

Reading Comprehension in Quiet and in Noise: Effects on Immediate and Delayed Recall in Relation to Tinnitus and High-Frequency Hearing Thresholds

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Abstract

Background: A common complaint by people with tinnitus is that they experience that the tinnitus causes attention and concentration problems. Previous studies have examined how tinnitus influences cognitive performance on short and intensive cognitive tasks but without proper control of hearing status.

Purpose: To examine the impact tinnitus and high-frequency hearing thresholds have on reading comprehension in quiet and in background noise.

Research Design: A between-group design with matched control participants.

Study Sample: One group of participants with tinnitus ($n = 20$) and an age and gender matched control group without tinnitus ($n = 20$) participated. Both groups had normal hearing thresholds (20 dB HL at frequencies 0.125 to 8 kHz).

Data Collection and Analysis: Measurements were made assessing hearing thresholds and immediate and delayed recall using a reading comprehension test in quiet and in noise. All participants completed the Swedish version of the Hospital Anxiety and Depression Scale, and participants with tinnitus also completed the Tinnitus Questionnaire.

Results: The groups did not differ in immediate nor delayed recall. Accounting for the effect of age, a significant positive correlation was found between best ear high-frequency pure tone average (HF-PTA; 10000, 12500, and 14000 Hz) and the difference score between immediate and delayed recall in noise.

Conclusions: Tinnitus seems to have no effect on immediate and delayed recall in quiet or in background noise when hearing status is controlled for. The detrimental effect of background noise on the processes utilized for efficient encoding into long-term memory is larger in participants with better HF-PTA. More specifically, when reading in noise, participants with better HF-PTA seem to recall less information than participants with poorer HF-PTA.

Key Words: cognitive performance, high-frequency hearing, normal hearing, tinnitus

Abbreviations: dB HL = decibel hearing level; HADS = Hospital Anxiety and Depression Scale; HF-PTA = high-frequency pure tone average; Hz = hertz; PTA = pure tone average; SD = standard deviation; TQ = Tinnitus Questionnaire

INTRODUCTION

The present study explores the impact tinnitus and high-frequency hearing thresholds have on reading comprehension in quiet and in background noise and how efficiently information is encoded into long-term memory in participants with normal

hearing. Tinnitus can be defined as a sound perception without the presence of an external sound source (Andersson et al, 2005). People with tinnitus often report that their tinnitus causes attention and concentration problems (Waechter and Brännström, 2015), but previous studies have mainly examined how tinnitus influences cognitive performance on short and intensive

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cognitive tasks (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 overall finding has been that participants with tinnitus show longer response times which have been assumed to indicate that tinnitus is the cause for this prolongation of response times (Andersson et al, 2000; Rossiter et al, 2006; Stevens et al, 2007; Jackson et al, 2014). However, these previous studies lack control for the participants' hearing status (Andersson et al, 2000; Hallam et al, 2004; Dornhoffer et al, 2006; Rossiter et al, 2006; Stevens et al, 2007; Jackson et al, 2014) which is known to influence cognitive performance (Lyxell et al, 1994; Lin et al, 2011). After controlling for the participants' hearing status under the assumption that hearing status influences cognitive performance, Waechter and Brännström (2015) found no significant differences on a Stroop task for participants with normal hearing with and without tinnitus. They concluded that the differences reported in previous studies may be caused by the participants' hearing status or the interaction between hearing status and tinnitus.

However, despite no difference in cognitive performance, participants still report that they experience that tinnitus causes attention and concentration problems (Waechter and Brännström, 2015). Furthermore, one of the most common challenges which seem to require high cognitive performance is focusing on work tasks while perceiving task-irrelevant speech signals (Banbury and Berry, 2005; Schlittmeier et al, 2008). Schlittmeier et al (2008) tested the effect of task-irrelevant speech signals using tasks assessing short-term memory and mental arithmetics and found that performance deteriorated in the presence of task-irrelevant speech at the conversational level compared with performance in quiet. Hygge et al (2003) reported poorer delayed recall (after approximately 80 min) of texts read in both road traffic noise and multitalker babble noise in young adults compared with text read in quiet. This suggests that the presence of noise at the time of encoding has a detrimental effect on what is stored in the long-term memory. Furthermore, Sörqvist et al (2010) also demonstrated a negative effect of a competing speaker on delayed recall of read texts compared to reading in silence mediated by a specific subprocess of the working memory capacity, which indicated that participants with higher performance in that subprocess were less affected by the competing speaker. Based on these findings, cognitive resources seem to be required to suppress the task-irrelevant signals, which in turn leaves less resources available for encoding into long-term memory for later recall. In the present study, by viewing the presence of tinnitus as a task-irrelevant noise source, participants with tinnitus would have poorer delayed responses in quiet than participants without tinnitus. In addition, the effect of task-irrelevant

speech on task performance is not known in participants with tinnitus.

Previous research indicates that participants with tinnitus display smaller amounts of subcallosal gray matter compared with participants without tinnitus (Mühlau et al, 2006; Leaver et al, 2011). Attentional processes require processing in this region (Melcher et al, 2013). This in combination with the reduced amount of gray matter in this region for participants with tinnitus could potentially be an explanation for why participants with tinnitus experience poorer cognitive performance. As in the case of many previous studies on cognitive performance in participants with tinnitus, the studies by Leaver et al (2011) and Mühlau et al (2006) lacked sufficient control of hearing status among the tinnitus participants. Melcher et al (2013) controlled for hearing status also in the high-frequency range and found a negative association between the amount of subcallosal gray matter and hearing thresholds for frequencies 9000–14000 Hz. However, contrary to the previous findings, Melcher et al (2013) found no association between the amount of subcallosal gray matter and presence of tinnitus or tinnitus severity, indicating the importance of examining tinnitus in relation to high-frequency hearing thresholds.

Based on this, the overall aim is to examine the impact tinnitus and high-frequency hearing thresholds have on reading comprehension in quiet and in background noise.

METHODS

Participants

The data collected are a part of a larger study on participants with tinnitus. Initially, 42 participants with and without tinnitus were recruited from audiological clinics, through advertisements, and personal contacts. Based on their personal reports on having tinnitus, these participants were allocated to two groups, one with tinnitus (tinnitus group; $n = 22$) and one without (control group; $n = 20$). To be included, all participants had to be 18 yrs old or older and demonstrate pure tone hearing thresholds <20 dB HL at octave frequencies from 125 to 8000 Hz. Furthermore, to be included in the tinnitus group, the participant was required to report the experience of tinnitus for the past 6 mo or more. In addition, the participants in the control group were age and sex matched to each tinnitus participant with a maximum age difference of 12 mo allowed. Based on this, two participants in the tinnitus group were excluded; one participant had too poor hearing thresholds, and in one case, we were unable to find an age and sex matched control fitting with our pure tone hearing threshold criterion. All participants provided written informed consent, and the Regional Ethics Board in

Lund, Sweden, approved the study (approval number 2014/95).

Pure Tone Hearing Thresholds

Pure tone hearing thresholds were measured according to ISO (1998) for frequencies 125, 250, 500, 1000, 1500, 2000, 3000, 4000, 6000, 8000, 10000, 12500, 14000, and 16000 Hz using a Madsen Astera² (GN Otometrics) audiometer connected to Sennheiser HDA 200 sound attenuating circumaural earphones. This setup was calibrated according to ISO (2004) and ISO (2006) (except 16000 Hz which was calibrated according to the manufacturers' instructions), and the test was performed in a soundproof booth.

Reading Comprehension Task

The reading comprehension task consisted of two texts and four content questions about each text collected from the standardized test for applications to higher education provided by the Swedish Council for Higher Education. The texts were "Transport av koldioxid" ("Transport of carbon dioxide") by Leif Andersson and "Arbetslösa i rörelse" ("Unemployed in motion") by Ulf Andréasson, both in Swedish. The texts were presented on paper (approximately 1100 words each), and the participants responded to the four content questions (e.g., "The amount of water that is transported north from the Atlantic Ocean is important for how much carbon dioxide that can be absorbed. What is the reason for that?") by marking one out of four possible response options using a pen. For all participants, one text was read in quiet and one in background noise. The presentation order of the texts and the background listening condition was balanced across the participants to avoid any order or fatigue effects. The participants responded to the content questions twice, thus assessing reading comprehension first immediately after reading the text (immediate recall) and then again after approximately 30 min (delayed recall).

The background noise was a multitalker babble noise consisting of three male speakers. The noise was generated by extracting 9 min and 50 sec from three audio books in Swedish using a 44.1 kHz/16 bit sampling frequency (Hägg, 2008; Brown, 2013; Hjort and Rosenfeldt, 2013). First, the three signals were normalized to the same average root mean square in dB after removing pauses and other silent sections. Then, the signals were combined into a single signal after adding the pauses and other silent sections. Finally, a calibration tone (1000 Hz) with the same average root mean square as the combined signal was made. Signal extraction and manipulations were all made in Adobe Audition (version 6; Adobe Systems, San José, CA).

The test was made in a soundproof booth complying with the maximum permissible background noise lev-

els in ISO (1998). The background noise was presented using Sennheiser HDA 200 sound attenuating circumaural earphones. Using the calibration tone, the presentation level was set to 77 dB SPL (corresponding to 55 dB HL) as verified by a Brüel and Kjaer 2231 sound level meter with a 4134 microphone in a 4153 coupler.

Questionnaires

As it has previously been shown that tinnitus distress, anxiety, and depression may have a negative influence on task performance for participants with tinnitus (Andersson et al, 2000; Hallam et al, 2004; Rossiter et al, 2006; Stevens et al, 2007; Cisler and Koster, 2010; Peckham et al, 2010), the participants in the tinnitus group completed both the Tinnitus Questionnaire (TQ) and the Hospital Anxiety and Disorder Scale (HADS). The participants in the control group without tinnitus completed HADS.

The individual level of anxiety and depression was assessed using the Swedish version of the HADS (Zigmond and Snaith, 1983; Andersson et al, 2003). The HADS consists of 14 items divided into two subscales, anxiety (uneven items) and depression (even items), respectively, each consisting of seven items. In each item, a statement is provided, and the participant is required to respond to what extent the statement applies to his/her own situation by selecting one out of four response options. For each item, scores can range from 0 to 3 depending on to what extent the statement applies to his/her own situation. The scores are summarized for each subscale (range 0–21). According to Zigmond and Snaith (1983), scores below eight are considered to be normal levels of anxiety or depression, whereas scores between eight and 10 represent borderline levels, and scores higher than 10 represent clinical levels. The test-retest reliability and test validity for the HADS is high (Herrmann, 1997; Bjelland et al, 2002).

Tinnitus distress was assessed using the TQ (Hallam, 1996). The TQ consists of 52 items. In each item, a statement is provided, and the participant is required to respond to what extent the statement applies to his/her own situation by selecting "not true" (score = 0), "partly true" (score = 1), or "true" (score = 2). Eleven items of the 52 are discarded at the stage of scoring, and the total score (range 0–82) is thus the sum of the responses on 41 items. A higher score indicates more tinnitus distress. These 41 items can also be arranged into five subscales assessing emotional distress (sum of items 3, 8, 13, 16, 17, 18, 19, 20, 21, 24, 27, 28, 30, 37, 39, 41, 43, 44, and 47), auditory perceptual difficulties (sum of items 2, 9, 14, 26, 33, 38, and 50), intrusiveness (sum of items 5, 7, 10, 11, 15, 35, and 45), sleep disturbances (sum of items 4, 12, 31, and 36), and somatic complaints (sum of items 22, 25, 29, and 34) caused by tinnitus. The test-retest

reliability and test validity for the TQ are high (Hiller et al, 1994; Snow, 2004).

Procedures

The tests were made in a soundproof booth complying with the maximum permissible background noise levels in ISO (1998). First, otoscopy was performed, and pure tone hearing thresholds were measured. Second, the reading comprehension task was made for both conditions. Third, additional tests (including, for example, a visual working memory task in quiet and in noise) were made, which are not reported in the present study. Fourth, after an approximately 30-min delay, the content questions in the reading comprehension task were responded to a second time. Finally, all participants completed the HADS, and the participants in the tinnitus group completed the TQ.

RESULTS

The results are reported as immediate and delayed recall for reading comprehension in quiet and in noise, and best ear average high-frequency pure tone average (HF-PTA) hearing thresholds for frequencies 10000, 12500, and 14000 (16000 Hz was excluded because it was not calibrated according to a standard).

Nonparametric statistics were used in all analyses because almost all variables were not normally distributed as assessed using the Komolgorov–Smirnov test. An alpha-level of 0.05 was considered significant in all analyses. Descriptive information on the tinnitus group and the control group is presented in Table 1. As seen in the table, significant differences in HADS total, HADS anxiety, and HADS depression scores were seen, indicating higher scores for the tinnitus group.

The average immediate and delayed recall for reading comprehension in quiet and in noise is shown in Figure 1 and in Table 2 along with standard deviations (SDs). No significant differences were seen between the tinnitus group and the control group in any condition using the Mann–Whitney *U* test ($Z \leq -1.333$, $p \geq 0.183$). A significant within-subject effect was seen for test condition using Friedman's test for the tinnitus group ($\text{Chi}^2 = 14.981$, $p = 0.002$). Post hoc test with Wilcoxon Signed Rank test showed only significant differences between immediate and delayed recall in quiet ($Z = -3.307$, $p = 0.001$) and in noise ($Z = -2.174$, $p = 0.030$). No significant within-subject effect was seen for test condition using Friedman's test ($\text{Chi}^2 = 3.651$, $p = 0.302$) for the control group.

As no significant differences were seen between the tinnitus group and the control group, all participants were pooled together into one group, and the within-

Table 1. Descriptive Information for the Tinnitus Group and the Control Group without Tinnitus

		Tinnitus Group (n = 20)	Control Group (n = 20)	Chi ² or Z
Sex	Female/Male	12/8	12/8	0.000
Age	Average (SD)	26.9 (6.2)	27.1 (6.1)	-0.150
	Median	24.7	24.8	
	Min-Max	20.9–44.3	21.1–43.8	
Educational level	High school/University	1/19	6/14	
Best ear PTA (dB HL)	Average (SD)	0.5 (4.3)	0.5 (3.6)	-0.041
	Median	0.0	0.0	
	Min-Max	-6.0 to 9.0	-5.0 to 9.0	
Best ear high-frequency PTA (dB HL)	Average (SD)	3.9 (0.6)	5.4 (8.6)	-0.502
	Median	1.7	4.2	
	Min-Max	-10.0 to 23.3	-6.7 to 20.0	
HADS total score	Average (SD)	10.4 (5.3)	6.7 (5.0)	-2.040*
	Median	10	6	
	Min-Max	1–20	1–20	
HADS anxiety score	Average (SD)	7.5 (4.0)	4.6 (2.8)	-2.002*
	Median	7	5	
	Min-Max	1–15	0–9	
HADS depression score	Average (SD)	2.8 (2.1)	2.1 (3.4)	-2.040*
	Median	2	2	
	Min-Max	0–7	0–14	
TQ total score	Average (SD)	30.3 (11.0)		
	Median	28.0		
	Min-Max	15–59		

Notes: Best ear PTA was calculated as the average pure tone hearing thresholds for frequencies 0.5, 1.0, 2.0, and 4.0 kHz. Best ear high-frequency PTA was calculated as the average pure tone hearing thresholds for frequencies 10.0, 12.5, and 14.0 kHz. *Indicates significant difference ($p < 0.05$).

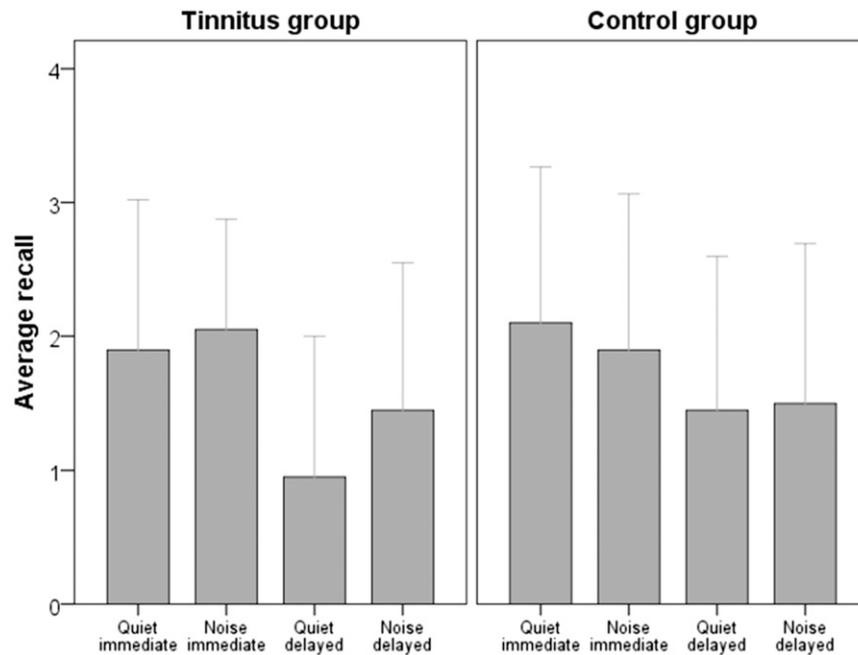


Figure 1. The average immediate and delayed recall for reading comprehension in quiet and in noise for the tinnitus group and the control group without tinnitus. Error bars denote SDs.

subjects effect was tested again. A significant within-subject effect was seen for test condition using Friedman's test ($\text{Chi}^2 = 17.550, p = 0.001$). Post hoc test with Wilcoxon Signed Rank test showed significant differences between immediate and delayed recall in quiet ($Z = -3.614, p < 0.001$) and in noise ($Z = -2.651, p = 0.008$).

Interaction with Age and High-Frequency Hearing Thresholds

Difference scores were calculated between the different background listening conditions for immediate and delayed recall to generate direct measures of the effect of the background listening conditions. Furthermore, difference scores were calculated between immediate and delayed recall within the same background condition to generate immediate measures of the efficiency to encode information into long-term memory for each background listening condition. The difference scores and their SDs are shown in Table 3. Spearman's rank correlation coefficient (ρ) was then used to estimate

the interaction between the effect of background listening condition, the efficiency to encode into long-term memory, age, and best ear HF-PTA. The correlation analyses were made using all participants pooled together into one group as no significant differences were seen between the tinnitus group and the control group.

A first correlation analysis demonstrated a significant correlation between best ear HF-PTA and the difference score between immediate and delayed recall in noise ($\rho = -0.457, p = 0.003$), indicating that participants with better best ear HF-PTA were less efficient at encoding the text content into long-term memory when reading in noise. However, the correlation analysis also showed that age was significantly associated with best ear HF-PTA ($\rho = 0.444, p = 0.004$), indicating that older participants had poorer best ear HF-PTA. Therefore, to remove the influence of age on the correlation between best ear HF-PTA and the difference score between immediate and delayed recall in noise, a second correlation analysis, the Spearman partial correlation analysis, was made using the same variables as in the first analysis while controlling for age (Conover,

Table 2. Mean and SD for Immediate and Delayed Reading Comprehension Recall in Quiet and in Noise for the Tinnitus Group and the Control Group without Tinnitus

		Quiet Immediate	Noise Immediate	Quiet Delayed	Noise Delayed
Tinnitus group (n = 20)	M	1.9	2.1	1.0	1.5
	SD	1.1	0.8	1.1	1.1
Control group (n = 20)	M	2.1	1.9	1.5	1.5
	SD	1.2	1.2	1.1	1.2

Note: M = mean.

Table 3. Mean and SD for the Difference Scores for Immediate and Delayed Reading Comprehension Recall in Quiet and in Noise for All Participants Pooled Together

	Quiet Immediate - Noise Immediate	Quiet Delayed - Noise Delayed	Quiet Immediate - Quiet Delayed	Noise Immediate - Noise Delayed
M	0.03	-0.28	0.80	0.50
SD	1.32	1.48	1.22	1.11

Note: M = mean.

1999). In this analysis, a significant correlation was still seen between best ear HF-PTA and the difference score between immediate and delayed recall in noise ($\rho = -0.469$, $p = 0.003$), indicating that the correlation between best ear HF-PTA and the measure of the efficiency to encode text content into long-term memory is not a result of the correlation between age and best ear HF-PTA.

DISCUSSION

The present findings showed that tinnitus had no effect on immediate and delayed reading comprehension recall obtained in quiet and in background noise. However, the findings showed that participants with better best ear high-frequency hearing thresholds were less efficient at encoding the text content into long-term memory while reading in noise. This indicates that high-frequency hearing thresholds might be important for the processes utilized for efficient encoding into long-term memory in noise.

The Effect of Tinnitus on Immediate and Delayed Recall in Quiet

Most previous studies have shown that participants with tinnitus show longer response times on cognitive tests which have been interpreted to indicate that tinnitus is the cause for the response time prolongation (Andersson et al, 2000; Rossiter et al, 2006; Stevens et al, 2007; Jackson et al, 2014). However, in these previous studies, it has not been possible to discern whether the differences between participants with and without tinnitus depend on tinnitus, hearing loss, or the combination of tinnitus and hearing loss. As it is known that hearing status influences cognitive performance (Lin et al, 2011; Lyxell et al, 1994), it is possible that the differences seen in previous studies between the tinnitus group and the control group depend on hearing status or hearing status in combination with tinnitus. Waechter and Brännström (2015) controlled for the participants' hearing status and used a short and intensive cognitive test similar to previous studies (a version of visual Stroop task). Waechter and Brännström (2015) found no difference between matched groups of normal-hearing participants with tinnitus and without tinnitus. In the present study, we also controlled for the

participants' hearing status and found similar results, although we used a different type of task (a reading comprehension task).

Previous studies suggest that the presence of noise at the time of encoding has a detrimental effect on what is stored in the long-term memory (Hygge et al, 2003; Sörqvist et al, 2010). These findings suggest that more cognitive resources have to be used to suppress the task-irrelevant signal, leaving less resources available for encoding into long-term memory for later recall. Initially, we assumed that the presence of tinnitus could be considered a task-irrelevant noise source that uses cognitive resources to suppress tinnitus which in turn leaves less resources available for encoding into long-term memory for later recall. This in turn would be seen in participants with tinnitus showing poorer immediate and delayed recall in quiet than participants without tinnitus. Despite the slightly poorer performance seen for delayed recall in quiet for the tinnitus group (Figure 1 and Table 2), the present findings indicate that there seems to be no difference between matched normal-hearing participants with and without tinnitus in immediate and delayed reading comprehension recall obtained in quiet is in contrast to this assumption. Together, the findings in quiet of the present study and those of Waechter and Brännström (2015) suggest that after removing the effect of hearing status, cognitive performance in quiet is similar for normal-hearing participants with tinnitus and normal-hearing participants without tinnitus.

There are several possible reasons why the present findings demonstrate no differences between matched normal-hearing participants with and without tinnitus in immediate and delayed reading comprehension recall obtained in quiet. The first may be that there are no differences in cognitive performance between the groups. This would be in contrast to previous studies reporting that the participants themselves experience their tinnitus causing attention and concentration problems, which makes them more tired at the end of the day (Waechter and Brännström, 2015). Also, this seems unlikely, as the present participants with tinnitus reported that their tinnitus had a negative impact on their concentration, but future studies are required to elucidate this matter. The second is that the measures applied (i.e., immediate and delayed recall) in the reading comprehension task have masked

any effects. The measures may well be valid but the low number of content questions in relation to the number of response options may have reduced the actual variance among test participants. In future studies, it is important to increase the number of content questions. The third is that the sample size is relatively small, making comparisons that in a larger sample would have rendered significant differences not significant. The fourth is that there may be differences between the individuals in the tinnitus group and the control group for which the matching did not account. For example, the participants in the tinnitus group reported higher educational level than those in the control group. Higher educational achievement is known to be related to higher working memory capacity (Alloway and Alloway, 2010) which is used for the encoding of information into long-term memory (Rönnerberg, 2003; Rönnerberg et al, 2008; 2013). Therefore, in future studies it is important to either include additional demographic details in the matching criteria or collect them to exclude potential covariates.

The Effect of Tinnitus on Immediate and Delayed Recall in Noise

The present findings indicate that the effect of task-irrelevant speech on task performance for the participants with tinnitus seems not to differ from the effects seen for the participants without tinnitus. A concern here is that when we pooled all participants and examined the effect of background noise, we found no effect of background noise on immediate or delayed recall. This is in contrast to previous studies that indicate that work tasks performed while perceiving task-irrelevant speech signals provide challenges that require high cognitive performance in comparison to those conducted in quiet (Hygge et al, 2003; Sörqvist et al, 2010). There are several possible reasons why the present findings differ from those previously reported. One reason is that the present findings could be an effect of a small sample size, although the sample size is similar to that of Sörqvist et al (2010). Another reason is that the small sample size in combination with the relatively small number of content questions for the reading comprehension task (only four questions) have masked the effects of performing the task in background noise. In addition, the participants' familiarity with the passage content may have influenced the present findings. Reading comprehension requires the participant to understand the content linguistically and to integrate previous experiences and knowledge about the world with linguistic knowledge (Kintsch, 1988; Bishop, 1997; Kim, 2016). Both Hygge et al (2003) and Sörqvist et al (2010) removed the effect of the participant's prior knowledge of the world and participant content by sometimes using imaginary words and by removing real names. In

the present study, we used texts collected from the standardized test for applications to higher education provided by the Swedish Council for Higher Education that were on real topics. Therefore, it is possible that our participants' knowledge about the world has influenced the results, occluding possible noise effects. On the other hand, in the studies by Hygge et al (2003) and Sörqvist et al (2010), no proper control of the participants' hearing status was made, which may be the cause of the differences in findings.

The Effect of High-Frequency Hearing on Immediate and Delayed Recall

Attentional processes require processing in the subcallosal region (Melcher et al, 2013), and reduced amount of gray matter in this region for participants with tinnitus could potentially be an explanation for why participants with tinnitus experience poorer cognitive performance (Mühlau et al, 2006; Leaver et al, 2011). However, after controlling for hearing thresholds, Melcher et al (2013) found no association between the amount of subcallosal gray matter and presence of tinnitus or tinnitus severity. On the other hand, they found a negative association between the amount of subcallosal gray matter and hearing thresholds for frequencies 9000–14000 Hz (Melcher et al, 2013), suggesting that high-frequency hearing thresholds could be related to the efficiency of attentional processes. It is unclear how the results in the present study fit with the findings by Melcher et al (2013). If less subcallosal gray matter is related to poorer hearing thresholds, it is possible that we would expect the opposite of the present finding that better best ear high-frequency hearing thresholds were correlated with poorer delayed recall on the reading comprehension task in noise. However, the present findings could also be in line with Melcher et al (2013): assuming that the task demand level makes the participants with poorer hearing thresholds use all available cognitive capacity for the task because of the less amount of subcallosal gray matter, the task level demands leave the participants with better hearing thresholds and thus more subcallosal gray matter with cognitive resources available for processing of the task-irrelevant noise input signal. However, as neurological structures were not examined in participants of the present study, future studies are required to answer this question.

We also found that high-frequency hearing thresholds increased with increasing age. This is an expected finding as it is well established that hearing thresholds increase with increasing age (ISO, 2000). However, when the effect of age was accounted for in the statistical analysis, we still found a significant correlation between best ear high-frequency hearing thresholds. Therefore, the present findings indicate that participants with better best ear high-frequency hearing

thresholds were less efficient at storing the text content into long-term memory when reading in noise. Therefore, it is possible to extend the findings of Hygge et al (2003) and Sörqvist et al (2010) that the presence of noise at the time of encoding has a detrimental effect on what is stored in the long-term memory: those with better high-frequency hearing thresholds have to suppress the task-irrelevant information to a higher extent. This would require a higher amount of explicit processing involving more cognitive resources, which in turn results in less resources available for encoding into long-term memory. And in the opposite direction, poorer high-frequency hearing thresholds resulting in less or lower levels of masking would require less resources for suppression of the task-irrelevant information. This finding also suggests that high-frequency hearing thresholds are more important than the presence of tinnitus for this type of task. However, future studies are required.

Study Limitations

We found significantly higher scores on the HADS total score, anxiety subscale, and depression subscale for the tinnitus group than for the control group. As higher level of anxiety and depression could affect task performance negatively (Cisler and Koster, 2010; Peckham et al, 2010), we could expect the tinnitus group to perform more poorly on the reading comprehension task. However, we found no significant difference between the groups, indicating that despite the fact that the tinnitus group had higher levels of anxiety and depression, they were not poorer performers than the control group. This provides additional support to the main finding of the present study that there was no significant effect of tinnitus on reading comprehension performance in quiet and in noise.

Previous studies have involved older participants with tinnitus that on average have reported higher degrees of tinnitus distress than seen in the present study (Stevens et al, 2007; Waechter and Brännström, 2015). This is a limitation in the present study as more severe tinnitus distress than encountered in the present study may affect reading comprehension performance. However, despite sufficient control of hearing status, the findings of Jackson et al (2014) suggest that even low degrees of tinnitus distress affect cognitive performance. Therefore, the influence of tinnitus distress cannot explain the lack of differences found in the present study. Future studies with control of hearing status that test reading comprehension in participants with more severe tinnitus could elucidate this matter more. It is also possible that tinnitus loudness could have influenced the present findings, but as no differences were found between the tinnitus and the control groups, this has most likely not had an impact.

Conclusions

The present findings showed that tinnitus had no effect on immediate and delayed reading comprehension recall in quiet and in background noise when hearing status is controlled for. In addition, the findings suggest that the detrimental effect of background noise on the processes utilized for efficient encoding into long-term memory is larger in participants with better high-frequency hearing thresholds. More specifically, when reading in noise, participants with better HF-PTA seem to recall less information than participants with poorer HF-PTA.

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