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Tinnitus suppression by means of cochlear implantation: does it affect cognition?

On the correlation between tinnitus suppression by an active cochlear implant and cognitive functioning: a prospective within-subjects pilot study.

INTRODUCTION

Tinnitus can be defined as the hearing of a sound, without any external auditory stimulus being present. The sound can be described as a pure tone, a noise or a combination of sounds, and can be heard in one or both ears, or more centrally inside the head [1]. In objective tinnitus, the sound has a physical origin inside the body, e.g., vascular abnormalities. Far more common, however, is subjective tinnitus, in which there is no objective physical cause to be found. Research shows that 10-16% of the population experiences tinnitus [2-5], and that this percentage increases to more than 30% in adults older than 50 years [3]. However, not all of these individuals experience significant problems due to this tinnitus. The prevalence of bothersome tinnitus is around 6% [5] and the prevalence of severe tinnitus is estimated to be 1-4% [4-6]. Biswas et al. [5] also noted a significantly higher prevalence of bothersome tinnitus in women (6.6%) than in men (5%).

Tinnitus can have a significant impact on emotional well-being and quality of life, due to sleep difficulties, increased listening effort, stress, anxiety and depression symptoms [2, 3, 7-9]. In addition, the possible effect of tinnitus on cognition has been described in literature. Several systematic reviews have been performed on this subject, but no definitive conclusions could be reached, due to the heterogeneity of the included studies [10-12]. A review by Andersson and McKenna [13] found that tinnitus patients show signs of cognitive bias, either in regard to selective attention or to selective memory, or both. However, the authors could not draw a more detailed conclusion, as the evidence was not consistent and relatively few studies were published on cognitive functioning in tinnitus patients at that point in time. Cardon et al. [14] investigated the relationship between cognition and tinnitus, by comparing the performance on the Repeatable Battery for Assessment of Neuropsychological Status for the Hearing Impaired (RBANS-H) of 28 chronic tinnitus patients with closely matched control participants. They reported no significant difference between the two groups for the total RBANS-H score. However, they did find that tinnitus patients scored significantly lower than controls on the verbal fluency subscale, which could reflect an impaired executive control. Tinnitus loudness (as measured by a visual-analogue scale (VAS)) showed a negative correlation with the total RBANS-H score and the attention subscale. Tegg-Quinn et al. [11] found a correlation between the presence of tinnitus and executive control of attention, suggesting that people with invasive tinnitus find it more difficult to decide which stimuli are relevant. Similarly, Clarke et al. [12] discovered a small significant effect of tinnitus on executive functions, leading to increased response times and higher error rates, specifically for the narrow domains of shifting and inhibition. A similar effect was found for processing speed, although the authors noted this could be an artefact of the correlation between tinnitus and executive functions, as tasks that measure processing speed usually also require cognitive control. These findings were confirmed by Neff et al. [15], who found a small negative effect of tinnitus distress on general and crystalized intelligence and executive functions, but not on processing speed. Finally, Wang et al. [16] found that patients with severe tinnitus performed worse on most of the Cognitive Abilities Screening Instrument (CASI) subdomains and on total CASI score than patients with mild tinnitus, suggesting that tinnitus severity plays an important role in its effect on cognition. Conversely, a recent study by Degeest et al. [2] did not find any significant effects of tinnitus on cognition.

The impact of tinnitus on cognition can be understood through the concept of load theory. Khan & Husain [17] examined the link between load theory and tinnitus and concluded that evidence from both behavioral and neuroimaging studies suggest an influence of tinnitus on cognitive load (i.e. the fact that it is more difficult to do two things at once, or switch attention between tasks, because this takes more cognitive resources), whereas the link with perceptual load (i.e. the limited resources a person has to process sensory stimuli, such as sounds or images) could not be clearly determined. However, they cautioned that none of the reviewed studies actually conducted their research through the approach of load theory. In addition, very few studies incorporated a task that measured the influence of perceptual load. Thus the influence of tinnitus on cognitive and/or perceptual load is still not entirely clear.

A comorbidity between tinnitus and hearing loss has already been established in past research [18, 19]. As such, hearing loss can be a possible confounding factor in research on tinnitus and cognition, as it is known that hearing loss has an important effect on cognition [20-22]. Lin et al. [20] found that a hearing loss of 25 dB HL already had an effect on cognition that is equivalent to aging 6.8 years. These findings were further confirmed by the studies of Claes et al. in research with Cochlear Implant (CI) users [21-25]. While there is no consensus on the exact working mechanism behind tinnitus, the most accepted hypothesis involves trauma to the outer hair cells (OHC) in the cochlea. This cochlear damage results in the brain receiving less auditory input, which may cause neuroplastic changes in central auditory structures. One possible effect of this process can be the increase of spontaneous auditory activity, which can lead to the hearing of a phantom noise (i.e. tinnitus). Cochlear implantation can have an impact on this compensatory activity, because a CI will directly stimulate the auditory nerve, thereby bypassing the OHC altogether. Additionally, a CI will provide (more) access to external sounds, which may, in itself, mask or distract from the tinnitus. The literature shows that 51-100% of CI patients experience tinnitus before implantation [18, 26, 27], with an average of 80% [28]. A CI can be highly effective in tinnitus management, with tinnitus being (partially) suppressed after implantation in 20-100% of CI users [19, 26, 27, 29-31]. Nevertheless, a CI does not provide a (total) tinnitus alleviation for every patient, as 13-50% of CI patients still experience tinnitus even after implantation [27, 32, 33]. Moreover, there is a small group of patients (0-10%) who suddenly experience tinnitus after implantation while they did not before [18, 19, 27]. Research indicates that a CI may also have a positive effect on depression and quality of life in individuals with tinnitus [25, 34, 35]. Interesting to note is that Olze et al. [9] showed that patients with more distress due to the tinnitus had higher stress levels, fewer coping mechanisms and a lower quality of life after implantation, compared to patients with less tinnitus distress. Considering the fact that tinnitus distress was not related to stress, coping mechanisms and quality of life before implantation, the authors stated that these differences are masked by the deafness itself before implantation.

In summary, earlier studies have shown a negative effect of tinnitus on cognition. However, the evidence is unclear, due to the variety in test batteries and criteria, which hampers comparison between studies. It is not entirely clear which domains of cognition are impaired by tinnitus, although research suggests that short-term memory and executive functions are most likely to be affected. An important limitation of past research on tinnitus and cognition is that these studies usually compare participants with and without tinnitus, thus not looking at the performance of people with tinnitus at different times. Hence, these studies do not prove whether the findings are specifically due to the presence of tinnitus and/or the loudness of the tinnitus at the moment of measurement, or whether other indirect factors also come into play, such as the role of the hearing loss or the impact of tinnitus on sleep or listening effort. Tegg-Quinn et al. [11] pointed out that across studies, tinnitus and control groups were often not matched for age or hearing loss, despite both factors having been reported as impacting cognitive function [20, 36-38]. On the other hand, research has been conducted on the impact of cochlear implantation on cognition [21-23]. However, these studies do not include the potential effect of tinnitus.

There is currently little or no research that combines these three factors: cochlear implantation, tinnitus and cognition. As such, the current study investigated whether tinnitus has an effect on cognition (as already shown in previous studies), in a population where tinnitus can be affected within the same patient: individuals with a CI. The objective was to evaluate cognition in CI patients (with a severe to profound hearing loss) with tinnitus and to assess whether tinnitus suppression due to a CI has an effect on cognitive performance. The hypothesis of this study was that when patients experience more tinnitus, they will have a higher cognitive load and, therefore, perform worse on (specific domains of) the RBANS-H. When patients experience less or no tinnitus (with it being suppressed by the CI), they will have a lower cognitive load and thus perform better on (specific domains of) the RBANS-H.

METHODS

A total of 45 patients were identified from the CI database at the Antwerp University Hospital (UZA) to participate in the current study. Inclusion criteria were adults (aged 18 years or older) with acquired severe or profound sensorineural hearing loss, who received a CI, had at least six months of CI experience and experienced tinnitus, either with or without the CI. Exclusion criteria were severe cognitive impairments, uncorrected visual impairments and insufficient knowledge of the Dutch language. When contacting their audiologists, eight patients were excluded for various reasons (Table 1). After contacting patients for participation, 20 of them (11 male, 9 female) agreed to participate. During the appointment, two participants reported that they did not experience any tinnitus, so they were excluded from all statistical analyses. Patient characteristics of the remaining 18 participants are described in Table 2. Written informed consent was obtained at the beginning of each appointment, prior to testing. The study was approved on June 20, 2022 by the Ethical Committee of the University Hospital Antwerp (EC number: B3002022000080).

The appointment consisted of an interview on the patient's hearing loss, tinnitus and demographic information (i.e. age and level of education) (Appendix 1). This was followed by two, consecutive administrations of the RBANS-H, once in unaided condition and once in best aided condition. In unaided condition, the patient had no hearing instruments (CI or hearing aid), while in the best aided condition the patient used all hearing implements that were available to him/her in daily life (CI, and contralateral hearing aid if any). The tinnitus with and without hearing instrument(s) was evaluated using a VAS for tinnitus loudness and distress (Appendix 2). VAS have been shown to be reliable instruments to measure tinnitus and correlate with both tinnitus questionnaires and loudness matching [39-41]. In an effort to minimize learning effects, the administration of the RBANS-H was randomized, both for the condition in which the test was taken (unaided vs. best aided) and for the version of the test that was used (version A vs. B). The two test versions contain different test items, thus eliminating direct learning effects. Indirect learning effects (such as knowing that one will be asked to repeat the presented words) were minimized through the randomization of the test condition.

The RBANS-H evaluates cognition on 5 domains (Immediate Memory, Visuospatial/constructional, Language, Attention and Delayed Memory), using 12 subtasks. The test has been adapted for the hearing impaired population by adding a PowerPoint presentation to the original test, so that all stimuli are presented both aurally and visually. This ensures that hearing (in this case: whether or not a CI and/or hearing aid is worn) does not have an effect on the subject's performance. The RBANS-H has been validated and adapted to a Dutch version, using forward-backward translation [23].

Statistical analysis

The results of this study were analyzed using IBM SPSS Statistics version 28.0. The test results of 18 participants were analyzed using non-parametric testing, due to the small size of the study sample. Tinnitus suppression was defined as a difference in VAS-score for loudness of 1/10 or more, following the findings of Adamchic et al. [41]. This was the case for 13 out of 18 patients. To compare RBANS-H scores in two different conditions (unaided vs. best aided) for the group as a whole (n=18) and for the tinnitus suppression group alone (n=13) the paired Wilcoxon-test was used. The Mann-Whitney-U test was utilized to compare the best aided cognitive results of patients without tinnitus suppression (n=5) and patients with tinnitus suppression (n=13). Spearman's correlation coefficient was calculated to examine the relationship between RBANS-H score in best aided condition and tinnitus loudness (as measured by a visual analogue scale).

RESULTS

Tinnitus characteristics
Tinnitus duration ranged between 2 and 48 years, with a mean duration of 17.6 years (SD: 12.62). Tinnitus was experienced as unilateral in 61.1%, bilateral in 27.8% and central in 11.1% of cases. For the participants with SSD, tinnitus was unilateral in 100% of cases and the CI side was always ipsilateral to the tinnitus side. For the participants with bilateral hearing loss, tinnitus was experienced as unilateral in 30%, bilateral in 50% and central in 20% of cases. For 36.4% of participants with bilateral hearing loss, the CI side was ipsilateral to the tinnitus side. In 18.2% of cases, the tinnitus side was contralateral to the CI side, and for the remaining 45.4% of participants, the CI was unilateral while tinnitus was experienced as bilateral or central. In all participants, tinnitus was most commonly described as a noise (55.6%), followed by a pure tone (27.8%) or polyphonic (16.7%).

Tinnitus loudness and distress
In unaided condition, all participants experienced at least some tinnitus (Figure 1), with loudness scores on the visual analogue scale ranging from 0.5 to 10 (median: 6.0, SD: 2.87). In best aided condition, loudness scores ranged from 0 to 7 (median: 2.5, SD: 2.44), with only 14 participants experiencing tinnitus (Figure 1). In terms of tinnitus distress, VAS scores in unaided condition ranged between 0 and 10 (median: 5.0, SD: 2.99), with 15 out of 18 participants experiencing some distress (Figure 2). In best aided condition, VAS scores ranged from 0 to 5.5 (median: 1.5, SD: 2.04), with 13 participants experiencing tinnitus distress (Figure 2). VAS scores for tinnitus loudness and tinnitus distress were significantly correlated. Spearman's rank correlation was computed to assess the relationship between loudness and distress in unaided condition, resulting in a positive correlation ($r(16) = 0.934$, $p<.001$). Spearman's correlation coefficient was also calculated for tinnitus loudness and distress in best aided condition, resulting in a positive correlation ($r(16) = 0.910$, $p<.001$).

A total of 13 participants experienced tinnitus suppression (i.e., a difference in VAS score for loudness of 1/10 or more). For this group, there was a significant difference in tinnitus loudness between best aided condition and unaided condition ($Z= -3.521$, $p<.001$), as well as a significant difference in tinnitus distress between best aided condition and unaided condition ($Z= -3.192$, $p=.001$). These differences were significant both for the participants with single sided deafness (SSD) ($Z= -2.371$, $p=0.018$ for loudness and $Z= -2.226$, $p=0.026$ for distress) and for the participants with bilateral severe hearing loss ($Z= -2.524$, $p=0.012$ for loudness and $Z= -2.214$, $p=0.027$ for distress).

Cognitive status in unaided and aided condition
The RBANS-H scores are displayed in Table 3. Accompanying boxplots can be found in Figure 3. No significant differences were found between RBANS-H scores in best aided condition and RBANS-H scores in unaided condition ($p>0.05$), either for the total score or for one of the subscales.

Cognitive status and tinnitus
The differences between best aided and unaided scores were calculated for the group with tinnitus suppression (n=13), but no significant differences were found, either for total score or RBANS-H subscales. The differences between best aided test scores and unaided test scores of the tinnitus suppression group (n=13) and the no tinnitus suppression group (n=5) were investigated as well, but no significant differences were found. Finally, the relationship between RBANS-H score and tinnitus

loudness and distress was calculated, both for unaided and best aided scores, but no significant correlations were found.

DISCUSSION

The aim of the current study was to determine whether tinnitus has an effect on cognition in CI users. To this end, the cognitive performance of 18 patients with tinnitus in best aided condition was compared with their performance in unaided condition. An important strength of this study is its within-subjects design. Each participant completed the cognitive test battery twice, once in best aided condition and once in unaided condition, making comparisons within each subject possible. As a result, there are no influences of possible confounding factors (e.g., age, hearing loss), which has not been the case in earlier studies on this subject. Learning effects were minimized, through the randomization of the test administration. Furthermore, men and women were equally represented and a large range of ages was included. Overall, no significant differences or correlations were found between tinnitus loudness and cognition. As expected, a significant difference between tinnitus loudness in best aided condition and unaided condition and tinnitus distress in best aided condition and unaided condition was found, reiterating the known positive effect of cochlear implantation on tinnitus perception in both patients with SSD and patients with bilateral severe hearing loss [19, 26, 27, 29, 42, 43].

The absence of an effect of tinnitus loudness on cognition is in contradiction with earlier findings. Cardon et al. [14] found a negative correlation between VAS score for tinnitus loudness and the RBANS-H score, both for total score and the attention subscale, which could not be reproduced in the current study. A possible explanation for this discrepancy is that Cardon et al. [14] used a between-subjects design, in which a tinnitus group was compared to a control group, while this study utilized a within-subjects design, thus ruling out the possible influence of any confounding variables. Furthermore, the tinnitus characteristics of the participants of the study of Cardon et al. were different than those in the current study. The mean tinnitus duration in this study was 17.6 years, which is considerably higher than the 5.7 years reported by Cardon et al. [14]. On the other hand, the average tinnitus severity of the participants of Cardon et al. [14] was higher than the tinnitus severity reported by the participants of this study. Previous literature suggests that tinnitus severity likely plays an important role in its effect on cognition. Wang et al. [16] found that there was a higher effect of tinnitus on cognition in patients with severe tinnitus than in patients with moderate tinnitus. This hypothesis is also addressed by Degeest et al. [2], who did not find a significant impact of tinnitus on cognition in their study. Like the participants in the current study, their subjects mostly experienced mild to moderate tinnitus. Another potential explanation for the lack of significant differences and correlations is the limited study size. Only 18 participants fulfilled all study criteria and were included in statistical analysis. Finally, the findings of this study could be explained by the fact that the RBANS-H was a moderately demanding cognitive task and was, as such, less likely to be impacted by tinnitus. Andersson & McKenna [13] hypothesized that the impact of tinnitus on cognition can be understood as an inverted U-function, meaning that tinnitus has a high impact on cognitively undemanding tasks, little to no impact on moderately demanding tasks and more impact on highly demanding tasks.

There is currently no consensus in the literature on the qualification of tinnitus suppression, i.e. the cut-off point that is used to determine whether a person experiences tinnitus suppression or not. In this study, a difference in tinnitus loudness of 1/10 or more on the VAS was used as a criterium, based on the results of Adamchic et al. [41]. Yet, other studies have used different criteria [e.g. 44].

Previous literature has shown a negative effect of tinnitus on executive functions [11, 12, 15]. As there is no separate scale for executive functioning in the RBANS-H (only indirectly through the verbal fluency task), the specific effect of tinnitus on executive functions was not measured in the current study. However, Spencer et al. [45] developed an RBANS executive errors scale, which could possibly be valuable in future research on this subject. Another suggestion for future research would be to not only assess the final score on the RBANS-H scales, but to also take into account the time that participants needed to complete the subtasks. It is possible that people with tinnitus are able to achieve the same results as people without tinnitus, but need more time to do so (e.g. to memorize a figure or to recall a set of words).

CONCLUSION

The effect of tinnitus on cognition remains unclear. The results of this study suggest that tinnitus loudness does not have a direct effect on cognition, but due to the small and heterogenous study sample no definitive conclusions can be drawn. Future research should further investigate possible confounding factors on cognition and should include a larger, more diverse study sample, as this would allow for more variation in duration and degree of tinnitus.

TABLES AND FIGURES

***Table 1**: Excluded patients (n=8)*

Reason for exclusion	Number of patients
Other health issues	2
Moved out of the country	1
No tinnitus	2
Non-user CI	1
Patient had not had a CI-fitting for several years	1
Participation in other study using RBANS-H	1

***Table 2**: Patient characteristics (n=18)*

		Number of patients
Sex	Female	9
	Male	9
Age	20-39	2
	40-49	2
	50-59	6
	60-69	5
	70-79	3
Education	Lower secondary	1
	Higher secondary	7
	Higher education	10
Type of hearing loss	Single Sided Deafness (SSD)	7
	Bilateral severe hearing loss	10
	Asymmetrical hearing loss	1
Duration of hearing loss	≤ 1 years	1
	1 - 5 years	3
	6 - 10 years	1
	11 - 20 years	6
	21 - 30 years	4
	> 30 years	3
CI side	Right	7
	Left	9
	Bilateral	2
CI experience	≤ 1 years	3
	1 – 5 years	5
	6 – 10 years	4
	11 – 20 years	5
	> 20 years	1
Best aided condition	CI	12
	CI + HA	4
	CI + CI	2

***Table 3**: Scores on the Repeatable Battery for Assessment of Neuropsychological Status for the Hearing Impaired in unaided and best aided condition (n=18)*

	Unaided	**Best aided**	***p*-value**
Total scale			0.618
Mean	96.83	97.83	
Standard deviation	12.66	12.06	
Median	97	98	
Minimum	73	80	
Maximum	123	118	
Immediate memory			0.641
Mean	104.78	106.28	
Standard deviation	14.81	14.66	
Median	106	103	
Minimum	76	73	
Maximum	132	129	
Visuospatial/constructional			0.437
Mean	90.28	92.67	
Standard deviation	12.65	13.75	
Median	88	88	
Minimum	75	69	
Maximum	126	121	
Language			0.851
Mean	100.44	99.39	
Standard deviation	9.33	8.84	
Median	99	101	
Minimum	85	78	
Maximum	128	113	
Attention			0.796
Mean	96.72	98.00	
Standard deviation	17.72	14.41	
Median	97	98,5	
Minimum	56	75	
Maximum	132	122	
Delayed memory			0.243
Mean	97.72	96.44	
Standard deviation	13.07	11.47	
Median	97	99	
Minimum	78	71	
Maximum	122	111	

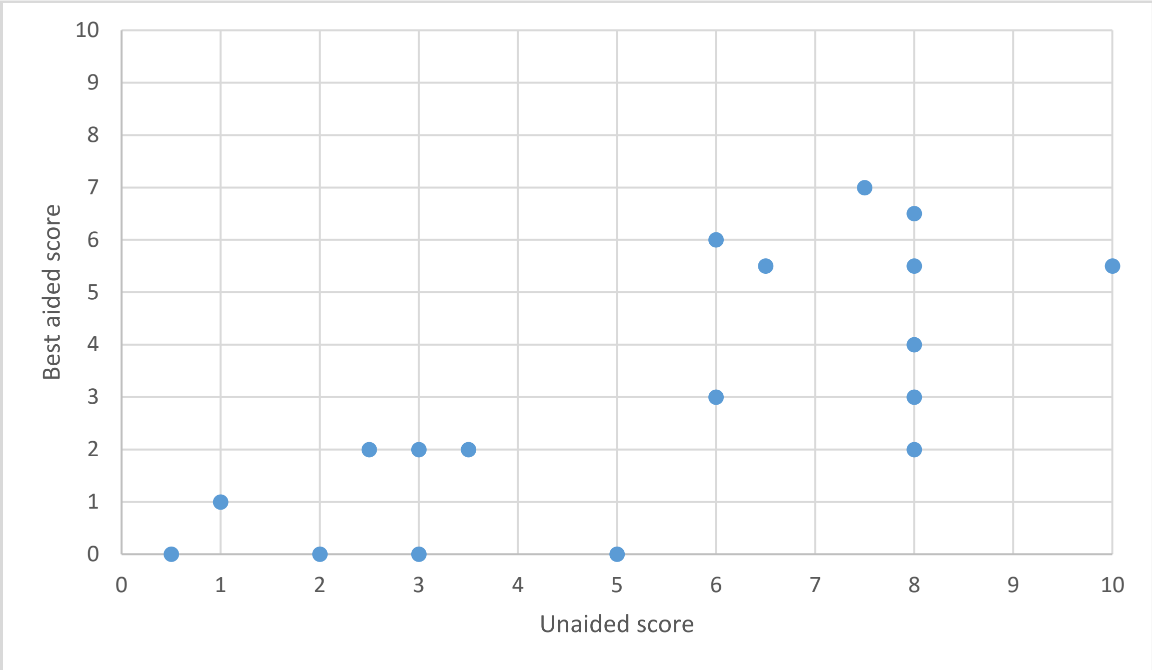

***Fig. 1** Visual-analogue scores for tinnitus loudness*

$r_s = 0.723$; $p < .001$; $n = 18$

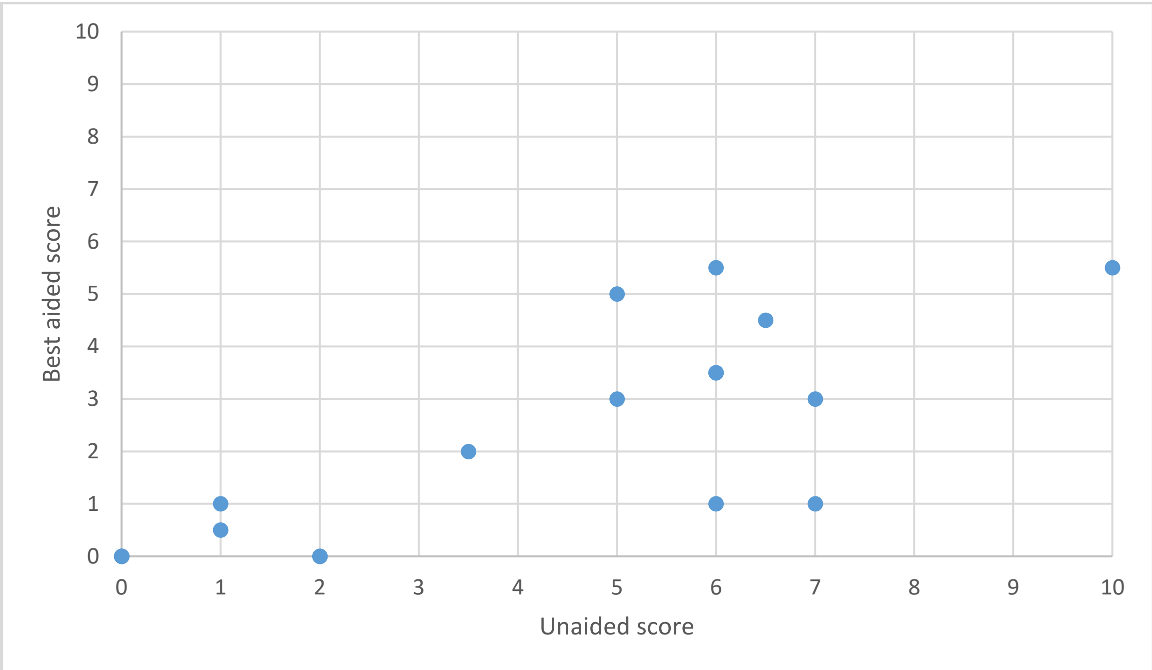

***Fig. 2** Visual-analogue scores for tinnitus distress*

$r_s = 0.750$; $p < .001$; $n = 18$

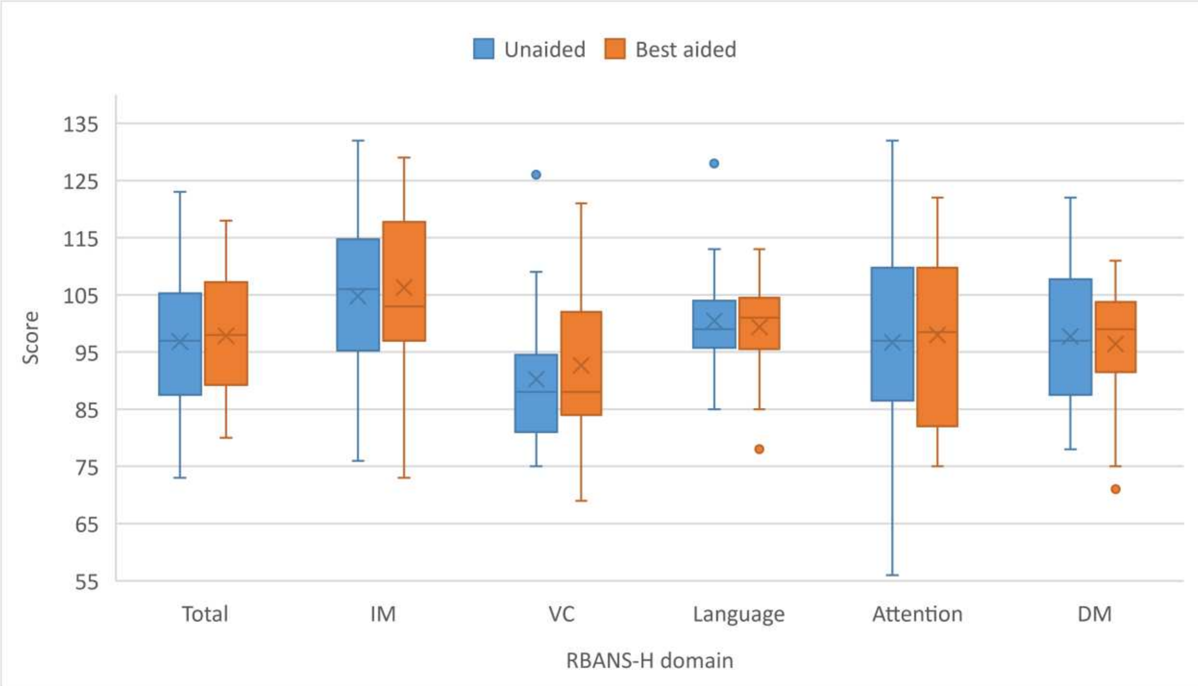

***Fig. 3** Boxplot of scores on the Repeatable Battery for Assessment of Neuropsychological Status for the Hearing Impaired (n=18)*

IM = Immediate memory, VC = Visuospatial/Constructional, DM = Delayed memory

No significant differences were found (p>0.05)

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APPENDIX 1: Appointment questions

Comment: *original in Dutch, translated for publication*

General information:	
Person conducting the assessment	
Date of assessment	/ /2022
Order of assessment	☐ 1: version A / B ☐ 2: version A / B ☐ 1: unaided / best aided ☐ 2: unaided / best aided

Subject identification:	
Identification code	
Sex	☐ Male ☐ Female
Date of birth	/ /
Education level	☐ No schooling ☐ Elementary school completed ☐ Lower secondary completed ☐ Higher secondary completed ☐ Higher education: ______________ ☐ Other: ______________________
Informed consent	Signed on / /2022

Audiological information:	
Hearing impairment	☐ SSD (single sided deafness) ☐ Bilateral severe hearing loss ☐ Other: ______________________
Duration of hearing impairment	_________months / years
Experience with CI	_________months / years
Financing of CI	☐ Self-financed ☐ Paid for by insurance ☐ Other: ______________________
Best aided condition	☐ CI ☐ CI + HA ☐ CI + CI

Tinnitus analysis:	
Tinnitus side	☐ Unilateral ☐ Bilateral ☐ Central
Duration of tinnitus	___________months / years
Type	☐ Noise ☐ Pure tone ☐ Polyphonic
Cause	☐ Otologic: ______________________ ☐ Somatic: ______________________ ☐ Idiopathic: ____________________ ☐ Non-otologic: ___________________ ☐ Other: ________________________

Visual Analogue Scale:	
VAS score *unaided*	
VAS score *best aided*	

Comments:

APPENDIX 2: Visual Analogue Scales

Comment: *original in Dutch, translated for publication*

<u>Visual Analogue Scale *unaided*:</u>

On the line below, indicate with a cross how LOUD your tinnitus sounded, where 0 represents ‘quiet’ and 10 represents ‘very loud, cannot be louder’.

0 10

Indicate with a cross on the line below how BOTHERSOME your tinnitus was for you, where 0 represents ‘not bothersome’ and 10 represents ‘very bothersome’, can't get any worse’.

0 10

<u>Visual Analogue Scale *best aided*:</u>

On the line below, indicate with a cross how LOUD your tinnitus sounded, where 0 represents ‘quiet’ and 10 represents ‘very loud, cannot be louder’.

0 10

Indicate with a cross on the line below how BOTHERSOME your tinnitus was for you, where 0 represents ‘not bothersome’ and 10 represents ‘very bothersome, can't get any worse’.

0 10