig. 1.

Table 1 Detailed subject demographics.

Subject	Age	Gender	Etiology	Implant side	Duration of CI experience (years)	Regular HI use contralateral	Note
1	74	F	progressive HL	R	2.5	yes	HA contralateral*
2	77	F	recurrent otitis media	R	2	yes	VSB contralateral*
3	83	F	N/A	R	8.5	no	
4	66	F	progressive HL	R	8	no	
5	74	F	fluctuating, progressive HL	R	7	no	
6	53	F	progressive HL	R	4	yes	HA contralateral*
7	65	M	progressive HL	R	7	yes	HA contralateral*
8	38	F	congenital	R	3	yes	HA contralateral*
9	38	M	temporal bone fracture	R	0.5	no	
10	61	M	sudden hearing loss	L	2	yes	CI contralateral*

F = female, M = male, CI = Cochlear Implant, HL = hearing loss, HI = hearing instrument, HA = hearing aid, VSB = vibrant soundbridge, * = no or only minimal benefit obtained from HI.

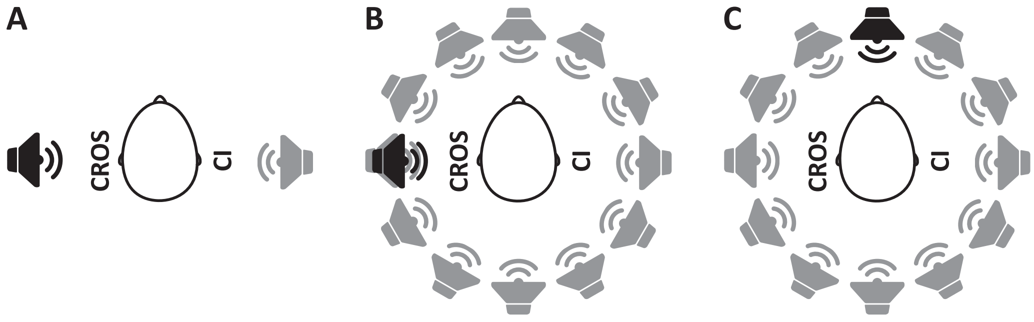


Figure 1 **Schematic representation of the speech in noise setups. A: $S_{CROS}N_{CI}$, B: $S_{CROS}N_{All}$, C: $S_{0°}N_{30°:330°}$. Speech source depicted in black, noise source(s) in grey.**

In all test setups, speech intelligibility was measured using the CI alone in omnidirectional mode and CI + CROS in omnidirectional mode. In the $S_{0°}N_{30°:330°}$ setup, measurements were additionally performed using CI + CROS in StereoZoom mode.

Speech intelligibility tests were performed at two test sessions, separated by a chronic trial. During the chronic trial, subjects used the CROS device in their everyday listening environments. Subjective feedback was collected at the end of the chronic trial.

All measurement procedures were approved by the Charité's ethics committee (Ethikausschuss 4 am Campus Charité Benjamin Franklin).

Statistical analysis

Statistical analyses were conducted using Statistica, version 12 (TIBCO Software Inc., Palo Alto, USA). Due to non-normally distributed data (Shapiro–Wilk test $p < 0.05$), Wilcoxon matched pairs tests were applied to determine significant differences between device configurations. When applicable, Bonferroni corrections for multiple comparisons were applied.

Results

Median results are reported for speech intelligibility and subjective feedback due to non-normal distribution of the data.

Speech intelligibility measurements

The SRT results for each test setup and each device condition are displayed in Fig. 2.

First, results for target speech located at the non-implanted (CROS) side are presented. For these two setups, $S_{CROS}N_{CI}$ and $S_{CROS}N_{All}$, measurements were conducted in omnidirectional microphone mode only. In the ideal $S_{CROS}N_{CI}$ condition, the median SRT score when listening with the CI alone was 3.9 dB, when listening with the CI in combination with the CROS device it was −2.4 dB. Performance between the two device configurations was found to be statistically significantly different ($Z = 2.80$, $p < 0.05$) with a median improvement of 7.2 dB. In the more realistic $S_{CROS}N_{All}$ setup, median SRTs with and without the CROS device were −3.5 and 0.8 dB, respectively. The performance difference was found

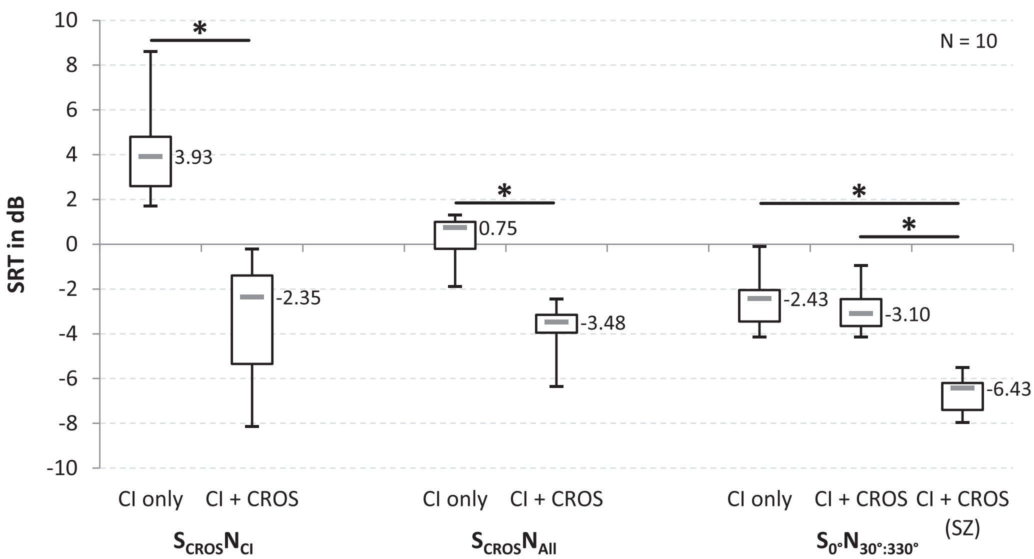


Figure 2 **SRT results from 10 subjects, displayed for each test setup and device condition. Median values are depicted by black lines with corresponding values annotated. Boxes represent lower and upper quartile, whiskers represent minimum and maximum SRTs. Bars and asterisks indicate statistically significant differences. Lower scores indicate better performance.**

to be statistically significant ($Z = 2.80$, $p < 0.05$) with a median improvement of 4.1 dB.

Next, results for target speech presented from the front are presented. Interfering noise was presented from all other loudspeakers ($S_{0°}N_{30°:330°}$). In this setup, the omnidirectional microphone mode as well as the directional StereoZoom mode were evaluated. In omnidirectional mode, the addition of the CROS device did not result in a statistically significant difference in performance compared to the CI alone (median SRTs of −2.4 dB and −3.1 dB, respectively, median improvement 0.5 dB). Using the CI and CROS devices in the directional StereoZoom mode however, yielded median improvements of 4.4 and 3.8 dB compared to listening with the CI alone in omnidirectional mode and the CI and CROS devices in omnidirectional mode. Significant differences in performance were found between the CI and CROS in StereoZoom mode and the CI alone in omnidirectional mode ($Z = 2.80$, $p < 0.05$) as well as the CI and CROS in omnidirectional mode ($Z = 2.80$, $p < 0.05$).

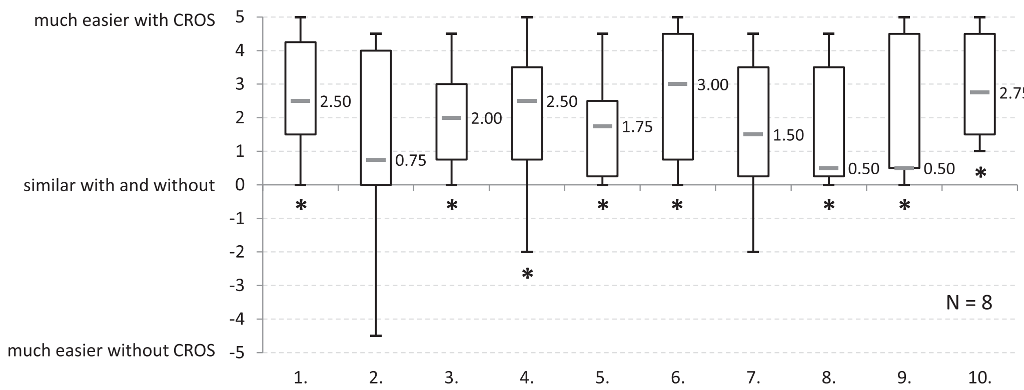
Subjective feedback

Subjects rated the perceived benefit of the additional CROS device using the BBSS questionnaire compared to listening with the CI alone. For each of 10 statements, the ratings of eight subjects were averaged and presented in Fig. 3. The perceived benefit varied considerably between subjects. Question 2 ('To understand a TV or radio speaker. For me this is:') shows a particularly large variation. Altogether however, the responses indicate a perceived benefit of using the CROS device compared to not using it: all median responses yield positive values, i.e. responses on the 'easier with the aid' side of the scale. For all questions except 2 ('To understand a TV or radio speaker. For me this is:') and 7 ('To understand speech in a reverberant room, such as a large entrance hall or a church. For me, this is:'), the responses were significantly different from 0 (see Table 2).

To compare responses between subjects with and without a clinical contralateral HI, each subject's responses to the 10 questions were averaged to yield one single score per subject. The median score of subject without a clinical contralateral HI was found to be 1.8 ($N = 3$, mean rating 2.6 ± 1.6) while the median score of subjects with a clinical contralateral HI was 1.1 ($N = 5$, mean rating 1.7 ± 1.4). Due to the low subject number in the respective groups, no statistical analysis was performed.

Discussion

The acute speech intelligibility measurements in background noise conducted within this study revealed significant speech intelligibility benefits when using the CROS device compared to listening with a unilateral CI alone. In the most favorable listening condition, when speech was presented to the non-implanted side and noise to the implanted side, the median difference between the CI only and CI + CROS conditions (i.e. the benefit provided by the CROS device) was 7.2 dB. The same spatial listening condition was also tested by Grewal *et al.* (2015) using a CI accessory microphone as CROS device in 10 unilateral CI users with a resulting average speech intelligibility benefit of 6.7 dB. Mosnier *et al.* (submitted) tested an identical CROS device in ten unilateral CI users and found median benefits of 7.5 dB to 9.1 dB at different test appointments in this listening condition while Snapp *et al.* (2018), using a similar prototype, found a median benefit of 9.75 dB. Theoretical



1. Hold a conversation with one person, quiet environment
2. Understand a TV or a radio speaker
3. Listen to music
4. Follow a conversation from some distance (> 5m)
5. Follow a conversation, background noise
6. Hold a conversation while driving in a car
7. Understand speech in a reverberant room
8. Participate in a group conversation, 3 or more participants
9. Localize a sound source
10. Overall hearing

Figure 3 Subjective responses to the BBSS questionnaire collected from 8 subjects. Median values are depicted by black lines with corresponding values annotated. Boxes represent lower and upper quartile, whiskers represent minimum and maximum responses. Asterisks indicate statistically significant differences.

Table 2 Wilcoxon signed rank statistics for BBSS questionnaire responses. Items not significantly different from 0 ('similar with and without CROS') are printed in italics.

	Z	*p*
Hold a conversation with one person, quiet environment.	2.37	<0.05
Understand a TV or a radio speaker.	*0.94*	*0.35*
Listen to music.	2.20	<0.05
Follow a conversation from some distance (>5 m).	2.03	<0.05
Follow a conversation, background noise.	2.20	<0.05
Hold a conversation while driving in a car.	2.37	<0.05
Understand speech in a reverberant room.	*1.86*	*0.06*
Participate in a group conversation, 3 or more participants.	2.20	<0.05
Localize a sound source.	2.37	<0.05
Overall hearing.	2.52	<0.05

model predictions (Taal *et al.* 2016) suggest a speech intelligibility benefit of 9.8 dB. The results obtained within this study are well in line with these previously reported CROS benefits.

In diffuse noise, median CROS benefits of 4.1 and 0.5 dB were found for speech presented from the CROS side and from the front respectively when using the CROS device in omnidirectional microphone mode. In comparison, Wimmer *et al.* (2017) showed a CROS benefit in diffuse noise of 1.7 dB for speech presented from the CROS side and 1.9 dB for speech presented from the front. In their study setup, a directional lapel microphone was used as the CROS device, likely resulting in the slightly lower CROS benefit for speech presented from the side and the slightly larger CROS benefit for speech presented from the front. When using the CROS device in the binaural beamformer mode (StereoZoom), our study results showed a median speech intelligibility benefit of 4.4 dB for speech presented from the front compared to using the CI alone, a benefit 2.5 dB larger than that reported by Wimmer *et al.* (2017) for their directional lapel microphone.

Unfavorable conditions where interfering noise is located on the CROS side were not included in this study as they have been studied previously. To present a balanced picture of CROS performance, this previous research should be considered. Weder at al. (2015) evaluated a S_0N_{CROS} spatial setup not included in this study and found a small performance decrement with the addition of CROS. In the $S_{CI}N_{CROS}$ setup, the mirror image of the $S_{CROS}N_{CI}$ setup included here, van Loon *et al.* (2014) found a performance decrement with CROS comparable in size to the performance benefit in the favorable $S_{CROS}N_{CI}$ setup. This symmetry is confirmed by intelligibility predictive modelling in Taal *et al.* (2016). In a diffuse noise field comparable to N_{all}, which more realistically represents real-world listening environments than two-source scenarios, the CROS benefit for speech on the CROS side (S_{CROS}) was found to outweigh the performance decrement for speech on the CI side (S_{CI}) by a factor of approximately 2.5 (Taal *et al.* 2016). In the CROS device investigated here, the mute button also offers a low-effort possibility to avoid speech intelligibility decrements in such unfavorable listening situations.

The study cohort tested here included many subjects that clinically used a HI in the contralateral ear. Four out of ten subjects regularly used a HA, one subject used a Vibrant Soundbridge and one subject was implanted bilaterally. While these subjects did not derive any speech intelligibility benefit from their contralateral HI, their clinical provision did provide stimulation of the contralateral ear. The clinical use of a contralateral HI is not expected to have influenced the speech test results as only within-subject comparisons were performed to contrast CI only and CI + CROS listening conditions. All subjects had a severe-to-profound hearing loss in the contralateral ear, clinically considered unaidable by hearing aids, therefore an effect of contralateral acoustic hearing on the speech in noise results is unlikely. In the subjective feedback questionnaire (BBSS), subjects were also asked to directly compare the CI only and CI + CROS listening conditions, however, we suggest that the subjects' usual experience may have influenced the responses nonetheless. During the chronic CROS trial, the contralateral side did not receive stimulation resulting in an unfamiliar and different hearing percept for subjects with a clinical contralateral HI, which may easily have been categorized as 'worse'. Indeed, a comparison of average BBSS scores across the two subject groups revealed slightly worse ratings by the subjects with a clinical contralateral HI. Additionally, the inhomogeneity of the subject group with respect to the clinical contralateral HI along with the small sample size are likely causes of the large variability seen in the BBSS responses. We therefore suggest that in a more homogenous study cohort of unilateral implantees without contralateral HI, who are consequently used to the contralateral side not receiving any stimulation, ratings may have been more homogenous and favorable. In line with this, Mosnier *et al.* (submitted) reported that out of their original study cohort, the only subjects to discontinue the study were clinically using contralateral HIs.

Localization abilities cannot be expected to improve with the addition of a CROS device. To localize a sound source, bilateral auditory input enabling at least some degree of binaural processing is required. Any CROS device however only provides unilateral or monaural input. While the current study did not include any localization testing, previous studies have investigated sound localization with a CROS device (Guevara *et al*. 2015; Weder *et al*. 2015; Wimmer *et al*. 2017, Snapp *et al*. 2018). Weder *et al*. (2015) showed that with a unilateral CI alone, subjects localized sounds mostly at 90° on the implanted side. With an additional CROS device, subjects tended to report central localizations (0°) more often than with the CI alone, but precise sound localization was not possible. Wimmer *et al*. (2017) showed no significant improvements in absolute localization error or the percentage of correctly identified directions through the addition of a CROS device. In contrast, Grewal *et al*. (2015) reported a significant improvement in the SSQ spatial subscale in their study cohort. The results of the BBSS questionnaire reported here also indicate a subjective benefit of the CROS device with respect to sound localization. We suggest however that this perceived improvement refers to better spatial awareness resulting from improved audibility of sound sources on the non-implanted side for detection used in combination with visual cues for source localization.

Robust sound localization is one the proven benefits of bilateral implantation (e.g. Brown and Balkany 2007). Additionally, bilateral implants ensure that the better ear is implanted and provide improved speech intelligibility in noise. Of these benefits, only improved speech intelligibility in noise can be achieved by the CROS device, though it can be argued that this is also the most noticeable and clinically relevant benefit. It has been shown that the main contribution of bilateral CIs to improved speech intelligibility in noise is providing relief of the head shadow (Litovsky, Parkinson, and Arcaroli 2009; van Hoesel *et al*. 2008). The CROS device has been designed to relieve the head shadow and in this study, median speech intelligibility benefits of 7.2 dB in single-source noise and 4.1 dB in diffuse noise could be shown for speech sources located on the non-implanted side. For comparison, Litovsky, Parkinson, and Arcaroli (2009) showed speech intelligibility benefits due to the relief of the head shadow effect of around 6 dB in bilateral CI users for target speech presented from the front.

With the CROS device investigated here, the binaural beamformer StereoZoom becomes available to unilateral CI users, who, with their CI alone, only have access to the monaural beamformer UltraZoom. While the monaural beamformer UltraZoom was not explicitly tested in this study, previous evaluations using Phonak CROS systems in HA users (BiCROS) showed a benefit of roughly 4 dB of StereoZoom compared to UltraZoom (Omisore 2015). In CI users presented with signals processed by bilateral Phonak HAs, StereoZoom was shown to provide a significant benefit of 1.9 dB over UltraZoom (Buechner *et al*. 2014).

Conclusion

Although bilateral cochlear implantation remains the gold standard in the treatment of bilateral severe-to-profound hearing loss, the wireless Phonak Naída™ Link CROS device is a non-invasive and relatively inexpensive alternative when bilateral implantation is not reimbursed, not medically indicated, or not desired by the individual. Access to sounds from the non-implanted (CROS) side improved speech understanding in challenging environments for unilateral listeners. The CROS device also enables beneficial bilateral features (e.g. StereoZoom) for understanding in complex noise environments and provided perceivable benefits in everyday life.

Disclaimer statement

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Conflicts of interest The first and last author have no conflict of Interest. The second author is an employee of Advanced Bionis GmbH. While conducting the study, the third author had no conflict of interest. She has since become an employee of Advanced Bionics GmbH.

Ethics approval Ethics approval was obtained from Ethikausschuss 4 am Campus Charité Benjamin Franklin.

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