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

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Vrijwaringsclausule (of disclaimer):

"Deze bachelorproef is gemaakt door Sarah van Genuchten, student aan de Hogeschool Gent, ter voltooiing van de bacheloropleiding Bachelor in de logopedie en audiologie. De standpunten die in deze bachelorproef zijn verwoord, zijn louter het persoonlijke standpunt van de individuele auteur en reflecteren niet noodzakelijkerwijs de mening, het officiële standpunt of het beleid van de Hogeschool Gent."

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Abstract

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

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Background: Recent literature suggests that tinnitus loudness can influence cognition, specifically for the domains of executive functions and/or short-term memory. However, most of these studies do not control for the possible influences of confounding factors, such as hearing loss.
Objective: To assess the impact of tinnitus loudness on cognition in cochlear implant (CI) users.
Study design: Prospective within-subjects design.
Methods: A total of 18 CI users completed two versions of the Repeatable Battery for Assessment of Neuropsychological Status for Hearing Impaired individuals (RBANS-H), once in unaided condition and once in best aided condition. The differences in test scores between conditions were compared between the group of participants that did and the group that did not experience tinnitus suppression. Tinnitus suppression was defined as a difference in score on a visual-analogue scale (VAS) for tinnitus loudness of 1/10 or more, between the two conditions.
Results: No significant differences in cognitive scores were found between the suppression and no suppression group, nor for the suppression group alone ($p>0.05$). No significant correlations between tinnitus loudness and cognition were found, neither for the suppression group alone, nor for the group as a whole ($p>0.05$).
Conclusions: The results of this study show no significant differences or correlations between tinnitus loudness and cognition. Comparing these results to earlier literature, it is noteworthy that this study, with its within-subjects design that eliminates the possible influences of confounding factors, does not have the same results as other studies with a between-subjects design. However, considering the limitations of the current study, no definitive conclusions regarding the impact of tinnitus loudness on cognition can be drawn. Future research should include a larger and more diverse study sample.
Key Words: Tinnitus – Cochlear implant – Cognition – RBANS-H.

Tinnitusonderdrukking met behulp van een cochleair implantaat: beïnvloedt het cognitie?

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Achtergrond: Recente literatuur suggereert dat tinnitusluidheid een invloed kan hebben op cognitie, specifiek voor de domeinen van executieve functies en/of kortetermijngeheugen. De meeste van deze studies controleren echter niet voor de mogelijke impact van beïnvloedende factoren, zoals gehoorverlies.
Doelstelling: Het onderzoeken van het effect van tinnitusluidheid op cognitie, bij gebruikers van een cochleair implantaat (CI).
Onderzoeksdesign: Prospectief within-subjects design.
Methode: In totaal werden bij 18 CI-gebruikers twee versies van de Repeatable Battery for Assessment of Neuropsychological Status for Hearing Impaired individuals (RBANS-H) afgenomen, één keer in niet-ondersteunde conditie (zonder CI en/of hoortoestel) en één keer in best ondersteunde conditie (met CI en/of hoortoestel). De verschillen in testscores tussen de condities werden vergeleken tussen de groep deelnemers die wel en de groep die geen tinnitusonderdrukking ervaarde. Tinnitusonderdrukking werd gedefinieerd als een verschil in score op een visueel-analoge schaal (VAS) voor tinnitusluidheid van 1/10 of meer, tussen de twee condities.
Resultaten: Er werden geen significante verschillen qua cognitieve scores gevonden tussen de groep met en zonder onderdrukking, noch voor de groep met tinnitusonderdrukking alleen ($p>0,05$). Er werden geen significante correlaties gevonden tussen tinnitusluidheid en cognitie, niet voor de suppressiegroep alleen, en ook niet voor de groep als geheel ($p>0,05$).
Conclusies: De resultaten van deze studie laten geen significante verschillen of correlaties zien tussen tinnitusluidheid en cognitie. In vergelijking met eerdere literatuur is het opmerkelijk dat deze studie, waarbij gebruik werd gemaakt van een within-subjects design dat de mogelijke effecten van verwarrende factoren elimineert, niet dezelfde bevindingen heeft als andere studies met een between-subjects design. Gezien de beperkingen van de huidige studie kunnen echter geen definitieve conclusies worden getrokken over het effect van tinnitusluidheid op cognitie. Toekomstig onderzoek zou een grotere en meer diverse studiesteekproef moeten omvatten.
Trefwoorden: Tinnitus – Cochleair implantaat – Cognitie – RBANS-H.

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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 (Cima et al., 2019). In objective tinnitus, the sound has a physical cause 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 (Assouly et al., 2021; Biswas et al., 2022; Degeest et al., 2022; McCormack et al., 2014), and that this percentage increases to more than 30% in adults older than 50 years (Assouly et al., 2021). However, not all of these people experience significant problems due to this tinnitus. A recent study made the distinction between any tinnitus, bothersome tinnitus and severe tinnitus (Biswas et al., 2022). Patients who described their tinnitus as being moderately annoying/worrying/upsetting in the past year were defined as having 'bothersome' tinnitus, patients who described their tinnitus as being severely annoying/worrying/upsetting in the past year were defined as having severe tinnitus. The prevalence of bothersome tinnitus is around 6% (Biswas et al., 2022), the prevalence of severe tinnitus is estimated to be 1-4% (Biswas et al., 2022; Jafari et al., 2019; McCormack et al., 2014). Biswas et al. (2022) 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, and increased stress, anxiety and depression symptoms (Assouly et al., 2021; Degeest et al., 2022; Fetoni et al., 2021; Olze et al., 2012; Pierzycki & Kitterick, 2020).
A more recent interest in research has been the possible effect of tinnitus on cognition. Andersson and McKenna (2006) 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. Cardon et al. (2019) 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 language subscale. Tinnitus loudness (as measured by a visual-analogue scale) showed a negative correlation with the total RBANS-H score and the attention subscale. Yet, a recent study by Degeest et al. (2022) did not find any significant effects of tinnitus on cognition. Several systematical reviews have been performed on this subject, but no definitive conclusions could be reached, due to the heterogeneity of the included studies (Clarke et al., 2020; Mohamad et al., 2016; Tegg-Quinn et al., 2016). Tegg-Quinn et al. (2016) did find 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. (2020) 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 as the authors note 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. (2021), 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. (2018) 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.

The impact of tinnitus on cognition can be understood through the concept of load theory. Load theory is based on the principle that a person only has a limited amount of resources to process stimuli, both internal and external. Once those resources have been spent, i.e. the load on the brain is too high, a person is no longer able to efficiently direct their attention towards important stimuli and ignore irrelevant stimuli. Khan & Husain (2020) 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. This means that 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 (Quaranta et al., 2004; Ramakers et al., 2015). As such, hearing loss can be a possible confounding factor in research on tinnitus and cognition, as hearing loss has an important effect on cognition (Claes et al., 2018; Claes, Van de Heyning, et al., 2018b; Lin et al., 2011; Mertens et al., 2021). Lin et al. (2011) found that a hearing loss of 25 dB HL 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 users (Claes et al., 2016; Claes et al., 2018; Claes, Van de Heyning, et al., 2018a, 2018b). The known comorbidity between tinnitus and hearing loss can have important implications for tinnitus management. 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 hypothesis states that damage to the OHC (due to noise exposure or aging, for example) results in the brain receiving less auditory input. The brain tries to compensate for this by increasing spontaneous auditory activity, which leads to the hearing of a phantom noise (i.e. tinnitus). Cochlear implantation (CI) can have an impact on this compensatory activity. The literature shows that 51-100% of CI patients experience tinnitus before implantation (Greenberg et al., 2015; Hsieh et al., 2020; Quaranta et al., 2004), with an average of 80% (Baguley & Atlas, 2007). A CI represents a tinnitus solution for some of these patients, in fact, research shows that in 20-100% of CI users tinnitus is (partially) suppressed after implantation (Greenberg et al., 2015; Hsieh et al., 2020; Poncet-Wallet et al., 2020; Ramakers et al., 2015). 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 (Assouly et al., 2022; Gomersall et al., 2019; Hsieh et al., 2020; Pierzycki et al., 2019). Moreover, there is a small group of patients (0-10%) who suddenly experience tinnitus after implantation when they did not before (Hsieh et al., 2020; Quaranta et al., 2004; Ramakers et al., 2015). Research indicates that a CI may also have a positive effect on depression and quality of life in individuals with tinnitus (Andries et al., 2021; Mertens et al., 2021; Yuen et al., 2021).

Olze et al. (2012) conducted research on the relationship between tinnitus, stress and quality of life in post-lingually deaf CI-users. They compared the performance of patients before and after CI implantation. The authors concluded that patients with more distress due to the tinnitus had higher stress levels, fewer coping mechanisms and a lower quality of life after CI 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 the CI 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. It is not entirely clear which domains of cognition are impaired by tinnitus and what other factors play a role, 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, 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. (2016) report that *"Across the studies, tinnitus and control groups were often not matched for age or hearing loss, despite both factors having been reported as impacting cognitive function (Lin et al, 2004, 2011; Jorgensen et al, 2014; Dupuis et al, 2015)"* (p. 537). On the other hand, research has also been conducted on the relationship between cochlear implantation and cognition (Claes et al., 2016; Claes, Van de Heyning, Gilles, Hofkens-Van den Brandt, et al., 2018; Claes, Van de Heyning, et al., 2018b). However, these studies do not include the potential effect of tinnitus. It is unknown whether a CI can provide a solution to the possible cognitive deficits in tinnitus patients, as many people only experience tinnitus suppression when the CI is on.

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 patients with profound hearing impairment (CI patients) and tinnitus, using the RBANS-H. The possible impact of tinnitus loudness on the cognition of adult post-lingually implanted CI patients, as measured by the RBANS-H, was investigated. Furthermore, it was assessed whether tinnitus suppression due to a cochlear implant 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 cochlear implant), 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 selected from the CI database at the University Hospital of Antwerp to participate in the current study. Inclusion criteria were adults (aged 18 years or older), who received a cochlear implant post-lingually, had at least six months of CI experience and experienced tinnitus, either with or without the CI. No minimum requirements for the tinnitus were set. Exclusion criteria were severe cognitive impairments, uncorrected visual impairments and insufficient knowledge of the Dutch language. When contacting their audiologists, 8 patients were excluded for various reasons (Table 1). After contacting the remaining patients for participation in the study, 20 of them (11 male, 9 female) agreed to participate. During the appointment, 2 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 anamnesis about 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 (cochlear implant 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 CI was evaluated using a visual analogue scale (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 (Adamchic et al., 2012; Nascimento et al., 2019; Raj-Koziak et al., 2018). 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 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 (Claes et al., 2016).

Statistical analysis

The results of this study were analyzed using IBM SPSS Statistics version 28.0. The test results of 18 participants (9 women, 9 men) 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. (2012). 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). Finally, the cognitive outcomes were compared with demographic characteristics, including age and sex. The difference in RBANS-H scores for men and women was calculated using the Mann-Whitney-U test, and to investigate the relationship between RBANS-H score and age, Spearman's correlation coefficient was calculated.

RESULTS

Tinnitus characteristics

Tinnitus duration ranged between 2 and 48 years, with a mean duration of 17.6 years (SD: 12.62). Tinnitus was unilateral in 61.1%, bilateral in 27.8% and central in 11.1% of cases. It was most commonly described as a noise (55.6%), followed by a pure tone (27.8%) or polyphonic (16.7%). In 55.5% of cases, the tinnitus side was the same as the CI side. There was a positive correlation between duration of hearing loss and duration of tinnitus ($r(16) = 0.911$, $p<.001$). No significant correlations between tinnitus and sex were found, either for tinnitus loudness, tinnitus distress or tinnitus suppression.

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 ($Z= -2.371$, $p=0.018$ 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, as measured by the RBANS-H. To this end, the performance of 18 patients with tinnitus in best aided condition was compared with their performance in unaided condition. Overall, no significant differences or correlations were found between tinnitus 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 positive effect of cochlear implantation on tinnitus perception. As mentioned, these differences were significant both for the participants with single sided deafness (SSD) and for the participants with bilateral severe hearing loss. These results confirm earlier findings (Bovo et al., 2011; Greenberg et al., 2015; Hsieh et al., 2020; Kim et al., 2013; Poncet-Wallet et al., 2020; Ramakers et al., 2015). Previous studies found a significant difference in pre- and post-implantation scores for tinnitus loudness and annoyance, both for patients with SSD and for patients with bilateral profound hearing loss (Bovo et al., 2011; Kim et al., 2013; Poncet-Wallet et al., 2020).

The results concerning the effect of tinnitus loudness on cognition differ from earlier findings. Cardon et al. (2019) 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. (2019) 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 significantly higher than the 5.7 years reported by Cardon et al. (2019). There might also be a difference in tinnitus severity, but specific VAS scores were not reported by Cardon et al. (2019). Previous literature suggests that tinnitus severity likely plays an important role in its effect on cognition. Wang et al. (2018) found that there was a higher effect of tinnitus on cognition in patients with severe tinnitus than in patients with moderate tinnitus. Assouly et al. (2021) define 'severe tinnitus' as a VAS score higher than six out of ten. Following this recommendation, 8 participants in this study experienced severe tinnitus in unaided condition and only 2 participants experienced severe tinnitus in best aided condition. This hypothesis is also addressed by Degeest et al. (2022), 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 possible explanation for the lack of significant differences and correlations is the small study sample. Only 18 participants fulfilled all study criteria and were included in statistical analysis, perhaps resulting in insufficient statistical power to reveal impacts of tinnitus on cognition. 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 (2006) 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.

This study had several limitations. First, tinnitus was only evaluated using a visual-analogue scale. Although VAS have been proven to be reliable, they are not very detailed. Furthermore, VAS might not be as sensitive to tinnitus distress as other instruments, such as the Tinnitus Handicap Inventory (THI). Second, 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. (2012). Yet, other studies have used different criteria (e.g. Demoen et al., 2023). Finally, during the study period, another study at the University Hospital of Antwerp was in progress that also used the RBANS-H, which prevented a number of potential subjects from participating in this study, leading to a possible selection bias.

However, an important strength of this study is its within-subjects design. Each participant completed the RBANS-H 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. Furthermore, men and women were equally represented and a large range of ages was included.

Previous literature has shown a negative effect of tinnitus on executive functions (Clarke et al., 2020; Neff et al., 2021; Tegg-Quinn et al., 2016). As there currently is no separate scale for executive functioning in the RBANS-H, the specific effect of tinnitus on executive functions was not measured. However, Spencer et al. (2018) 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). Finally, future research could not only benefit from a larger and more diverse study sample, but also from a longitudinal research design, as this would further eradicate the influence of possible learning effects.

CONCLUSION

The effect of tinnitus on cognition remains unclear. The results of this study seem to suggest that tinnitus loudness does not have an effect on cognition, but due to the small study sample no definitive conclusions can be drawn. Future research should investigate the possible effects of tinnitus distress on cognition and should try to include a larger, more diverse study sample, as this would allow for more variation in duration and degree of tinnitus, and allow for more statistical power to test different hypotheses.

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SUPPLEMENTARY MATERIALS

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	

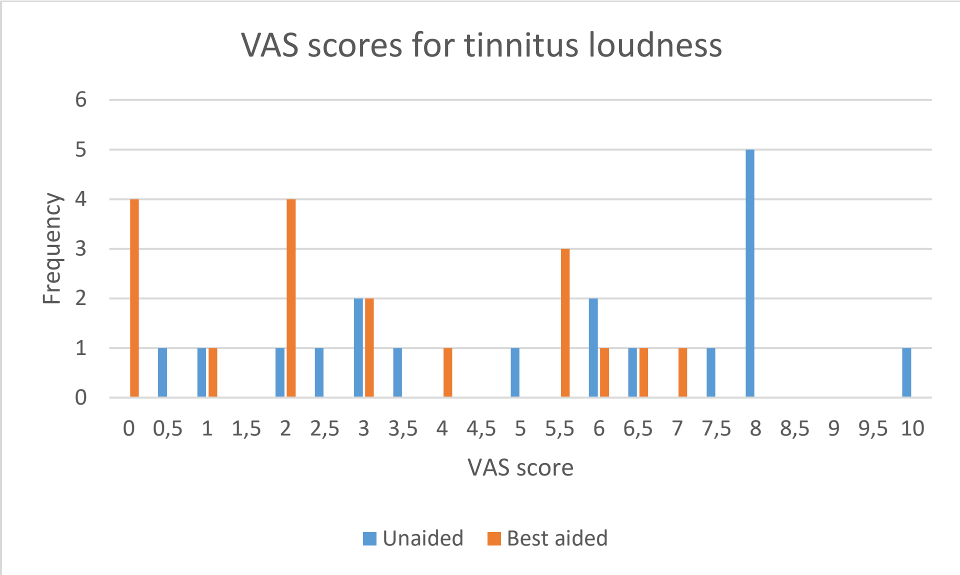

Figure 1: Visual-analogue scores for tinnitus loudness (n=18)

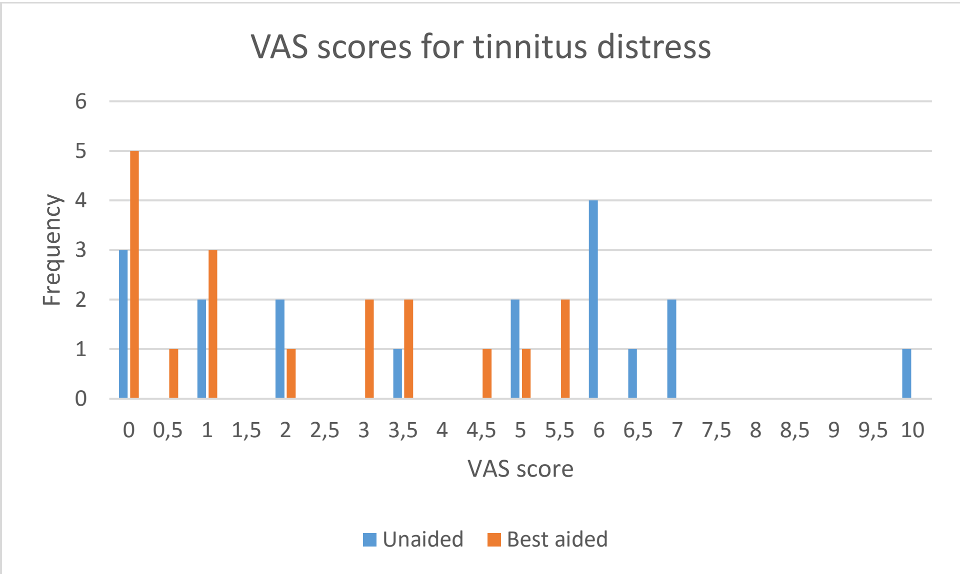

Figure 2: Visual-analogue scores for tinnitus distress (n=18)

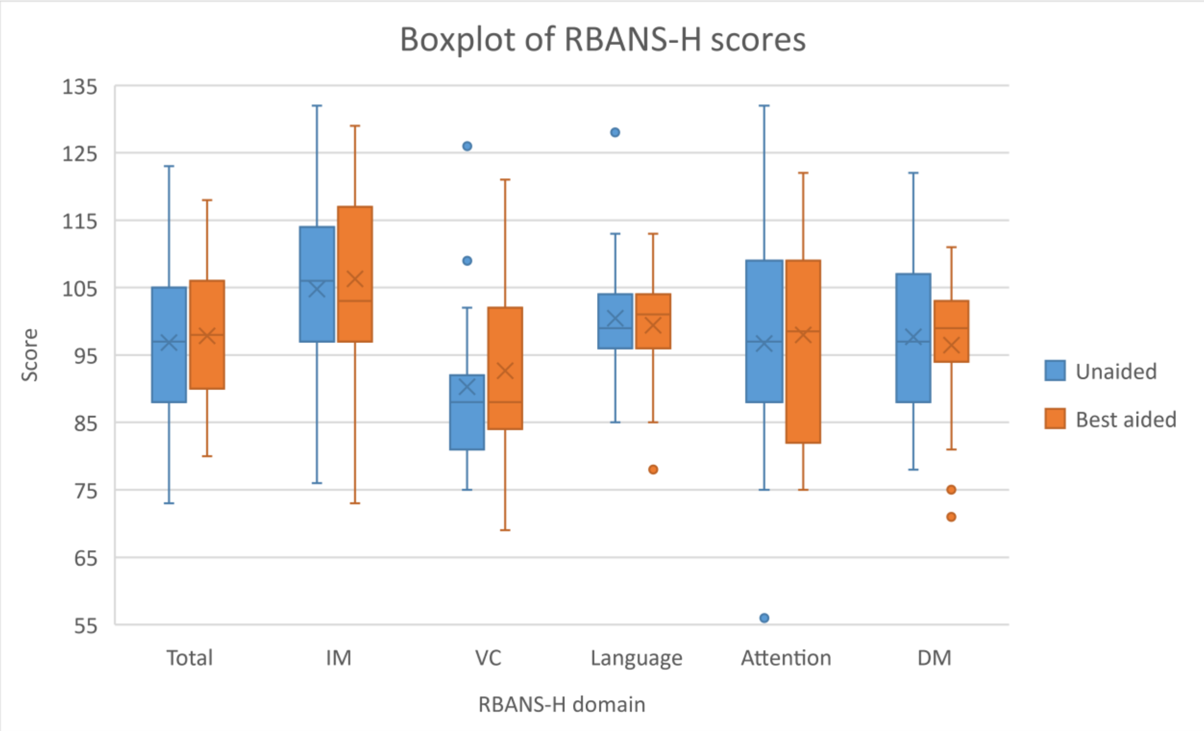

Figure 3: Boxplot of scores on the Repeatable Battery for Assessment of Neuropsychological Status for the Hearing Impaired (n=18)

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

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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*

Visual Analogue Scale ***unaided***:

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 BURDENSOME your tinnitus was for you, where 0 represents ‘not burdensome’ and 10 represents ‘very burdensome, can't get any worse’.

0 10

Visual Analogue Scale ***best aided***:

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 BURDENSOME your tinnitus was for you, where 0 represents ‘not burdensome’ and 10 represents ‘very burdensome, can't get any worse’.

0 10

SWOT-analyse

STERKTES	ZWAKTES
• Door het within-subjects onderzoeksdesign worden mogelijk beïnvloedende factoren (zoals gehoorverlies) geëlimineerd. • Aangezien de algemene prevalentie van tinnitus 10-15% van de populatie bedraagt, is er een grote groep mensen die potentieel geholpen kan worden met de resultaten van dit onderzoek. • De testafname zelf duurde slechts 1 uur, wat de drempel laag maakte voor participanten om deel te nemen. • Zowel de individuele als de collectieve onderzoeksresultaten werden ook teruggekoppeld naar de participanten zelf.	• Het onderzoek bestond uit een kleine proefgroep (18 participanten). • Tinnitus werd alleen beoordeeld met een visueel-analoge schaal, die mogelijk minder gevoelig is voor tinnitusbelasting. Daarnaast konden er hierdoor geen gradaties qua tinnitusernst onderscheiden worden, terwijl dit wel mogelijk is met een vragenlijst (bv. TFI). • Er is geen consensus in de literatuur over de gehanteerde afkapwaarde voor tinnitusonderdrukking. • Er was terwijl dit onderzoek uitgevoerd werd in het UZA tegelijkertijd ook een andere studie gaande waarbij de RBANS-H gebruikt werd. Dit zorgde dus voor een beperking van de proefgroep en een mogelijke selectiebias.
KANSEN	BEDREIGINGEN
• Tinnitus is momenteel een 'hot topic' in het werkveld, wat het waarschijnlijker maakt dat er aandacht zal zijn voor dit onderzoek. • Dit is één van de eerste keren dat dit onderzoeksdesign gebruikt werd binnen dit onderwerp. Deze bachelorproef voegt met andere woorden dus iets nieuws toe aan de bestaande literatuur.	• Er was slechts een beperkte variatie qua tinnitusluidheid in de proefgroep. Hierdoor zijn de resultaten mogelijk niet generaliseerbaar voor de volledige populatie. • Er komen geen concrete aanbevelingen uit dit onderzoek, waardoor het misschien niet direct toepasbaar is in het werkveld.