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The Impact of Tinnitus on N-Back Performance in Normal Hearing Individuals

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Abstract

Background: Tinnitus sufferers commonly report concentration difficulties. Despite several previous studies investigating this, the underlying cause and the role of hearing status remains unclear.

Purpose: To investigate whether there are any differences between normal hearing individuals with and without tinnitus in terms of working memory capacity, and whether working memory capacity correlates with high-frequency hearing thresholds.

Research Design: Participants had their hearing thresholds measured (0.125–16 kHz) and performed a visual n-back test. All participants completed the Hospital Anxiety and Depression Scale, in addition tinnitus participants filled out the Tinnitus Questionnaire.

Study Sample: Sixty-two individuals participated, 31 had tinnitus (tinnitus group) and 31 did not have tinnitus (control group). Groups were age- and sex matched, and all participants had normal hearing thresholds (20 dB HL or better at 0.125–8 kHz).

Data Analysis: Friedman test of differences among repeated measures was conducted on the collected data of n-back performance, and Mann–Whitney *U*-test was used to compare groups. Age-corrected correlations were calculated for high-frequency hearing and each n-back condition.

Results: We found no significant differences between the groups in terms of n-back task performances, except for the 2-back condition where the tinnitus group performed significantly better than the controls ($p = 0.007$). Furthermore, we found high-frequency hearing thresholds of the best ear (10–16 kHz) to correlate with performances at more demanding n-back conditions ($p = 0.029$ for 1-back and $p = 0.015$ for 2-back).

Conclusion: This suggests that presence of tinnitus might not imply poorer working memory capacity and that deteriorated high-frequency hearing thresholds.

Key Words: cognitive performance, high-frequency hearing, n-back, normal hearing, tinnitus, working memory

Abbreviations: HADS = Hospital Anxiety and Depression Scale; SD = standard deviation; TQ = Tinnitus Questionnaire; WM = working memory

INTRODUCTION

Tinnitus is defined as the perception of sound when no external acoustic source is present and is a common condition that is believed to affect about 15% of all adults (Andersson et al, 2005). Until recently, research has indicated poorer cognitive performance in tinnitus sufferers compared with individuals without tinnitus, usually in the form of longer response times of intense short duration tests such as the Stroop

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test (Andersson et al, 2000; Stevens et al, 2007; Jackson et al, 2014). The interpretation has usually been that the presence of tinnitus is likely to be the underlying cause of the differences between the groups' performances. However, previous research has consistently been limited by the lack of proper control of hearing status among participants (Andersson et al, 2000; Hallam et al, 2004; Dornhoffer et al, 2006; Rossiter et al, 2006; Stevens et al, 2007; Jackson et al, 2014). This is highly relevant because hearing loss itself seems to have negative impact on cognitive performance (Lyxell et al, 1994; Lin et al, 2011). To address the lack of thorough examination of the participants' hearing status in previous research, Waechter and Brännström (2015) examined normal hearing individuals with and without tinnitus and reported equal performances between the two groups. This indicates that the differences in cognitive performance between the tinnitus group and control group in earlier studies could be a result of hearing loss, alternatively the combination of hearing loss and tinnitus. However, the fact remains that part of the tinnitus population experience concentration deterioration as a result of their tinnitus. This was also highlighted by Waechter and Brännström (2015) as a majority of their tinnitus participants reported that their tinnitus had a negative impact on concentration. Overall, this means that tinnitus is possibly having an effect on cognition, although perhaps solely the presence of tinnitus might not explain the aforementioned differences in terms of response times.

Rossiter et al (2006) proposed that the prolonged response times in tinnitus patients could be a result of poorer working memory (WM) capacity in subjects with tinnitus and reported results indicating significantly smaller reading span in tinnitus subjects compared with controls. However, as Rossiter et al (2006) only controlled hearing status by assuring that "all participants could hear normal conversation," the possible confounder of hearing loss cannot be excluded. One way to test WM capacity and avoid the risk of not detecting differences between tinnitus group and control group due to too high or too low cognitive load is to administrate a visual n-back test which increases the load in steps throughout the task. N-back was first introduced by Kirchner (1958) and tests the participant's WM (Braver et al, 1997; Cohen et al, 1997) as well as mental arithmetic (Hubber et al, 2014).

Previous studies of magnetic resonance imaging have indicated less gray matter in the subcallosal region in tinnitus sufferers compared with the controls (Mühlau et al, 2006; Leaver et al, 2011). This could be an explanation for the experienced decline in cognitive performance in tinnitus patients as the region, among other, is involved in attentional processes (Melcher et al, 2013). However, this type of study has been repeated by Melcher et al (2013) with the difference that the latter study controlled their participants' hearing status more carefully. Melcher et al (2013) reported amount of gray matter in subcallosal region to correlate negatively with hearing thresholds of 9–14 kHz, but not with the presence or degree of tinnitus. This implies that the relationship between high-frequency hearing thresholds and cognitive performance in tinnitus sufferers should be further investigated.

Therefore this study aims to

- determine whether there are any differences between tinnitus group and control group in terms of response time and accuracy on a visual n-back task.
- determine whether there is a correlation between high-frequency hearing thresholds and n-back task performance for all participants regardless of group affiliation.

METHODS

Participants

All included participants (n = 62) were recruited via public advertising, through personal contacts and from audiological clinics in southern Sweden. Participants were split into two groups; tinnitus (n = 31, of which 19 were female and 12 were male) and control (n = 31, of which 19 were female and 12 were male). Inclusion criteria for all participants were hearing thresholds <20 dB HL at octave intervals 0.125–8 kHz (see Table 1 for data on hearing status–group wise and all participants together) as well as being more than 18-yr old. An additional inclusion criterion for the tinnitus group was experience of tinnitus for the past six mo or more (see Table 2 for tinnitus characteristics). Control participants were age- (maximum 18 mo difference of age) and sex matched to each tinnitus participant. Ages among the included participants were spanning from 20.9 to 44.3 yr for the tinnitus group (average age = 26.9 yr) and from 21.1 to 43.8 yr for the control group (average age = 27.1 yr). Fifty of the 62 included participants had University education (27 individuals from the tinnitus group and 23 individuals from the control group), whereas remaining 12 participants (4 from the tinnitus group and 8 from the control group) had completed high school.

Initially 64 (33 tinnitus and 31 controls) volunteers were recruited for the study; however, one tinnitus participant was excluded because of hearing thresholds poorer than 20 dB HL and another tinnitus participant was excluded because of difficulties finding an age- and sex-matched control participant meeting our hearing status criteria. Before participation all volunteers were informed about the purpose and conditions of the study. All participants agreed in writing and no participant withdrew their participation neither at the time of testing nor afterward. Ethical approval for this study was granted from Regional Ethical Review Board in Lund (approval number 2014/95).

Table 1. Hearing Status

		Total	Tinnitus Group	Control Group
PTA (0.5–4 kHz)				
Right ear	Span	−6 to 14	−6 to 10	−5 to 14
	Average	1.6	0.9	2.3
	SD	4.3	4.6	4.0
Left ear	Span	−6 to 15	−6 to 15	−6 to 10
	Average	1.7	2.0	1.4
	SD	4.2	4.7	3.7
High-frequency PTA (10–16 kHz)				
Right ear	Span	−10 to 39	−10 to 38	−9 to 39
	Average	8.1	8.6	7.6
	SD	11.8	11.7	12.0
Left ear	Span	−9 to 43	−6 to 30	−9 to 43
	Average	8.7	7.5	10.0
	SD	12.2	10.7	13.6

PTA = pure tone audiometry.

Materials

Technical Equipment

Madsen Astera[2] (GN Otometrics, Taastrup, Denmark) audiometer was used for assessment of pure-tone hearing thresholds. Auditory stimuli were presented via HDA 200 (Sennheiser, Wedemark, Germany) earphones calibrated in accordance with ISO 389-8 (2004) and ISO 389-5 (2006).

N-Back

The n-back gives a measure of the participant's WM (Braver et al, 1997; Cohen et al, 1997) and mental arithmetic (i.e., ability to perform calculations in your mind without writing them down) (Hubber et al, 2014). This is done by presenting a range of stimuli, one stimulus at the time. The participant's task is to report whether the present stimulus is identical to the stimulus presented n presentations ago. This is a task requiring a combination of "maintenance as well as active manipulation, that is, executive processes, because of the necessity to continuously encode, update, and discard the information held in WM with the presentation of each new stimulus" (Jaeggi et al, 2003, pp. 212). There are several levels of difficulty for the n-back test, depending on the n. When n equals 0 (i.e., 0-back), the task is to report whether a given stimulus is presented or not; when n equals 1 (i.e., 1-back), the task is to report whether the present stimulus is identical to the previous or not; when n equals 2 (i.e., 2-back), the task is to report whether the present stimulus is identical to the presentation before the last—and so on. The load on the participant's WM is considered to be proportional to the value of n (Braver et al, 1997). The test was written in E-Studio 2.0 (E-Prime Professional, Sharpsburg, PA) and presented via E-Run 2.0 (E-Prime Professional). The n-back version used in the present study was developed by Ben Robinson and Becky Fuller. It was downloaded from http://step.psy.cmu.edu/scripts-plus/ and adapted by the last author for Swedish testing. It consisted of a 0-back, 1-back, and 2-back task. Each n-back condition was repeated twice, one after the other. Stimuli used were capital letters presented in random order. In each trial, stimulus was presented for 500 msec followed by a 3,000 msec white screen before the next trial. For each trial, responses were allowed during these 3,500 msec and the participant had to decide whether the presented letter was a target or not by pressing the corresponding button on a keyboard. Each run consisted of 30 trials,

Table 2. Tinnitus Characteristics

		N
Lateralization	Bilateral	19
	Unilateral	6
	Undefined	6
Tinnitus character	Combination of tonal and noise	9
	Strictly tonal	18
	Strictly noise	2
	Undefined	2
Fluctuation in	Combination of intensity and pitch	11
	Strictly intensity	13
	Strictly pitch	2
	No fluctuations/constant tinnitus	5
Time with tinnitus (mo)	Min–Max	8–300
	Mean	117
	SD	76
Previous contact with health care	Yes	14
	No	17
Subjectively affected concentration due to tinnitus	Yes	20
	No	10

Note: n = 31.

where 10 were target stimuli. Before the actual trials, the participants carried out one practice session (consisting of 20 presentations, where 7 were targets) in each n-back subtask before the actual testing. When analyzing the results, participants' accuracy scores (i.e., percentage correct responses) was divided by average response times to obtain a measure of WM capacity (Stenbäck et al, 2016).

Questionnaires

Previous studies have typically controlled for parameters such as depression, anxiety, and tinnitus distress among their participants as these have been suggested to possibly have impact on task performance (Andersson et al, 2000; Kaiser et al, 2003; Hallam et al, 2004; Rossiter et al, 2006; Stevens et al, 2007; Cisler and Koster, 2010; Peckham et al, 2010). The most common ways to control for these conditions have been by letting participants fill out Hospital Anxiety and Disorder Scale (HADS) and the Tinnitus Questionnaire (TQ).

HADS

The Swedish version of the HADS questionnaire (Zigmond and Snaith, 1983; Andersson et al, 2003) was used to assess the participants' level of anxiety and depression (see scores in Table 3). HADS consists of 14 items, 7 of them measuring anxiety and 7 of them measuring depression. Each item is a statement, which the respondent scores 0–3 depending on how well the statement applies to the individual's situation. This results in scores ranging from 0 to 21 for each subscale, where scores less than 8 are categorized as normal, scores of 8–10 as borderline, and scores higher than 10 as clinical levels of anxiety or depression depending on subscale (Zigmond and Snaith, 1983). HADS has shown good validity and test–retest reliability (Herrmann, 1997; Bjelland et al, 2002).

TQ

The TQ, introduced by Hallam (1996), was used to assess tinnitus distress. TQ is a 52-item questionnaire that provides an estimate of tinnitus complaint across five dimensions; intrusiveness, auditory perceptual difficulties, sleep disturbances, emotional distress, and somatic complaints. Each item is a statement, which the respondent marks as "not true," "partly true," or "true" depending on how well the statement applies to the individual's situation. The score is based on 41 of the 52 items. Thus, a score range of 0–82 where a total score of 82 on the questionnaire indicates immense tinnitus distress and a score of 0 indicates very low tinnitus distress. TQ can be divided into five subscales: emotional distress (items 3, 8, 13, 16, 17, 18, 19, 20, 21, 24, 27, 28, 30, 37, 39, 41, 43, 44, and 47), auditory perceptual difficulties (items 2, 9, 14, 26, 33, 38, and 50), intrusiveness (items 5, 7, 10, 11, 15, 35, and 45), sleep disturbances (items 4, 12, 31, and 36), and somatic complaints (items 22, 25, 29, and 34). The TQ has shown good test–retest reliability (Hiller et al, 1994) and high validity (Snow, 2004).

Procedure

All testing was carried out in a sound-proof booth complying with ISO 8253-1. Each participant went through the following test battery:

- First, each participant's hearing thresholds were measured in accordance with ISO 8253-1 (2010) at octave intervals 0.125–8 kHz and also at higher frequencies (10, 12.5, 14, and 16 kHz).
- Thereafter, each participant was seated approximately one meter in front of a computer screen. They were presented with written instructions for the visual n-back test and were asked to indicate target and nontarget stimulus by pressing the designated key on a keypad as fast as possible. The participants performed 0-back, 1-back, and 2-back subtasks.
- Finally, each participant completed the HADS questionnaire, and the participants of the tinnitus group also completed the English version of the TQ as no Swedish translation was available. Ten participants of the tinnitus group completed the TQ at a later date and one participant did not complete the TQ, both deviations from the standard procedure because of administrative failure.

Table 3. Anxiety and Depression

		Total	Tinnitus Group	Control Group
HADS total score	Span	1–23	1–23	1–20
	Average	9.6	11.0	8.0
	SD	5.8	5.8	5.4
HADS anxiety score	Span	0–17	1–17	0–11
	Average	6.3	7.6	5.0
	SD	3.9	4.4	2.9
HADS depression score	Span	0–14	0–11	0–14
	Average	3.1	3.3	3.0
	SD	3.2	2.6	3.7

Further tests were carried out; however, those will not be reported in the present article.

RESULTS

HADS

Visual inspection of the histograms and Q-Q plots, calculation of skewness, and kurtosis z-values of collected data indicated normal distribution of HADS scores. See Table 3 for ranges, average, and standard deviations (SDs). T-tests revealed significant differences between the groups in terms of total ($t = 2.127$, $p = 0.038$) and anxiety scores ($t = 2.748$, $p = 0.008$), but no significant differences were seen between the groups in terms of depression scores ($t = 0.360$, $p = 0.720$) on HADS, indicating the tinnitus group to be more anxious but equally depressed compared with the control group.

TQ

The collection of the TQ revealed mean scores of 35.17, SD = 14.350 (range 15–72) for the tinnitus participants. Mean subscale scores: emotional distress: 11.7 (SD = 9.4), auditory perceptual difficulties: 3.7 (SD = 3.9), intrusiveness: 6.5 (SD = 2.7), sleep disturbances: 2.0 (SD = 1.9), somatic complaints: 3.7 (SD = 2.0). Twenty of the 30 tinnitus participants who filled out the TQ reported the statement "the noises have affected my concentration" to be true or partly true, whereas the remaining 10 participants reported that their tinnitus noises did not affect their concentration. When controlling for age, partial correlation between TQ score and 2-back performance was nonsignificant ($r = -0.214$, $p = 0.265$).

N-back

Visual inspection of the histograms and Q-Q plots, calculation of skewness, and kurtosis z-values of collected data indicated significant deviation from normal distribution for both response times and accuracy on the visual n-back test. Because of this, all n-back test data were analyzed using nonparametric statistical methods.

Friedman test of differences among repeated measures was conducted on the collected data of n-back performance, which rendered a χ^2 value of 74.00, which was significant ($p < 0.001$). Wilcoxon signed-rank tests indicated all n-back conditions to generate performances statistically significant different from each other, 0-back condition resulting in significantly higher scores than 1-back condition performances ($z = -4.58$, $p < 0.001$), and 1-back condition resulting in significantly higher scores than 2-back condition performances ($z = -6.44$, $p < 0.001$).

Figure 1 shows group performance on the visual n-back test. See Table 4 for ranges, average, SDs, and z- and p-values for each n-back condition. Mann–Whitney U-test revealed no statistical differences between the tinnitus group performance and the control group, with the exception of 2-back task where the tinnitus group had greater compared with the control group ($p = 0.007$, $z = -2.696$). This difference was still statistically significant when using the Benjamini–Hochberg procedure to adjust p-values for false discovery rate (Benjamini and Hochberg, 1995) (as the adjusted p-value = 0.01).

High-Frequency Hearing Thresholds

See Table 1 for average hearing thresholds at 10, 12.5, 14, and 16 kHz for all participants together and both groups separately. The following data analysis was done for all participants, irrespective of the groups. As age may be a confounding factor for both hearing status and WM capacity, we performed an initial Spearman's rank coefficient to examine the relationship between those parameters. This analysis showed age to be significantly correlated with mean hearing thresholds at 10, 12.5, 14, and 16 kHz of the participants' best ear ($r = 0.290$, $p = 0.022$), and therefore, a partial correction for age was included in the following analysis.

When controlling for age, we found significant partial correlations between mean hearing thresholds at 10, 12.5, 14, and 16 kHz of the participants' best ear and 1-back performance ($r = -0.280$, $p = 0.029$), as well as 2-back performance ($r = -0.309$, $p = 0.015$), but not between mean hearing thresholds at 10, 12.5, 14, and 16 kHz of the participants' best ear and 0-back

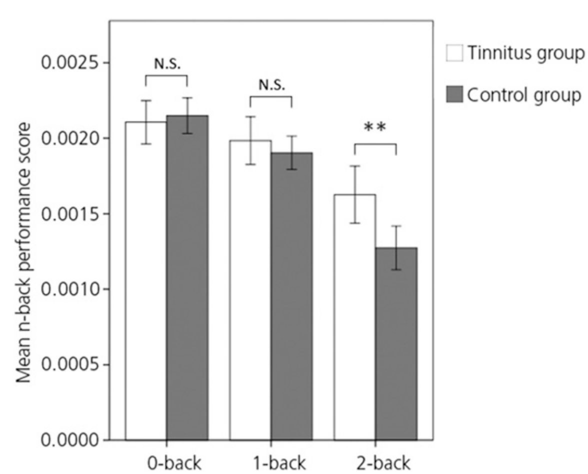

Figure 1. Mean performance scores (percentage correct responses divided by average response time) on the n-back test for each group and condition. Confidence interval for error bars: 95%. N.S. indicates nonsignificant difference ($p > 0.05$), asterisks indicate significant difference (*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$).

Table 4. Performance Scores (Accuracy Divided by Average Response Times) on Each N-Back Condition for Each Group

		0-Back	1-Back	2-Back
Tinnitus group	Range	0.0010–0.0028	0.0013–0.0031	0.0008–0.0028
	Average	0.0021	0.0020	0.0016
	SD	0.0004	0.0004	0.0005
Control group	Range	0.0013–0.0027	0.0012–0.0025	0.0007–0.0020
	Average	0.0021	0.0019	0.0013
	SD	0.0003	0.0003	0.0004
Mann–Whitney U	*z*	−0.317	−0.443	−2.696
	p	0.751	0.657	0.007

performance ($r = -0.150, p = 0.248$) (see visual presentation in Figure 2). These correlations were still significant when using the Benjamini–Hochberg procedure to adjust *p*-values for false discovery rate (Benjamini and Hochberg, 1995), as the adjusted *p*-values were equal to 0.044 for the 1-back condition and 0.023 for the 2-back condition.

DISCUSSION

Overall, there appeared to be no negative impact on WM capacity because of the presence of tinnitus. Although there were significant differences between the groups in terms of performance, it only occurred in one test condition of three possible and it indicated better performances in the tinnitus group than the control group. This finding is inconsistent with most of the previous studies investigating cognitive performances in tinnitus sufferers as they generally have indicated poorer performances on cognitive tests in participants with tinnitus compared with participants without (Andersson et al, 2000; Hallam et al, 2004; Dornhoffer et al, 2006; Rossiter et al, 2006; Stevens et al, 2007; Jackson et al, 2014). However, most previous studies have had a major limitation in common—poor control and matching of hearing status (Mohamad et al, 2016), which could play a critical role for the results as hearing impairment can have a negative impact on cognitive performance (Lin et al, 2011). However, the finding of this study is overall in line with the findings of Waechter and Brännström (2015), indicating tinnitus do not have a negative impact on cognitive performance in normal hearing individuals. The fact that the tinnitus group performed better on the 2-back condition may have several explanations. It is not impossible to by chance find a single significant difference between the two groups; however, the *p*-value of the effect is small enough to still be statistically significant after adjusting *p*-value using the Benjamini–Hochberg procedure, indicating that this difference probably is not a false discovery due to multiple testing. A more likely explanation could lie in the fact that the groups are not entirely optimally matched in terms of educational level. Tinnitus participants at group level had somewhat higher education than the control participants, which may have provided a slight advantage as higher education could lead to a greater experience of heavy load on WM. Furthermore, it is possible that the tinnitus participants were more motivated to perform their best, knowing that the study examined possible cognitive interference due to tinnitus. To compensate for such parameters, future studies should also include subjective or objective measures of effort while performing cognitive tasks.

HADS scores indicated equal levels of depression in tinnitus and control group, which leads us to conclude that level of depression cannot explain the lack of differences in response time between the groups. Nevertheless, we detected differences in terms of anxiety between the groups. However, anxiety, which has been suggested to imply poorer task performance (Cisler and Koster, 2010; Peckham et al, 2010), was higher in the tinnitus group. Therefore, the difference in terms of anxiety detected in the present study would not be an advantage for the tinnitus group and cannot be accounted for the results of this study being inconsistent with previous studies.

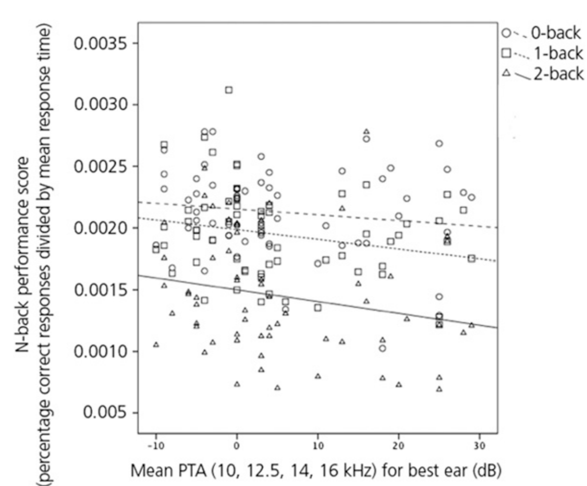

Figure 2. Correlation between n-back performance scores and mean pure tone audiometry (PTA) (10, 12.5, 14, and 16 kHz) of the best ear, for each participant and condition.

The presence of tinnitus does not seem to affect the participants' performance negatively, but hearing status may play a role. We found negative correlations between n-back performance and high-frequency hearing thresholds (10–16 kHz) of the participants' best ear (i.e., the poorer the high frequency hearing in best ear the lower WM capacity) for the more demanding n-back conditions (1-back and 2-back). The correlations had *p*-values indicating statistical significance after compensating for multiple testing, indicating that they were not false discoveries due to multiple testing. Furthermore, the trend was present even in the 0-back condition (as seen in Figure 2). A possible explanation for this effect could be the findings of Melcher et al (2013) indicating an amount of gray matter in subcallosal region to correlate negatively with high-frequency hearing thresholds (>8 kHz), but not the presence of tinnitus as previously proposed. As the subcallosal region is involved in attentional processes (Diamond, 2013), less gray matter in that region could imply greater difficulty with demanding cognitive tasks such as the visual n-back which supposedly could lead to the aforementioned poorer performances in individuals with poorer high-frequency hearing. It is possible that an individual with tinnitus would suffer from a decline in high-frequency hearing thresholds simultaneously with the initial experience of tinnitus (as both could follow an acoustic trauma). In such case individuals with tinnitus might experience cognitive decline due to their deteriorated high-frequency thresholds, but might subjectively link the effect on cognitive performance to their tinnitus as it is a more distinct symptom that arose same time as the actual underlying effect. Whether this indeed is the explanation is currently unclear, and further research is needed to better understand the underlying causes.

The fact that the effect on cognitive performance is not found in all n-back conditions could be due to floor effects which would be in line with the results presented in Figure 1 and results of Friedman test and Wilcoxon signed-rank tests conducted on the collected n-back performance data, indicating greater cognitive load for increased value of n at the n-back test. In other words, the 0-back condition might have constituted insufficient cognitive load. Another possible explanation could be that the effect size might be smaller for the 0-back condition, which in such case means that the lack of significance of less demanding n-back conditions could be a matter of sample size. Optimally one would define a minimal clinically important difference in advance to know critical sample size. However, because of scant previous empirical basis, any definition of minimal clinically important difference would essentially be guesses.

The finding that n-back performance and high-frequency hearing thresholds correlates could explain the conflicting findings among previous research. As most of the previous studies have a clear and common lack of proper control of hearing status among its participants (Andersson et al, 2000; Hallam et al, 2004; Dornhoffer et al, 2006; Rossiter et al, 2006; Stevens et al, 2007; Jackson et al, 2014), the possibility of hearing status in general and high-frequency hearing in particular having influenced the results cannot be ruled out. Furthermore, the probability of differences in terms of high-frequency hearing thresholds (10–16 kHz) to be present between the tinnitus and control groups in the study of Waechter and Brännström (2015) would be considerably lower as their participants had equal hearing thresholds on group level and every single subject had confirmed normal hearing thresholds between 0.125 and 8 kHz.

A limitation of the present study is that the participants were mainly young and with a relatively mild degree of tinnitus distress on average. The average TQ score was slightly lower for participants in the present study compared with previous studies—35.17 (maximum 82) compared with 47.64 reported by Stevens et al (2007) and 40.05 reported by Waechter and Brännström (2015). Previous studies have indeed indicated that impaired cognitive performance appears to be present even for groups with a low degree of tinnitus distress (Jackson et al, 2014). However, Jackson et al (2014) used a different questionnaire to evaluate tinnitus distress which makes it difficult to carry out an adequate comparison. Furthermore, because of the lack of control of hearing status in the study presented by Jackson et al (2014), it is also difficult to know to what extent these findings are applicable, thus it is possible that examination of individuals with more severe tinnitus could generate different results. We did, however, investigate whether tinnitus sufferers with greater distress performed worse than ones with milder degrees of distress, but as TQ score did not correlate with 2-back performance when controlling for age ($r = -0.214$, $p = 0.265$), we concluded that greater tinnitus distress did not imply poorer cognitive performances in our sample. Regarding the role of age, the empirical basis is too scant at the time of writing. Therefore, future research should investigate whether the tinnitus sufferer's age is of importance for the tinnitus' impact on cognitive performance.

Future studies should also investigate whether there is a link between subcallosal brain structure and n-back performance in individuals with and without tinnitus. The results of the present study and the results of Melcher et al (2013) suggests this could be the case, but to the authors' knowledge, no study has investigated this so far. Another point worth mentioning is that there is a growing empirical basis for determining which structures in the brain are active when performing the n-back task and how the neurological activity is affected by increased cognitive load (see Owen et al, 2005 for an overview). Investigating whether such functional magnetic resonance imaging data differ in tinnitus sufferers compared with individuals without tinnitus could entail a significant contribution to the current state of knowledge in the area of tinnitus and its relation to cognition.

CONCLUSIONS

Our present data suggest that presence of tinnitus might not have a negative impact on performance on a WM test with increasing load in normal hearing individuals, which is consistent with the findings of Waechter and Brännström (2015). However, the collected data indicate high-frequency hearing (10–16 kHz) to correlate with WM capacity, which is in line with the findings of Melcher et al (2013). Taken together, we suggest that hearing thresholds seem to be a critical parameter in the perceived effect of tinnitus on cognitive performance and that the relationship should be further investigated to enable establishment of proper interventions for tinnitus sufferers experiencing decline in cognitive performance.

REFERENCES

Andersson G, Baguley DM, McKenna L, McFerran DJ. (2005) *Tinnitus: A Multidisciplinary Approach*. London, United Kingdom: Whurr.

Andersson G, Eriksson J, Lundh L-G, Lyttkens L. (2000) Tinnitus and cognitive interference: a stroop paradigm study. *J Speech Lang Hear Res* 43(5):1168–1173.

Andersson G, Kaldo-Sandström V, Ström L, Strömgren T. (2003) Internet administration of the Hospital Anxiety and Depression Scale in a sample of tinnitus patients. *J Psychosom Res* 55(3):259–262.

Benjamini Y, Hochberg Y. (1995) Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J R Stat Soc* 57:289–300.

Bjelland I, Dahl AA, Haug TT, Neckelmann D. (2002) The validity of the Hospital Anxiety and Depression Scale. An updated literature review. *J Psychosom Res* 52(2):69–77.

Braver TS, Cohen JD, Nystrom LE, Jonides J, Smith EE, Noll DC. (1997) A parametric study of prefrontal cortex involvement in human working memory. *Neuroimage* 5(1):49–62.

Cisler JM, Koster EHW. (2010) Mechanisms of attentional biases towards threat in anxiety disorders: an integrative review. *Clin Psychol Rev* 30(2):203–216.

Cohen JD, Perlstein WM, Braver TS, Nystrom LE, Noll DC, Jonides J, Smith EE. (1997) Temporal dynamics of brain activation during a working memory task. *Nature* 386(6625):604–608.

Diamond A. (2013) Executive functions. *Annu Rev Psychol* 64(1): 135–168.

Dornhoffer J, Danner C, Mennemeier M, Blake D, Garcia-Rill E. (2006) Arousal and attention deficits in patients with tinnitus. *Int Tinnitus J* 12(1):9–16.

Hallam RS. (1996) *Manual of the Tinnitus Questionnaire*. London, United Kingdom: Psychological Corporation.

Hallam RS, McKenna L, Shurlock L. (2004) Tinnitus impairs cognitive efficiency. *Int J Audiol* 43(4):218–226.

Herrmann C. (1997) International experiences with the Hospital Anxiety and Depression Scale—a review of validation data and clinical results. *J Psychosom Res* 42(1):17–41.

Hiller W, Goebel G, Rief W. (1994) Reliability of self-rated tinnitus distress and association with psychological symptom patterns. *Br J Clin Psychol* 33(Pt 2):231–239.

Hubber PJ, Gilmore C, Cragg L. (2014) The roles of the central executive and visuospatial storage in mental arithmetic: a comparison across strategies. *Q J Exp Psychol (Hove)* 67(5):936–954.

ISO 389-8. (2004) *Acoustics—Reference Zero for the Calibration of Audiometric Equipment—Part 8: Reference Equivalent Threshold Sound Pressure Levels for Pure Tones and Circumaural Earphones*. Geneva, Switzerland: International Organization for Standardization.

ISO 389-5. (2006) *Acoustics—Reference Zero for the Calibration of Audiometric Equipment—Part 5: Reference Equivalent Threshold Sound Pressure Levels for Pure Tones in the Frequency Range 8 to 16 kHz*. Geneva, Switzerland: International Organization for Standardization.

ISO 8253-1. (2010) *Acoustics—Audiometric Test Methods*. Geneva, Switzerland: International Organization for Standardization.

Jackson JG, Coyne IJ, Clough PJ. (2014) A preliminary investigation of potential cognitive performance decrements in non-help-seeking tinnitus sufferers. *Int J Audiol* 53(2):88–93.

Jaeggi SM, Seewer R, Nirkko AC, Eckstein D, Schroth G, Groner R, Gutbrod K. (2003) Does excessive memory load attenuate activation in the prefrontal cortex? Load-dependent processing in single and dual tasks: functional magnetic resonance imaging study. *Neuroimage* 19(2 Pt 1):210–225.

Kaiser S, Unger J, Kiefer M, Markela J, Mundt C, Weisbrod M. (2003) Executive control deficit in depression: event-related potentials in a Go/Nogo task. *Psychiatry Res* 122(3):169–184.

Kirchner WK. (1958) Age differences in short-term retention of rapidly changing information. *J Exp Psychol* 55(4):352–358.

Leaver AM, Renier L, Chevillet MA, Morgan S, Kim HJ, Rauschecker JP. (2011) Dysregulation of limbic and auditory networks in tinnitus. *Neuron* 69(1):33–43.

Lin FR, Ferrucci L, Metter EJ, An Y, Zonderman AB, Resnick SM. (2011) Hearing loss and cognition in the Baltimore longitudinal study of aging. *Neuropsychology* 25(6):763–770.

Lyxell B, Rönnberg J, Samuelsson S. (1994) Internal speech functioning and speechreading in deafened and normal hearing adults. *Scand Audiol* 23(3):179–185.

Melcher JR, Knudson IM, Levine RA. (2013) Subcallosal brain structure: correlation with hearing threshold at supra-clinical frequencies (>8 kHz), but not with tinnitus. *Hear Res* 295:79–86.

Mohamad N, Hoare DJ, Hall DA. (2016) The consequences of tinnitus and tinnitus severity on cognition: a review of the behavioural evidence. *Hear Res* 332:199–209.

Mühlau M, Rauschecker JP, Oestreicher E, Gaser C, Röttinger M, Wohlschläger AM, Simon F, Etgen T, Conrad B, Sander D. (2006) Structural brain changes in tinnitus. *Cereb Cortex* 16(9): 1283–1288.

Owen AM, McMillan KM, Laird AR, Bullmore E. (2005) N-back working memory paradigm: a meta-analysis of normative functional neuroimaging studies. *Hum Brain Mapp* 25(1):46–59.

Peckham AD, McHugh RK, Otto MW. (2010) A meta-analysis of the magnitude of biased attention in depression. *Depress Anxiety* 27(12):1135–1142.

Rossiter S, Stevens C, Walker G. (2006) Tinnitus and its effect on working memory and attention. *J Speech Lang Hear Res* 49(1): 150–160.

Snow JB. (2004) *Tinnitus: Theory and Management*. Hamilton, OH: BC Decker Inc.

Stenbäck V, Hällgren M, Larsby B. (2016) Executive functions and working memory capacity in speech communication under adverse conditions. *J Speech Lang Hear Res* 19(4):218–226.

Stevens C, Walker G, Boyer M, Gallagher M. (2007) Severe tinnitus and its effect on selective and divided attention. *Int J Audiol* 46(5):208–216.

Waechter S, Brännström KJ. (2015) The impact of tinnitus on cognitive performance in normal-hearing individuals. *Int J Audiol* 54(11):845–851.

Zigmond AS, Snaith RP. (1983) The hospital anxiety and depression scale. *Acta Psychiatr Scand* 67(6):361–370.