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Cognitive performance of severely hearing-impaired older adults before and after cochlear implantation: Preliminary results of a prospective, longitudinal cohort study using the RBANS-H

Cognitive performance after cochlear implantation

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Abstract

Objective: To evaluate cognitive change in severely hearing-impaired older adults after cochlear implantation.

Study design: Prospective, longitudinal cohort study with assessments prior to, and at 6 and 12 months after implantation.

Patients: Twenty older adults (median age: 71.5 years).

Main outcome measures: Change in the *Repeatable Battery for the Assessment of Neuropsychological Status for Hearing-impaired individuals* (RBANS-H) total score and subdomain scores were used to assess cognitive evolution. In addition, change in best-aided speech audiometry in quiet (monosyllabic words) and in noise (Leuven Intelligibility Sentences Test (LIST)) was examined, as well as patient-reported measures of health-related quality of life (Nijmegen Cochlear Implant Questionnaire (NCIQ)), self-perceived hearing disability (Speech, Spatial and Qualities of hearing Scale – 12 (SSQ12)), sound quality (Hearing Implant Sound Quality Index – 19 (HISQUI19)) and states of anxiety and depression (Hospital Anxiety and Depression Scale (HADS)).

Results: The RBANS-H total scores improved significantly after 12 months CI usage ($p<0.001$). At subdomain level, significant improvements were observed in the *Immediate* and *Delayed memory* domain ($p=0.005$ and $p=0.002$, resp.), and to a lesser extent also in the *Attention* domain ($p=0.047$). Furthermore, speech perception in quiet and in noise improved significantly after 6 months and remained stable after 12 months. Similarly, a significant improvement was observed on all patient-reported measures after 6 months of CI usage. These results remained stable after 12 months, except for the HADS.

Conclusions: A significant improvement in overall cognition after 12 months of CI usage was established. However, future research is imperative to further disentangle possible practice effects from the effects of the cochlear implantation. The significant, positive effect of cochlear implantation on speech perception and patient-reported measures was confirmed.

Introduction

Several researchers found a persisting correlation between hearing and cognition in the aging population, with age-related hearing loss being linked to poorer cognitive functioning[1-6]. However, the nature of the association between hearing loss and cognitive decline is still ambiguous[7]. Several longitudinal studies indicated that hearing loss precedes the onset of cognitive impairments. Furthermore, hearing impairment was put forward as a possible modifiable risk factor for the development of dementia[8-12]. If hearing loss is indeed a risk factor for accelerated cognitive decline and dementia, improving hearing by means of auditory rehabilitation may potentially alleviate the accelerated cognitive decline observed in hearing-impaired older adults. However, studies investigating the impact of hearing aid use on cognition among older adults with moderate hearing loss yield mixed results, with some studies observing a positive effect of hearing aids on cognition[13-15] and others finding no effect[9,16].

According to Lin, et al. [11], the rate of cognitive decline is linearly associated with the severity of an individual's hearing loss, suggesting that someone with profound hearing loss tends to have a more accelerated cognitive decline than someone with a mild hearing loss. For individuals with profound hearing loss a cochlear implant (CI) is considered a safe and viable solution with good outcomes in terms of speech perception and quality of life, even in older adults[17-19]. Recently, Mosnier, et al. [20] investigated the effect of hearing rehabilitation through cochlear implantation on cognition in 94 older, profoundly hearing-impaired adults. The authors established that intervention by means of cochlear implantation was associated with improvements in preoperatively impaired cognitive capabilities after six and twelve months of cochlear implant use. Since then, five other research groups have investigated the cognitive outcomes after cochlear implantation in older adults, with the majority confirming the results of Mosnier, et al. [20] [21-24]. Only Sonnet, et al. [25] did not find any significant changes in cognition after one year of CI usage.

The present study aims to elaborate on earlier work by investigating the cognitive evolution up to one year after cochlear implantation among severely hearing-impaired older adults by means of a cognitive test battery specifically adjusted for the hearing-impaired. This cognitive test battery is the *Repeatable Battery for the Assessment of Neuropsychological Status for Hearing-impaired individuals* (RBANS-H)[26]. In addition, the change in speech perception in quiet and in noise, and in health-related quality of life, self-perceived hearing disability and sound quality, and anxiety and depression is examined after implantation.

Materials and methods

Study protocol

The present study reports on the preliminary results up to one year after implantation of a 10-year follow-up cohort study. The protocol of the study is described in detail in Claes, et al. [26] and only a short summary is given below.

Participants

Twenty consecutive, older participants (twelve males and eight females) with a postlingual bilateral severe hearing impairment were enrolled in the study and unilaterally implanted with a cochlear implant. Every participant met the Belgian criteria for reimbursement of the cochlear implant. The median age at implantation was 71.5 years (range: 54.8 to 84.8 years). The number of years of formal education ranged from seven to sixteen years (median: 10 years). Prior to implantation, six of the participants (30%) used bilateral hearing aids, nine unilateral (45%) (six right, three left) and five participants (25%) did not use hearing aids at all. More information on the demographics can be found in Table 1. The speech processor was activated approximately four weeks after implantation and the processor settings were optimized during regular programming sessions. In addition, a postactivation auditory rehabilitation program was offered to every CI recipient. This program consists of individual training sessions with a speech therapist one hour a week for at least three months. During these sessions, speech perception tasks are given in order to improve communication skills with the cochlear implant. Although this rehabilitation program is strongly recommended, three of the twenty participants (15%) did not enter the program.

Primary outcome measurement: RBANS-H

The primary outcome measurement is the change in cognitive performance across the three test moments; preoperatively and at six and twelve months after implantation. Cognition was assessed by means of the RBANS-H[26]. The RBANS-H is a modification of the RBANS[27], and was especially developed to examine cognition in individuals with a hearing impairment. This cognitive test battery consists of twelve subtests and assesses five cognitive domains, namely *Immediate memory*, *Visuospatial/constructional*, *Language*, *Attention*, and *Delayed memory* (Table 2). The subdomain scores and the total score are age-corrected standard scores, scaled to a normal distribution with a mean of 100 and a standard deviation of 15. In contrast to the original RBANS, the RBANS-H provides a PowerPoint presentation presenting the written instructions to the participant on an external screen, along with the standard oral instructions. In addition, simultaneous auditory and visual stimulation is provided in four of the twelve subtests, in which the items are presented solely orally in the original RBANS. These four subtests are *List learning*, *Story memory*, *Digit span* and *List recognition*. A detailed description of the modified RBANS-H can be found in Claes, et al. [26]. RBANS-H alternate forms A and B were used in the present study.

Secondary outcome measurements

Best-aided speech audiometry in quiet and in noise was performed at each of the three evaluations. The NVA-lists developed by the Nederlandse Vereniging voor Audiologie (NVA) (Dutch Society for Audiology) were used to assess speech perception in quiet[28] and the Leuven Intelligibility Sentences Test (LIST)[29] was performed to quantify speech perception in noise. The best-aided situation preoperatively was either unaided or with unilateral or bilateral hearing aid(s) and postoperatively either with unilateral CI or with unilateral CI and contralateral hearing aid. In addition, four questionnaires were administered at every assessment. (1) The Nijmegen Cochlear Implant Questionnaire (NCIQ) measures health-related quality of life in CI users[30]. In the present study, the NCIQ scores were calculated according to the corrected code book, published in the corrigendum[31]. (2) The Speech, Spatial and Qualities of hearing Scale – 12 (SSQ12)[32] assesses hearing disabilities. (3) The Hearing

Implant Sound Quality Index – 19 (HISQUI19)[33] quantifies the self-perceived level of auditory benefit experienced by hearing implant users in everyday listening situations. (4) The Hospital Anxiety and Depression Scale (HADS) evaluates states of anxiety and depression[34].

Ethics

This study was conducted in accordance with the recommendations of the ethics committee of the Antwerp University Hospital/University of Antwerp. The protocol was approved on June 15th, 2015 (protocol number: 15/17/181). All participants gave written informed consent in accordance with the Declaration of Helsinki prior to participation. The study is registered at Clinical Trials (ClinicalTrials.gov) on June 9th, 2016. The protocol identifier is NCT02794350.

Statistics

IBM SPSS Statistics version 24 (IBM Corp., New York, NY, USA) was used for the statistical analyses. Linear mixed models (LMM) were run across the three measurements for the RBANS-H total score and subdomain scores, NCIQ total score and subdomain scores, SSQ12 total score, HISQUI19 total score and HADS anxiety and depression scores. When a significant result was found using an alpha level of 0.05, pairwise comparisons were performed to investigate in which of the three pairs a significant difference was present (preoperatively <> 6 months postoperatively; 6 months postoperatively <> 12 months postoperatively; preoperatively <> 12 months postoperatively). Bonferroni correction was applied to correct for multiple testing within the pairwise comparisons (p-value multiplied by three). For the speech recognition scores in quiet (percentage correct) and the speech reception thresholds (SRTs) in noise, Friedman's tests and Wilcoxon pairwise comparisons with Bonferroni correction were used in order to account for the non-parametric distribution of these variables.

Results

Primary outcome measurement: RBANS-H

The mean RBANS-H total score was 89.6 (±15.2) prior to implantation and changed to 93 (±12.8) and 95.3 (±13.7) at respectively six and twelve months after implantation (Fig 1.). The change in RBANS-H total score across the three measurements was significant (LMM: p<0.001). Pairwise comparisons with Bonferroni correction indicated that only the change between the preoperative RBANS-H total score and the 12-months total scores was significant (p<0.001) (mean change: 5.7 (±7.8)).

Additionally, the change of the five subdomain scores was explored. *Immediate memory* improved significantly (LMM: p=0.005) from a mean score of 91.4 (±16.3), to 98.4 (±17.9) and 101.4 (±19.3) across the three test intervals. Only the change between the preoperative and the 12-months postoperative evaluation was significant (p=0.005) (mean change: 10.0 (±14.5)). The *Visuospatial/constructional* and *Language* subdomain scores remained stable across the measurements. The *Attention* subdomain scores changed significantly with mean scores improving from 82.1 (±21.0) to 83.9 (±15.2) and 88.1 (±13.8) (LMM: p=0.047). Again, only a significant improvement was observed between preoperative and 12-months postoperative scores (p=0.050) (mean change: 6.0 (±11.5)). Finally, the fifth domain, *Delayed memory*, also presented a significant improvement. The mean scores changed from 94.1 (±

13.2) preoperatively, to 97.6 (± 12.1) and 101.5 (± 14.2) at 6 and 12 months postoperatively (LMM: p=0.002). Pairwise comparisons with Bonferroni correction revealed only a significant change between the *Delayed memory* score prior to implantation and at 12 months after the implantation (p=0.002) (mean change: 7.4 (±9.1)).

In short, significant change was demonstrated after 12 months of CI usage for overall cognition, and for the *Immediate memory*, *Attention* and *Delayed memory* domains. When correction for multiple testing was applied across the LMMs of the five subdomain scores, the change in *Attention* did not remain significant.

Secondary outcome measurements

Audiometric assessment

Both at six and twelve months postimplantation, all twenty participants used the speech processor each day and all day long. Four of the nine participants (44%) who could continue to use the contralateral hearing aid, actually did (Table 1).

The median best-aided speech recognition score in quiet was 18% (range: 0% to 85%) prior to implantation and improved to respectively 79% (range: 39% to 94%) and 75% (range: 42% to 88%) at six and twelve months after implantation (Fig 2A). Friedman's test revealed that the speech scores in quiet significantly changed across the three time points ($\chi^2(2)=21.494$, $p<0.0001$). Wilcoxon post hoc comparisons with Bonferroni correction pointed out that speech recognition in quiet significantly improved at six months after the implantation (Z=-

3.865, $p<0.001$) and remained stable between six and twelve months postoperatively (Z=-1.350, $p=0.531$).

Preoperatively, seventeen of the twenty participants (85%) could not perceive the LIST sentences correctly at the highest, i.e. easiest, signal to noise ratio of +20 dB SNR (median SRT: +20.00 dB SNR; range: +5.00 to +20.00 dB SNR) (Fig 2B). In contrast, at six and twelve months after implantation all but one participants (95%) could finish the test at a speech-noise ratio lower than +20 dB SNR. The median SRT at 6 months postoperatively was +6.00 dB SNR (range: 0.00 to +20.00 dB SNR) and at 12 months postoperatively +4.33 dB SNR (range: 0.00 to +20.00 dB SNR). Overall, a significant change in SRT was found ($\chi^2(2)=30.658$, $p<0.0001$). More specifically, the SRT decreased, i.e. improved, significantly at six months (Z=-3.825, $p<0.001$) and remained stable at twelve months postoperatively (Z=-1.219, $p=0.669$).

NCIQ

NCIQ data were missing for two participants preimplantation and for one participant at twelve months postimplantation. Both the total score and the subdomain scores increased considerably after six months of cochlear implant use (Fig 3). For instance, the mean NCIQ total score was 31.8 (±11.4) at the first measurement and improved to 64.3 (±10.5) and 64.0 (±12.2) at the second and the third measurement respectively. LMM analysis indicated a significant change ($p<0.0001$). Post hoc comparisons with Bonferroni correction pointed out that the NCIQ total scores increased significantly between the preoperative and the 6-months postoperative measurement ($p<0.0001$) and remained stable afterwards ($p=1$). The exact same pattern of a significant improvement at six months after implantation and no additional improvement at twelve months after implantation was observed in all six subdomains.

SSQ12

The SSQ12 was not filled out by one participant prior to implantation. The preoperative scores marked a high degree of self-perceived hearing disability (mean: 1.4 (±1.0)) (Fig 4A). The mean SSQ12 increased to 4.4 (±1.8) after six months and 4.3 (±1.5) after twelve months of CI usage, indicating a moderate degree of hearing disability. This change was significant ($p<0.0001$). Pairwise comparison with Bonferroni correction pointed out that the SSQ12 scores improved significantly at six months postoperatively ($p<0.0001$) and stabilized afterwards ($p=1$).

HISQUI19

Fig 4B shows the results of the HISQUI19 questionnaire. Prior to implantation, two participants did not complete the HISQUI19 and both at six and twelve months after implantation, one participant did not complete the questionnaire. Preoperatively, the mean score was 30.9 (±9.0), classified as poor subjective sound quality. After six and twelve months of CI usage, the mean score increased to 69.3 (±18.9) and 67.1 (±14.6), which indicates moderate sound quality. Overall, the change in HISQUI19 scores was significant (LMM: $p<0.0001$). The improvement between the first and the second assessment was significant ($p<0.0001$), but no significant additional improvement was observed between the second and the third assessment ($p=1$).

HADS

The change in the HADS subscale scores, anxiety and depression, are presented in Figure 5. There was one missing value at the preoperative evaluation for the HADS. LMM revealed a significant change in anxiety scores across the three evaluations (p=0.003), reporting a mean score of 6.6 (±3.2) preoperatively, 4.3 (±2.0) at 6 months postoperatively and 5.7 (±2.2) at 12 months postoperatively. Anxiety scores decreased significantly between the first and the second measurement (p=0.002). Also the overall change in depression score was significant (LMM: p=0.003), with a significant decrease in depression scores at the 6 months postimplantation (p=0.002). The mean score at the first evaluation was 6.9 (±4.0), followed by 4.1 (±2.6) and 5.2 (±3.5). The results at 12 months did not differ significantly from the results at 6 months postoperatively for both subscales, but neither did these data differ significantly from the preoperative data. This suggests that the anxiety and depression signs decreased significantly after 6 months of CI use, but this initial improvement was only partly sustained after 12 months of CI usage.

Discussion

Primary outcome measurement: RBANS-H

A significant improvement in overall cognition was observed at twelve months after cochlear implantation, based on the results of twenty older severely hearing-impaired participants. More specifically, in three of the five RBANS-H domains a significant increase was established after one year of CI usage, namely in the *Immediate memory*, *Attention* and *Delayed memory* domain. The *Visuospatial/constructional* and *Language* domain remained stable across the three measurements. The *Immediate memory* domain taps into short-term memory of ten words and a short story. The *Attention* domain includes a digit span task, in which series of digits with increasing length need to be repeated in the same order, and a symbols-to-numbers substitution task. This domain measures working memory, processing speed and sustained attention. Delayed recall of the words, the story and the complex figure, and recognition memory are assessed in the *Delayed memory* domain. After correction for multiple testing, all the improvements remained significant, except the one in the *Attention* domain. Thus, the observed significant improvement in overall cognition could mainly be attributed to improvements in immediate and delayed memory, and to a lesser extent also to changes in working memory, processing speed and sustained attention.

In general, these findings are consistent with the results of previous research, indicating improvements in cognitive performance after cochlear implantation in older adults[20-24]. Improvements after cochlear implantation have been reported on measures of overall cognition, for example on the MoCA[22,24], the MMSE[20] and the CODEX[24]. Yet, Sonnet, et al. [25] did not establish significant changes in MMSE scores after 12 months of CI usage. With regard to memory measures, the results are more mixed with two studies finding improvements[20,21] and two finding no change[23,25]. It must be noted however, that comparisons between the present study and previous studies are difficult due to differences in cognitive tests, and, more strikingly, due to differences in statistical analyses. Indeed, two studies did not analyze the change in cognition statistically. Instead, they only described the changes qualitatively[21,24]. For instance, Cosetti, et al. [21] used the RBANS, which is very similar to the RBANS-H used in the present study, and reported *moderate* and *pronounced* -not *significant*- improvements on almost all subtests of *Immediate* and *Delayed memory*. This is in line with our results, but more detailed information is lacking as to whether these changes reflect a significant improvement in cognition generated by the cochlear implantation or merely reflect natural variation, learning effects and/or the influence of improved hearing on cognitive performance. Moreover, one study split the initial group of participants into a good performing and a poor performing group for each test separately, based on the preoperative results of that given cognitive test[20]. In the vast majority of the cognitive tests, significant improvements were demonstrated in the poor performers, but not in the good performers. In contrast, in the present study the group is analyzed as a whole, consisting both of preoperatively poor and good performers. Again, this difference makes comparison between studies more difficult.

The negative effect of hearing loss on the cognitive performance was kept to the minimum in the present study, by using a cognitive test battery that provides audiovisual presentation especially for the hearing-impaired. Indeed, if such an adaptation was not done, participants with a severe hearing impairment may underperform prior to implantation, due to the hearing impairment [35], and may improve their performance to their actual level after implantation, when the hearing capabilities are improved with the cochlear implant. Thanks to the RBANS-H, it is unlikely that the improvements in cognitive performance observed in the present study were due to improved hearing after implantation. Another possible confounding effect is a practice effect generated by multiple testing. By making use of RBANS-H alternate forms A and B the practice effect was minimized in the present study. Yet, the confounding effect of practice cannot be ruled out completely. Indeed, a control group which is assessed along the same time line as the interventional group is required to measure this effect, and to correct for it.

Nevertheless, the present study provides evidence of significant improvements in immediate and delayed memory after cochlear implantation in older adults, even after Bonferroni correction for multiple testing. Future research is necessary to disentangle the possible confounding effect of practice from the effects of the auditory rehabilitation. Moreover, even if the auditory rehabilitation is responsible for the improvements in cognition, it is not clear to what extent this effect is generated by the CI or by the additional care and auditory rehabilitation program. Although this program is exclusively geared towards improving auditory perception with the CI, it may indeed indirectly influence cognition as well. Alternatively, it may also be interesting to investigate the effect of specific cognitive training among poor performing CI recipients on their speech perception capabilities with the CI.

Secondary outcome measurements

Also for the secondary outcomes significant improvements were established. Speech perception, both in quiet and in noise, improved significantly after six months and remained stable after twelve months of CI usage. These speech perception results are in line with many previously reported studies establishing a benefit in terms of speech perception after cochlear implantation, in older adults as well[17-19,36-39]. Furthermore, health-related quality of life (NCIQ), self-perceived hearing disability (SSQ12), and subjective sound quality (HISQUI19), all showed a significant progress six months postoperatively and no further change at twelve months after the implantation. All these results are consistent with previous research[17,19,20,40,41]. For instance, Clark, et al. [17] systematically reviewed studies investigating CI outcomes in older adults. They concluded that cochlear implantation in older adults is safe, improves speech understanding and communication, and mental health within the first six months after implantation. In addition, the degree of anxiety and depression, as quantified by the HADS, decreased significantly at six months postoperatively in the current study. Yet, in contrast to the outcomes of the other questionnaires, these results did not remain significant after twelve months of CI usage, indicating that the initial positive effect at six months after implantation diminishes slightly, however not significantly, at twelve months after implantation. This corresponds to the clinical experience of audiologists in the hospital. During the first months after activation of the speech processor, CI recipients are in general very happy with their hearing abilities. Yet, later on, CI recipients may be more faced with the limitations of the implant, possibly resulting in slightly higher degrees of anxiety and depression at one year after implantation. These results express the need of prolonged counseling and assistance throughout the rehabilitation process.

Conclusion

The present study established a significant improvement in overall cognition after 12 months of CI usage among older CI recipients. This improvement was mainly attributable to significant improvements in the immediate and delayed memory domain, and to a lesser extent also to changes in working memory, processing speed and sustained attention. By using two alternate forms of the RBANS-H, an attempt was made to control for practice effects. However, future research is imperative to further disentangle possible practice effects from the effects of the cochlear implantation and the auditory rehabilitation. Finally, current data confirm the significant positive effect of cochlear implantation on speech intelligibility, quality of life, self-perceived hearing handicap and hearing quality, and states of anxiety and depression in the older population.

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Legends

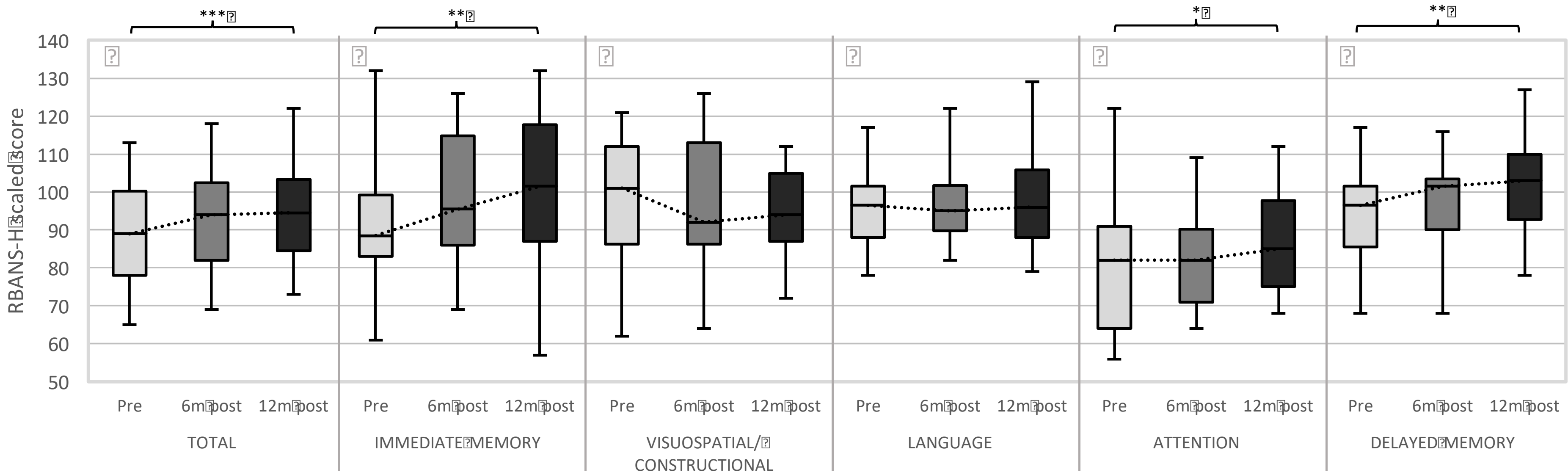

Fig 1. The RBANS-H total scores and subdomain scores. The boxplots represent the minimum, 1st quartile, median, 3rd quartile and maximum of the RBANS-H total scores and subdomain scores prior to implantation (pre) and at six and twelve months after implantation (resp. 6m post and 12m post) (n=20). The dotted line connects the median scores. Higher scores indicate better cognition. * indicates p<0.05, ** indicates p<0.01, *** indicates p<0.001 and **** indicates p<0.0001.

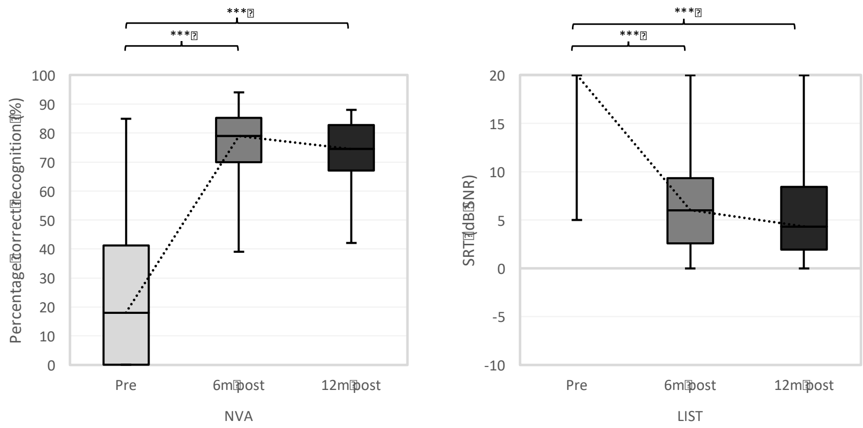

Fig 2. The results of speech audiometry in quiet (A) and speech audiometry in noise (B). The boxplots show the minimum, 1st quartile, median, 3rd quartile and maximum of (A) the speech recognition scores for the speech test in quiet using the NVA material and (B) the speech reception thresholds (SRT) for the adaptive speech test in noise using the LIST, preoperatively (pre), and 6 and 12 months postoperatively (resp. 6m post and 12m post) (n=20). The dotted line connects the median scores. (A) Higher scores indicate better speech recognition. (B) A lower SRT reflects better speech in noise perception. * indicates p<0.05, ** indicates p<0.01, *** indicates p<0.001 and **** indicates p<0.0001.

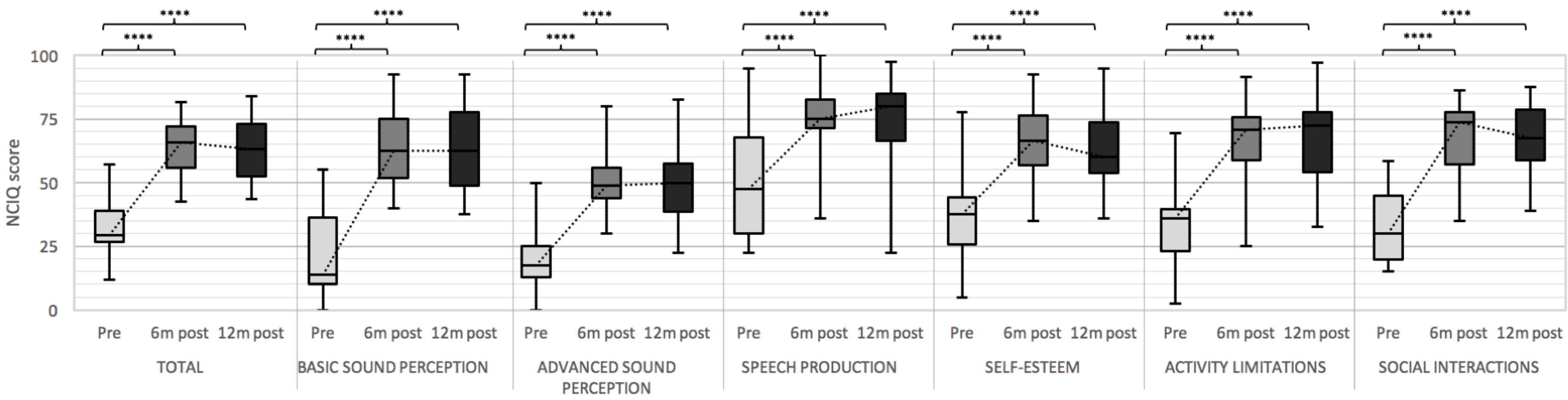

Fig 3. NCIQ results. The minimum, 1st quartile, median, 3rd quartile and maximum of the NCIQ total score and subdomain scores are presented as boxplots at the preoperative (pre), six months postoperative (6m post) and twelve months postoperative (12m post) measurement. The dotted line shows the median change. A higher NCIQ score reflects a better health-related quality of life. * indicates $p<0.05$, ** indicates $p<0.01$, *** indicates $p<0.001$ and **** indicates $p<0.0001$.

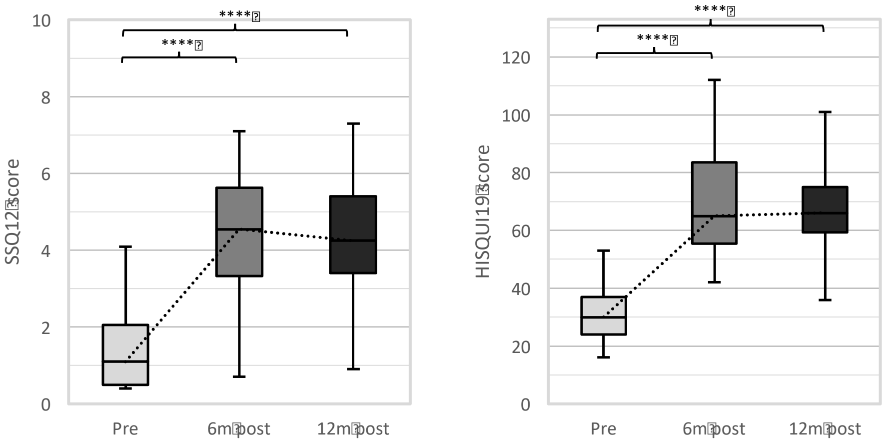

Fig 4. The SSQ12 (A) and HISQUI19 results (B). (A) The boxplots represent the minimum, 1st quartile, median, 3rd quartile and maximum of the SSQ12 scores at the preoperative (pre), six months postoperative (6m post) and twelve months postoperative (12m post) assessment. A lower SSQ12 score reflects a higher degree of hearing disability. (B) The boxplots represent the minimum, 1st quartile, median, 3rd quartile and maximum of HISQUI19 scores at the preoperative (pre), six months postoperative (6m post) and twelve months postoperative (12m post) assessment. Subjective sound quality is classified as very poor (< 30), poor (30 – 59), moderate (60 – 89), good (90 – 109) and very good (110 – 133). * indicates p<0.05, ** indicates p<0.01, *** indicates p<0.001 and **** indicates p<0.0001.

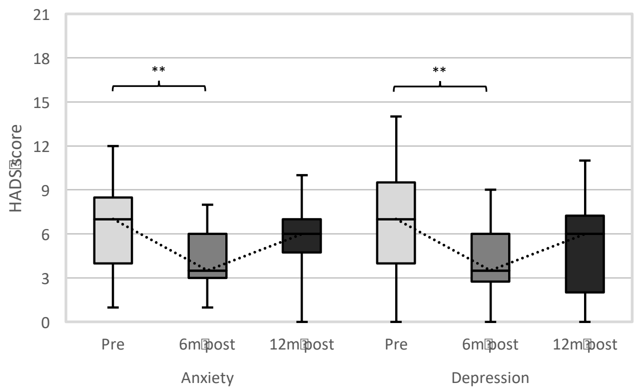

Fig 5. Change in the anxiety and depression subscales of the HADS. The boxplots represent the minimum, 1st quartile, median, 3rd quartile and maximum of the HADS scores at the preoperative (pre), six months postoperative (6m post) and twelve months postoperative (12m post) assessment. A higher HADS score reflects a higher degree of anxiety and depression. * indicates p<0.05, ** indicates p<0.01, *** indicates p<0.001 and **** indicates p<0.0001.

Table 1. Characteristics of the twenty participants. f: female, HA: hearing aid, m: male, N/A: not applicable.

	SEX	**DURATION OF HEARING LOSS** (YEAR)	**CAUSE OF HEARING LOSS**	**HA USE PREOP.**	**FORMAL EDUCATION** (YEAR)	**AGE AT IMPLANTATION** (YEAR)	**SIDE OF IMPLANTATION**	**COCHLEAR IMPLANT AND ELECTRODE**	**SPEECH PROCESSOR**	**CONTRALATERAL HA USE POSTOP.**	**REHABILITATION?**
1	m	15	Trauma	Bilateral	11	71.5	Left	Concerto flex28	SONNET	No	No
2	f	11	Unknown	Bilateral	16	71.4	Left	Concerto flex28	SONNET	Yes	Yes
3	f	47	DFNA9	Bilateral	8	76.0	Left	Concerto flex28	SONNET	Yes	Yes
4	f	20	DFNA9	No	13	70.7	Left	Concerto flex28	RONDO	N/A	No
5	m	30	Unknown	Right	9	84.8	Right	Synchrony flex28	SONNET	N/A	Yes
6	f	18	Unknown	Bilateral	11	72.1	Right	Synchrony flex28	SONNET	No	Yes
7	m	50	Unknown	Bilateral	8	77.0	Right	Synchrony flex28	SONNET	No	Yes
8	f	30	Trauma	Right	10	69.1	Right	Synchrony flex28	SONNET	N/A	Yes
9	m	38	Unknown	Bilateral	10	54.8	Right	Synchrony flex28	SONNET	No	No
10	m	40	Unknown	No	9	83.9	Left	Synchrony flex24	SONNET	N/A	Yes
11	m	45	Unknown	Left	12	76.7	Left	Synchrony flex28	SONNET	N/A	Yes
12	m	10	Unknown	Right	10	70.1	Left	Synchrony flex28	SONNET	Yes	Yes
13	f	55	Ototoxicity	Left	7	67.3	Right	Synchrony flex28	SONNET	Yes	Yes
14	f	35	Otosclerosis	No	9	65.8	Right	Synchrony flex28	SONNET	N/A	Yes
15	m	10	Unknown	No	14	57.1	Left	Synchrony flex28	SONNET EAS	N/A	Yes
16	m	16	Unknown	Right	10	77.8	Right	Synchrony flex28	SONNET	N/A	Yes
17	f	18	Unknown	Right	8	80.4	Left	Synchrony flex28	SONNET	No	Yes
18	m	45	Unknown	Right	10	63.9	Right	Synchrony flex28	SONNET	N/A	Yes
19	m	4	Unknown	Left	8	62.8	Left	Synchrony flex24	SONNET	N/A	Yes
20	m	0.3	Trauma	No	13	76.5	Right	Synchrony flex28	SONNET	N/A	Yes

Table 2. Description of RBANS-H domains and subtests.

Domain	Subtest	Description
Delayed memory	(1) List learning	A list of ten unrelated words is presented *audiovisually* to the participant and he or she is asked to recall as many words as possible after each of four learning trials.
	(2) Story memory	A short story of two sentences is presented *audiovisually* to the participant and he or she has to retell the story as accurately as possible after each of two learning trials.
Visuospatial/ constructional	(3) Figure copy	The participant has to copy a geometric figure, while this figure remains on display.
	(4) Line orientation	A semi-circular, fan-shaped pattern of thirteen lines is shown to the participant. The lines are identical, except for their orientation. Below this pattern are two lines that match the orientation of two of the lines from the pattern. The participant is instructed to identify those two matching lines.
Language	(5) Picture naming	Ten line drawings of objects are to be named by the participant.
	(6) Semantic fluency	The participant has to list as many exemplars as possible from a given semantic category, e.g. fruits and vegetables, within one minute.
Attention	(7) Digit span	The participant is instructed to repeat a string of digits, presented *audiovisually*, in the same order. The length of the strings increases by one on each trial, starting from two up to nine digits.
	(8) Coding	A form with symbols is given to the participant. He or she has to fill out the corresponding number below each symbol, using the key on top of the page. The time limit is 90 seconds.
Delayed memory	(9) List recall	The participant is asked to recall as many words as possible from the list of words learned earlier in the *List learning* subtest.
	(10) List recognition	Twenty words, of which ten are targets and ten are distractors, are presented *audiovisually* to the participant. The participant has to indicate whether each word was on the original list or not.
	(11) Story recall	The participant is asked to retell the story learned earlier from memory.
	(12) Figure recall	The geometric figure shown earlier in the *Figure copy* subtest has to be drawn from memory as accurately as possible.