

Tuning Out Background Noise

How do we tune out background noise?

Identifying Psychological and Neurobiological Mechanisms in Tinnitus

May 2017 | Prepared for the Department of Health and Ageing

A final report for the “Signals and noise: a study of the neurocognitive mechanisms underpinning habituation to noise in normal and damaged hearing” project funded by the National Health and Medical Research Council 2012-15, Award No. 1032042.

Report Date

12 May 2017

Title

How do we tune out background noise? Identifying Psychological and Neurobiological Mechanisms in Tinnitus

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Suggested Citation:

Trevis, KJ & Wilson, SJ. (2017). How do we tune out background noise? Identifying Psychological and Neurobiological Mechanisms in Tinnitus. University of Melbourne, Parkville, Victoria, Australia.

Acknowledgements

We thank our collaborators; Associate Professor Neil McLachlan, Professor David Grayden, Dr Chris Tailby and Professor Graeme Jackson. We thank the participants who kindly volunteered their time in this study.

Disclaimer

This research report was funded by the Hearing Loss Prevention Program for the Department of Health and Ageing and is released to the Department of Health and Ageing. The views expressed and the recommendations contained herein are those of the authors and do not necessarily reflect Department of Health and Ageing policy. Judicious discretion should be applied when using, quoting or applying any of the information contained in the Report.

Executive Summary

Our ability to tune out, or habituate to background noise is a core feature of healthy hearing. Habituation is also an important contributor to our wellbeing. A common complaint among people with damaged hearing or auditory processing is the inability to suppress or ‘tune out’ background sounds. This includes internally generated or phantom sounds, known as tinnitus. Across the lifespan our ability to tune out background sounds seems to decline as we age or as hearing health declines. This can lead to difficulties in social situations, for example tuning out background music or kitchen noises in a café. As a result, it can be difficult and mentally exhausting to tune in to conversations, and it can be harder to focus on certain tasks, like reading a book in a noisy environment. Difficulties like these can compound the impact of poor hearing health, leading to poor concentration, frustration and worry, and social withdrawal.

How the process of habituation occurs at a neurological and cognitive level is not well understood. Our research program aimed to address these issues through identifying the psychological and neurobiological processes that facilitate our ability to tune out or habituate to background sounds. By identifying the mechanisms that help us habituate, our research aimed to provide the foundation for the development of future treatments and hearing technologies that alleviate difficulties associated with tuning out background sounds. To explore how we tune in and out to background sounds we used chronic tinnitus as a model, as it provides a natural example of what happens when habituation fails to occur.

Tinnitus is a phantom experience of a ringing, buzzing or hissing type sound in the ears or head. This sensation is something most of us hear from time to time but in its chronic state there is an ongoing failure to habituate to the tinnitus sound. Chronic tinnitus is a prevalent health condition affecting approximately 42% of the general population (McCormack, Edmondson-Jones, Somerset, & Hall, 2016). It is associated with both hearing loss and ageing and has significant negative effects on health and wellbeing. It can pose a burden on families and the community and has significant economic impact (Maes, Cima, Vlaeyen, Anteunis, & Joore, 2013; Tyler & Baker, 1983). There is no cure for chronic tinnitus, likely due to the lack of agreement about what mechanisms drive the failure to habituate to it. Our work aimed to determine the psychological and neurobiological mechanisms driving chronic tinnitus, and thus driving the failure to habituate to background sounds. To achieve this objective, we conducted five studies using a range of psychological, neurophysiological and neuroimaging techniques in people with and without chronic tinnitus and hearing loss.

Key Findings To Date

- A broad array of psychological functions are involved in chronic tinnitus. These include:
 - reduced cognitive functioning, predominantly presenting as reduced mental control over the ability to switch attention.
 - reduced emotional wellbeing, predominantly presenting as symptoms of depression that moderate hypervigilance to the tinnitus sound and the link between anxiety and tinnitus impact.
 - use of less adaptive coping strategies, such as self-blame and avoidant behaviours such as “hoping for a miracle” .
- Altered regulation of certain networks in the brain may underpin the failure to tune out tinnitus sounds. These include:
 - Cognitive control and salience networks, which helps us switch our attention to focus on important information and inhibit distractors;
 - Autobiographical memory and affective networks, which underpin emotional experiences and internal reflections. These networks play a key role in attaching emotional significance to sensations.



Chief Investigator Professor Sarah Wilson. Prof. Wilson is a Clinical Neuropsychologist and Head of the Melbourne School of Psychological Sciences at The University of Melbourne. As the chief investigator of this project, she has overseen the development of this research program in addition to providing mentorship and supervision of the PhD student involved in the project, Krysta Trevis.¹

¹ Credit: This image was captured by Michael Amendolia as part of a story by Peter Meredith called ‘The Symphony of the Mind’. This story featured in the March-April 2014 issue of Australian Geographic (issue 119, pp 40-55). Re-used here with permission.

Recommendations

- Optimisation of chronic tinnitus treatments focusing on restoring the balance to affected brain networks to promote improved wellbeing and habituation to the tinnitus sound. These include:
 - Assessment of emotional wellbeing, including symptoms of anxiety and depression and their relationship to tinnitus impact, as part of routine treatment.
 - Use of well established psychological treatments for depression, such as cognitive behavioural therapy, and consideration of pharmacological treatment of depression where indicated.
 - Use of neurofeedback treatments as a means of retraining brain network function and restoring the balance to affected networks.
- Ongoing research into the functioning of brain networks in chronic tinnitus and auditory habituation to further characterise how they contribute to the failure to habituate and the severity of the impact of habituation failures.
- New investigations into the functioning of brain networks in different types of hearing loss to determine their contribution to difficulties faced by the hearing loss community. This could include:
 - Investigating the relationships between hearing health, cognitive functioning and emotional wellbeing in other disorders.
 - The development of superior hearing prosthetics that incorporate our new understanding of the importance of network functioning to our ability to habituate to, or focus on, sounds in the environment.
 - Investigating the use of emotion regulation and attention-switching strategies to help patients adjust to new hearing prosthetics and habituate to their new soundscape.

Table of Contents

How do we tune out background noise?	i
Identifying Psychological and Neurobiological Mechanisms in Tinnitus	i
Executive Summary	iii
Key Findings To Date	iv
Recommendations	vi
Table of Contents	vii
Scope of the Report	1
Introduction	2
What is Chronic Tinnitus?	4
What do we know about Chronic Tinnitus?	5
Project Aims	8
Project Activities	10
Study One. Beyond the auditory system: The contribution of psychology to chronic tinnitus	10
Study Two: What Mediates the ‘Vicious Cycle’ of Tinnitus	12
Study Three: The Contribution of Cognition to Chronic Tinnitus	15
Study Four: Is it the sound or your relationship to it?	18
Study Five: Brain Networks Involved in Habituation	20
Conclusions	21
Recommendations & Future Directions	22
Dissemination	23
Publications	23
Presentations	23
Media Interviews	24
References	25

Scope of the Report

This final report is prepared for the Department of Health and Ageing to summarise the work conducted to date for the research project titled “Identifying sounds in noise in normal and damaged hearing” which was funded by the NHMRC over a three-year period. This project aimed to determine what makes tinnitus a chronic condition with a significant impact on day-to-day life for many people.

This report provides a brief overview of the significance and impact of chronic tinnitus. We also provide information relating to the processes, outcomes and achievements of this project, highlighting our contribution to this field of research. In particular, this report contains detailed summaries of the five primary studies that constituted this project, including their methodology, outcomes and the impact and significance of the results. First, we confirmed a core role of psychological process in maintaining chronic tinnitus. Next, we performed four experimental studies to determine how our mood, ability to switch attention, and attachment to the sound could be preventing habituation.

Introduction

Noise is everywhere! From clocks ticking, fans ‘whirrrrring’, fridges buzzing and the occasional enthusiastic lawn mower droning away next door on a Sunday morning. As our communities grow, so does our exposure to increasing noise levels and sound pollution. Our ability to tune out background sounds such as these is critical to our mental health and wellbeing. If we ‘tuned in’ to all the sounds around us we would be overwhelmed with auditory sensations. Instead, our brain helps us to ‘tune out’ or habituate to sounds that aren’t important for what we are doing at a given moment in time. This is a ‘top-down’ process that helps us to focus on the task at hand, ignore distractors, and prevent us from being constantly overwhelmed and bombarded by our noisy world.

There are some exceptions to this rule – for example, alarm sounds that are loud, high pitched and hard to ignore, or the ‘cocktail party effect’ where our attention can be quickly drawn to the sound of our name even when it is part of the ‘soundscape’ of background noise. However, for the most part, our brain does an exceptional job of ignoring the ignorable. This process of filtering out the multitude of sensory experiences we encounter is an important aspect of what allows us to interact with our environment most efficiently. Part of this process is referred to as habituation, which enables us to tune out unnecessary stimuli, and focus on important or what we call ‘salient stimuli’, such as alarms and task-related information.

Difficulties in tuning out sounds can be a problem for people with mild to severe hearing loss. Symptoms of hearing damage can include difficulties in tuning out background noise to focus on conversations or relevant tasks. In addition, some people report that hearing aids can amplify these background sounds, which can further hinder habituation. Failures in habituation have been linked to the experience of chronic health conditions such as tinnitus, leading to intensified reactions and heightened awareness of this phantom auditory sensation. Author Will Storr aptly described this process in his article on his experience of chronic tinnitus, comparing sound habituation to how we habituate to touch:

“We’re habituated to the sensation of the elastic in our underpants clinging to our skin. It’s there all the time, but we just don’t notice it. What I need to do then, is develop a pants-esque response to the ringing in my

Will Storr, p35, of ‘Shattered’ a feature article in *‘Good Weekend’*, October 3, 2009.

How we habituate to these types of background sensations remains a mystery. There may be a number of contributing factors: our ability to control where our attention is directed, aspects of the stimulus we try to habituate to, or our ability to regulate our emotions. This project used chronic tinnitus, a highly prevalent and often disabling condition, as a model to investigate factors that may contribute to habituation. Specifically, we investigated factors influencing the failure to tune out from the tinnitus sound, leading to chronic awareness of this phantom auditory sensation.

What is Chronic Tinnitus?

Tinnitus is most often described as a ringing, buzzing, or hissing sensation in the ears or head and is a phantom auditory phenomenon. Most people experience sounds like these from time to time, particularly when in a silent room (Del Bo et al., 2008). However, for 10-15% of the general population this sound can become intrusive and chronically present (Henry, Dennis, & Schechter, 2005a). Tinnitus is reported to be more prevalent in elderly populations, individuals with hearing loss, and veterans, with tinnitus ranked as the second most common service-related disability in the United States of America (Salvi, Lobarinas, & Sun, 2009).

As a chronic health condition, tinnitus is associated with significant negative effects on an individual's mental health and wellbeing, and poses a significant economic burden to society (Maes et al., 2013; Tyler & Baker, 1983). At present, there is no cure for chronic tinnitus, in part due to the lack of consensus on the mechanisms maintaining the presence and impact of this chronic auditory sensation.

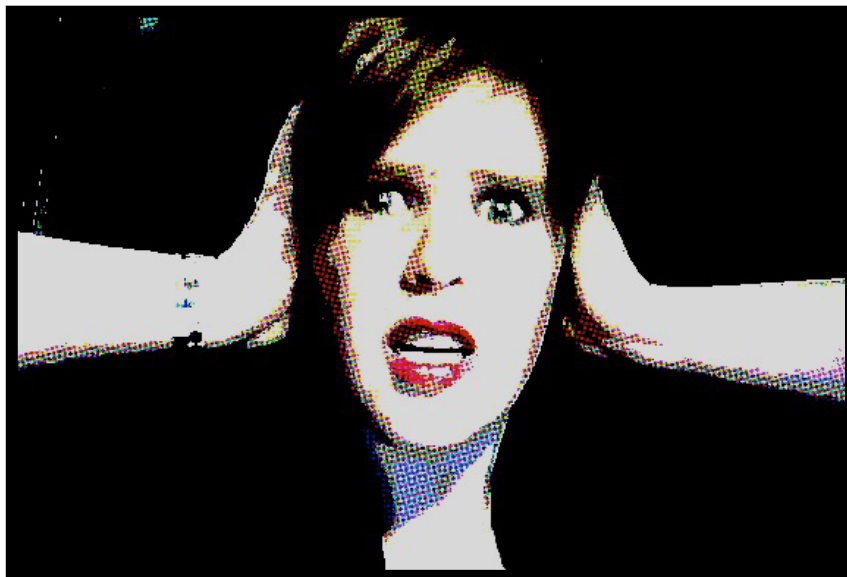
What do we know about Chronic Tinnitus?

Causes

The cause of the tinnitus sound is a source of much debate in tinnitus research and clinical practice. Studies have shown that most people in a silent environment can hear a tinnitus sound, suggesting a universality about the potential to temporarily perceive internal auditory sensations or 'phantom' sounds (Del Bo et al., 2008; Heller & Bergman, 1953; McCombe et al., 2001). In terms of chronic tinnitus, research suggests the majority of people report sudden onset of the condition (Savastano, 2004). While the majority of people often can not identify a specific cause, for those who can, there are consistent themes, including auditory damage (e.g. hearing loss, Meniere's disease), neurological conditions (e.g. whiplash or head injuries), temporary health changes (e.g. ear infections, drug side effects, colds), temporomandibular-joint or other dental concerns, noise trauma, and auditory hallucinations (Coles & Hallam, 1987; Eggermont, 2003; Lockwood & Salvi, 2002).

Symptoms

Audiological research indicates that tinnitus presents with a high degree of variation in timbre (ringing, hissing, whistling, buzzing, sea/machine noise), pitch (0.11-14kHz), location (lateralised or bilateral (central)) and perceived impact (e.g. bothersome, non-bothersome) (Dineen, Doyle, & Bench, 1997; Savastano, 2004). The subjective loudness of the tinnitus sound is also a source of perceived variation, and consistent with other psychoacoustic properties such as pitch, volume does not appear to impact the perception or intrusiveness of the tinnitus sound (McCombe et al., 2001; Savastano, 2004). As such, tinnitus perception is often thought of in terms of awareness of, and reactions to, the tinnitus sound itself rather than its auditory or psychoacoustic properties (Jastreboff, Gray, & Gold, 1996).



The psychological impact of tinnitus is well recognised. Ninety percent of chronic tinnitus sufferers report life-style issues such as poor sleep, social withdrawal and interference with work, while 70% report emotional difficulties including suicidal thoughts, confusion and worry (Tyler & Baker, 1983). This has led to many researchers further classifying chronic tinnitus into 'bothersome' (or 'decompensated') chronic tinnitus and 'non-bothersome' (or 'compensated') chronic tinnitus. This distinction is reflected in treatment options, where the aim of the treatment is a reduction in a person's reactions to the sound and its impact, rather than silencing the sound itself (Henry, Zaugg, & Schechter, 2005b). These severity-based subgroupings of chronic tinnitus are also seen in prevalence studies attempting to distinguish the presence of tinnitus from its psychological impact. For example, an Australian study investigating the health of individuals over 49 years of age found that 30% reported experiencing tinnitus, of which 33% reported no annoyance, 49% reported mild annoyance, and 16% reported severe annoyance (2% did not provide annoyance ratings) (Sindhusake et al., 2004).

Treatment

At present there remains no definitive patient management protocol for the diagnosis and treatment of chronic tinnitus. However, a range of possible treatments have been proposed to alleviate chronic tinnitus, including both pharmacological and non-pharmacological approaches. Pharmacological treatments include anticonvulsants, antidepressants, melatonin and zinc. Relaxation, psychoeducation about tinnitus, and sound masking are common aspects of a range of non-pharmacological treatments, including cognitive behaviour therapy (CBT), tinnitus retraining therapy (TRT) and music therapies. The range of treatments reflects both the broad range of ideas regarding mechanisms of tinnitus perception, and the diversity of health professionals that are interested in tinnitus and often approached by patients with chronic tinnitus to provide help. These professionals include audiologists, otolaryngologists/ear nose throat (ENT) specialists, neurologists, psychiatrists and psychologists (Holmes & Padgham, 2009; Maldonado Fernández, Shin, Scherer, & Murdin, 2015).

Rationale for this project

While the generation of the tinnitus sound has been linked to peripheral and central auditory system dysfunction (Eggermont & Roberts, 2012; Muhlnickel, Elbert, Taub, & Flor, 1998), the mechanisms that maintain persistent awareness of the tinnitus sound remain unknown. Research has suggested they may involve neuropsychological processes, typically captured in a ‘vicious cycle’ of hypervigilance, shown in Figure 1, which occurs when the tinnitus sound is associated with negative emotions (Husain, 2016; Jastreboff et al., 1996).

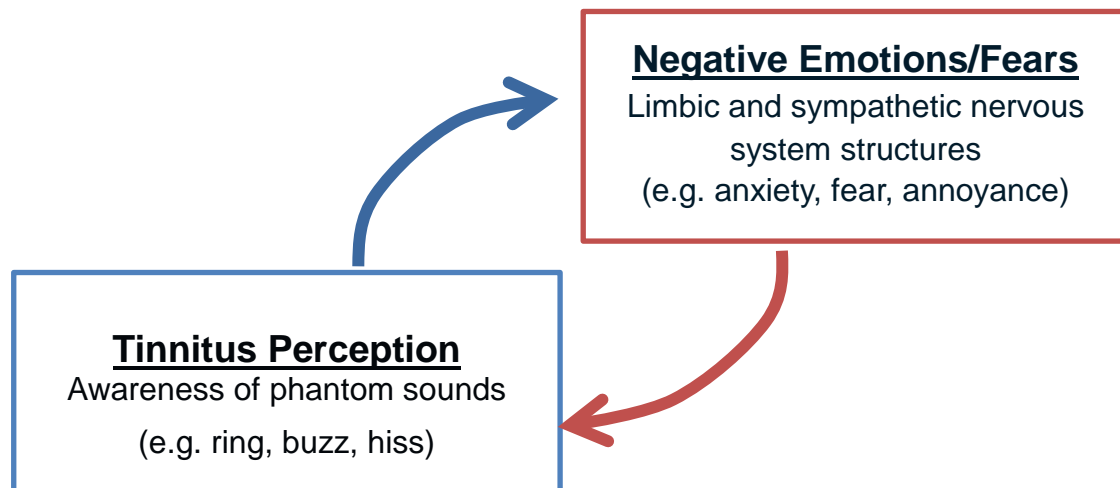


Figure 1. The ‘vicious cycle’ of chronic tinnitus. Perception of the tinnitus sound leads to negative emotions (blue arrow) such as worrying about the sound. In turn, this maintains awareness of the sound as a ‘threat’ to wellbeing. As a result of this hypervigilance, the sound is hard to habituate, and becomes strongly linked with negative emotions, namely anxiety, fear, and annoyance.

At the moment psychological factors are typically characterised as secondary features or symptoms of the chronic tinnitus experience i.e. a *consequence* of experiencing chronic tinnitus. Could, however, psychological factors be part of the mechanism *driving* chronic perception of tinnitus?

Advancing our understanding of how psychological factors and their neurobiological underpinnings may be involved in chronic tinnitus is an important extension of current research to address this question. In other words, while auditory mechanisms may relate more to the generation of the tinnitus sound, higher-order psychological mechanisms may have a core role in maintaining ongoing awareness of the sound and its associated daily impact.

“Could psychological factors be more than a side effect of tinnitus? Our project investigates if psychological factors are actually driving the failure to ‘tune out tinnitus.

Project Aims

Objective

There is a need to determine how we habituate to sounds to improve our understanding of hearing habituation. Here, we use chronic tinnitus to investigate psychological and neurobiological factors that underpin the failure to ‘tune out’ or habituate to the tinnitus sound. Answering this question will lead to the identification of the mechanisms that drive chronic tinnitus and habituation, and in turn, these mechanisms can be targeted in future treatments.

Aims

1. To determine if psychological functioning is impaired in people with chronic tinnitus and contribute to ongoing awareness of the tinnitus sound (Study 1 and 2).
2. To determine if cognitive factors contribute to ongoing awareness of the tinnitus sound (Study 1 and 3).
3. To determine if the failure in habituation is specific to the tinnitus sound, or if it reflects broader difficulties in attention switching and emotion regulation (Study 3 and 4).
4. To determine if a failure in the brain networks that help us direct and switch attention could be maintaining awareness of the tinnitus sound (Study 5).



PhD candidate, Krysta Trevis, demonstrating what an electroencephalogram (EEG) cap looks like. The cap feels like a swimming cap, and has small electrodes all over it where a bit of gel is squeezed into, to help pick up brain signals that the computer records as ‘brain waves’.²

² Credit: This image was captured by Michael Amendolia as part of a story by Peter Meredith called ‘The Symphony of the Mind’. This story featured in the March-April 2014 issue of Australian Geographic (issue 119, pp 40-55). Re-used here with permission.

Project Activities

Study One. Beyond the auditory system: The contribution of psychology to chronic tinnitus

Aims

The first study comprehensively reviewed existing literature to investigate the contribution of psychological functioning to the presence and impact of chronic tinnitus. While tinnitus has traditionally been thought of as an auditory disorder, there has been growing interest in the role of non-auditory processes such as attention, memory, and emotional wellbeing. As such, we aimed to identify the full range of psychological processes involved in the tinnitus experience.

Methods

We searched for existing literature that investigated the psychological functioning of people with chronic tinnitus to establish the potential role of psychology in 1) the ongoing awareness of tinnitus, and 2) the severity of chronic tinnitus. We then used meta-analytic techniques to specifically address the contribution of anxiety and depression to chronic tinnitus, as these two factors were identified as highly salient psychological factors in the existing literature.

Results

We initially identified 752 papers based on our search criteria. After removing duplicates and excluding studies that did not meet criteria (e.g. studies about animals, other conditions, or acute tinnitus) we were left with 52 studies. These studies had been published between 1991 and 2015 with the majority of studies from European countries (69%). Only 6% of studies were from Australia.

Our results indicated that a broad range of psychological factors is related to both the presence and impact of chronic tinnitus (Figure 2). These include aspects of cognitive functioning, such as attention and memory, as well as those associated with mood and emotional wellbeing.

A subset of 30 studies was eligible for meta-analyses, which allowed for more powerful comparisons with larger groups of people than individual studies can typically collect. For example, we were able to analyse the association between depressive symptoms and severity of tinnitus impact based on 15 studies, giving a sample size of 7991 people with chronic tinnitus. We performed four meta-analyses investigating the contribution of anxiety

and depression to the presence and severity of chronic tinnitus (summarised in Table 1). Together, these analyses revealed compelling evidence for the involvement of decreased emotional wellbeing in chronic tinnitus.

Table 1. Summary of meta-analytic results.

	Depressive Symptoms	Anxiety Symptoms
Presence of Tinnitus	More depressive symptoms were reported by people with tinnitus than people without tinnitus.	More anxiety symptoms were reported by people with tinnitus than people without tinnitus
Impact of Tinnitus	Greater depressive symptoms associated with a worse impact of tinnitus	Greater anxiety symptoms are associated with a worse impact of tinnitus

Summary

The results of this study clearly show that psychological factors are involved in chronic tinnitus and may contribute to difficulties ‘tuning out’ to the tinnitus sound.

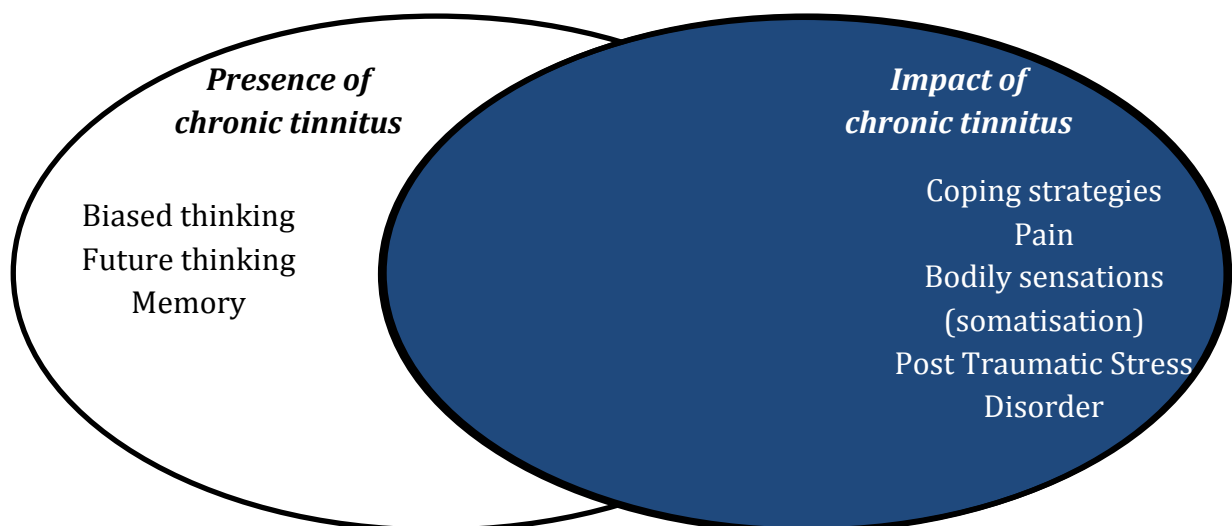


Figure 2. Venn diagram highlighting the contribution of psychological factors found to be impaired in people with chronic tinnitus, and/or associated with its impact.

Study Two: What Mediates the ‘Vicious Cycle’ of Tinnitus

Aims

The second study addressed the complexity of relationships between psychological factors identified in Study One that may be interacting to maintain the experience of chronic tinnitus. Traditional ‘vicious cycle’ models place a core emphasis on the relationship between tinnitus and anxiety (see Figure 1, page 7). In contrast, Study One indicated a much larger range of psychological factors are involved in chronic tinnitus. As such, we interrogated the role of these factors in the ‘vicious cycle’. Specifically, we investigated depressive symptoms, illness attitudes (including bodily sensations), coping strategies, and obsessive-compulsive tendencies which can reflect less flexible thinking styles (or ‘meta-cognition’).

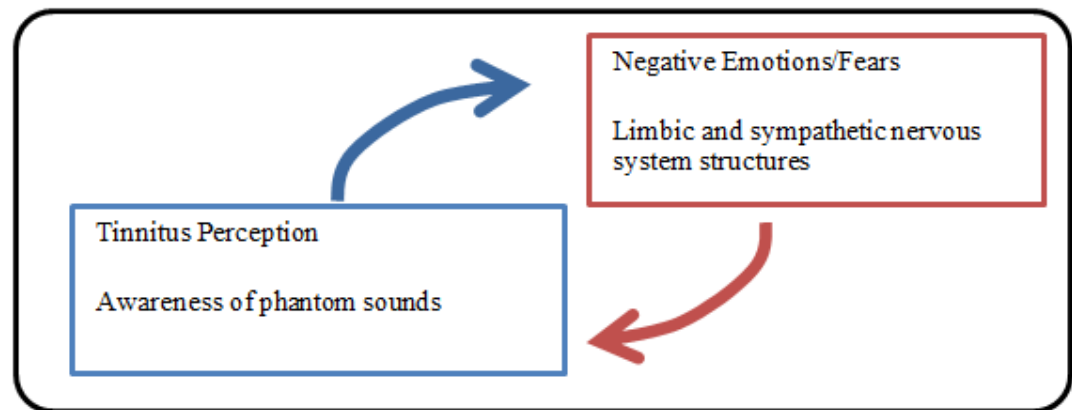
Methods

Eighty-one people with chronic tinnitus were recruited from our community through newsletters, flyers and online advertisements on university, community, and audiology clinic noticeboards. Participants answered questions about their experience of living with tinnitus, and their psychological wellbeing. We used statistical analysis to show if the ‘vicious cycle’ prevents habituation to the tinnitus sound, and to assess whether other psychological factors may be involved in the ‘vicious cycle’.

Results

Our results first replicated the vicious cycle of hypervigilance to the tinnitus sound, whereby awareness was associated with anxiety, which in turn increased awareness of the tinnitus sound. We also discovered a new finding, showing that the experience of the ‘vicious cycle’ is conditional on the presence of depressive symptoms, as shown in Figure 3.

A. Traditional 'vicious cycle'



B. Extending the 'vicious cycle'

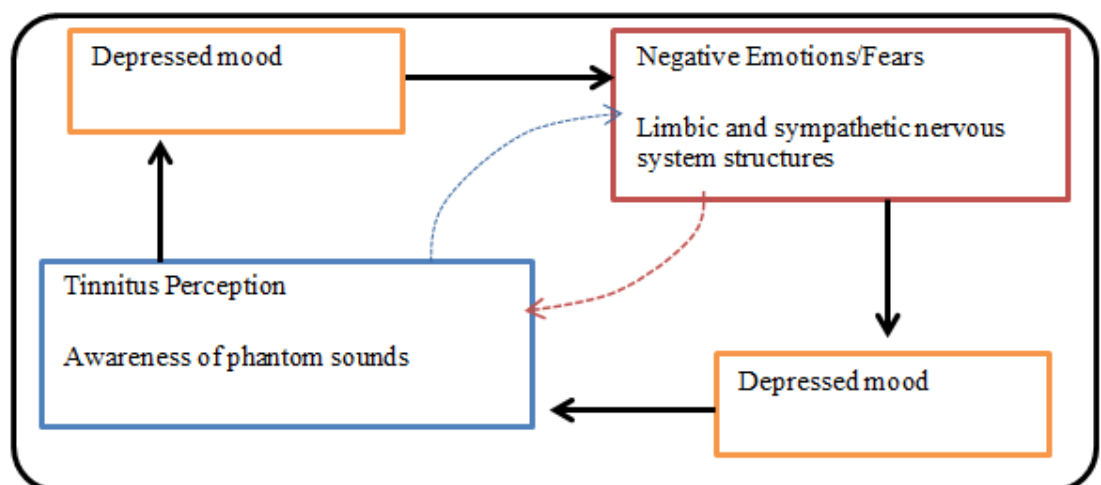


Figure 3. How our work extends our understanding of the 'vicious cycle' and factors that maintain chronic tinnitus.

Note that the traditional relationship between tinnitus perception and negative emotions/fears shown in Figure 3a is extended in Figure 3b, where this relationship only occurs in the presence of depressed mood (orange). This figure is adapted from Trevis et al., (2016), published in the *Journal of Affective Disorders*, doi:10.1016/j.jad.2016.06.055.

Finally, we identified two less adaptive coping strategies in people with chronic tinnitus experiencing depressive symptoms. The two coping strategies associated with depressive symptoms were (1) self-blame e.g. "I criticized or lectured myself" and (2) escape-avoidance e.g. "I hoped for a miracle". For detailed results, refer to our full article published by Trevis, McLachlan, & Wilson (2016) in *Journal of Affective Disorders* (doi:10.1016/j.jad.2016.06.055).

Summary

For the first time this study revealed a critical role of depressive symptoms in both the awareness of the tinnitus sound and its negative impact, extending our understanding of the vicious cycle. Our work indicates the ‘vicious cycle’ only occurs in the context of depressive symptoms, which suggests low mood may account for down-stream effects of poor emotion regulation (e.g. anxiety symptoms) and difficulty directing our attention (e.g. hypervigilance and a failure to habituate). Thus depression may act as a mechanism for both ongoing awareness of the sound and the severity of its impact.

The identification of less adaptive coping strategies will improve the effectiveness of psychological therapies for tinnitus. For example, therapists may find it helpful to determine if patients with habituation difficulties such as tinnitus are trying to cope with it by using these strategies, and equip individuals with alternative coping strategies.

Study Three: The Contribution of Cognition to Chronic Tinnitus

Aims

Our third study aimed to investigate whether chronic tinnitus results from a failure in the process of attention switching. Attention switching is how we ‘tune in’ to important sensations (e.g. alarms, our name, a hard task requiring concentration) and ‘tune out’ to distractors (e.g. background noises, sights, smells). We investigated two cognitive markers of the ability to switch attention to determine its role in habituation to the tinnitus sound:

- (1) cognitive control – our ability to direct our attention resources to achieve our goals
- (2) emotional wellbeing - our ability to control or ‘regulate’ our emotional responses

Methods

We recruited 26 people with chronic tinnitus and 26 healthy-hearing controls from the general community using flyers and advertisements in online noticeboards. Participants completed questionnaires about their emotional wellbeing and completed tasks that assessed aspects of cognitive functioning that help us to switch our attention. The cognitive control task we used was called the ‘*n*-back’ task. In the easy version of the *n*-back task people click a button whenever they see a target letter appear on their screen (e.g. click when you see and ‘X’). In the hard version of the *n*-back task people click a button if the letter on their screen is the same as the letter they saw two screens before.

Results

We found that people with chronic tinnitus were less proficient at the cognitive control task. In other words, people with chronic tinnitus were slower to perform the same process suggesting they experienced greater difficulty in directing or controlling their attention resources (Figure 4). This effect remained after accounting for other aspects of cognitive functioning, such as inhibitory control (our ability to resist distractors) and working memory (our ability to keep relevant information in mind). This effect also remained after accounting for emotional wellbeing (symptoms of anxiety and depression), hearing ability, tinnitus impact and loudness.

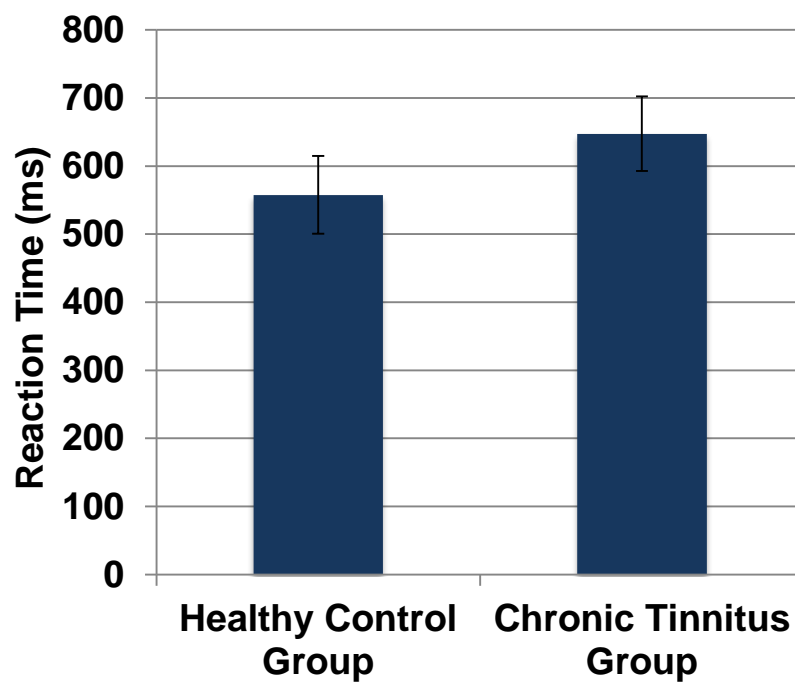


Figure 4. The chronic tinnitus group performed worse overall on the cognitive control task. Performance on the hard version of the n-back task is shown here.

Adapted from Trevis et al., (2016), published in *Frontiers in Psychology*, doi: 10.3389/fpsyg.2016.01262.

We also checked that this result wasn't due to one group performing a task with a distracting background sound (tinnitus sound) and one group working in silence. To do this the control group performed the task while a background sound was played and compared this to the chronic tinnitus group (with and without the background sound playing). Regardless of the presence or absence of a background sound, we consistently found that the chronic tinnitus group was less proficient at the cognitive control task. This suggests that it is not the presence of a sound causing poorer performance on the task, rather, poor performance is more likely to result from poor cognitive control.

Finally, we found that people with chronic tinnitus also reported greater depressive symptoms. The combination of depressive symptoms and performance on the cognitive control task successfully predicted who experienced chronic tinnitus.

Summary

The results of this study suggest impaired cognitive control is not due to the presence of the tinnitus sound per se, but may arise due to a failure in cognitive control mechanisms down-regulating awareness of the tinnitus sound.

Study Four: Is it the sound or your relationship to it?

Aims

Building on Study Three, we investigated if tinnitus sounds were harder to habituate, due to the emotional salience associated with the sound in chronic tinnitus. To answer this question, we compared habituation rates to neutral sounds and tinnitus sounds.



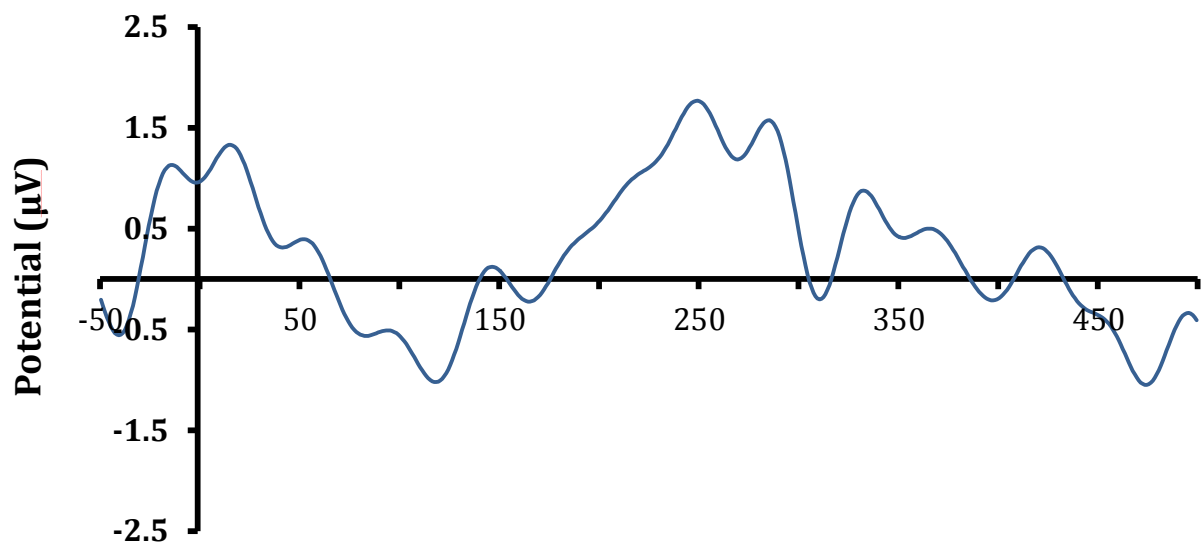
Professor Sarah Wilson and her PhD student, Krysta Trevis, demonstrate what an electroencephalogram (EEG) cap and experimental set-up looks like. The caps feel like wearing a swimming cap, and have small electrodes which a bit of gel is inserted into to help pick up brain signals which the computer records as ‘brain waves’.³

³ Credit: This image was captured by Michael Amendolia as part of a story by Peter Meredith called ‘The Symphony of the Mind’. This story featured in the March-April 2014 issue of Australian Geographic (issue 119, pp 40-55). Re-used here with permission.

Methods

We recruited 20 people with chronic tinnitus, 20 people with healthy hearing, and 20 people with hearing loss who did not have tinnitus from advertisements in the general community and hearing clinics. We recorded brain activity using electroencephalography (EEG) while people listened to sounds over a 1.5 hour session.

Results



The results of this study are under analysis at present, and will be published in due course (Figure 5).

Figure 5. Example of a recording of the neural signal or ‘brain wave’ (y-axis) from a single electrode over a 500ms time period (x-axis). Here the participant was played a sound at the 0ms mark. The neural signal shows markers of interest including the negative dip in the wave around 100ms, known as the N100 involved in sound perception, and the positive rebound around 270ms, known as the P300, involved in the cognitive evaluation of a sound (i.e. salience).

Study Five: Brain Networks Involved in Habituation

Aims

The final study of this project interrogated the functioning of the brain networks that facilitate how we switch our attention, which was shown to drive chronic tinnitus in Study Three. We used brain scanning to examine the functioning of these networks in people with chronic tinnitus compared to a group of healthy-hearing individuals who were of a similar age and sex, and reported similar levels of emotional wellbeing.

Methods

This study employed functional magnetic resonance imaging (fMRI) to measure brain activation during a cognitively demanding, attention-switching task. We used the same task as Study Three (the *n*-back task), which is known to activate the cognitive control network that underpins how we direct attention resources (Figure 6).

We wanted to take what people told us about their experience of tinnitus to the next level...to see the neural signature of this experience.

We compared the brain activation patterns of 15 people with chronic tinnitus to 15 people without chronic tinnitus who volunteered in response to community advertisements, and involvement in earlier studies. This method provides insight into the neurocognitive basis of how we switch attention, the core process that allows us to habituate to sounds by tuning out less important information (e.g. the noise of the MRI scanner) in order to focus on more important information (e.g. performing the *n*-back task).

Results

The results of this study are currently under review for publication, and will be released in due course.

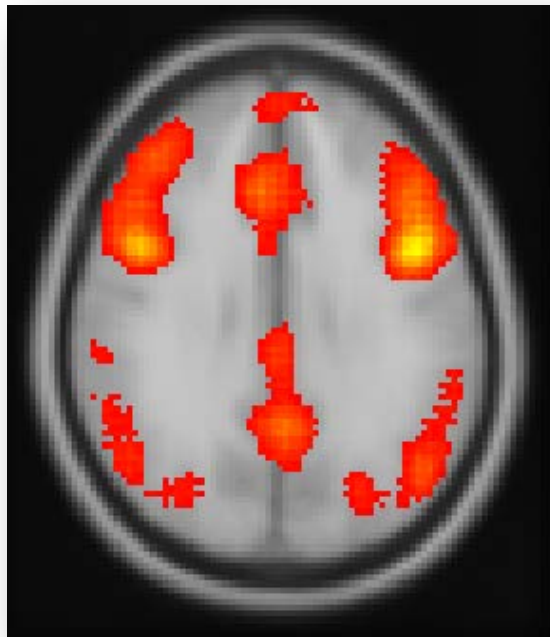


Figure 6. An example of a brain network (the cognitive control network) that helps us switch our attention so we can habituate to less relevant information.

To generate this image we performed a meta-analysis of 2633 fMRI studies that used cognitive task to activate the brain. To do this analysis we used NeuroSynth, and identified using the search term 'cognitive' (Yarkoni, Poldrack, Nichols, Van Essen, & Wager, 2011).

Conclusions

The results of this project provide new behavioural and neuroimaging evidence that psychological and cognitive mechanisms may maintain chronic tinnitus rather than arise as a consequence of the tinnitus. In particular we have shown that mechanisms relating to how we switch attention such as our ability to direct our attention resources, and our ability to regulate our mood, have a core role in driving our ability to habituate to sounds.

As a result of altered brain function in the cognitive control and mood networks, a failure to habituate to background sounds may result in:

- ongoing awareness of irrelevant sounds such as tinnitus,
- increased salience of irrelevant sounds such as tinnitus,
- increased emotional impact of irrelevant sounds such as tinnitus.

Together, our findings suggest that these factors contribute to an ongoing failure to shift attention away from and habituate to chronic tinnitus. The relevance of these findings to other hearing and auditory processing problems provides an exciting new avenue for future research.

Recommendations & Future Directions

Further Research

Additional research is needed to understand how our brain networks contribute to our ability to tune in to, and out from, our auditory world. Verifying the results of this project and exploring the unique contributions and interactions of these networks to habituation and wellbeing will be an important next step in the science of how we ‘tune out’ sounds. Addressing the progression of habituation difficulties, and how difficulties in habituation may differ in clinical and community cohorts with and without hearing difficulties will also be important to investigate.

Investigating New Avenues for Treatment Development

The results of this project indicate that exploring treatment strategies aimed at improving attention switching and retraining the functioning of brain networks will be important to facilitate healthy habituation to sounds and recovery from tinnitus. Strategies such as cognitive behaviour therapy, mindfulness/meditation techniques, auditory or attention training, and music therapy are likely to be helpful in altering the psychological salience of sounds that are hard to habituate to, both in terms of their ability to improve our wellbeing and the regulation of the networks that help us switch attention. Future studies specifically targeting the role of these factors in psychological treatments will ultimately lead to more effective, tailored treatments for people with chronic tinnitus.

Mood and wellbeing

Importantly, the functioning of the brain networks identified in this project are known to be involved in the experience of some symptoms of low mood. Depressed mood may be contributing to difficulties in habituation and should be routinely assessed in the care of people with tinnitus, as well as those with other forms of hearing damage and auditory disorders.

Dissemination

The results of this project have been shared with the scientific and general community through peer-reviewed publications, conference presentations, and media interviews. The work of this research program has also contributed to a PhD thesis, which is currently under examination.

Publications

Published manuscripts

Trevis KJ, McLachlan NM, Wilson SJ (2016). Psychological mediators of chronic tinnitus: The critical role of depression. *Journal of Affective Disorders*, 204, 234-240, doi:10.1016/j.jad.2016.06.055.

Trevis KJ, McLachlan NM, Wilson SJ. Cognitive mechanisms in chronic tinnitus: Psychological markers of a failure to switch attention. *Frontiers in Psychology*, 7:1262, doi: 10.3389/fpsyg.2016.01262.

Manuscripts under review

Trevis KJ, McLachlan NM, Wilson SJ. Impaired psychological functioning in chronic tinnitus: Evidence from a systematic review and meta-analysis.

Trevis KJ, Tailby C, McLachlan NM, Jackson G, Wilson SJ. Identification of a neurocognitive mechanism underpinning awareness of chronic tinnitus.

Presentations

Callander KJ, McLachlan NM, Wilson SJ. (2014). Habituation to self-identified tinnitus sounds in chronic tinnitus sufferers. *International Tinnitus Seminar*, Berlin, Germany.

Callander KJ, McLachlan NM, Wilson SJ. (2014). Characterising the psychosocial experiences of chronic tinnitus sufferers. *Tinnitus Research Initiative*, Auckland, New Zealand.

Callander KJ, McLachlan NM, Wilson SJ. (2013). "Tuning In or Out to the Melody": The Neurophysiological Mechanisms Underlying the Role of Recognition in Auditory Habituation. *Music, Mind & Health*, Melbourne, Australia. (poster)

Callander KJ, McLachlan NM, Grayden DB, Irving S, Wilson SJ. (2012) 'The sound of silence: Introducing an integrated model of chronic tinnitus', *SOBR Student Symposium*, Melbourne, Australia.

Callander KJ (2014) "Do you hear what I hear?", PhD Up and Comers: From the bionic eye to stem cell tourism, *Melbourne Neuroscience Institute Seminar*, Melbourne, Australia. (Invited speaker and panel member).

Callander KJ, McLachlan NM, Wilson SJ (2013) 'Tuning out Tinnitus', *Neurocognitive and Neuroimaging Workshop*, Melbourne, Australia.

Media Interviews

- 2016 Interviewed by Jane Marwick, ABC radio, Perth, for a story on Misophonia.
Interviewed by Genevieve Jacobs, ABC radio, Canberra, for a story on Sound Sensitivity.
- 2015 Interviewed by Russell Wolfe, ABC radio, Perth, for a story on Misophonia.
Interviewed by Mark White, *Sydney Morning Herald*, for an article on Misophonia.
Interviewed by Helen Foster, *Good Health Magazine*, for an article on sound sensitivities.
- 2014 Online survey 'Do you hear what I hear?' featured on primetime television show 'The Project' as part of a 'Living with Misophonia' news story.
- 2013 RRR radio interview on 'Tuning out Tinnitus' with Jacinta Parsons.

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