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Severe tinnitus and its effect on selective and divided attention

Acufeno severo y sus efectos sobre la atención selectiva y dividida

Abstract
The effect of chronic, severe tinnitus on two visual tasks was investigated. A general depletion of resources hypothesis states that overall performance would be impaired in a tinnitus group relative to a control group whereas a controlled processing hypothesis states that only tasks that are demanding, requiring strategic processes, are affected. Eleven participants who had experienced severe tinnitus for more than two years comprised the tinnitus group. A control group was matched for age and verbal IQ. Levels of anxiety, depression, and high frequency average hearing level were treated as covariates. Tasks consisted of the say-word (easy) and say-color (demanding) conditions of the Stroop task, a single (baseline) reaction time (RT) task, and dual tasks involving word reading or category naming while performing a concurrent RT task. Results supported the general depletion of resources hypothesis: RT of the tinnitus group was slower in both conditions of the Stroop task, and in the word reading and category naming conditions of the dual task. Differences were not attributable to high frequency average hearing level, anxiety, or depression.

Sumario
Se investigó el efecto del acufeno crónico y severo en dos tareas visuales. La hipótesis de la reducción general de recursos dice que el desempeño general estaría disminuido en un grupo con tinnitus en relación con un grupo control; mientras que la hipótesis de procesos controlados dice que sólo las tareas demandantes que requieren procesamiento estratégico estarían afectadas. Once pacientes que habían padecido acufeno severo por más de dos años conformaron el grupo. Se formó un grupo pareado según su edad y CI verbal. Se consideraron covariantes los niveles de ansiedad, depresión y los niveles de audición en frecuencias elevadas. Las tareas fueron "decir palabra" (fácil) y "decir color" (exigente), condiciones de las tareas de Stroop, una tarea sencilla (base) con tiempo de reacción (RT), y tareas duales que involucraban lectura de palabras o nombrar categorías mientras de realizaban las tareas RT concomitantes. Los resultados apoyan la hipótesis de reducción general de las fuentes: el RT del grupo con acufeno fue más lento en ambas condiciones de las tareas de Stroop, y en la lectura de palabras y en nombrar categorías, en la condición dual. Las diferencias no son atribuibles al promedio de audición en frecuencias altas, a la ansiedad o a la depresión.

Experimental investigations of the effect of chronic tinnitus on attention and memory (Andersson et al, 2000; Andersson et al, 2003; Andersson et al, 2002; Hallam et al, 2004) corroborate self-reports of chronic tinnitus and poor mental concentration (Andersson et al, 1999; Tyler & Baker, 1983; Wilson et al, 1991). At least two tasks remain to be done in order to explain an association between tinnitus and poor concentration. First, theories that explain the links between chronic tinnitus and cognitive impairment need to be explicated (e.g. Andersson, 2002; Cuny et al, 2004b; Zenner & Zalaman, 2004), and hypotheses deduced and put to experimental test (McKenna, 2004). Second, there is a need to systematically examine the way in which variables such as depression, anxiety, and hearing loss are related to tinnitus and cognitive impairment. The present preliminary study has been designed with these goals in mind. The aim is to investigate a theory of the cognitive sequelae of tinnitus. Two experiments are reported in which divided and selective attention of participants with severe chronic tinnitus are recorded in response to visual stimuli, and potentially interacting variables, high frequency average hearing level, anxiety, and depression, are examined as covariates. The experiments enable scrutiny of two competing hypotheses: that severe tinnitus affects voluntary, strategic, controlled cognitive processes which manifests as relatively poor performance on demanding conditions of visual and selective divided attention tasks, or that tinnitus depletes attention resources generally, manifesting as poorer performance on all conditions of selective and divided attention tasks.

Experimental investigation of a tinnitus–cognition nexus
To examine the relationship between tinnitus and cognitive task performance, McKenna et al (1996) administered a battery of tests of cognitive function to people with and without tinnitus. McKenna et al reported that participants with tinnitus performed more poorly than a control group on arithmetic, letter cancellation (a test of sustained attention and vigilance), verbal fluency, and trail making (a test of visual conceptualization and visuo-motor tracking) tasks. This pattern held even when the effects of trait anxiety and IQ were controlled. The results suggest that tinnitus affects performance on tasks requiring memory and/or attention.

Selective attention as measured by the Stroop color word test appears to be impaired among people with tinnitus (Andersson

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et al, 2000). The Stroop test involves the visual presentation of color words that conflict with the color of the ink or pixels used to form that word. Interference occurs in the say-color condition because the word reading response interferes with the color naming response (e.g. the word blue written in green) but there is little interference in the say-word condition. An overall cognitive impairment, particularly attention, is implied by Anderson et al (2000) although the authors note that a possible confounding with hearing loss cannot be ruled out. Using a web-based version of the emotional Stroop task, Andersson et al (2005) reported that participants with tinnitus named the color of tinnitus words faster than naming the color of neutral words. One interpretation of this result supports a vigilance-avoidance model of information processing wherein initial vigilance toward information of emotional concern is followed by subsequent avoidance of that information. An alternative explanation is that tinnitus is associated with a cognitive bias at late, elaborative stages of information processing (Andersson et al, 2005, p. 36). Results are inconclusive given the difference in sample sizes of the tinnitus and control groups and the likelihood that computer processing speeds varied within and across the groups.

An effect of chronic tinnitus on attention, gauged from performance on five cognitive tasks that measured sustained attention, reaction time, verbal fluency, and immediate and delayed memory, has also been reported by Hallam et al (2004). Participants with tinnitus performed more poorly on one task only – the variable fore-period reaction time task under dual task conditions. Hallam et al concluded that cognitive inefficiency is related to control of attentional processes and that tinnitus is a competing stimulus that attracts attention and disrupts complex tasks that involve switching of attention. The tinnitus group appears to have greater difficulty inhibiting attention to irrelevant tinnitus schemata (Hallam et al, 1984). Rossiter et al, (2006) reported an effect of moderate chronic tinnitus on reading span and visual divided attention tasks. Participants with moderate tinnitus recorded poorer reading spans and longer reaction times, but only on the most demanding of the dual task conditions. One interpretation is that the direction of attention to tinnitus is evident when a task is new or unfamiliar (e.g. reading span), particularly demanding (e.g. dual task), and requires controlled, strategic cognitive processes (Posner & Snyder, 1975). By contrast, tasks that are well learned and automatic (La Berge, 1975; 1990) show little impediment from tinnitus. Similarly, Andersson et al (2003) demonstrated effects of tinnitus on long-term, autobiographical memory. Although the authors note the need for further research, they suggest that the information processing deficit seen in people with chronic tinnitus shares features with deficits seen in people with depression. An implication is that conceptual, conscious, controlled cognitive processes may be disrupted.

The hypothesis that there is reorganization of cerebral functions resulting from tinnitus has been considered empirically (Cuny et al, 2004a; Cuny et al, 2004b) and theoretically (Zenner & Zalaman, 2004). Cuny et al (2004a) proposed that tinnitus modifies the organization of functions associated with auditory language processes. They concede that an explanation in terms of attention cannot be eliminated. Cuny et al (2004b) report a difficulty in direction of attention among people with tinnitus when attention location corresponds with the tinnitus ear and suggest a focus of attention on the tinnitus ear. A common theme that emerges from these accumulating experimental studies is that an attentional problem is associated with chronic tinnitus and the completion of certain kinds of cognitive tasks. (Andersson, 2002; Cuny et al, 2004b; McKenna, 2004; McKenna et al 1996).

Depletion of attentional resources in chronic tinnitus: A general or specific effect?

Performance on cognitive tasks may be affected by tinnitus because attention is directed to tinnitus or thoughts related to tinnitus, and this uses cognitive resources. Severe tinnitus, like chronic pain, is a competing stimulus that attracts attention (Eccleston, 1995). In cognitive terms, this means that capacity is reduced because attention is already divided over tasks (where one task is orienting to tinnitus or pain). That is, attention to severe tinnitus makes all tasks dual tasks (or greater than dual), and performance is impaired across all conditions of selective and divided attention task experiments. This is the 'general depletion of resources hypothesis'.

An alternative hypothesis is that for many people with tinnitus, attention is disrupted at the point of onset when attending to tinnitus is a voluntary, strategic process that requires attentional resources. For most people, although tinnitus may persist, their orienting and attention to it becomes automatic. That is, it is learned and eventually uses few attentional resources. As an automatic process, orienting to tinnitus will be difficult to disrupt (Posner & Snyder, 1975). However, for some individuals, attending to tinnitus does not become automatic but remains a cognitively demanding, voluntary process. Continual orienting to tinnitus makes every situation at the very least a dual task, and performance is impaired when other demanding tasks involving controlled processes are required. Therefore, we may expect that impaired performance manifests on the most difficult or unfamiliar cognitive task conditions. The 'controlled processing hypothesis' states that tinnitus impairs cognitive performance where there is a sharing of resources as in experimentally-manipulated dual task conditions, but that there is no effect of tinnitus on cognition on familiar or single task (baseline) conditions.

The differential effect of tinnitus on task performance in the latter hypothesis is conceptualized in terms of controlled and automatic processes. It is hypothesized that only processes under strategic conscious control manifest effects of tinnitus. In the present experiments such processes are operationalized as the most demanding and unfamiliar of two dual task conditions (naming a superordinate category to which a word belongs while performing a reaction time task), or as the unfamiliar task of inhibiting a word-reading response and naming the incongruent color in the Stroop task.

Assessing the effect of hearing loss, depression, and anxiety

The present study builds on experimental investigations of attention mechanisms and tinnitus. Andersson et al (2002), Hallam et al (2004), and Rossiter et al (2006) did not obtain audiometric data for all participants. It is conceivable that peripheral auditory damage has some subtle effect on the ability to extract information from complex stimulation (Gallacher, 2005; Granick et al, 1976; van Rooij & Plomp, 1990). In the present investigation, pure-tone auditory thresholds data, obtained using the revised Hughson Westlake procedure, are available for all participants, both those with severe tinnitus and control group participants.

Categories of high frequency average hearing level (HFAHL): normal, mild, moderate, severe, profound loss, were used in an analysis of covariance. The four frequency average hearing level (4FAHL = mean threshold at 500, 1000, 2000, 4000 Hz) is a useful index of hearing loss in the context of speech perception. The range covered by the 4FAHL also corresponds to the frequency range of conventional hearing aids. However, the HFAHL retains differences between audiograms when there are differences in the high frequencies. Such differences are not represented in the 4FAHL. There are important consequences of the HFAHL for the statistical analysis. For the 4FAHL the range of scores will be compressed, thus limiting the size of any correlation that could be obtained and making it difficult to obtain significant outcomes. The purpose of including hearing loss data in this study was to control it and eliminate the possibility that hearing loss contributed to the results. By using the HFAHL data with its greater range there is the greatest chance of finding a relationship between hearing loss and the experimental results, and we can be more confident in concluding that hearing loss is not a factor in the outcome of the study. Finally, the HFAHL was used because, with the exception of conductive tinnitus, tinnitus is predominantly high frequency (Douek & Reid, 1968; Graham & Newby, 1967; Nodar & Graham, 1965).

There is a recognized complex network of relations between tinnitus and the psychological variables depression and anxiety. Causal connections between these factors and cognition are tangled. For example, does severe tinnitus cause cognitive impairment directly, or is another factor involved? Anxiety and tinnitus are related (Andersson & Vretblad, 2000; Halford & Anderson, 1991; McKenna et al, 1991; McKenna et al, 1996; Rutter & Stein, 1999), and anxiety and cognitive performance are related (Broadbent et al, 1986; Eysenck & Calvo, 1992). Cognitive impairment among those with severe tinnitus may not be the result of tinnitus but the co-occurrence or mediation of high levels of anxiety or depression (Budd & Pugh 1995; Hiller et al, 1997). Alternatively, tinnitus may cause the anxiety and emotional distress that, in turn, disrupts cognitive processes. A range of causal networks is conceivable. For example, Noble (2000) noted that a history of depression may be a predisposing factor to greater tinnitus handicap; and that long term experience of tinnitus induces depressive mood. Langenbach et al, (2005) concluded that ‘patients with psychological disturbances and sleep difficulties at first presentation shortly after onset of tinnitus have a higher risk of developing tinnitus related distress’ (p. 73).

Attentional mechanisms have been invoked to explain these relations and possible effects on cognition (Hallam et al, 1984; Newman et al, 1997). Attending constantly to the sound may increase the intrusiveness of tinnitus (Hallam et al, 1988). Emotional distress associated with tinnitus appears to be heightened by its uncontrollability (Halford & Anderson 1991; Jakes et al, 1985). A cycle develops of increasing negativity and anxiety, and decreasing cognitive function (Hallam et al,1984). High ‘self attenders’, who tend to focus more attention on somatic sensations and their thoughts and beliefs relative to low self attenders, are more depressed, more distressed due to tinnitus, and have greater perceived tinnitus handicap (Newman et al, 1997). In the present study, the state-trait anxiety inventory (Spielberger et al, 1983) and Beck depression inventory (Beck, Steer & Brown, 1996) scores were used as covariates to examine the contribution of self-reported anxiety and depression toward cognitive task performance. Tinnitus severity was measured using the tinnitus questionnaire (Hallam, 1996).

Aim, design and hypotheses

The aim was to investigate the effect of severe chronic tinnitus on performance of visual tasks that involve sustained selective and divided attention. The independent variables were participant group (tinnitus, control), and conditions of a selective attention task (Stroop say-word, Stroop say-color) and divided attention task (baseline, word reading, category naming). The dependent variables were accuracy and reaction time. It was hypothesized that if severe tinnitus uses attentional resources, then performance of the tinnitus group is poorer than that of the control group on all conditions of the selective and divided attention tasks. Alternatively, if severe tinnitus affects only controlled, strategic processes then performance of the tinnitus group is poorer than that of the control group on the unfamiliar say-color condition of the Stroop task, and the most demanding dual task (category naming) condition. In some ways the work reported here is a single experiment with the above aims. The tests were carried out on the same day and on the same participants. It can also be regarded as two different experiments dealing with different aspects of the problem. This fact is reflected in the structure of the paper. Matters common to both tasks, such as the characteristics of the sample, are dealt with first, followed by descriptions of each test and discussion of outcomes.

Method

Participants

Experimental group

The experimental group consisted of eleven participants (seven males, four females) between the ages of 18 and 65 years ($M = 49.73$ years, $SD = 16.53$). They all reported experiencing constant, bilateral ($N = 9$) or unilateral ($N = 2$, right ear) tinnitus for more than two years. The participants were recruited through an advertisement placed in a local suburban newspaper in southwest Sydney, or were new clients of the Audiology Clinic at Concord Repatriation Hospital.

The revised Hughson Westlake procedure was used to determine pure tone thresholds at 125, 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, and 8000 Hz. The high frequency average hearing level (HFAHL) was calculated from mean frequency thresholds at 4000, 6000, and 8000 Hz. The overall mean for the tinnitus group was 37.24 dB HFAHL. The HFAHL values were then classified as normal hearing (-10–25 dB HFAHL), mild loss (25–40 dB HFAHL), moderate loss (40–60 dB HFAHL), severe loss (60–80 db HFAHL), and profound loss (> 80 dB HFAHL). These classifications were later used in an analysis of covariance. Of the 11 participants in the tinnitus group, eight had high frequency hearing loss: six with moderate loss (40–60 dB HFAHL) and two with severe loss (60–80 dB HFAHL). Audiometric characteristics of the sample are shown in Table 1.

Table 1. Sample audiometric characteristics showing high frequency average hearing level values for left and right ears.

	HFAHL[L]	*HFAHL[R]*	*Mean HFAHL*	*HL Category**
Tinnitus	46.6	45	45.8	2
	33.3	38.3	35.8	2
	43.3	41.6	42.45	2
	43.3	38.3	40.8	2
	55	71.6	63.3	3
	63.3	60	61.65	3
	50	43.3	46.65	2
	43.3	58.3	50.8	2
	11.6	6.6	9.1	0
	1.6	8.3	4.95	0
	8.3	8.3	8.3	0
Mean	36.33	38.15	37.24	1.64
Control	11.6	13.3	12.45	0
	15	30	22.5	0
	30	21.6	25.8	1
	25	35	30	1
	13.3	10	11.65	0
	35	30	32.5	1
	6.6	18.3	12.45	0
	23.3	8.3	15.8	0
	30	23	26.5	1
	28.3	33.3	30.8	1
	90	78.3	84.15	4
Mean	28.01	27.37	27.69	0.82

* HL Category refers to: 0: normal hearing =-10–25dB; 1: mild loss = 25–40dB; 2: moderate loss =40–60dB; 3: severe loss =60–80dB; 4: profound loss = >80dB.

Control group

The control group, which also contained 11 participants, was selected after the experimental group. Individuals selected for the control group were matched to individuals from the experimental group according to age, education level, and an estimate of verbal IQ. Control group participants were recruited from undergraduate and staff populations at the University of Western Sydney. The inclusion criteria were the same as for the experimental group, except that they had not experienced tinnitus in the preceding six months. The group consisted of five male and six female adults between the ages of 18 and 64 years ($M = 49.91$ years, $SD = 16.05$). The overall mean HFAHL for the control group was 27.69 dB (see Table 1). Using the HFAHL calculations and classification scheme outlined above, it was determined that six members of the control group had high frequency hearing loss: five with mild loss (25–40 dB HFAHL), and one with profound high frequency loss (<80 dB HFAHL).

Screening

The suitability of volunteers for inclusion in the tinnitus and control groups was assessed by interview, during which general demographic data and a brief medical history were obtained. The inclusion criteria were: That they had had constant tinnitus for at least two years without any indication of spontaneous recovery experimental group (Vesterager, 1997); That their corrected vision was sufficient for them to see the visual stimuli on a computer screen; That they did not suffer from any medical condition that may cause cognitive dysfunction (e.g. tumor, serious head injury, dementia); That they had not recently undergone any medical procedure and were not taking any medication that could affect cognitive functioning. The latter includes drugs that may cause drowsiness, confusion or agitation.

Psychological Test Materials

A single test session of 2.5 hours began with collection of demographic data and administration of the national adult reading test (NART) (Nelson, 1991). Participants then completed three tests in random order: the state/trait anxiety inventory (STAI) (Spielberger et al, 1983), the Beck depression inventory (BDI-II) (Beck et al, 1996), and the tinnitus questionnaire (TQ) (Hallam, 1996), followed by experimental tasks 1 and 2 (counterbalanced across participants to distribute serial order effects) and, finally, the revised Hughson-Westlake procedure.

The NART provides a quick but valid and reliable estimate of verbal IQ by assessing the ability to read irregular (or non-phonetic) words (Crawford et al, 1989). The NART has split-half and test-retest reliabilities of .93 and .98, respectively. Note that split-half reliability refers to the reliability of a test by evaluating the test's overall internal consistency and dependability as a measuring device. A single test is split into two forms and a coefficient of reliability between the two is obtained. NART was used to match members of the tinnitus and control groups. The NART raw scores were: experimental group $M = 13.63$, $SD = 5.71$ and control group $M = 13.54$, $SD = 4.87$.

The STAI consists of two, twenty item self-report scales. 'State anxiety' refers to how the respondent feels 'right now', while 'trait anxiety' refers to how the respondent 'generally' feels. The two scales are correlated. The maximum score on each scale is 80. The STAI was used to help in the interpretation of results with anxiety scores used as covariates. The mean state anxiety score for the tinnitus group was 46.09, $SD = 12.15$ and for the control group $M = 31.36$, $SD = 10.59$. Mean trait anxiety score for the tinnitus group was 47.55, $SD = 12.10$ and for the control group, $M = 34.55$, $SD = 13.42$. The control group mean scores are comparable with normative data reported by Spielberger et al (1983): state $M = 35.72$, $SD = 10.40$; trait $M = 35.85$, $SD = 10.91$, and scores reported by Wilson et al (1991) in the development of the tinnitus reaction questionnaire: state $M = 35.85$, $SD = 10.91$; trait $M = 38.73$, $SD = 12.18$.

The Beck depression inventory (BDI-II) is a 21-item self-report instrument for measuring severity of depression in adults (Beck et al 1996). Total scores can range from 0 to 63. Test-retest reliability of the BDI-II is 0.93. The mean BDI score for the tinnitus group was 16.9, SD =9.85, and for the control group 9.4, SD =11.66. The former BDI mean suggests levels of mild depression among participants in the tinnitus group compared with minimal depression among participants in the control group.

The TQ (Hallam, 1996) is a 52-item questionnaire that provides an estimate of tinnitus complaint across five dimensions. The mean TQ score of the experimental group was $M = 47.64$, $SD = 24.50$ (range 2–81; maximum possible =84). Mean scores within each of the five dimensions for the tinnitus group were: emotional distress: 22.64, auditory perceptual difficulties: 6.18, intrusiveness: 11.55, sleep disturbances: 4.18, somatic complaints: 3.09. Mean emotional distress, intrusiveness and sleep disturbance subscale scores fell in the 51–75% quartile of the distribution reported in Hallam (1996). The mean TQ score of the control group was $M = 1.55$, $SD = 1.57$ (range 0–4).

Experimental task 1a: selective attention

Stimuli

The experimental trial stimuli of the Stroop task consisted of five color words (red, blue, brown, green, purple) presented in an incongruent manner. In the say-word (easy) condition each of five color words was presented incongruently using the pixels of the other four colors (a total of 20 trials presented in a random order five times each). The task was to say the word and ignore the color of the pixels. In the say-color (demanding) condition each of five color words was presented incongruently using the other four colors (presented in a random order, five times each) and the task was to name the color and ignore the word. In this latter condition, the familiar word-reading response needed to be inhibited in favor of the color-naming response. There were also control trials where a color word written in black had to be read aloud or the hue of colored crosses had to be named. All participants completed all possible congruent and incongruent trials. Stimuli were presented in the centre of the monitor and remained there until the participant gave a verbal response (saying word or color aloud) that was picked up by a voice-key microphone.

Stimuli included practice items at the beginning of the experiment and before the say-word or say-color blocks. There were 110 trials in which participants had to respond by saying the word. Ten of these trials were control trials wherein the five color words were written in black (two presentations each of five color words). The remaining 100 say-word experimental trials consisted of a random order of the five color words each presented in the incongruent color pixels (four) and presented five times each. There were 110 trials in which the participant responded by saying the color. Ten of these trials were control trials wherein the five colors were presented as crosses twice each. The remaining 100 say-color experimental trials consisted of a random order of the five color words each presented in incongruent color pixels (four), and presented five times each.

Equipment

The task was programmed in SuperLab v.1.74, and presented on an iMac computer running System 9. A Macintosh microphone, that stopped the internal iMac clock, picked up spoken responses. The experimenter recorded accuracy of response manually.

Procedure

Participants sat at the computer and wore a small voice-key microphone. The task was explained and practice say-word and say-color trials were given. Trials were blocked into say-word and say-color conditions. The order of the conditions was counterbalanced across participants. Control and experimental trials within blocks were presented in a new random order for each participant. The task took 20 minutes to complete.

Results

Reaction time data refer to response latencies recorded from the onset of the stimulus to verbal response. As it has been established that voice-keys may be differentially sensitive to the initial phoneme of a verbal response, such as vowels versus plosives versus fricatives (Tyler et al, 2005), reaction time data were analysed from trials that involved the correct response 'purple'. The reasoning here was that the plosive at the start of the word purple would provide a clear trigger for the voice-key. In the following results, say-color refers to the task of naming the color of the word 'purple' written in incongruently colored pixels (blue, brown, green, red), and say-word refers to the task of naming the 'purple' color of the four color words.

The mean reaction times on the Stroop task recorded for the two different tasks (say-word and say-color) were analysed using a mixed repeated measures analysis of variance (ANOVA), with tinnitus group as the between-subjects factor (severe tinnitus or control). Although homogeneity of variance was not achieved, the ANOVA test assumptions were deemed satisfactory given the equal group sizes, normal distributions, and the fact that there were no statistical outliers. With alpha set at .05 both main effects were significant: task $F(1, 20) = 54.45$, $p < .001$, partial $\eta^2 = .731$; tinnitus group $F(1, 20) = 10.68$, $p = .004$, partial $\eta^2 = .348$. The task by tinnitus group interaction was also significant $F(1, 20) = 5.46$, $p = .03$, partial $\eta^2 = .215$. Mean reaction times of the two groups across stimuli are shown in Figure 1.

Post hoc analyses

Two analytical comparisons (two independent samples t-tests) were conducted using a Bonferroni adjusted alpha of .025 to control for familywise error. In the say-word trials, the difference between the severe tinnitus and control group was significant $t(12.19) = 3.20$, $p = .008$; reaction times being significantly longer in the severe tinnitus group ($M = 873.20$, $SD = 311.68$),

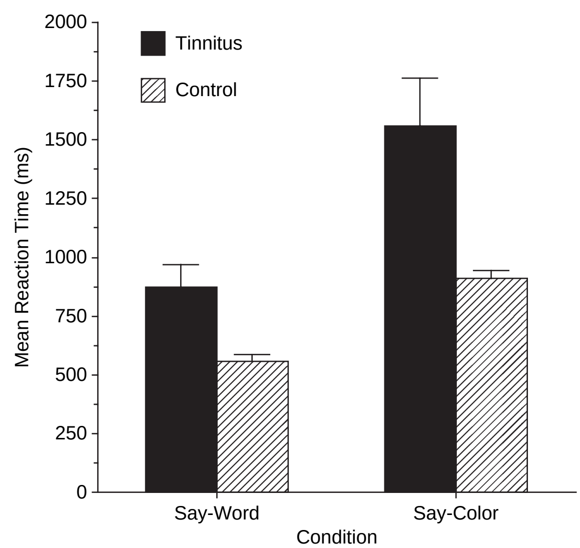

Figure 1. Mean reaction times in milliseconds for say-word and say-color conditions of the Stroop task (Experiment 1a) for severe tinnitus and control groups. Error bars refer to standard error of the mean.

compared to the control group ($M = 556.38$, $SD = 103.82$). Say-color trials also revealed a significant difference between the two levels of tinnitus $t(10.48) = 3.10$, $p = .011$; the severe tinnitus group ($M = 1558.71$, $SD = 684.40$) again recording significantly longer reaction times compared with the control group ($M = 912.09$, $SD = 105.84$).

Analysis of covariance

To assess the potential effects of level of high frequency average hearing level, as well as scores on depression (BDI), anxiety (STAI), and the TQ, another mixed repeated measures analysis of variance was conducted controlling for these variables by entering them as covariates. This revealed that hearing level, depression, and anxiety had no significant effect on reaction times ($p > .37$), hence the analysis was conducted again with only the TQ factored in as a covariate.

Results revealed a significant main effect of task $F(1, 19) = 5.16$, $p = .035$, partial $\eta^2 = .214$, but this time the main effect of tinnitus group and task by tinnitus group interaction were both *not* significant ($p > .29$). The task by TQ interaction, however, was significant $F(1, 19) = 11.55$, $p = .003$, partial $\eta^2 = .378$.

Two subsequent Pearson product-moment correlations revealed strong, significant, positive correlations between the task and TQ variables for both the say-word $r(20) = .77$, $p < .001$ and say-color conditions $r(20) = .81$, $p < .001$. The higher people scored on the TQ, the greater (longer) were their reaction times.

Discussion

The results of Experiment 1a suggest that tinnitus may have a general degenerative effect on selective attention performance, as measured by the Stroop task. Reaction times of participants with severe levels of tinnitus were significantly longer compared to that of the control group on both say-word and say-color trials. The results are not explained by co-variation with anxiety, depression or high frequency average hearing level. The significant relationship found between reaction time and the TQ lends support to the validity of the TQ as an index of tinnitus complaint including the effect of tinnitus on selective attention.

Experimental task 1b: divided attention

Experiment 1b includes three separate tasks involving attention, and which provide conditions of increasing attentional demand. It includes a simple visual reaction time task, a divided attention word recognition task, and a divided attention word categorization task. The aim was to investigate the ability of the two groups of participants to divide attention between tasks under conditions of increasing difficulty.

A dual task paradigm was used wherein the difficulty of the primary task was increased from easy to hard while reaction time to the secondary task was recorded. The 2×3 factorial design consisted of participant group (tinnitus, control) and task difficulty (baseline-single task, word recognition, category naming) conditions with repeated measures on the latter factor. The dependent variables were reaction time and errors. It was hypothesized that if tinnitus has an undifferentiated, general effect on cognition then performance of the tinnitus group is poorer than that of the control group on all conditions. Alternatively, if tinnitus affects controlled process, the tinnitus group should perform more poorly than the control group on the category naming, but not on the baseline or word recognition conditions.

Stimuli and equipment

The secondary task stimulus and the sole stimulus in the baseline condition consisted of a grey rectangle that appeared on the computer screen and remained there until the mouse button was clicked. The rectangle appeared at random inter-stimulus intervals ranging from 1 s to 9 s. The easy primary task consisted of 90 English words that belonged to one of three superordinate categories, namely cooking, animal, or seascape. A word appeared at one of the four corners of the computer screen every 1.5 s. The task was to name the word. The same 90 words, in a new random order, were used in the difficult primary task. The task was to name the subordinate category to which the word belonged. The experiment was programmed in SuperLab v.1.74 and presented on a Macintosh laptop computer. The accuracy of the word reading and category naming responses was recorded manually.

Procedure

The baseline task was always completed first. The order of the word recognition and category naming conditions was counterbalanced across participants to distribute serial order effects. As a baseline measure of reaction time, participants clicked the mouse button as quickly as possible each time a grey rectangle appeared in the centre of the computer screen. After a series of practice trials, baseline data were collected across 30 trials. In the easy primary task, participants read aloud each word as it appeared in one of four corner locations on the computer screen. Concurrently, they performed the secondary task, clicking the mouse button when a rectangle appeared in the centre of the screen. In the difficult primary task, rather than reading the word as it appeared on one of the corners of the screen, participants had to name the superordinate category to which the word belonged. For example, when the word ‘wine’ appeared, they were to respond ‘cooking’. At the same time as naming the categories aloud participants clicked the mouse button as quickly as possible each time the grey rectangle appeared. The task took 25 minutes.

Results

The mean reaction times for correct responses on the three different task types (baseline, word reading, and category naming) were analysed using a mixed repeated measures analysis of variance (ANOVA), with tinnitus group as the between-subjects factor (severe tinnitus or control). Data screening indicated some departure from normality, specifically in the word reading task for both groups and for the tinnitus group’s baseline scores. There were no statistical outliers.

Although ANOVA test assumptions were not met with regards to homogeneity of variance for the baseline and category naming groups, it was decided to proceed with the parametric analysis due to the normal distributions, equal group sizes, homogeneity of covariance, and the absence of any outliers. With alpha set at .05, the main effect of task type was significant $F(2, 40) = 64.20$, $p < .001$, partial $\eta^2 = .762$; as was the main effect of tinnitus group $F(1, 40) = 8.27$, $p = .009$, partial $\eta^2 = .293$. However, the task type by tinnitus group interaction did not reach significance $F(2, 20) = 1.45$, $p = .246$, partial $\eta^2 = .068$. Mean

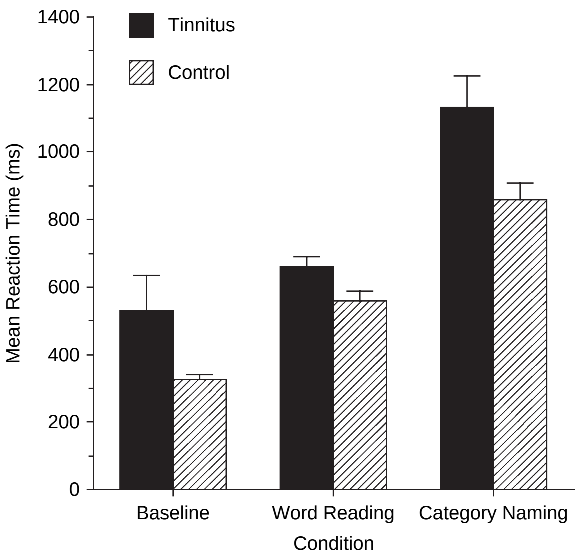

Figure 2. Mean reaction times in milliseconds for baseline, word reading and category naming conditions of Experiment 1b for severe tinnitus and control groups. Error bars refer to standard error of the mean.

reaction times of the two groups across the three task types are shown in Figure 2.

Post hoc analysis

Post hoc comparisons of the three task types using the Tukey HSD procedure revealed that all three pair-wise comparisons were significant ($p < .004$); the mean reaction times were significantly greater in the category naming condition compared with both the word reading and baseline conditions, and the word reading condition also produced significantly higher reaction times than the baseline condition. Furthermore, three independent sample t-tests revealed that the tinnitus group produced significantly higher (longer) reaction times than the control group in both the word reading and category naming tasks ($p < .025$). The difference in baseline reaction times between the tinnitus group and the control group did not reach significance ($p = .08$).

Analysis of covariance

To control for the effects of high frequency average hearing level as well as scores on depression (BDI), anxiety (STAI), and the TQ, a subsequent mixed repeated measures analysis of variance was conducted with these four variables entered as covariates. This revealed that none of the four covariates had a significant impact on reaction times ($p > .15$).

Error variance

A mixed repeated measures analysis of variance was conducted on the mean error rates across the two tasks (word reading and category naming) with tinnitus group as the between-subjects factor. This indicated that there was no significant difference between the tinnitus and the control groups in the mean number of errors made on the word reading task, but that the tinnitus group made significantly more errors on the category naming task compared with the control group $t(11.96) = 2.77$, $p = .017$.

Discussion

Results suggest that only the level of task difficulty and tinnitus had a significant effect on the reaction times of participants. Furthermore, there was no evidence of a speed-accuracy trade-off, with the tinnitus group not only responding more slowly but also less accurately than the control group on the category naming condition. The absence of a significant difference between baseline scores of tinnitus and control groups, but the presence of a difference on the two levels of the dual task suggest that severe tinnitus is associated with a general depletion of attentional resources.

General Discussion

The results of two experiments involving sustained selective and divided attention provide support for the general depletion of resources hypothesis. Individuals with chronic severe tinnitus responded significantly more slowly than the matched control group on both the say-word (easy) and say-color (demanding) conditions of the Stroop task. A significant interaction between participant group and task suggests that performance of the tinnitus group was poorest when the task was unfamiliar and demanding. Significantly slower reaction times were also recorded by the tinnitus group compared with the control group on the word reading and category naming conditions of a dual task. There was no significant difference in reaction times recorded under single task (baseline) conditions. Error rate was also higher among the tinnitus group on the demanding category naming condition. Any differences between the tinnitus and control groups with respect to state-trait anxiety inventory scores, Beck depression inventory scores, and high frequency average hearing level did not account for reaction time or accuracy differences observed in the two experiments.

It appears that one mechanism that links chronic tinnitus and impaired cognition is attentional, with the direction of attention to irrelevant stimuli or schema. Constant orienting to tinnitus uses attentional resources, meaning that in most situations individuals with tinnitus are dividing attention across a range of tasks. Even on relatively automatic tasks such as word reading in the Stroop task and word reading in the dual task, a significant difference between severe tinnitus and control groups has been observed. This suggests a general depletion of attentional resources. However, the group by task interaction in the Stroop task and the significantly poorer accuracy as well as slower RT in the category naming condition of the dual task implies that unfamiliar, demanding tasks are the most affected.

The present results corroborate findings of Andersson et al (2000, 2003), Hallam et al (2004), and Eccleston (1995). Hallam reported an effect of tinnitus on one of five experimental tasks, specifically a dual task. In the context of chronic pain, Eccleston observed a difference between experimental and control groups when the task was at its most difficult. He argued that the processing of chronic, persistent pain demands central and executive attention, and that attention to chronic pain sets up a competition for limited attention resources when a second task is undertaken.

It is plausible that the general depletion of resources hypothesis holds when tinnitus is severe. Depletion may occur in a small portion of individuals (possibly non-copers, self-attenders (Newman et al, 1997)), for whom attending to tinnitus is maintained as a controlled, strategic, and resource-intensive process. For this group, cognitive impairment manifests when performing difficult or unfamiliar tasks. Over-learned tasks involving automatic processes such as simple reaction time (e.g. the baseline condition in Experiment 1b) show no effect, whereas strategic attention to tinnitus impairs performance when there is a sharing of resources needed for demanding tasks.

Although participants in the tinnitus and control groups were matched on verbal IQ and socioeconomic status, and levels of anxiety, depression, and hearing level were recorded, there is potential heterogeneity in the tinnitus group because of: time since tinnitus onset, cause of tinnitus, hearing level, and participants' variability in experiencing tinnitus during the experiment session. If attending to tinnitus consumes attentional resources then performance should only be affected when tinnitus is present. The present procedure was designed to maximize the presence of tinnitus for participants. The TQ and psychological tests were administered to all participants at the beginning of the testing session to deliberately draw attention to tinnitus and associated depression and anxiety, and tests were conducted in a quiet room with few environmental noises that could have masked tinnitus. The presence of tinnitus during testing could be manipulated systematically in future experiments by testing individuals at times when they report that tinnitus is present compared with times when it is not. A further control condition could be introduced by using a masker that, in some cases, may cancel perception of tinnitus frequencies. Note that it would be important to investigate the most appropriate level of masker, particularly as it too may draw attention, but presumably not trigger negative thoughts and emotions associated with tinnitus. Future studies should also scrutinize the complex relation between hearing loss, tinnitus, and cognition.

There are four implications of the present results. First, it has been demonstrated that chronic, severe tinnitus impedes low and high demand visual selective and divided attention. The theory under development is that for most people who acquire tinnitus, attention to tinnitus becomes automatic and, once automatic, consumes few resources. For a small portion of people, attention to tinnitus does not become automatic but requires voluntary conscious orienting that consumes attention resources, leaving fewer resources for other tasks. It may involve a failure to habituate, and intrusion from learned associations between negative thoughts, emotions, and tinnitus. Second, the effect has been observed when the task is visual, that is, in another modality from tinnitus. The present results and those of Hallam et al (2004) suggest a need to use relatively demanding tasks for the effects of tinnitus to manifest. Future experiments will use an EEG/ERP paradigm to scrutinize these controlled and automatic processes at an electrophysiological level. Third, the significant effect on reaction time is not explicable in terms of higher levels of anxiety, depression or high frequency hearing level among the tinnitus group. The co-occurrence of these factors with tinnitus should not be underestimated but, importantly, the present results suggest a direct link between chronic tinnitus and cognitive processes. Finally, although tinnitus is a phenomenon marked by heterogeneity of causes and experience, the visual selective and divided attention tasks documented here provide a set of easily administered systematic tools that shed light on an individual's experience of tinnitus and measurable effects on attention. The effects are quantified as easy-to-interpret accuracy and reaction time scores.

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