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Cochlear implants and cognitive function in patients aged over 55

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1. INTRODUCTION

More than 5% of the world's population (466 million people) have disabling hearing loss, and it is estimated that by 2050 this will affect more than 900 million people (one in ten)[1]. Meanwhile, around 47 million people were believed to have dementia in 2015, with the number expected to triple by 2050[2]. On this basis, we face the challenge of not only living longer, but doing so without or with few disabilities.

It was in 1989 that it first became apparent that hearing loss in older adults was strongly and independently associated with the likelihood of developing dementia[3]. Recently, one of the key messages of the *Lancet* Commission's report on "dementia prevention, intervention, and care"[4], is the need to promote prevention. The authors estimated that up to 35% of dementia cases could be prevented by focusing on the nine modifiable risk factors: education, hypertension, obesity, smoking, depression, physical inactivity, diabetes, social isolation and hearing loss. Hearing loss may account for 9% of dementia cases occurring during middle age *(Fig. 1).*

The literature contains several works that attempt to find a link between hearing loss and cognitive status, most of them in elderly subjects, since both phenomena are highly prevalent in the older population[5-7]. Gallarcher et al.[8] established 55 years as the youngest mean age at which hearing loss was shown to increase the risk of dementia.

There are several hypotheses that attempt to explain the relationship between hearing loss and cognitive impairment: (1) cognitive load hypothesis; (2) common cause hypothesis; (3) cascade hypothesis; and (4) overdiagnosis or "presage hypothesis"[9]. Although presented as alternative hypotheses, they may not be mutually exclusive. Instead, several or all mechanisms are more than likely to work together[10] *(Fig. 2).*

As several authors have already published, hearing impairment causes limitations and can affect both cognitive abilities and quality of life and sound quality[11], thus increasing the vulnerability of people with hearing loss.[12]

It seems reasonable to assume that correcting hearing impairment, with hearing aids or cochlear implants, could serve to arrest cognitive impairment

In the light of these studies, it seems reasonable to assume that by correcting hearing impairment, with hearing aids or cochlear implants (CIs), cognitive impairment could be arrested. Regarding hearing aids, the literature shows conflicting results as to the positive effect of hearing aid use on cognitive impairment.[7, 13, 14] Similarly, studies analysing the effects of CI on cognitive outcomes are few in number and not very conclusive.[15-17] Different tests have been used to assess cognitive impairment. In 2016, Claes et al.[18] first used a version of the Repeatable Battery for Assessment of Neuropsychological Status[19], adapted for subjects with hearing impairment (RBANS-H). In RBANS-H, all spoken instructions are supported by written explanations via a PowerPoint presentation. Recently, Hillyer et al.[20] confirmed that cognitive evaluation in deaf patients could be improved by the application of visual presentation.

Based on these premises, the objective of our study is to determine changes in cognitive abilities, quality of life and sound quality perceived by patients over 55 years of age after cochlear implantation.

2. MATERIALS AND METHODS

Study Design

A prospective study was conducted in the ENT Services of Hospital Universitario La Paz and Hospital Universitario Ramón y Cajal, Madrid, Spain. The study procedures were previously approved by the ethics committee of both sites.

The recruitment criteria were: 1) post-lingual adults scheduled for a first CI over 55 years of age, 2) no known diagnosis of neurological disease or cognitive impairment, 3) fluency in Spanish, and 4) willingness to undergo an assessment of approximately one to one and a half hours.

All tests were performed before surgery, and one year after activation of the audio processor

The tests included a cognitive assessment, quality of life and sound quality tests, and an audiological assessment. All tests were performed before surgery, and one year after activation of the audio processor.

Procedures

- Cognitive assessment

Cognitive status was assessed using RBANS-H[18] (a modification of RBANS[19] that was developed to assess cognitive abilities in subjects with hearing loss, via a PowerPoint presentation with written instructions). It evaluates five cognitive domains or subgroups using 12 subcategories *(Fig. 3).* Research staff at both hospitals were trained to evaluate with RBANS-H (in Spanish), thus minimizing the bias of the person evaluating. The "gross" total test scores for each domain are required for conversion to an "index" score. These "index" scores are calculated using corrected tables with the following age categories: 50-59, 60-69, 70-79, 80-89 years. The total RBANS-H score is calculated as the sum of the 5 index scores. One of the main advantages of RBANS-H is that it provides a total score for cognitive status, which can be converted to an age-corrected standard score with a mean of 100 and a standard deviation of 15, which is called the "total scale" on the score conversion sheet; in addition, the percentile value is also shown (see [Claes et al., 2016]) *(Fig.3).*

- Audiological assessment

Audiological tests were performed in a double-walled soundproof booth. The two-channel Madsen Astera² audiometer was used for evaluation (Otometrics, Taastrup, Denmark). If a subject had better hearing in the non-implanted ear, the subject was masked during the test. All subjects underwent the following tests: before surgery, tonal and verbal audiometry was performed as part of the protocol for cochlear implantation[21]; after implantation, free field pure-tone audiometry with CI was performed at frequencies of 250, 500, 1,000, 2,000, 4,000, 6,000 and 8,000 Hz. For statistical calculation purposes, we considered the mean PTA thresholds at 500, 1,000, 2,000 and 4,000 Hz (PTA4)[22]. Speech perception was assessed using bisyllables[23] and free-field phrases[24] both in silence and with noise, with the results expressed as percentages. The subjects sat 1 metre from the speakers at 0º azimuth. The tests were performed without lip reading, at 65dB SPL and with a signal/noise ratio of 10dB SPL with s-noise below the signal.

- Subjective questionnaires

Subjective benefit after CI was assessed using the Spanish version of the following questionnaires: the Nijmegen Cochlear Implant Questionnaire (NCIQ); the Glasgow Benefit Inventory (GBI); the hearing implant sound quality index ($HISQUI_{19}$); and the language, spatial hearing and sound quality questionnaire (SSQ_{12}). These questionnaires were completed by all subjects twice: before surgery and one year after activation; except GBI which is only completed after implantation.

- NCIQ

The NCIQ is a questionnaire with closed answers, validated in Spanish in 2015 by the Hospital La Paz group with quantifiable scores[25]. It distinguishes 3 general domains: physical, psychological and social functioning. Each general domain consists of subdomains. The physical domain consists of basic sound perception, advanced sound perception and speech production; the social domain, social activity and functioning; and the psychological domain contains only one sub-domain: self-esteem. Each item is answered with a 5-point response scale indicating the degree to which the statement was true.

• GBI

The GBI is a quality of life questionnaire also validated by the La Paz group in 2015[26], developed to retrospectively assess the outcome of operations[27]. It consists of 18 questions (total score and 3 subscales) and generates a scale from -100 (maximum detriment) to 0 (no change) to +100 (maximum benefit). It evaluates an individual subject's perception of the overall success of CI use in social and physical functioning (overall benefit, overall health, social support, and physical health).

• $HISQUI_{19}$

$HISQUI_{19}$ is a questionnaire validated in 2016 by the La Paz group[28] that is used to determine the sound quality of an individual in daily life. It measures how good or bad a person finds sound quality with their best listening condition in everyday hearing situations. It consists of 19 items and each item is answered according to frequency on a 7-point scale, the end points of which are "always" (7 points) and "never" (1 point). Total scores are assigned a qualitative level of sound quality: a score of 19–29 indicates very poor sound quality; 30–59 poor sound quality; 60–89 moderate sound quality; 90–109 good sound quality and 110–133 very good sound quality.

• SSQ_{12}

The SSQ_{12} is a 12-item questionnaire that quantifies the severity of hearing impairment. Individual items are answered on a 10-point Likert scale: the higher the score, the less disability you experience. The SSQ total $score_{12}$ (maximum 10, minimum 0) is the average of the scores[29].

Data analysis

Demographic characteristics and outcome measures are shown as absolute frequencies (n) and, if applicable, as mean plus standard deviation (SD) and range. To compare the change in cognitive status and the evolution of audiological data and the results reported by the patient in the different subjective tests (RBANS-H, NICQ, GBI, $HISQUI_{19}$, SSQ_{12}) after implantation, the Wilcoxon test was used. The Mann-Whitney U-test and the T-test (the latter when data are normally distributed) were used to examine the difference between the RBANS-H subgroups. A correlation analysis using the Pearson coefficient was performed to assess the relationship between the RBANS-H scores with the different questionnaires (NICQ, GBI, $HISQUI_{19}$, SSQ_{12}) and audiological data (PTA4, and speech perception tests - bisyllables and sentences in silent and noisy conditions). Values not completed and response option "not applicable" were considered as "lost" values. A level of p≤0.05 (2 tails) was considered significant. Statistical analyses were performed using the SPSS v26.0 software package (IBM Corp., Armonik, NY, USA).

3. RESULTS

Participants

The demographic data of the sample are shown in *Table 1* of the Annex. 34 patients met the recruitment criteria. Adults with severe to profound hearing loss over 55 years of age with a mean age of 67.8 years (SD=7.4, range 56-82 years), of whom 15 were men and 19 were women. The mean duration of hearing loss was 20.4±15.0 years and the years spent in education were 9.7±6.3. The etiologies were diverse, with the most common being of unknown cause (38%).

Participants were adults with severe to profund hearing loss over 55 years of age with an average age of 67.8 years, 15 of whom were men and 19 women.

Cognitive status

Wilcoxon's statistical test revealed significant post-implantation improvements in the RBANS-H total score and in all domains except "visuospatial/constructional". *Fig. 4* of the Annex shows the mean and median RBANS-H total scores and domain scores before implantation and after twelve months with the CI. Higher scores indicate better cognitive status. Meanwhile, in three patients the difference between the values obtained in the final total score and the preoperative assessment was negative, which implies that the cognitive status of the patient worsened after one year with the implant. When this same analysis is performed in the different domains, the subgroup in which a greater number of patients had a negative score (impairment) was that of "visuospatial/constructional" with 32% of patients, followed by the subcategories of "immediate memory" and "delayed memory" and "language" (21% of patients in each), and 15% of patients experienced a deterioration in the "attention" domain.

Audiological testing

Twelve months after surgery, all subjects used the processor daily. *Table 2* of the Annex shows the mean pure-tone audiometry values only with the CI, as well as the percentages obtained in the intelligibility tests (bisyllables and sentences in silent and noisy conditions). The Wilcoxon test determined a significant difference (p=0.011) in the values obtained in the sentences test in silence (90.4±12.1%) compared to sentences with noise (79.1±2.0%). A significant change from the preoperative values evaluated in the ear to be implanted was also observed (PTA4: 107.0±18.9 vs 34.6±5.3dB; % bisyllables in silence: 16.5±23.9 vs 68.7±21.7%).

Subjective questionnaires

• NCIQ

Scores for all subdomains increased significantly after twelve months of CI use *(Fig. 5)*, the order in which the increase was greatest being: basic sound > speech > activity limitations > advanced sound > self-esteem > social interactions.

• GBI

The mean total score (+37.0) and mean overall subscale score (+48.0) were positive. The mean score of the social support subscale was also positive (+23.3), although 48.5% of subjects indicated "no change". The mean physical health subscale score was positive but low, at +6.6; 69.7% of subjects expressed no change (*Table 3* in the Annex).

• $HISQUI_{19}$

The mean score before surgery was 43.6±19.3, implying a "poor" level of sound quality. Twelve months after surgery this value changed statistically significantly to 73.4±2.0, "moderate" level of sound quality *(Fig. 6A)*; 1 subject (3.1%) rated the sound quality as "very good", 5 (15.1%) as "good", 19 (57.6%) responded "moderate", 8 (24.2%) responded "poor" and none responded "very poor".

• SSQ_{12}

The preoperative scores marked a high degree of subjectively perceived hearing impairment 1.23±1.19. After twelve months of CI use, the mean SSQ_{12} increased significantly to 3.7±2.0 *(Fig. 6B)*. When the difference between post-surgery and pre-surgery scores was calculated, 12.1% of patients had a negative value, involving a decrease in perceived hearing impairment.

Relationship of assessment of cognitive status to studied variables

- Age

We did not find a significant correlation between the age at implantation and the change in RBANS-H before and after surgery, either in the total score or in the different subcategories. In contrast, an inverse correlation was observed between age and values obtained in the domains "visuospatial/constructional", "language", "attention" and "delayed memory", both in preoperative and postoperative evaluation; as the patient's age increased, the scores were worse for each individual value.

The results indicate improvements in cognitive performance after cochlear implantation in adults

- Educational level

The more years of formal education, the better the total score of RBANS-H and for all subdomains (except "language"), both before and after implementation.

- Audiological results with CI

The percentages obtained in the sentence test with noise were positively and significantly related to the results obtained in the immediate and delayed memory domains before surgery, as well as to the language subcategory after implantation. Similarly, there is a positive correlation with bisyllables with noise and the difference in post- and preoperative results in the delayed memory subcategory.

- Subjective questionnaires

The highest number of positive significant correlations are with the advanced sound and self-esteem subcategories of the NCIQ and the different RBANS subgroups; a higher pre- and postoperative score in these subcategories implies a higher score for different cognitive test sublevels (*Table 4* of the Annex).

4. DISCUSSION

In this study we have shown a significant improvement in the general cognitive status of people over 55 with severe hearing impairment after twelve months of CI use. More specifically, we found a significant increase in scores across four of the five RBANS-H domains: "Immediate memory", "Language", "Attention" and "Delayed Memory".

The highest performance is identified in "Immediate Memory", "Delayed Memory", "Language" and "Attention"

Cognitive test used

Various tests for assessing cognitive status have been described, the most common being the *Montreal Cognitive Assessment (MoCA), the *Mini-Mental State Examination (MMSE), and the *Mini-Cog. In this study, we used RBANS-H to avoid potential bias in the assessment of cognitive status in people with deafness.[15] When administering a verbal memory test to a person with hearing loss, they may not correctly perceive the words to be memorized and, as a result may not perform as well as possible.[30] Also, even if one is able to perceive words, it may take more effort to do so correctly, decreasing the cognitive resources available to remember them later.[31] This may condition an underestimation of the cognitive abilities of a person with hearing loss. On the other hand, since CI improves hearing perception, the negative effect of hearing loss on cognitive assessment is likely to be greater before than after implantation[32, 33]. Therefore, if an inadequate assessment tool is chosen or not properly adapted, there may be an improvement in test scores after implantation due to better hearing, rather than better cognitive status. The RBANS-H thus includes an audiovisual presentation of both the instructions (written, presented in PowerPoint, in combination with the spoken instructions) and the test items to avoid this risk of bias.[18] Another recently adapted tool to assess cognition in adults with hearing impairment is the MoCA for the hearing impaired (HI-MoCA)[34]. It is a visual-only cognitive screening test, but it is less sensitive and can only differentiate between normal and abnormal cognitive function, unlike RBANS-H, which is able to quantify different levels of cognitive status.

Baseline cognitive status

At the start of the study, our patients had a mean total RBANS-H score of 77.5±14.5 (the highest score possible is 160). These values are in line with other studies on hearing loss and cognitive impairment. The study by Lin et al. showed that people with hearing loss had an accelerated rate of cognitive decline from 32% to 41%[35] In another study[36] using the same cognitive test as us, the mean total RBANS-H score before implantation was 89.6±15.2, higher even than our mean after twelve months with the CI (83.7±18.0). In the study by Claes et al.[37], when assessing results after one year with the CI, the mean was 88.1±14.9. To analyse why our patient sample obtained lower scores (both pre- and postoperative assessments), we need to look at the characteristics of the populations. Because the three studies ([36, 37] and ours) recruited implantation patients >55 years of age and the RBANS-H score includes an age correction, the age factor should not be the source of the difference. The study by Claes et al.[37] found, like us, a positive correlation between educational level and cognitive status (the more years of formal studies, the better cognitive outcomes). Our study population had a patient-reported median of 8 years of education, while for a study by Claes et al.[37] it was 11, and for a study by the same author[36] 10 years. We could therefore say that our patients have a worse cognitive state before being implanted than the rest of the studies carried out so far, and this fact could be attributed to the lower educational level of our study population. Another factor at play is the aspect already been indicated in the 2017 report[4], that education was one of nine modifiable risk factors involved in 35% of dementia cases.

Effect of cochlear implant on cognitive status

Caution is required when comparing our results with previous studies, as there are differences in the cognitive tests used: MoCA in Ambert et al.[38] and in Castiglione et al.[39], MMSE in Sarant et al. 17 and in Mosnier et al.[40]. Overall, our results are consistent with previous research, which suggests improvements in cognitive performance after cochlear implantation in older adults.[38-42] However, other authors[17, 43] found no significant changes in their studies. A study published in the journal *The Lancet*[4] stated that the mechanism underlying cognitive decline associated with peripheral hearing loss is not yet clear; nor is it established whether its correction, with hearing aids or CI, can prevent or delay the onset of dementia. Advanced age and microvascular disease increase the risk of dementia and peripheral hearing loss, and may therefore confound the association.

Compared to people with normal hearing, adults with mild to severe hearing loss are two to five times more at risk of developing dementia

As stated at the outset of the discussion, the general cognition status of our patients significantly improves after one year of implantation (from 77.5±14.5 to 83.7±18.0; difference: 6.2). Claes et al.[36] also demonstrated an increase in total RBANS-H score (difference of 5.7). This significant improvement could be primarily attributed to improvements in "immediate and delayed memory" as well as "language" and "attention". Patients who had slightly worsened cognitive status after one year of implantation (9%) were those whose cognitive level was very low (percentile <0.01) before surgery and who also had a lower educational level.

Do they achieve the same results as a normal patient?

Compared with people with normal hearing, adults with mild to severe hearing loss have a two- to five-fold increased risk of developing dementia.[44] Claes et al.[37] simultaneously performed the cognitive test in patients with normal hearing, obtaining a mean total RBANS-H score of 100.5±13.2, which was higher than that obtained in our implanted patients. This could be explained by the fact that a CI does not completely restore hearing. In addition, our sample has 44% of patients with bilateral severe hearing impairment who only receive hearing information through their unilateral CI, since they do not currently use a contralateral hearing aid. This makes perception of binaural signals extremely difficult or impossible, leading, for example, to poor location in the horizontal plane.[45]

Changes in objective and quality of life variables

Significant improvements were also found in audiological testing and quality of life questionnaires. Speech perception improved significantly a year after implantation, as demonstrated in previous studies also in older patients.[46, 47] In addition, the related quality of life (NCIQ and GBI), the patient's perceived hearing impairment (SSQ_{12}) and subjective sound quality ($HISQUI_{19}$) showed a significant change twelve months after implantation, all these results also being consistent with previous research[32, 46-48].

- Age

Patients do not necessarily experience greater cognitive impairment simply because they are older (assessed by the difference between the postoperative values minus the preoperative values of RBANS-H), since RBANS-H incorporates a correction by age range. However, in our patients we found that as the patient's age increased, scores worsened in all domains except "immediate memory", where we assumed that the difficulty of the tasks posed was less influenced by this variable.

- Educational level

We previously mentioned that one of the factors associated with the best score in RBANS-H is years of formal education.[18, 37] We found this in our sample of patients: less educated subjects scored lower. This effect was also described by Franco-Marina et al.[49], who stated that using the MMSE as a cognitive test can create a "ceiling" effect when used for people with low education and a "floor" effect for those with higher education.

- Audiological results

The correlation between intelligibility with CI and cognitive status was also examined. Speech perception in noisy conditions was found to be correlated with improved cognitive function. This can be explained by the model of the ease of understanding language[50], since understanding speech against noise is considered more cognitively demanding. The result of this correlation is also in line with that stated by Zhan et al.[51] who support the proposal that cognitive factors, in addition to technological and physiological factors, contribute to CI performance. It is therefore suggested that it might be of interest to investigate the effect of specific cognitive training on intelligibility among low-performing CI users.[36]

Significant improvements were also found in audiological testing and quality of life questionnaires. Speech perception improved significantly a year after implantation, as demonstrated in previous studies also in older patients.

- Subjective results

The positive correlation observed between the cognitive state and the advanced sound subcategory of the NCIQ questionnaire could be explained by the items that this domain assesses: control of volume and tone of voice, speaking on the phone... These are adverse tasks for an implanted patient[11], who, if successful, could be better able to carry out other also complicated matters such as those raised by RBANS-H.

Implanted patients who increase their self-esteem[52], assessed using the NCIQ test, have also been shown to have better cognitive outcomes. With an approach similar to that expressed in the previous paragraph, those patients who after implantation had greater confidence in themselves, are better able to undertake any task they are set.

Skidmore et al.[53] assrted that including cognitive measures as predictors could help explain variability in outcomes, especially for quality of life domains.

Limitations of the study

Claes et al.[36] proposed that further studies would be needed to find out whether the improvement in cognitive status is actually due to the auditory rehabilitation effect of the CI or to practice at the exercise. In other words, whether the patient scores better in the different tests the second time because they have the experience of having performed them before (although the improvement observed in the "attention" subgroup due to the type of exercise employed - see *Fig.3 in the Annex* - is difficult to explain by the "practice effect" if not through a positive change in cognition). One way to address this limitation would be to use two versions of RBANS-H, although Claes et al.[15] stated that this would not be sufficient to eliminate this practice effect. It is therefore important to establish a design that includes a control group: patients without hearing impairment or patients with hearing impairment for whom CI is not indicated (they do not meet the clinical criteria for implantation, health problems that prevent surgery, or no motivation for CI).

In addition to the practice effect bias, the review by Claes et al.[15] stresses the importance of tailored cognitive testing for older adults with deafness, thereby avoiding the underestimation of results. In our study, participants were not formally evaluated for reading ability, although prior to the test they were asked whether they could easily read the RBANS-H instructions on their computer screen (in case of suspected illiteracy or visual impairment, they were excluded from the study).

Meanwhile, the impact of other known risk factors for cognitive decline and dementia (diabetes, smoking, hypertension, etc.) should be considered in future research.[4]

5. CONCLUSIONS

Use of CI improves cognitive functioning after one year of use in patients over 55 years of age. The data also confirm the positive effect of cochlear implantation on intelligibility, quality of life, self-perceived hearing impairment and sound quality in the elderly population.

Increased patient follow-up may reveal the effects of CI on all evaluated variables, particularly if it could delay cognitive decline.

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Cochlear implants and cognitive function in those aged over 55

Annex

Figure 1. Model of potentially modifiable and non-modifiable risk factors for dementia during a person's lifespan.

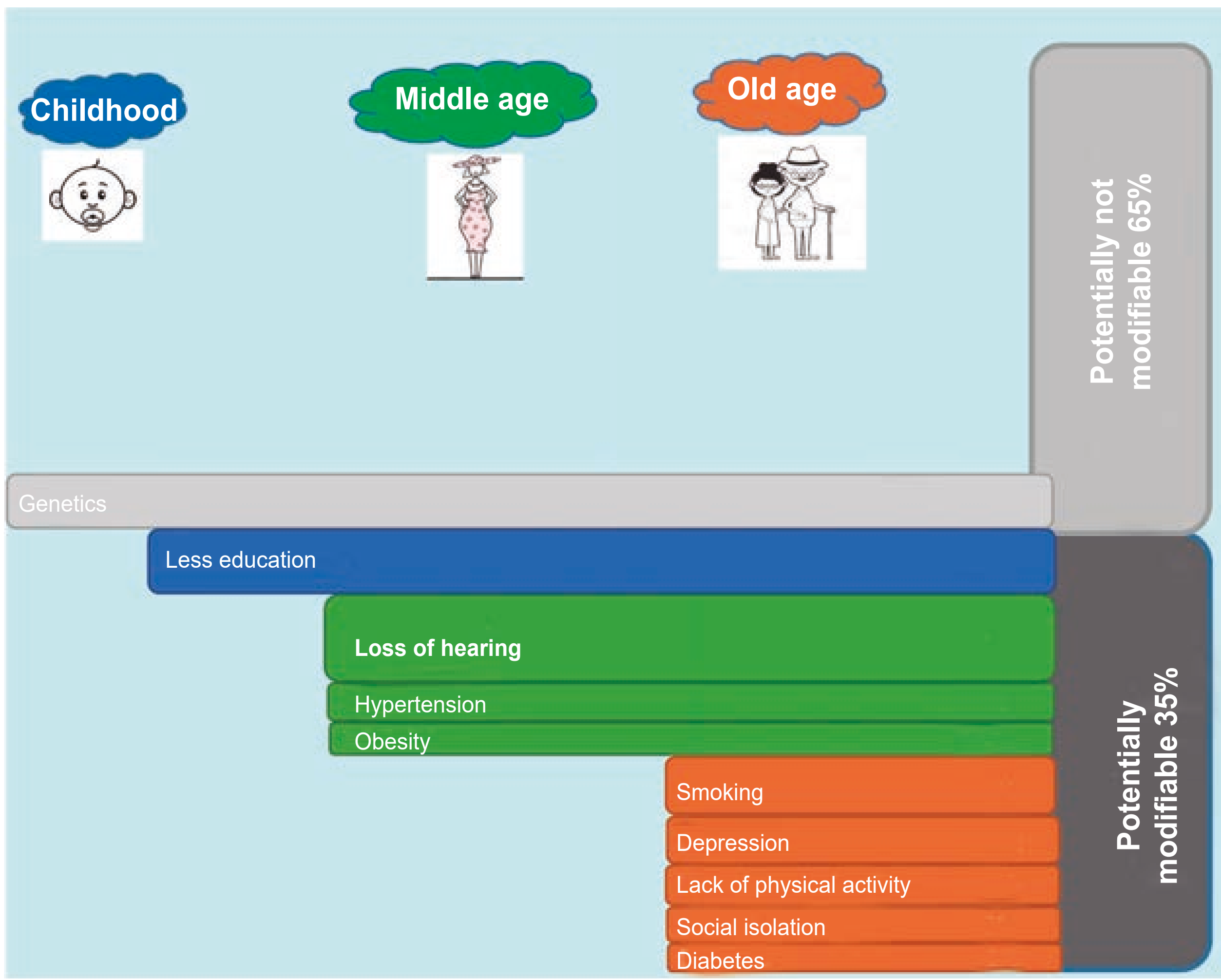
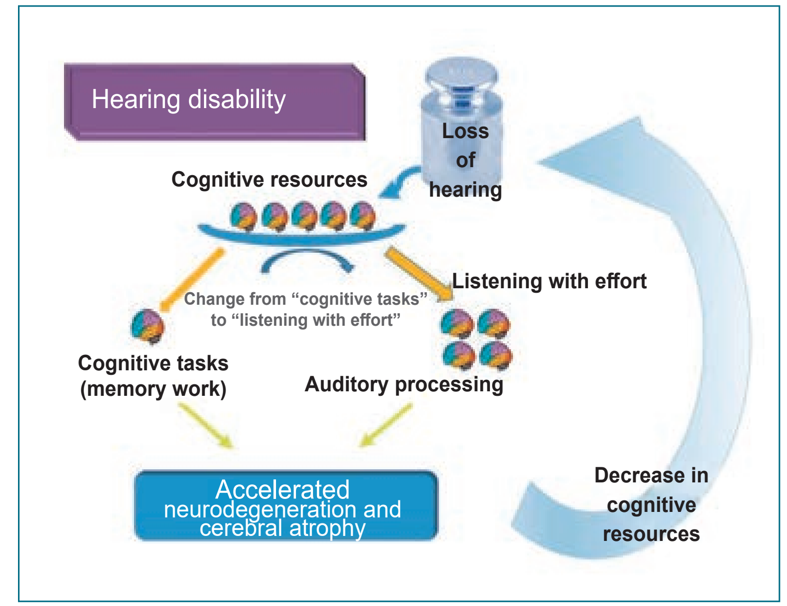
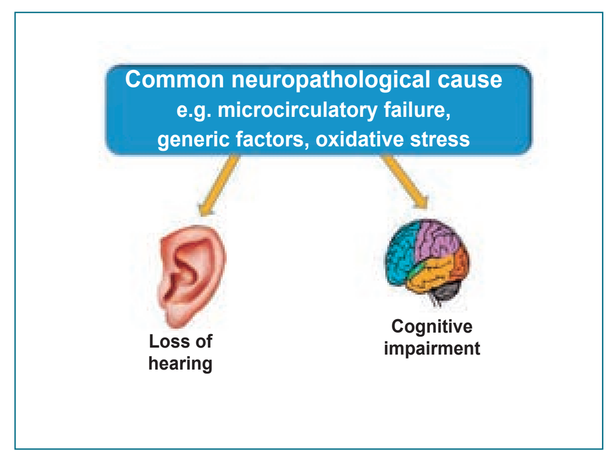


Figure 2. Hypotheses that attempt to explain hearing loss and its relationship to cognitive impairment.

1) Cognitive load hypothesis: hearing loss may increase auditory effort during speech perception. Hearing loss would increase the cognitive load of a vulnerable brain and cause changes in the brain[1] and accelerated atrophy[2], potentially contributing to accelerated cognitive decline.





2) Common cause hypothesis: both hearing loss and cognitive impairment are the result of a common neurodegenerative process in the brain as it ages[2, 3]

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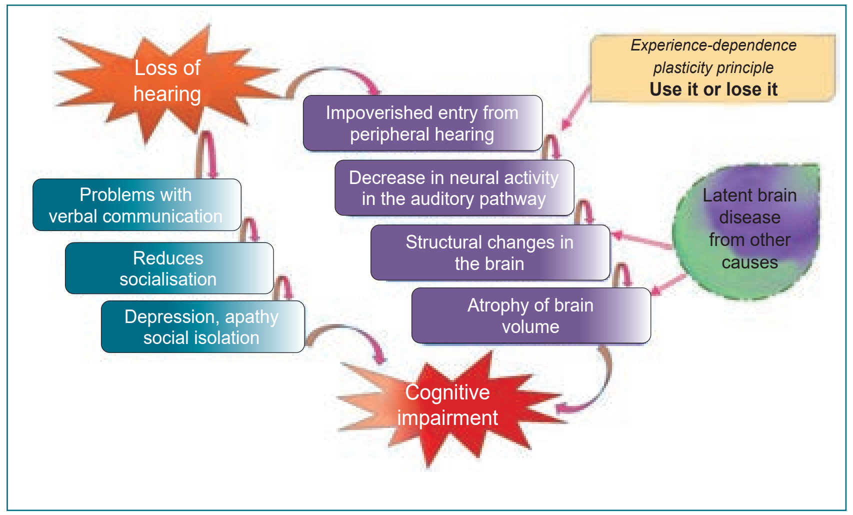
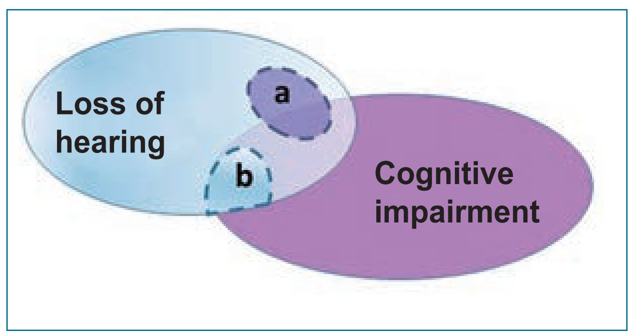
Figure 2. Hypotheses that attempt to explain hearing loss and its relationship to cognitive impairment.

3) Cascade hypothesis: altered peripheral hearing affects the structure of the brain directly through impoverished sensory input. If listening and processing skills are not used, those skills could be lost. Impairments related to hearing loss (social isolation, depression[4], loneliness[5], apathy[6]) can cascade directly or indirectly, leading to cognitive decline.





4) Overdiagnosis or "presage hypothesis": Area a: overdiagnosis or even erroneous diagnosis of cognitive impairment due to the detection of hearing impairment in certain neuropsychological tests[7]. Area b: But it may be that early cognitive decline is potentially hidden behind symptoms treated as hearing loss.[8]

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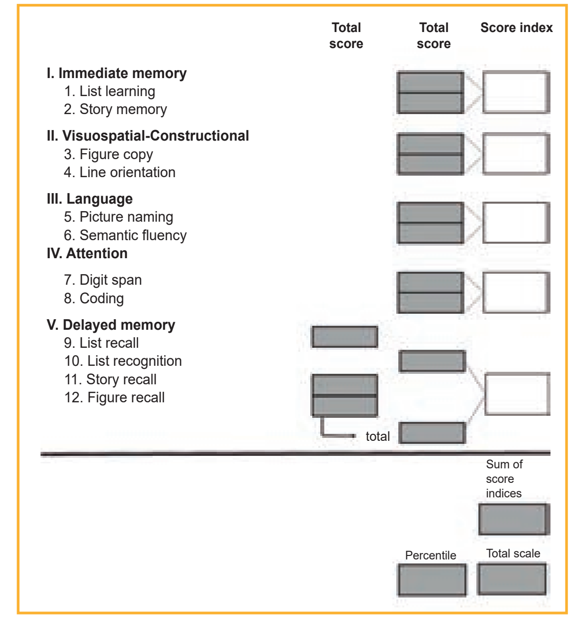
Figure 3. Score conversion sheet with the five domains (I-V) and the twelve subtests (1-12) and description of the different RBANS-H domains.

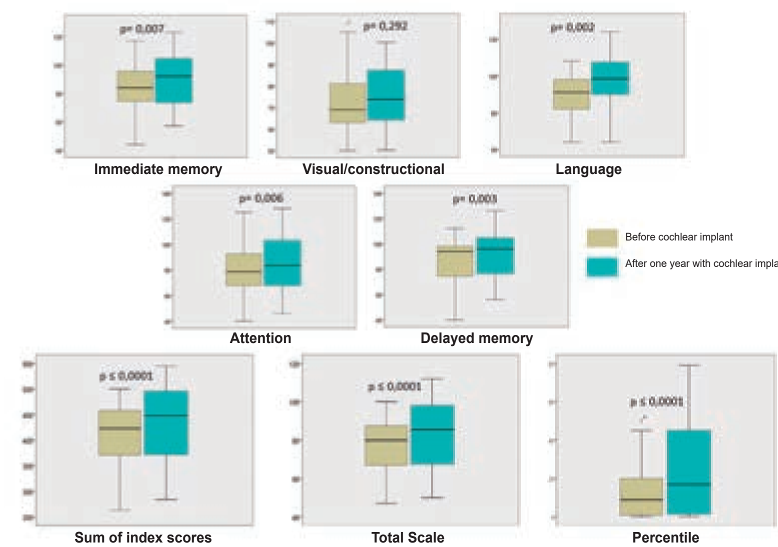


Domains	Subtests	Description
Immediate memory	(1) List learning	A list of 10 unrelated words is presented to the participant audibly, and they are asked to recall as many words as possible after each of the four learning attempts.
	(2) Story memory	A short two-sentence story is presented audibly to the participant who then has to be as accurate as possible again after each of the two learning tests.
Visuospatial/Constructional	(3) Figure copy	The participant must copy a geometric figure, while this figure remains displayed on the computer.
	(4) Line orientation	The participant is shown a semicircular pattern in the form of a fan of 13 lines. The lines are identical except for their orientation. Below this pattern are two lines that match the orientation of two of the pattern lines. The participant is told to identify those two matching lines.
Language	(5) Picture naming	The participant will name ten drawings of objects presented in sequence on the computer.
	(6) Semantic fluency	The participant should list as many examples as possible of a given semantic group. For example, fruits and vegetables, in 1 minute.
Attention	(7) Digit span	The participant is instructed to repeat a series of digits, presented audibly, in the same order. The length of the number of digits to be memorized increases by one in each test, starting from two to nine digits.
	(8) Coding	A form with symbols is given to the participant. This should fill in the number below each symbol, using the "key" at the 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 previously learned in the list learning subtest (1).
	(10) List recognition	Twenty words are presented to the participant audiovisually, of which 10 were on the list at the beginning (1). They must indicate whether each word was in the original list or not.
	(11) Story recall	The participant is asked to retell the previously learned story (2).
	(12) Figure recall	The geometric figure shown above in the figure copy subtest (3) must be repeated from memory as accurately as possible.

Table 1. Demographics of patients evaluated in the study. *if no response is detected when the pure-tone audiometry is performed, the numerical value of 140dB is used.

n		34
Age (years) (mean±SD) (range)		67.8 ± 7.4(56-82)
Sex (n)	Male	15
	Female	19
Formal education (years) (mean±SD) (range)		9.7 ± 6.3(0-20)
Aetiology (n)	Unknown	13
	Infection	2
	Ototoxicity	2
	Otosclerosis	8
	Trauma	2
	Menière	2
	Meningitis	3
	Cholesteatoma	2
PTA4 ear to be implanted (dB)*		107.0 ± 18.9(70-140)
% Maximum bisyllables in silence in ear to be implanted		16.5 ± 23.9(0-80)
Duration of hearing loss (years) (mean±SD) (range)		20.4 ± 15.0(0-57)

Figure 4. RBANS-H total scores and those of the different subdomains. The box diagrams represent the minimum, first quartile, median, third quartile and maximum of total RBANS-H scores and subdomain scores before implantation and twelve months after implantation (n = 34).
(Note that the scales are different on each chart.)



	Median	Mean	Standard deviation	Mini-mum	Maxi-mum
PRE Immediate memory	85.0	83.3	15.7	44.0	117.0
POST Immediate memory	92.0	89.6	19.7	57.0	123.0
PRE Visuospacial/Constructional	69.0	72.9	15.0	50.0	109.0
POST Visuospacial/Constructional	73.5	75.0	14.1	50.0	100.0
PRE Language	90.0	89.2	10.1	64.0	108.0
POST Language	98.5	96.4	14.1	64.0	124.0
PRE Attention	82.0	79.8	21.3	40.0	125.0
POST Attention	83.5	84.6	22.9	46.0	128.0
PRE Delayed memory	94.0	86.7	17.4	40.0	112.0
POST Delayed memory	96.0	91.8	18.4	56.0	126.0
Sum of PRE score index	428.0	411.9	62.4	263.0	500.0
Sum of POST score index	448.0	437.4	3.6	284.0	545.0
Total PRE Scale	81.0	77.5	14.5	47.0	100.0
Total POST Scale	85.5	83.7	18.0	50.1	112.0
PRE Percentile	10.0	13.5	14.2	,1	50.0
POST percentile	17.0	25.7	24.1	,1	79.0

Table 2. Mean, minimum and maximum values together with the standard deviation in the different audiological assessments after twelve months with CI.

Free-field results	PTA4	(%) Bisyllables in silence	(%) Bisyllables in noise	(%) Sentences in silence	(%) Sentences in noise
n	30	29	16	29	16
Mean	34.6	68.7	48.9	90.4	79.1
Standard deviation	5.3	21.7	22.7	12.1	22.0
Minimum	27.5	17.0	12.0	58.0	12.0
Maximum	43.8	100.0	92.0	100.0	100.0

Figure 5. Bar diagram showing the means and standard deviations of each of the subcategories of the NCIQ questionnaire. * indicates p ≤ 0.05.

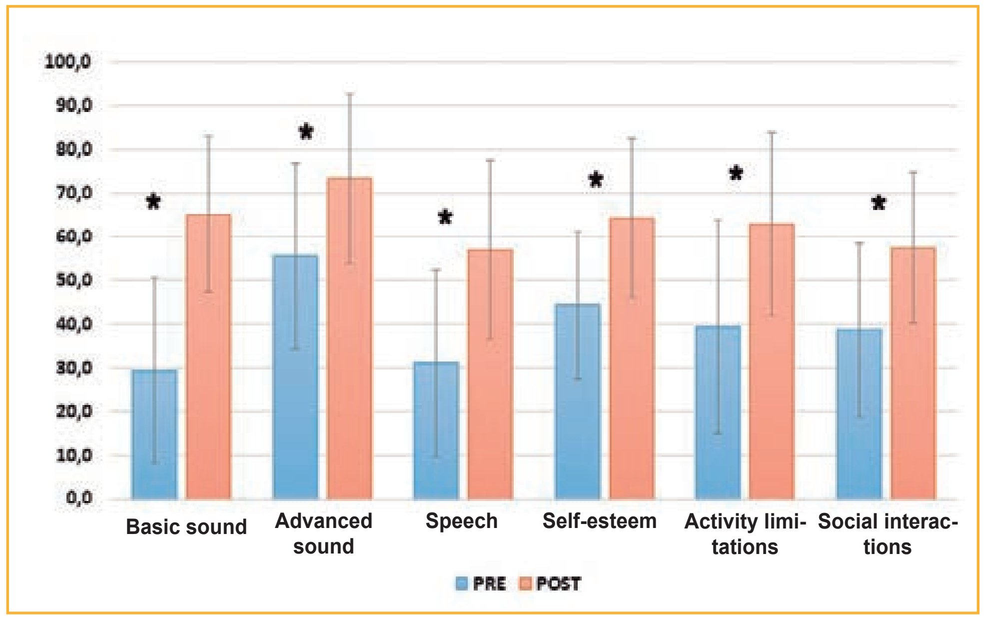


Table 3. GBI scores: total and subscales. + is positive change, - is negative change, NC is no change.

GBI score	Mean (±SD)	N			Range
		+	-	NC	
Total	+ 37.0(± 22.0)	31	2	0	-19 - +81
Overall subscale	+ 48.0(± 30.9)	31	2	0	-38 - +100
Social subscale	+ 23.2(± 28.2)	17	0	16	-0 - +100
Physical subscale	+ 6.6(± 23.2)	7	3	23	-33 - +88

Figure 6. HISQUI$_{19}$ (A) and SSQ$_{12}$ (B) total scores. Box diagrams represent the minimum, first quartile, median, third quartile and maximum of RBANS-H total scores and subdomain scores before implantation and twelve months after implantation; * means p ≤ 0.05, a significant improvement after one year with the cochlear implant.

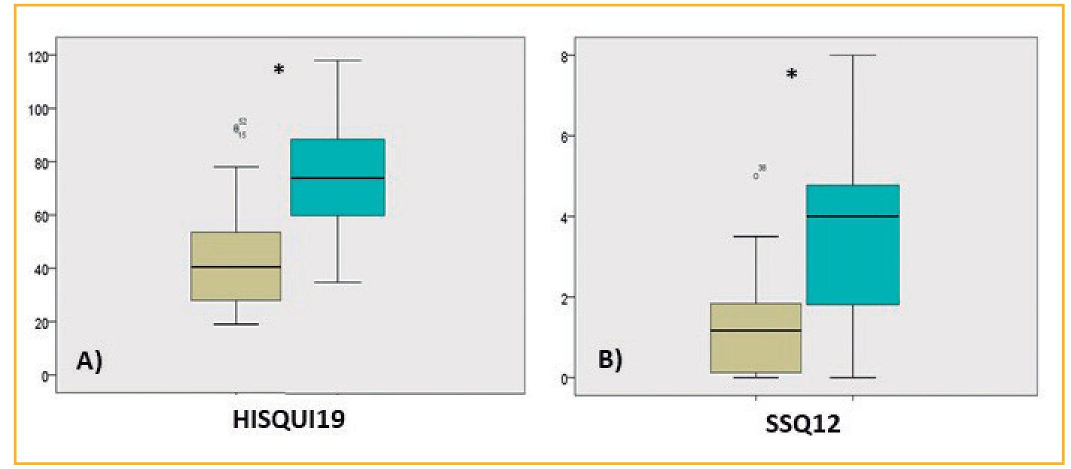


Table 4. Correlations between the cognitive test subcategories and the different subjective questionnaires. X means statistically significant positive correlation, p≤0.05.

		NCIQ												GBI				HISQUI$_{19}$		SSQ$_{12}$	
		Basic s.		Advanced s.		Self-esteem		Speech		Activity		Social		Total	Gen	Phy-sical	Social				
		PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	POST				PRE	POST	PRE	POST
PRE	Immediat m.																				
	Vis/const		X	X	X		X		X		X		X				X				X
	Language	X			X															X	
	Attention			X	X		X				X		X								
	Delayed m.						X														
	Total score			X	X		X				X		X								
POST	Immediat m.																				
	Vis/const						X														
	Language				X	X															
	Attention			X	X		X				X		X								
	Delayed m.																				
	Total score				X		X														

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