
**Do individuals with bothersome tinnitus have different auditory selective
attention and working memory abilities compared to non-tinnitus controls?
— an exploratory study**

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Abstract

Tinnitus is the perception of sounds heard in the ears or head in the absence of an external sound source (Luck, 2005; Stephens, 1987). Most individuals with tinnitus are able to habituate to the tinnitus signal and notice it to a lesser degree, while the sound remains salient for others (Coles, Baskill, & Sheldrake, 1984). Research has pointed to the persistence of tinnitus sounds as an abnormal response of the central auditory system (Noreña & Farley, 2013). Tinnitus has been frequently linked with reduced cognitive function (Andersson, Lyttkens, & Larsen, 1999; Jacobson et al., 1996; Stevens, Walker, Boyer, & Gallagher, 2007; Wilson, Henry, Bowen, & Haralambous, 1991) and working memory deficits (Hallam, McKenna, & Shurlock, 2004; Rossiter, Stevens, & Walker, 2006). Research has shown that tinnitus can also have an impact on auditory selective attention (Andersson, Eriksson, Lundh, & Lyttkens, 2000), with patients reporting difficulties with concentrating due to their tinnitus (Andersson et al., 1999).

The aim of this study was to characterise and compare auditory selective attention and working memory ability in individuals with tinnitus against healthy, non-tinnitus controls, and investigate the relationship between cognitive abilities, self-perceived tinnitus impact on functional life, and severity of tinnitus.

Twenty tinnitus participants and 22 control participants age 21 to 75 years completed the study. Tinnitus participants completed the following questionnaires: Tinnitus Sample Case History Questionnaire (TSCHQ) (Langguth et al., 2007), Tinnitus Functional Index (TFI) (Meikle et al., 2012), Tinnitus Severity Numeric Scale (TSNS) (The Tinnitus Research Initiative, 2009) and the Tinnitus Handicap Inventory (THI) (Newman, Jacobson, & Spitzer, 1996). Participants also

underwent tinnitus characterization procedures to obtain psychophysical measurements of tinnitus: pitch, loudness, and minimum masking levels. All participants received audiometric assessment to determine hearing threshold levels, completed the Depression, Anxiety, Stress Scale (DASS) (Lovibond & Lovibond, 1996), and were screened for dementia using the Mini Mental State exam (MMSE) (Folstein & Folstein, 1975). Auditory selective attention was assessed via a brief, computerised dichotic listening task adapted from the protocol employed by Humes, Lee, and Coughlin (2006) using Millisecond Inquisit Lab software (Draine, 2015). This software was also used to administer forward and backward order auditory digit span tasks, indexing short-term and working memory abilities.

Findings revealed no between-group differences in auditory selective attention or digit span performance. However, significant negative correlations were found within the tinnitus group between a digit span task determining the maximum length of numbers recalled in forward order and TSNS sub-scales indicating tinnitus discomfort ($r_s = -.614$, $p = 0.004$) and annoyance ($r_s = -.566$, $p = 0.009$) as well as the TFI overall score ($r_s = -.536$, $p = 0.015$). Tinnitus group TFI scores were also significantly correlated with the DASS stress sub-scale, $r_s = 0.448$, $p = 0.048$.

The lack of between-group differences detected indicate that tinnitus participants do not appear to differ in auditory selective attention and working memory abilities compared to the control group, for this study. However, higher degrees of self-reported overall tinnitus functional impact, and specific subsets of discomfort and annoyance were associated with poorer short-term memory ability, as indexed by the forward-order digit span task. Previous research has demonstrated atypical neural indicators of short-term memory for individuals with tinnitus, as compared to controls (Husain, Akrofi, Carpenter-Thompson, & Schmidt, 2015; Husain, Pajor, et al., 2011). A

positive correlation revealed between TFI overall scores and stress lends further support to the relationship between tinnitus and negative emotional states. Due to a lack of international consensus on the links between tinnitus and cognitive processes of attention and memory (Andersson & McKenna, 2006; Mohamad, Hoare, & Hall, 2015), and limitations of study power and lack of well-matched groups in the current study, further examination is recommended. Tinnitus remains an incurable symptom, but future research with better-designed studies may help to shed further light on tinnitus and cognitive processes—specifically short-term memory—and help inform tinnitus management practice.

Acknowledgements

First and foremost, I wish to express my gratitude to my primary supervisor, Dr Kim Wise, for your constant support and encouragement during this journey. Thank you for enabling me to carry out a research project on an area that truly sparks my interest, for the knowledge you have imparted, and for your countless hours dedicated to helping me with this study and reviewing my work with incredible speed.

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Lastly, I would like to thank my family for their unconditional support through this thesis journey and this degree; and for their guidance which has led me to where I am today. There is no place I would rather be. Mum and Dad, this thesis is dedicated to you.

This thesis is presented in a New Zealand English format.

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List of Abbreviations

| | |
|----------|---|
| ACT | Acceptance and Commitment Therapy |
| AM-101 | Currently Trialled Drug for Tinnitus |
| ASA | Auditory Selective Attention |
| B-ML | Backward Maximum Length (digit span) |
| B-TE | Backward Two Error (digit span) |
| CAS | Contralateral Acoustic Stimulation |
| CBT | Cognitive Behavioural Therapy |
| CI | Confidence Interval |
| CN | Cochlear Nuclei/Nucleus |
| CNS | Central Nervous System |
| CRM | Coordinate Response Measure |
| DASS | Depression Anxiety Stress Scale |
| DS | Digit Span |
| DSS | Digit Symbol Substitution (test) |
| ERP(s) | Event-related Potential(s) |
| F-ML | Forward Maximum Length (digit span) |
| F-TE | Forward Two Error (digit span) |
| fMRI | Functional Magnetic Resonance Imaging |
| GABA | Gamma Amino Butyric Acid |
| HA | Hearing Aid(s) |
| Hz | Hertz |
| IC | Inferior Colliculus |
| IHC | Inner Hair Cell |
| LTS | Long-term Store |
| MGB | Medial Geniculate Body |
| MML/MMLs | Minimum Masking Level/(s) |
| MoCA | Montreal Cognitive Assessment |
| MRI | Magnetic Resonance Imaging |
| NART | National Adult Reading Test |
| Nd | Negative-difference (waveform) |
| NMDA | N-methyl-D-aspartate |
| OHC | Outer Hair Cell |
| PTA | Pure-tone Average |
| SD | Standard Deviation |
| SL | Sensation Level |
| SOC | Superior Olivary Complex |
| SPSS | Statistical Package for the Social Sciences |
| SSNHL | Sudden Sensorineural Hearing Loss |
| STS | Short-term Store |
| TACTT0 | Name for Phase II Trial for AM-101 |
| TAQ | Tinnitus Acceptance Questionnaire |
| TFI | Tinnitus Functional Index |
| THI | Tinnitus Handicap Inventory |

| | |
|-------|--|
| THQ | Tinnitus Handicap Questionnaire |
| tF | Tinnitus Frequency (tinnitus pitch-match) |
| tLM | Tinnitus Loudness-match |
| TRQ | Tinnitus Reaction Questionnaire |
| TRT | Tinnitus Retraining Therapy |
| TSCHQ | Tinnitus Sample Case History Questionnaire |
| TSNS | Tinnitus Severity Numeric Scale |
| 2AFC | 2-Alternative-Forced-Choice |
| 3MS | Modified Mini-Mental State |

1 Introduction

1.1 Overview: Tinnitus, Attention and Working Memory

The role of attention and associated cognitive networks in tinnitus perception have received much attention over the last 10 – 15 years (Acrani & Pereira, 2010; Cuny, Noreña, El Massioui, & Chéry-Croze, 2004; Cuny, Noreña, Koenig, Bougeant, & Chéry-Croze, 2002; Knobel & Sanchez, 2008). Attention has been investigated as a potential contributing factor to tinnitus' subjective prominence, and the diversion of attention away from the tinnitus signal has been trialled as a treatment (Spiegel et al., 2015; Wise, 2013; Wise, Kobayashi, & Searchfield, 2015).

Tinnitus is often perceived as an endogenous signal which arises without any contributing external stimuli (Eggermont & Roberts, 2004; Hazell & Jastreboff, 1990). It is most commonly described as a ringing or buzzing sound perceived in, or near, the head or ear(s) (Eggermont & Roberts, 2004). However, it can also be characterised by other sounds or more than one sound (Meikle & Taylor-Walsh, 1984).

The major risk factor for tinnitus is hearing loss, with 90% of individuals reporting tinnitus in a clinical setting, also presenting with a measurable degree of hearing loss (Vernon & Sanders, 2001a). Therefore, anything that produces hearing loss may potentially cause tinnitus for some individuals, including: presbycusis, head injuries, and ototoxic drugs (Folmer, Martin, & Shi, 2004; Møller, Langguth, DeRidder, & Kleinjung, 2011). It is well-supported that many cases of tinnitus are linked to some degree of injury or deterioration of the inner ear (Baguley, 2002; Eggermont & Roberts, 2004; Hazell & Jastreboff, 1990; Jastreboff, 1990). Over time, changes in the peripheral auditory system appear to lead to unusual neural activity arising in the central

auditory pathway. This, in turn, is theorised to promote neuroplastic changes in auditory cortical regions, which may be perceived as sound by the tinnitus sufferer (Eggermont & Roberts, 2004).

Jastreboff's (1996) model of tinnitus suggested that much of the severity associated with the impact of tinnitus, is related to the individual's psychological response to abnormal auditory input and emotional aspects (Jastreboff, Gray, & Gold, 1996). Factors such as anxiety, stress and depression have been shown to co-exist with tinnitus and may contribute to overall tinnitus impact (Heinecke, Weise, Schwarz, & Rief, 2008; Zöger, Svedlund, & Holgers, 2006).

However, the relationship between tinnitus and anxiety, stress, and depression appear to be dual-directional (Halford & Anderson, 1991). Pre-existing tinnitus has been linked with concurrent negative affective states (Tyler & Baker, 1983), whereas pre-existing poor mental and emotional health have been linked with tinnitus emergence (Andersson & McKenna, 1998; Hinton, Chhean, Pich, Hofmann, & Barlow, 2006); cases have been made for both per the research literature (Halford & Anderson, 1991).

Therefore, as emotional and cognitive processes may also affect how dominant and difficult to ignore the tinnitus may be, including the ability to divert attention away from this signal, it becomes a topic of research interest (Cuny et al., 2004; Jacobson et al., 1996).

Tinnitus patients frequently report difficulty concentrating (Sanchez & Stephens, 1997; Tyler & Baker, 1983) and several studies have found differences in attentional cognitive abilities in those with and without tinnitus (Cuny et al., 2004; Hallam et al., 2004; Singh, 2006). As tinnitus is thought to stem from failed habituation for some individuals (Hallam, Rachman, & Hinchcliffe, 1984), it has been theorised to increase demand on auditory processes, concentration, and thus

working memory, which is a limited capacity resource (Baddeley, 2000; Mohamad et al., 2015; Rossiter et al., 2006).

2 Literature Review

The topics of tinnitus, attention and working memory contain research from multiple disciplines. To focus the review, the literature will primarily assist the reader in a basic understanding of the broad topics of tinnitus, attention and working memory; review research literature summarising how tinnitus perception, attention, and working memory may be interrelated; and present theories explaining how attention and working memory are thought to differ for those with tinnitus, compared to those without tinnitus. The literature review will be presented using a narrative style. This style is an established method used to shape a literature review (Rumrill, Fitzgerald, & Merchant, 2010), and will support the presentation of information from the current body of research in such a way, that fresh perspectives may be sown. This chapter will open with an introduction to the auditory system and pathways. Following this will be an introduction to tinnitus, its presentation in sufferers, demographic and epidemiological information pertaining to tinnitus globally. This will be followed by theories around tinnitus generation and perception, and pathophysiology. Also discussed will be the way in which tinnitus is currently diagnosed and managed, as well as novel approaches which are currently in development. Subsequently, the topics of selective attention and working memory will be presented, and their proposed relationship(s) to tinnitus will be explored. The review will conclude with a statement of the aims of the present study.

2.1 Anatomy and Physiology of the Auditory System

This section is presented to introduce the anatomy and physiology of the auditory system, to facilitate the presentation of topics and discussion, related to anatomical and physiological underpinnings for tinnitus genesis or sustaining factors. Readers may wish to refer to the

following sources for more comprehensive information on the auditory system (Gelfand, 2001; Gelfand, 2010; Møller, 2013; Pickles, 2012).

2.1.1 *The Peripheral Auditory System*

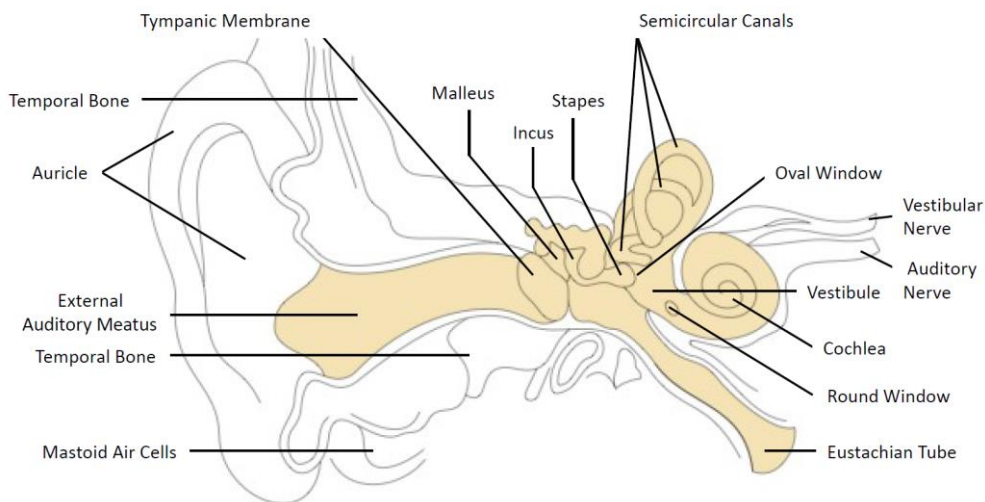


Figure 2-1. Cross-sectional schematic representation of the human ear (Wise, 2013, p. 8)(with permission).

In normal perception of sound, sound waves reach the external ear. The external ear is comprised of the pinna which is an irregularly-shaped, semi-oval flap of elastic cartilage, continuous with the cartilaginous portion of the ear canal (Johnson, Hawke, & Jahn, 2001; Møller, 2013). The ear canal consists of the outer cartilaginous section which roughly makes up one-third to one-half of the total ear canal length, and the bony inner portion which makes up the remainder (Alvord & Farmer, 1997; Johnson et al., 2001). The bony portion is formed by a cylinder of bone which begins at the osseo-cartilaginous junction, and extends to the tympanic annulus (Johnson et al., 2001). The skin of the ear canal is approximately 0.2 mm thick in the bony portion (Alvord & Farmer, 1997), but thicker in the cartilaginous portion (0.5 – 1 mm), where it contains glands that

secrete cerumen (Alvord & Farmer, 1997; Gelfand, 2004; Johnson et al., 2001). Sound waves enter the external ear and are directed down the ear canal towards the tympanic membrane where the ear canal terminates (Johnson et al., 2001; Møller et al., 2011).

The external ear and ear canal channel sound energy and serve as the passageway for sound to the tympanic membrane, the gateway to the middle ear (Gelfand, 2004; Johnson et al., 2001). The external canal should be largely unimpeded but can build up with cerumen (Wilson, 1987) or sometimes foreign objects may be present (Olajide, Ologe, & Arigbede, 2011). Blockage of the ear canal may exacerbate internal noises, and it can in some cases promote tinnitus, as the masking effect provided by external ambient or environmental sounds, is reduced (Wilson, 1987). The ear canal also serves as a resonator, generating peak resonance for frequencies necessary for perception of human voices (Gelfand, 2004). Resulting sound vibrations reaching the tympanic membrane are transmitted through the air-filled middle ear cavity via the middle ear bones (called ossicles), to the cochlea of the inner ear (Geisler, 1998; Gelfand, 2004; Møller et al., 2011).

The inner ear consists of the cochlea, otherwise known as the organ of hearing, and the vestibular system, the organ of balance (Gelfand, 2010). The cochlea is a coil/shell-shaped structure which sits within the temporal bone of the skull (Gelfand, 2010; Møller, 2013). The ossicles (malleus, incus and stapes) mechanically conduct sound vibrations from the tympanic membrane to the oval window of the cochlea (Geisler, 1998). The cochlea has three fluid-filled cavities: the scala vestibuli, scala media, and scala tympani (Gelfand, 2010; Møller, 2013; Santi & Tsuprun, 2001). The scalae vestibuli and tympani are filled with perilymph (Gelfand, 2004; Santi & Tsuprun, 2001), a fluid with similar composition to extra-cellular fluid (Pickles, 2008), while the scala

media is filled with endolymph, which is similar in composition to intra-cellular fluid (Gelfand, 2010; Møller, 2013).

The scala media houses the organ of Corti, which contains the primary sensory receptor cells (Gelfand, 2010). These cells feature sensory filaments located at their top ends termed “stereocilia” and are often referred to as “hair cells” (Gelfand, 2001, p. 63). The hair cells are arranged into three to five rows of outer hair cells (OHCs) and one row of inner hair cells (IHCs), both lying along the length of the basilar membrane (Gelfand, 2010; Møller, 2013). The role of the cochlea is to transfer sound vibrations into neural impulses (Geisler, 1998). Different sound frequencies associated with incoming sound vibrations, generate different travelling wave patterns resulting in peak sound energy amplitudes generated at different regions of the cochlea (Gelfand, 2010). The cochlea is arranged in a frequency-specific fashion with hair cells sensitive to high frequencies at the basal end, and low frequencies at the apical end, analogous to a rolled up piano keyboard (Geisler, 1998; Møller et al., 2011). The cochlea’s OHCs serve to amplify pressure waves, and IHCs convert sound vibrations into neural signals (Gelfand, 2001). They transmit this sensory information via the vestibulo-cochlear nerve (the VIIIth cranial nerve) also known as the auditory nerve (Gelfand, 2010; Malmierca & Hackett, 2010; Møller et al., 2011). This provides input to the central nervous system (CNS), which involves structures in the pons, midbrain, thalamus and cerebral cortex (Malmierca & Hackett, 2010; Møller et al., 2011; Wilson, 1987).

2.1.2 The Central Auditory System

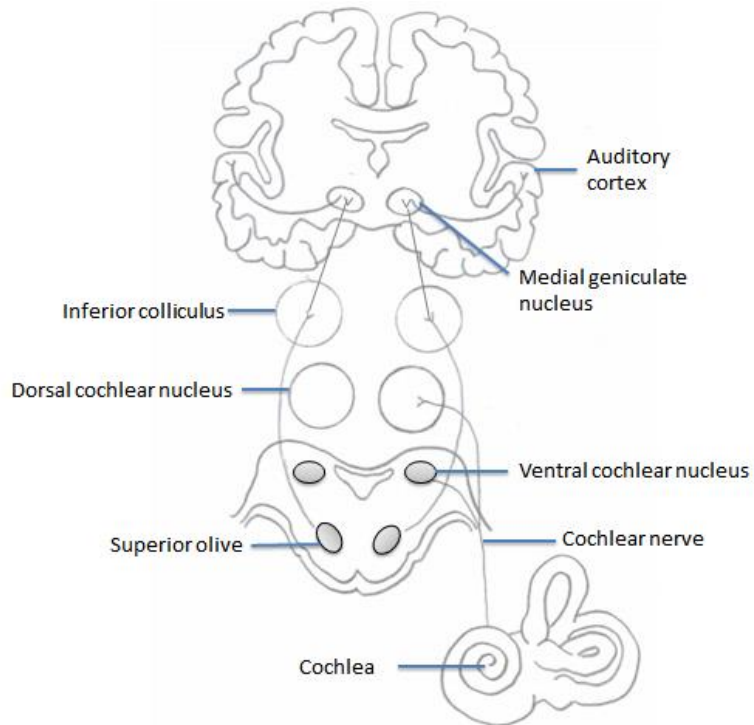


Figure 2-2. Ascending central auditory system pathways. Adapted from Butler and Lomber (2013, p. 7) (with permission).

The auditory nerve is part of the eighth cranial nerve which also includes the vestibular nerve branch, and has type I (large, myelinated) and type II (small, unmyelinated) fibres (Møller, 2013). The nerve fibres have their cell bodies in the spiral ganglion located in the modiolus of the cochlea (Pickles, 2008), with peripheral portions of the type I fibres terminating on IHCs and central portions terminating on cells of the cranial nerve (Geisler, 1998; Møller, 2013). These fibres are thought to carry all the auditory information from the organ of Corti to higher centers of the cochlear nuclei CN (Gelfand, 2010; Pickles, 2012). The type II fibres form the outer spiral fibres and constitute approximately 5% of the total population of nerve fibres in the auditory

nerve (Møller, 2013); they innervate the OHCs and project mostly to the dorsal CN (Møller, 2013).

The auditory nerve reaches the CN which is the first relay nucleus of the ascending auditory pathways (Pickles, 2012). The CN is located in the lower brainstem ipsilateral to both ears from which it receives stimulation (Gelfand, 2010).

The superior olivary complex (SOC) consists of three, main nuclei which receive input from the CN bilaterally (Møller, 2013). The SOC is the first group of nuclei that integrates information from both ears (Møller, 2013; Pickles, 2012).

The lateral lemniscus and its nuclei are formed by three striae that emanate from the CN and pass through the SOC (Møller, 2013). The central nucleus on both sides are connected, allowing the thalamus and auditory cortex on one side to receive signals from both ears (Pickles, 2012).

The inferior colliculus (IC), located in the midbrain, is a relay nucleus through which ascending and descending auditory information are conveyed (Møller, 2013). It also provides some links that are not auditory in nature (Malmierca, 2003), with the dorsal portion of the IC thought to control some aspects of auditory attention (Schofield, 2010).

The medial geniculate body (MGB) is the thalamic auditory relay nucleus that receives afferent signals from the inferior colliculus, and projects them to the cerebral cortex (Møller, 2013; Pickles, 2008). The dorsal part of the MGB has been shown to make connections with the amygdala, associated with emotional responses which can be fear-based (Doron & LeDoux, 1999).

The auditory cerebral cortex is located deep in the superior portion of the temporal lobe in the transverse gyrus of Heschl (Møller, 2013). The primary auditory cortex and the posterior auditory field receive input from the ventral division of the MGB (Durrant & Lovrinic, 1995; Pickles, 2012). Fibre tracts for the primary auditory cortex project to other regions of the auditory cortex and association cortices where auditory signals are integrated with other sensory inputs, and information from other parts of the CNS (Møller, 2013). Neurons in the primary auditory cortex respond only to sound, while some neurons in the other areas of the auditory cortex respond to somatosensory and visual stimuli (Møller, 2013). Secondary cortex areas provide connections to other parts of the brain, including areas associated with memory (e.g. amygdala, hippocampus, prefrontal cortex) (Arnold, 2013) and attention (e.g. cerebral cortex, hippocampus, amygdala, reticular formation) (Cohen, 2013; van Zomeren & Brouwer, 1994).

2.1.3 *The Auditory Pathways*

The auditory nervous system consists of ascending and descending pathways connecting the ear with the auditory cerebral cortex (Gelfand, 2004). The major structures that transmit ascending neural activity through the central auditory system include the cochlear nucleus, superior olivary complex, inferior colliculus, medial geniculate nucleus, and the auditory cortex (Gelfand, 2010).

Within the ascending auditory pathways, the auditory nerve provides input to the cochlear nuclei, in a parallel processing fashion whereby each fibre connects with neurons in anterior, posterior-ventral, and dorsal divisions of the cochlear nucleus (Gelfand, 2010). From the CN, the neural fibres project in an ascending fashion to the: SOC, lateral lemniscus, IC, MGB, and finally to the auditory cortex; enabling the perception of sound (Gelfand, 2004). Two parallel ascending

systems have been identified (Gelfand, 2001). These are known as the classical and non-classical pathways (Gelfand, 2001). They differ mainly by the involvement of different parts of the thalamus. The non-classical pathway system uses the dorsal and medial nuclei of the thalamus and project to secondary cortices rather than primary cortices, while the classical pathways use the ventral thalamus (Gelfand, 2001; Møller, 2013). The abnormal neural activity facilitated by a reduction of input at the auditory periphery (Eggermont, 1990; Heinz & Young, 2004; Liberman & Dodds, 1984; Møller, 1984; Wang et al., 1997), resulting in atypical synchronous and spontaneous neural activity present within the auditory pathways (Gerken, 1996; Schaette & Kempster, 2006), may be involved in the promotion of conditions such as: tinnitus, hyperacusis (loud sound over-sensitivity), misophonia (sound dislike), and phonophobia (sound fear) (Møller, 2013).

Although less is known about the descending pathways, they appear as profuse as the ascending pathways (Winer, Chernock, Larue, & Cheung, 2002; Winer, Diehl, & Larue, 2001). The descending auditory pathways largely run parallel to the ascending pathways and can be considered as reciprocal (Ehret & Romand, 1997). From the auditory cortex, fibre tracts form direct descending synaptic links to the MGB and IC (Schofield, 2010; Winer & Prieto, 2001). Efferent pathways from the cortex also reach the SOC which has connections to the CN, and ultimately terminate at the inner and outer hair cells of the cochlea (Guinan, Warr, & Norris, 1984; Harrison & Howe, 1974; Warr, 1992).

2.2 *Tinnitus*

2.2.1 *Tinnitus: A Brief History*

Evidence of tinnitus symptomology dates back to the historic Egyptian and Mesopotamian eras (Hawkrigde & Sheppard, 1987; Stephens, 1984). Hippocrates (460 – 366 B.C.) was linked to written passages using words synonymous with tinnitus-like sounds, as described by those experiencing it (Dietrich, 2004). Though disagreements exist regarding the translation and true authorship of the writings (Dietrich, 2004), it is evident that tinnitus as a symptom is not a modern condition. This concise summary has been provided to show that tinnitus sensation is not a novel consideration. The scope of this thesis constrains an exhaustive approach, but readers seeking more in-depth, historical information may consider the following: (Shulman, Aran, Tonndorf, Feldmann, & Vernon, 2004); (Feldmann, 2004) or (Dietrich, 2004; Stephens, 1984; Stephens, 2000).

2.2.2 *Tinnitus: Definition and Presentation*

Tinnitus is the term describing noises heard in the head or one or both ear(s) that lack corresponding engagement of the cochlea (McFadden, 1982; Stephens, 1987). The word tinnitus derives from the Latin ‘tinnire’, which means ‘to ring’ (Baguley, McFerran, & Hall, 2013, p. 1600). Tinnitus can be differentiated into two broad categories: objective tinnitus, which is a sound experienced by the patient that may be audible to an examiner; and subjective tinnitus, which is the perception of sound without an exogenous sound source (Møller et al., 2011).

Objective tinnitus can be heard by others close to the patient’s ear, usually an examiner using a stethoscope featuring amplification (Arenberg & Balkany, 1984). This form accounts for far less

cases than subjective tinnitus (Møller et al., 2011). One form of objective tinnitus is pulsatile tinnitus, which can synchronise with the heartbeat, and is therefore most likely of vascular origin (Folmer et al., 2004). Vascular compression of the auditory nerve by surrounding blood vessels is also documented to contribute to pulsatile types of tinnitus and vertigo in some individuals (Wuertenberger & Rosahl, 2009).

The present research project focuses on subjective tinnitus, which is frequently described by those experiencing it as: ringing, hissing, sizzling, whistling, buzzing, cricket-like, or humming (Baguley, 2002; Stephens, 2000). Jastreboff's (1990, p. 223) definition of tinnitus as a "phantom auditory perception" has been used considerably in tinnitus journals and textbooks, since its introduction. Tinnitus may consist of one primary sound, such as a tone, or be comprised of a composite sensation encompassing two or more sounds (Noreña, Micheyl, Chéry-Croze, & Collet, 2002; Vernon & Meikle, 2003). On rare occasions, tinnitus can be perceived as more complex sounds, such as music or even voices (Baguley et al., 2013). As tinnitus in the form of music and voices tend to be vague and often convey no meaning, they can be differentiated from auditory hallucinations that can co-occur with psychotic illnesses (Baguley et al., 2013). Tinnitus can also be characterised by the location it is perceived. It most commonly perceived bilaterally (Stouffer & Tyler, 1990) but can also be perceived unilaterally, centrally in the head, or even outside of the head (Henry & Meikle, 2000; Stouffer & Tyler, 1990; Wallhäusser-Franke et al., 2012). Tinnitus loudness, or intensity, can also be measured, typically using a loudness-matching technique in a clinical setting, which assists in identifying a patient's level of intensity-based tinnitus annoyance and quantifying its severity (Andersson, 2003).

2.2.3 *Tinnitus: Epidemiology and Demographics*

Tinnitus is estimated to affect 25.3% of the population (Shargorodsky, Curhan, & Farwell, 2010). Not all who experience tinnitus are significantly afflicted by the condition (Møller et al., 2011). Most individuals with tinnitus are able to largely ignore it and carry on with little impact on their daily lives (Coles et al., 1984). A study in the United Kingdom found that of the 17.5% of participants who reported having tinnitus, 30% classified it as moderate or severe (Coles et al., 1984) and were therefore likely to seek treatment. For people experiencing more severe, chronic forms of tinnitus, its presence can be associated with depression, loss of concentration, and sleeping difficulties, reducing their overall quality of life (Erlandsson, 2000).

2.3 *Prevailing Theories of Tinnitus*

2.3.1 *Central Mechanisms*

Historically, tinnitus was believed to occur at the level of the cochlea, arising from increased spontaneous neural activity in the auditory nerve (Noreña & Farley, 2013). Since then, research has shifted from the cochlear model for tinnitus's origin, towards more central mechanisms (Noreña & Farley, 2013). The theory of a central basis for tinnitus arose from studies in patients with acoustic tumours, where tinnitus persisted following transection of the auditory nerve (House & Brackman, 1981), indicating involvement of higher structures. Most models now propose peripheral damage as a trigger, driving CNS changes (Møller et al., 2011; Noreña & Farley, 2013). Homeostatic plasticity has been observed throughout the central auditory pathway, with acoustic sensory deprivation found to modify excitatory synapses in the CN (Whiting, Moiseff, & Rubio, 2009), and reduce markers of inhibition in the IC (Argence et al., 2006). A reduction of peripheral input can result in reorganisation of the auditory cortex, referred to by

some authors as “cortical reorganisation” (Eggermont & Roberts, 2012, p. 1). It has been suggested that the characteristic frequency which dominates the reorganised cortical map may contribute to the perceived pitch of tinnitus (Kaltenbach, Zhang, & Zacharek, 2004), with the maximal amount of reorganisation occurring at the boundary of normal and impaired hearing (Rauschecker, 1999).

2.3.2 *Tinnitus and ‘Perceptual Silence’*

The auditory pathways maintain a high level of spontaneous activity in the absence of sound stimuli (Lieberman & Dodds, 1984). An external sound stimulates an increase in neural activity which promotes regular firing and synchronisation of neural communication to higher level structures (Noreña & Farley, 2013). A study in [presumed] normal hearing individuals found the absence of sound stimulation lead to the perception of tinnitus within minutes of being in a sound-treated environment (Heller & Bergman, 1953, p. 78). The study involved individuals (n = 80, aged 18 – 60 years) with normal hearing based on self-report, precluding previous or present aural disease, and all whom considered themselves to be healthful (Heller & Bergman, 1953). Roughly five minutes of exposure to a quiet environment lead 94% of participants to report tinnitus presence. The authors concluded that tinnitus appears to be consistently present, even for those with reportedly normal hearing, but may be effectively covered by everyday environmental sounds; remaining sub-audible (Heller & Bergman, 1953). However, some important limitations were noted for this study: including lack of verification of normal hearing participants (Knobel & Sanchez, 2008); missing details for the characteristics of sound-treated chamber used; and omission of gender and race data (Tucker et al., 2005), as tinnitus severity has been reported to vary by gender and race (Cooper, 1994). Tucker et al. (2005) and later, Knobel and Sanchez

(2008) replicated part of the Heller and Bergman (1953) study. Tucker et al. (2005) found 64% of normal hearing young adults (n = 120, aged 18-30 years) reported the perception of sounds consistent with tinnitus, after 20 minutes exposure to a sound-treated booth. There were no gender differences, but race differences were revealed: tinnitus-like sounds emerged more frequently in Caucasian participants, but the number of different tinnitus-like sounds perceived was higher in African American participants. A similar study by Knobel and Sanchez (2008), involving individuals with normal hearing (n = 66, aged 18 – 65 years), found that 68.2% of participants undergoing an auditory task, reported tinnitus-like sounds following five minutes exposure to a low ambient noise environment. This percentage dropped when the participants' attention was directed away from the auditory domain (Knobel & Sanchez, 2008). These findings suggest that tinnitus-like sounds appear in many individuals when environmental sound is minimised, particularly when attention is directed to the auditory modality.

2.3.3 *Hearing Loss and Tinnitus*

Although tinnitus can occur in the absence of hearing loss, hearing loss and tinnitus often co-exist (Sanchez & Stephens, 1997). It has been reported that 90% of patients presenting with tinnitus in a clinical setting, also have measurable hearing loss (Vernon & Sanders, 2001a). The degree of hearing loss has been proposed to contribute to tinnitus severity (Davis, 1996), with higher tinnitus incidence with increasing hearing loss (Coles, 1995; Lindberg, Lyttkens, Melin, & Scott, 1984). The perceived tinnitus pitch also relates to hearing loss, as it is often found in a frequency region of hearing loss (Henry, Meikle, & Gilbert, 1999). Tinnitus also accompanies sudden sensorineural hearing loss (SSNHL) in 70 – 90% of cases (Hikita-Watanabe et al., 2010; Mamak et al., 2005; Saeki & Kitahara, 1994), and can persist after hearing improvement from

pharmacological treatment of SSNHL (Michiba et al., 2013). Although tinnitus patients often complain that their tinnitus interferes with their hearing ability, there is little objective evidence to support this (Levi & Chisin, 1987).

2.3.3.1 Reduction of Peripheral Input

Sounds in our environment stimulate the cochlea and send action potentials up the ascending auditory pathway to the auditory cortex (Burkard, Don, & Eggermont, 2007). As these potentials propagate, each structure in the ascending pathway is activated in turn (Burkard & Secor, 2002). It is generally agreed-upon that tinnitus arises from altered neural processing (Noreña & Farley, 2013). A popular theoretical model of tinnitus has been that a decrease in peripheral input associated with decreased cochlear function such as hearing loss, results in reduced auditory sensory input reaching central structures (Noreña & Farley, 2013). When the central auditory system encounters sensory deprivation such as hearing loss, homeostatic mechanisms are activated to maintain the neural activity at a fixed level (Cai, Ma, & Young, 2009). Animal studies have shown that reduced peripheral input from the cochlea can also lead to cortical reorganisation in the auditory cortex (Eggermont & Komiyama, 2000). Compensation by increasing central gain leads to a heightened activity state in the auditory CNS, resulting in tinnitus (Noreña & Farley, 2013). This is supported by recordings of spontaneous activity in the cat primary auditory cortices which have been revealed to be higher in reorganised maps than normal un-reorganised maps (Seki & Eggermont, 2003). This increase in central gain may also offer an explanation for hyperacusis – over-sensitivity presenting as a pain response to sound(s) perceived to be comfortably loud for others – often resulting from compromised hearing, which sometimes presents alongside tinnitus (Dauman & Bouscau-Faure, 2005).

Some well-known pharmaceutical drugs which damage the cochlea and can therefore potentially induce tinnitus are: aminoglycoside antibiotics, chemotherapy agents, anti-malarial drugs, salicylates, and loop diuretics (Pirodda, Borghi, & Ferri, 2010). Tinnitus can also be a symptom of a number of otological conditions which may also impact normal cochlear function, including: otosclerosis, vestibular schwannoma, Meniere's disease, meningioma, mastoiditis, labyrinthitis, and impacted cerumen (Baguley, 2002; Baguley et al., 2013).

2.3.4 *Atypical Neural Activity*

A central gain theory may not entirely account for tinnitus perception (Noreña & Farley, 2013). The presence of tinnitus has also been associated with hyperactivity of the cochlear nerve (Baguley, 2002). In normal auditory function, there is a low level of spontaneous neural activity in the cochlear nerve even in the absence of sound, attributed to neurotransmitter release from the IHCs (Eggermont, 2000). The reason this activity is not typically perceived as sound may be that sound perception requires synchronised firing activity of neurons which does not typically occur with spontaneous activity (Eggermont, 1984; Eggermont, 1990; Johnson & Kiang, 1976). There is evidence that abnormal/asynchronous transmission of neural activity through the auditory system may be an important factor for initiating tinnitus (Eggermont, 2007; Eggermont & Roberts, 2004). A peripheral model of tinnitus suggests that normal stimulation of the afferent nerve relies on normal cochlear synaptic function, and so inner ear disease may lead to dysfunction in the pathway resulting in increased spontaneous neural firing (Sun, Lu, & Landrie, 2007).

Evidence from animal studies investigating neural activity have been mixed. Kiang, Moxon, and Levine (1970) found a decrease in spontaneous auditory nerve activity in cats administered with kanamycin, while Evans, Wilson, and Borerwe (1981) reported administering salicylate to cats (in equivalent quantities known to induce tinnitus in humans) increased spontaneous activity. Tyler (1984) considered these contrasting findings, and noted that recordings of single cochlear nerve units have limitations in that hyperactivity occurring outside of the measured area can be missed. There is also evidence from animal studies of increased neural activity in structures above the auditory nerve, including the DCN (Kaltenbach & McCaslin, 1996), IC (Chen & Jastreboff, 1995; Jastreboff & Sasaki, 1986), and the cortex (Wallhäusser-Franke, 1997; Wallhäusser-Franke, Braun, & Langner, 1996).

Eggermont (2000) proposed a disinhibition mechanism for the DCN interneurons, which inhibit spontaneously active type IV neurons. He postulated that reduced afferent stimulation to the inhibitory interneurons may result in decreased inhibition and therefore higher levels of spontaneous activity, which may become audible (Eggermont, 2000).

There is continued investigation into the neural basis of tinnitus and how the brain generates phantom sounds. Lasting, curative treatment for tinnitus has yet eluded researchers worldwide (Baguley, 2006).

2.3.5 *Tinnitus 'Networks'*

Many researchers propose that tinnitus likely encompasses a wide central network, including the involvement of higher brain structures beyond the peripheral and central auditory pathways (De

Ridder, Elgoyhen, Romo, & Langguth, 2011; Müller, Schlee, Hartmann, Lorenz, & Weisz, 2009; Noreña & Farley, 2013). There is evidence that after a period of time, the pathophysiology of chronic tinnitus becomes different to that of acute tinnitus, and becomes progressively centralised (Møller et al., 2011; Salvi, Lockwood, & Burkard, 2000). In patients with chronic tinnitus, neuroplastic changes do not appear to be limited to the central auditory structures. Human neuroimaging studies have found evidence of changes in the parietal, frontal and limbic areas (Adjajian, Sereda, & Hall, 2009; Schlee, Weisz, Bertrand, Hartmann, & Elbert, 2008). The parietal lobe controls the integration of sensory information from the sense organs to form perception, and constructs a spatial map of ourselves in the world around us (Baars & Gage, 2010; Kandel, Schwartz, & Jessell, 2000). The frontal lobe controls the execution of behaviour, ranging from the control of motor movements to high-level processes like the planning and initiation of activities, and the expression of language (Baars & Gage, 2010). The frontal lobe is divided into four different areas: the prefrontal cortex, orbitofrontal cortex, primary motor cortex, and the premotor cortex, each controlling a specific function (Baars & Gage, 2010). The limbic system is involved in emotion, behaviour, and memory (Lövlblad, Schaller, & Isabel Vargas, 2014). There is currently no universal agreement among authors regarding precisely which central structures comprise the limbic system (Rajmohan & Mohandas, 2007). Despite this, the hippocampus and the amygdala are generally agreed upon (Lövlblad et al., 2014). The amygdala is the fear centre of the brain, receiving afferent signals from the auditory system via the auditory extralemniscal pathway involving the dorsal and medial geniculate body, and via the secondary auditory cortex (LeDoux, 2007). Limbic structures may be more responsive to sound stimulation in some tinnitus patients (Lockwood et al., 1998).

2.3.6 *Analogy with Phantom Pain*

Tinnitus has also been suggested as the auditory system analogue of phantom pain (House & Brackman, 1981), a sensory phenomenon produced following peripheral nerve trauma or removal of one or more limbs (Flor et al., 1998). Tinnitus and phantom pain are proposed to share similarities, including their subjectivity, continuity in some cases, and possibility of changing in quality over time (Tonndorf, 1987). Cortical reorganisation has also been associated with the reduction of sensory input in cases where a limb has been neurally compromised or removed (Folmer, Griest, & Martin, 2001). This theory is supported by studies demonstrating that tinnitus is accompanied by tonotopic map reorganisation in the auditory cortex, with greater severity with more reorganisation (Dietrich, Nieschalk, Stroll, Rajan, & Pantev, 2001; Mühlnickel, Elbert, Taub, & Flor, 1998). Additionally, strong correlates exist between subjective tinnitus loudness and the extent of cortical reorganisation (Mühlnickel et al., 1998).

2.3.7 *Tinnitus Loudness and Pitch Perception*

The main perceptual correlates of tinnitus are its loudness and pitch (Noreña et al., 2002). Studies using external sounds to obtain tinnitus loudness matches have found somewhat low variance between participants, with around 70% matching to 6 dB SL or less, and 84% matching to 9 dB SL or less (Vernon & Meikle, 2003). Loudness matches appear to be unrelated to the subjective severity and annoyance of the tinnitus, with the estimation of tinnitus annoyance better-reflected with the use of direct loudness ratings (Vernon, Griest, & Press, 1990). When tinnitus is perceived tonally, the frequency can correspond with the downward slope of associated hearing loss on the audiogram (Tonndorf, 2004). In a large survey of 1800 tinnitus patients, Meikle and Taylor-Walsh (1984) found that 54% of patients matched their tinnitus pitch to tones above 3

kHz, which consisted of: 30% from 3 - 5 kHz, 19% from 5 – 9 kHz, 4% from 9 - 11 kHz, and 1% from 11– 15 kHz. Below 3 kHz, 21% of tinnitus pitch matches were from 1 – 3 kHz, and 11% were below 1 kHz (Meikle & Taylor-Walsh, 1984). Tinnitus pitch however, is often estimated by a matching technique using a two-alternative-forced-choice (2AFC) procedure using external sounds (Vernon, 1987). It has been consistently shown to correspond with audiometric frequencies where hearing loss is present (Noreña, 2011; Noreña et al., 2002; Sereda et al., 2011). The steepness of the hearing loss on the audiogram has also been shown to be a positive predictor of the risk of tinnitus (König, Schaette, Kempter, & Gross, 2006).

Shekhawat, Searchfield, and Stinear (2014) examined the relationship between tinnitus pitch and audiometry, subjective tinnitus loudness, minimum masking levels (MML), and distortion-product otoacoustic emissions (DPOAE), through a retrospective analysis data from 192 patients with chronic tinnitus persisting 18 months or longer. The majority (76%) of participants pitch-matched to 8 kHz or less, with matches most often occurring at frequencies where hearing loss was 40 – 60 dB HL; with the frequency at which hearing loss is 50 dB HL being the best predictor of tinnitus pitch (Shekhawat et al., 2014). However, the Shekhawat et al. (2014) authors did reveal tinnitus pitch patches also occurring above 8 kHz (24%), suggesting the inclusion of high-frequency audiometry in tinnitus assessment. No correlates were found between tinnitus pitch and DPOAEs, MML, audiometric edge and worst threshold (Shekhawat et al., 2014).

2.3.8 *Incongruent Subjective Tinnitus Loudness*

A puzzling aspect of tinnitus is the apparent mismatch between the perceived tinnitus loudness experienced by the individual, and behavioural, psychophysical loudness-matching of the tinnitus

(Goodwin & Johnson, 1980b). Although most patients who seek help for their tinnitus report that the sounds are loud, loudness-matching studies indicate that the loudness is typically near the hearing threshold at the tinnitus pitch (Henry & Meikle, 2000; Meikle, Vernon, & Johnson, 1984). Compared to individuals with non-bothersome tinnitus, tinnitus complainers typically have psychoacoustically-matched tinnitus loudness levels of not more than 10 dB sensation level (SL) (Dobie, 2004). Tinnitus loudness may be a factor, but is not always the key driver of tinnitus annoyance and distress (Hallam et al., 1984). Factors such as the subjective characteristics of the tinnitus signal, the duration, and the patient's psychological state may also have important influence (Tyler, 2000).

2.3.9 *Tinnitus and 'Normal' Hearing*

Tinnitus patients presenting with apparently normal hearing, challenge tinnitus models underpinned by peripheral auditory dysfunction and subsequent hyperactivity. Some research has suggested that subtle peripheral auditory damage in individuals presenting with normal hearing thresholds may be sufficient to trigger tinnitus (Schaette & McAlpine, 2011). Though cochlear damage is normally clinically diagnosed as an elevation in audiometric hearing thresholds, normal hearing thresholds cannot exclude cochlear damage, as supported by an animal study showing temporary threshold shifts (with thresholds ultimately returning normal), yet enduring auditory nerve fibre damage after exposure to acoustic trauma (Kujawa & Liberman, 2009).

McKee and Stephens (1992) investigated evidence of peripheral auditory dysfunction in tinnitus (n = 18) by comparing age and sex-matched control participants (n = 19) with normal-hearing, to support the theory of peripheral damage as a tinnitus trigger. Their study was essentially a repeat

of a previous experiment by Barnea, Attias, Gold, and Shahar (1990) with the addition of otoacoustic emissions (OAEs) and inclusion of personality tests in the study battery. The tinnitus group had worse OAEs, and stronger neurotic personality traits as measured by the Crown-Crisp Experiential Index (Stephens & Hallam, 1985) compared to the control group (McKee & Stephens, 1992). Tinnitus sufferers of both sexes had increased somatic anxiety scores, and male tinnitus sufferers also had higher scores for obsessiveness and free-floating anxiety (McKee & Stephens, 1992). There were no significant differences for audiometric thresholds, notched-noise testing results or brainstem latencies (McKee & Stephens, 1992). These findings are consistent with those of Barnea et al. (1990), similarly finding no differences in high-frequency audiometric thresholds or auditory brain stem responses (ABR), between young tinnitus sufferers and controls. The finding of reduced OAEs in the participants with unaffected hearing thresholds supports the theory of underlying peripheral dysfunction (McKee & Stephens, 1992).

OAEs are a widely-used clinical measure that assess cochlear integrity, in particular the OHCs (Probst, Lonsbury-Martin, & Martin, 1991). Spontaneous OHC activity has been linked to tinnitus generation (Penner, 1992). By applying contralateral acoustic stimulation (CAS) during OAE measurement, the technique may also assess functioning of the efferent system, as OAEs measured with CAS were lower than OAE-only measurements in individuals with normally-functioning efferent systems (Collet, 1993). Paglialonga, Fiocchi, Del Bo, Ravazzani, and Tognola (2011) examined the fine structure of transient evoked otoacoustic emissions (TEOAEs) and effects of CAS on tinnitus and control participants with normal hearing to determine whether subtle differences existed which could suggest sub-clinical OHC damage. Although significantly lower reproducibility was found in the recordings for the tinnitus group, there were no

differences in latency or suppression effects (Paglialonga et al., 2011). As reproducibility reflects the functional and structural integrity of OHCs at the corresponding frequency on the basilar membrane (Tognola, Grandort, Avan, Ravazzani, & Bonfils, 1999), the reduced reproducibility found in tinnitus participants may indicate subtle dysfunction (Paglialonga et al., 2011).

Melcher, Knudson, and Levine (2013) investigated differences in brain structure between tinnitus and control participants using Magnetic Resonance Imaging (MRI) analysed with Voxel-Based Morphometry (Ashburner & Friston, 2000). The researchers focused particularly on the subcallosal brain region where structural differences between tinnitus and control participants have previously been reported in some studies (Leaver et al., 2011; Mühlau et al., 2006), but not others (Husain, Medina, et al., 2011; Landgrebe et al., 2009). All participants had essentially normal hearing thresholds up to 8 kHz, and the groups for matched for age, sex, and handedness, as well as audiometric thresholds up to 14 kHz (Melcher et al., 2013). There were no differences in grey matter volume between the groups, but further analyses revealed negative correlations between supra-clinical frequencies (above the speech-dominant frequency range, 9 – 14 kHz) and modulated grey matter probabilities in the ventral posterior cingulate cortex, and the dorsomedial and ventromedial prefrontal cortices (Melcher et al., 2013). These findings offer an explanation for the discrepant findings in previous studies as participants' supra-clinical frequencies may not have been accounted for.

Although the literature largely describes tinnitus experience in adults, tinnitus also occurs in the paediatric population (Savastano, Marioni, & de Filippis, 2009). The rate of occurrence documented has varied from 6.5% for spontaneous reports, to 34% when specifically questioned

(Savastano, 2007). Of the children who experience tinnitus, most have normal clinical hearing results (Martin & Snashall, 1994; Savastano, 2007).

2.3.10 *Habituation Deficit in Tinnitus*

Another important question raised in tinnitus research is the separation of individuals with clinically-significant tinnitus from those who are not significantly affected. Habituation describes the brain's ability to adapt and desensitise to stimuli that are, or become, repetitive or irrelevant (Groves & Thompson, 1970; Thompson & Spencer, 1966). Based on this concept, Hallam et al. (1984) proposed a model suggesting that tinnitus-related distress is caused by an inability to habituate to the constant and repetitive tinnitus signal. Therefore, individuals who are distressed by their tinnitus are assumed to have greater habituation deficit than individuals who are not bothered by it. This has been supported by an electrophysiological study using event-related potentials (ERPs) which showed that tinnitus complainers had differences in typical ERP amplitudes, compared to tinnitus non-complainers (Walpurger, Hebing-Lennartz, Denecke, & Pietrowski, 2003). A previous study by Carlsson and Erlandsson (1991) measured changes in heart rate and skin conductance as indicators of habituation in response to external tinnitus-like auditory stimuli, in tinnitus complainers ($n = 7$) and tinnitus non-complainers. No differences were found between the groups.

2.3.11 *Factors Sustaining or Promoting Tinnitus*

2.3.11.1 *Affective-emotional*

Jastreboff's neurophysiological model (Jastreboff, 1990) included the perceptual, emotional and reactive experiences involved in tinnitus. Jastreboff (1990) theorised that tinnitus perception can be enhanced when negative emotional reinforcers such as fear, anxiety or tension, are facilitated by the limbic system. This may create a feedback loop promoting the perception of tinnitus to persist (Jastreboff et al., 1996). This perspective has given rise to a clinical treatment protocol entitled Tinnitus Retraining Therapy (TRT) which is based on facilitating habituation to the tinnitus signal and reducing tinnitus reaction, through directive counselling and sound therapy (Jastreboff et al., 1996; Jastreboff & Hazell, 2004). Although tinnitus perception is often near the threshold of audibility, it can evoke an emotional reaction which heightens the response in some tinnitus sufferers (Jastreboff & Hazell, 1993). Negative emotional states such as anxiety, depression, stress and fear can co-occur with tinnitus, and also have a role in contributing to the overall persistence and severity of the tinnitus (Andersson, 2002b; Heinecke et al., 2008). Halford and Anderson (1991) considered the relationship between tinnitus and anxiety as bi-directional, with each having the ability to mediate the other. More disturbing forms of tinnitus may lead to stress and anxiety due to tinnitus-related insomnia, interrupted peace and quiet, and reduced quality of life (Halford & Anderson, 1991). The progression of tinnitus to a disabling condition occurs in roughly 1-3% of the general adult population (Axelsson & Ringdahl, 1989; Fujii et al., 2011; Gallus et al., 2015), and has been suggested to occur when alarm and/or stress responses are sustained (Alpini, Cesarani, & Hahn, 2007).

2.3.11.2 Personality

Personality describes an individual's behavioural traits that may motivate decisions and actions throughout life (Caspi, 2000), and has been shown to influence health risk-taking and associated outcomes (Krueger, Caspi, & Moffitt, 2000). Personality can be assessed with a variety of structured or semi-structured clinical interviews or assessment instruments based on the Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association, 2013).

A recent systematic review by Mucci, Geocze, Abranches, Antúnez, and Penido (2014) examined the existing evidence base for a link between tinnitus and personality. Of the 17 articles selected, most were cross-sectional studies; but longitudinal studies, a validation study, and a birth cohort study were also included. Although cross-sectional and validation studies cannot shed light on predictive relationships, increased presentation of disorders including neuroticism (which is inclusive of depression, hypochondria and hysteria), psychasthenia (which is characterised by fear, obsessions and compulsions), and schizoid features were found in the tinnitus samples compared with the general population (Mucci et al., 2014). A brief summary of two of the studies (Bartels, Middel, Pedersen, Staal, & Albers, 2010; Welch & Dawes, 2008) included in the review will be summarised below.

Bartels et al. (2010) investigated personality characteristics of otorhinolaryngology patients pursuing tinnitus advice compared to those seeking advice for conditions unrelated to tinnitus. Of the following personality traits: neuroticism, extraversion, emotional stability, and distressed personality (Type D), assessed using a suite of self-report assessments, tinnitus patients were rated more highly for neuroticism, showed less extraversion and emotional stability, and were

more likely to exhibit Type D personality (negativity and decreased socialization) (Bartels et al., 2010). Over a third (35.5%) of tinnitus patients exhibited a Type D personality (Bartels et al., 2010).

Welch and Dawes (2008) examined the association between personality factors and tinnitus in a New Zealand longitudinal birth cohort, once they had reached the age of 32 (n = 970). Tinnitus interview data and personality data (Multidimensional Personality Questionnaires) (Patrick, Curtin, & Tellegen, 2002) were collected. Participants reporting more frequent tinnitus had higher scores for stress, estrangement and hostility, and lower scores for social intimacy, self-restraint, averting injury and conservatism (Welch & Dawes, 2008). In addition to the commonly referenced generation and maintenance phases in the development of chronic tinnitus, Welch and Dawes (2008) proposed a third aspect, involving tinnitus awareness, suggesting personality may influence tinnitus suffering and tinnitus perception.

Research has also shown that tinnitus sufferers with higher internalised locus of control are able to better cope with their tinnitus symptoms (Budd & Pugh, 1995; Sirois, Davis, & Morgan, 2006). Resilience is a personality characteristic that can influence capability to cope with negative life circumstances, including challenging health conditions, and can be measured with the Wagnild and Young Resilience Scale (Wagnild, 2009). Resilience is associated with emotional stability, extraversion and internal locus of control (Lundman, Strandberg, Eisemann, Gustafson, & Brulin, 2007; Sells et al., 2009).

Wallhäusser-Franke, Delb, Balkenhol, Hiller, and Hörmann (2014) aimed to characterise the relationship between resilience and tinnitus severity in a cross-sectional study of 4705

participants. Tinnitus-related distress was measured using the 12-item Mini-Tinnitus Questionnaire (Hiller & Goebel, 2006), and subjective tinnitus loudness was measured on a numeric scale from 0 to 10. Resilience was assessed with the short version of the Resilience Scale Questionnaire comprised of 13 items (Leppert, Koch, Brähler, & Strauß, 2008). Depression, generalised anxiety and somatic symptom severity were addressed with modules of the Patient Health Questionnaire (Kroenke, Spitzer, Williams, & Lowe, 2010). The findings showed that tinnitus-related distress and subjective tinnitus loudness have an inverse relationship with resilience, which appeared to be mediated by emotional health (Wallhäusser-Franke et al., 2014). This suggested that resilience was linked to better emotional health, and less depression, anxiety, and somatic symptom severity, which was associated with lower tinnitus-related distress (Wallhäusser-Franke et al., 2014).

2.3.11.3 Neurotransmitters associated with the generation and perception of tinnitus

One of the key current hypotheses of tinnitus development is that it may result from a maladaptation of the central auditory system following peripheral injury (Auerbach, Rodrigues, & Salvi, 2014). A decrease in inhibitory neurotransmission is one mechanism which may facilitate this. As signal transduction via the release of neurotransmitters from neuronal presynaptic to postsynaptic structures are an essential part of auditory signal transmission and perception, dysfunction in the chain may have a role in generation and perception of tinnitus (Sun et al., 2007).

An imbalance of the neurotransmitters: Glutamate, gamma amino butyric acid (GABA), serotonin and dopamine have been proposed to have a role in inhibiting habituation to tinnitus (Georgiewa et al., 2006; Lopez-Gonzalez & Esteban-Ortega, 2005).

Glutamate is a key excitatory neurotransmitter, released by hair cells in the inner ear as they synapse onto the dendrites of afferent spiral ganglion neurons (Ruel, Chen, Pujol, Bobbin, & Puel, 1999; Wenthold, 1981). N-methyl-D-aspartate (NMDA) receptor activation has been proposed as the source of aberrant excitation of the auditory nerve following glutamate excitotoxicity (Puel, Ruel, Guitton, Wang, & Pujol, 2002). This can be triggered by ischemic or traumatic (Pujol & Puel, 1999) incidents, or provoked by pro-inflammatory cytokines (Hwang, Chen, Yang, Wang, & Chan, 2011).

GABA and glycine are well-established as the main inhibitory neurotransmitters of the CNS (Lee & Godfrey, 2015). Serotonin is a neurotransmitter with varying in biological and behavioural roles, playing a part in regulating emotions, stress and anxiety. It has been suggested to have a role in tinnitus perception, based on the consideration that disrupted or modified serotonin function might cause a reduction in auditory filtering abilities and thereby affect tinnitus habituation (Simpson & Davies, 2000).

Animal studies have found that administering salicylate increases spontaneous firing of auditory nerves in cats (Evans & Borerwe, 1982; Evans et al., 1981). Other amino acids such as aspartate and taurine may also have a role in central auditory system signalling (Albrecht & Schousboe, 2005; Lee & Godfrey, 2015; Wenthold, 1981). Other neurotransmitters that have also been cited as having potential involvement in auditory disorders include: Acetylcholine, norepinephrine,

dopamine, neuroactive peptides, and opioids (Eggermont & Roberts, 2012; Romand & Avan, 1997).

Studies examining neurotransmitters involved in hearing disorders and tinnitus typically involve biochemical measurement following peripheral auditory system damage (Lee & Godfrey, 2015). Measurements of synaptic chemistry, including: neurotransmitter levels, synthesis, release and uptake, are taken at different time points after damage occurs in order to fully encapsulate both the rapid and gradual onset changes in the CAS (Lee & Godfrey, 2015). Current evidence of neurochemical alterations following cochlear injury suggest that neurotransmission disinhibition, resulting in increased spontaneous activity, is likely too simplistic of an explanation to solely account for tinnitus pathogenesis (Lee & Godfrey, 2015)

AM-101 is a drug which contains esketamine hydrochloride gel which selectively blocks cochlear NMDA receptors (Staecker et al., 2015). A recent double-blind, randomised, placebo controlled phase II clinical trial (TACTT0) has shown that AM-101 significantly improved acute peripheral tinnitus; tinnitus triggered by acute acoustic trauma or otitis media for which centralization had not yet occurred (Staecker et al., 2015).

2.4 Tinnitus Assessment Procedures

With any audiological investigation, a thorough patient interview and history is an important initial step (Henry, Zaugg, & Schechter, 2005) As tinnitus is a highly subjective perceptual experience, diagnosis is facilitated by case history, and is assessed by its effect on the patient (Baguley et al., 2013; Henry et al., 2005). The clinician should enquire on the onset of tinnitus, the characteristic of the sound(s) perceived, level of intrusiveness/annoyance, exacerbating

factors, and whether any treatments have been attempted (Coles et al., 1984). Patient interview should determine whether tinnitus is subjective or objective in nature (Baguley et al., 2013).

There is currently a lack of objective assessments for tinnitus that can accurately account for the patient's experience (Goodwin & Johnson, 1980b; Henry & Meikle, 2000). Due to this, questionnaires are commonly used to help determine the impact of tinnitus (Henry et al., 2005). There are many questionnaires which may be employed, including: The Tinnitus Functional Index (TFI) (Meikle et al., 2012), Tinnitus Handicap Inventory (THI) (Kuk, Tyler, Russell, & Jordan, 1990), Tinnitus Reaction Questionnaire (TRQ) (Wilson et al., 1991), and the Tinnitus Severity Numeric Scale (TSNS) (The Tinnitus Research Initiative, 2009). As tinnitus sufferers may have associated conditions such as hyperacusis, and negative psychological states, these can also be explored further with the appropriate questionnaires which investigate these aspects (Belli et al., 2008; Dauman & Bouscau-Faure, 2005).

Audiometric assessment is also an essential part of tinnitus management as up to 90% of patients who present with tinnitus as their primary concern also have a measurable hearing loss (Vernon & Sanders, 2001b).

2.4.1 *Residual Inhibition*

Residual inhibition (RI) is the term describing temporary reduction or cessation of tinnitus, immediately after masking is applied (Vernon & Fenwick, 1984). Measuring RI involves presenting broadband noise (for 1 minute) at an intensity level 10 dB above the level required to just suppress the tinnitus (Vernon & Meikle, 1988). A positive test for RI occurs when the

tinnitus is reduced or becomes inaudible after the noise presentation (Vernon & Meikle, 1988). It has been reported that 80 – 90% of patients experience RI to some extent (Henry & Meikle, 2000). It is important to consider the potential effects of RI when obtaining psychoacoustic tinnitus measures, as it may serve as a potential indication of the effectiveness of external sounds in reducing tinnitus perception (Vernon & Meikle, 2000). As audiometric testing exposes patients to many supra-threshold sounds which have the potential to induce RI (Henry, Jastreboff, Jastreboff, Schechter, & Fausti, 2002), it has been recommended that tinnitus measurements (loudness and pitch matching) be obtained before attempting assessments that require presentation of supra-threshold sounds (Henry et al., 2005).

2.4.2 *Tinnitus Pitch-matching Techniques*

Though most patients do not describe their tinnitus as an exclusively tonal sound, most are able to select a single, pure-tone frequency that is closest to the predominant pitch (tF) of their tinnitus (Tyler, 2000). The 2AFC method is recommended for pitch matching, using adjacent frequencies separated by 1000 Hz (Henry & Meikle, 2000). Of the two tones presented, the patient must decide on the better match to their most salient tinnitus signal. The procedure continues until a reliable and repeatable tinnitus pitch-match is established (Henry & Meikle, 2000). The loudness level of the tones presented should be similar to the tinnitus loudness for each tone presented, as intensity can affect the perception of pitch (Tyler, 2000).

2.4.3 *Tinnitus Loudness-matching Techniques*

Tinnitus loudness-matching (tLM) is typically obtained by presenting a pure-tone at the (tF), and increasing the intensity of the tone in small steps until it is determined by the patient to be the same loudness as their tinnitus (Henry & Meikle, 2000). The procedure is repeated for at least 3 ascending trials, to ensure a reliable tLM is obtained (Henry & Meikle, 2000). The intensity level of the hearing threshold can then be subtracted from the level of the loudness match to give the tinnitus loudness in dB SL (Henry & Meikle, 2000). Ascending trials are recommended to reduce the likelihood of residual inhibition affecting the later trials, and maintaining test-retest reliability (Tyler, 2000; Vernon & Meikle, 2000). It is also recommended that thresholds are determined each time the loudness-match is measured, to avoid false differences (Henry & Meikle, 2000). Tinnitus loudness-matches are often only a few dB above hearing threshold (Fowler, 1943), even when the tinnitus is reported to be quite loud (Fowler, 1940). There appears to be no correlation between the measured loudness-matches and the severity/distress reported by patient through subjective measures (Henry & Meikle, 1996), though Tyler and Conrad-Armes (1983) found high correlations between tLM (dB SL) and the noise required to mask the tinnitus (dB SL). However, this finding was not supported by Burns (1984). As such, tinnitus severity cannot be well-predicted from tinnitus loudness-matching.

2.4.4 *Tinnitus Masking Assessments*

The use of modern masking methods to alleviate tinnitus was introduced by Dr. Jack Vernon in the 1970s (Vernon, 1977). The rationale behind this form of clinical treatment was that presenting an external masking noise can either cover the patient's tinnitus (complete masking), or reduce tinnitus awareness (partial masking), and therefore help to reduce the negative

emotional response directed at it (Vernon & Meikle, 2000). The optimal sound intensity to facilitate tinnitus habituation needs to be carefully considered (Jastreboff, 1999). Masking levels below an individual's threshold are likely to have no impact, while masking levels that overpower the tinnitus signal and render it undetectable, have been claimed to prevent the retraining process from occurring when considering a TRT treatment approach (Jastreboff, 1999).

2.4.4.1 Complete Masking

Complete masking involves the application of external stimuli until tinnitus is inaudible (Hoare, Searchfield, El Refaie, & Henry, 2014). This is not suitable for all tinnitus patients as some patients require very high masking intensity levels, or complete masking cannot be achieved at any level (Tyler, 2006; Vernon & Meikle, 2000). For individuals who require very high masking intensities, the level is often excessive to provide relief, and not an appropriate therapy (Vernon & Meikle, 2000). It is important to note that the effectiveness of masking can also change over time (Tyler, 2000). It has been shown that for some, masking levels may need to be increased up to 45 dB in a short time period (approximately 30 minutes) to keep the tinnitus inaudible (Penner, Brauth, & Hood, 1981).

2.4.4.2 Minimum Masking

The Minimum Masking Level (MML) is defined as the lowest level of masking noise that is able to completely eliminate tinnitus perception (Vernon & Meikle, 2000). Andersson and McKenna (1998) conducted a pilot study investigating the relationship between depression and tinnitus maskability in patients with bothersome tinnitus (n = 30). All participants underwent audiometric

testing, tinnitus matching (pitch, tLM, MML), and completed the Beck Depression Inventory (Beck, Steer, & Brown, 1996). Average hearing loss was calculated from the pure-tone average (PTA) for the better ear from 0.5, 1, 2, and 3 kHz. Cluster analysis characterised three types of tinnitus patients according to their results compared to the rest of the group: cluster one (n = 18) had low depression scores, and average tLMs, MMLs and pure-tone averages (PTA); cluster two (n = 9) had high depression scores, and low tLMs, MMLs, and PTAs; cluster three (n = 3) rated very highly for depression, and had high tLMs, MMLs, and PTAs. The pattern that emerged from data analyses revealed a U-shaped function between depression and MML. Although from an older study, findings may help guide treatment recommendation for tinnitus patients when considering their tinnitus maskability and depressive degree.

2.4.4.1 Partial Masking

Partial masking differs from complete masking in that perception of the tinnitus signal is only partially covered, and both the tinnitus and masking signal remain audible (Hoare et al., 2014). Tinnitus masking therapy often employs partial masking with the aim to provide a degree of relief from tinnitus, by reducing its saliency or loudness (Vernon, 1977; Vernon, 1998; Vernon & Meikle, 2000). To obtain benefit, the masking sound should be delivered continuously, potentially through a wearable device (Henry, Schechter, Nagler, & Fausti, 2002). An advantage of this approach is that the lower masking intensity may be more tolerable to patients, while still providing relief and reducing tinnitus interference (Vernon & Meikle, 2000).

2.4.4.2 'Mixing Point' Approach

“Mixing point” masking describes the level of partial masking just below the point of total masking, where tinnitus remains audible while blending with the masking stimulus (Hazell, 1999; Jastreboff, 1999, p. 492). An argument in favour of this approach in tinnitus therapies is that total masking may prevent the habituation process, as it renders the tinnitus inaudible (Jastreboff, 2000). However, a randomised study comparing the effectiveness of TRT found no difference in treatment benefit, per the THQ, between groups using mixing-point or total masking, which suggests that mixing-point masking may similarly facilitate habituation as compared to total masking (Tyler, Noble, Coelho, & Ji, 2012).

2.4.4.1 Energetic and Informational Masking

Based on psychoacoustic characteristics, masking can be classified into two general categories: energetic and informational (Bennett, Billings, Molis, & Leek, 2012). Kidd, Mason, Richards, Gallun, and Durlach (2008) describe energetic masking as the suppression of stimulus activity resulting from cochlear influence. Informational masking is more complex, as it depends upon factors of uncertainty and similarity (Durlach et al., 2003). Uncertainty refers to the mismatch between the listener’s expectation and what is actually heard, while similarity refers to the difficulty in discerning the tinnitus signal from the masker (Durlach et al., 2003). Energetic and informational masking processes can also be considered as “bottom-up” and “top-down”, processes, respectively (Hoare et al., 2014, p. 64).

2.5 *Tinnitus Treatments*

The vast majority of tinnitus cases concern subjective tinnitus, for which there is presently no cure. Instead, treatment approaches have focused on helping the patient to manage their condition, usually attempting to reduce their awareness of their tinnitus (Searchfield, 2003). Eliminating tinnitus completely is often not a realistic goal, but reducing tinnitus-related distress and impact on quality of life may be a more practical focus (Moller et al., 2010).

An overview of current tinnitus treatments predominantly recommended or provided is presented. An inclusive and exhaustive review of all tinnitus treatments is not within the scope of this thesis. Readers seeking additional information may wish to consider the following: (Wong & Hickson, 2012); (Tyler, 2006); (Jastreboff & Hazell, 2004); (Langguth, 2007).

2.5.1 *Sound Therapy*

An ear-level tinnitus masking device contains small noise generator that delivers sound into the ear (Vernon & Meikle, 2000). However, masking devices may also deliver noises, sounds or music from: iPods or smartphones (Pedemonte et al., 2010; Pope, Silva, & Almeyda, 2010), pillow speakers (O'Connor & Zappia, 1993) or from units designed for sound-field delivery (Folmer, Martin, Shi, & Edlefsen, 2006). Schleuning, Johnson, and Vernon (1980) found ear-level maskers improved the suppression of tinnitus, with 68% (n = 598) receiving either partial or complete relief. Combination devices consist of a sound generator coupled with a hearing aid (HA), and are commonly used when tinnitus is also accompanied by some degree of hearing loss (Vernon & Sanders, 2001a). Ogut et al. (2012) investigated the effectiveness of tinnitus masking therapy using the Earnet Nano® combination device in participants who had tinnitus for three

months or more. Tinnitus frequency, intensity and minimum masking levels were determined, and the tinnitus masking sound was applied at a level high enough to mask the tinnitus (although a partial or full-marking paradigm was not clearly stated) (Ogut et al., 2012). The device was worn for 15 minutes every two hours until bedtime for seven days, and participants returned for a follow-up during which masking parameters could be modified if needed, based on participants' subjective report. After four weeks of treatment, 42 of the 67 participants initially included the study reported treatment benefit, continued with the study and were included in the analysis. For the 42 participants who were included, the treatment reduced tinnitus annoyance and negative affect of life per the TRQ (Wilson et al., 1991) at the end of a three-month treatment duration, compared to baseline measures.

Surr, Montgomery, and Mueller (1985) surveyed 200 veterans who were new HA users with a tinnitus questionnaire and found that of the 62% who experienced tinnitus, approximately half reported beneficial effects at 1 month and 2 months post HA fitting. Searchfield, Kaur, and Martin (2010) investigated differences in pre- and post-treatment tinnitus distress using Tinnitus Handicap Questionnaire (THQ) responses (Kuk et al., 1990), between a group of tinnitus patients who were fitted with HAs and those who opted for a counselling session. The two groups were matched for pre-treatment THQ scores, as well as for age and duration of tinnitus, though the HA group had higher hearing thresholds at 4 and 6 kHz (Searchfield et al., 2010). At 12 months post-treatment, the aided group had significantly reduced THQ score compared with the counselling group (Searchfield et al., 2010).

2.5.2 *Physical-medical Interventions and Referral*

In some cases, further investigations will be required. These include, but are not limited to: when patients also present with asymmetric hearing loss or neurological symptoms, when tinnitus is unilateral, or when tinnitus is pulsatile and synchronous with the heart beat (Baguley et al., 2013). Pulsatile tinnitus is often due to vascular conditions such as: carotid stenosis, atypical carotid artery position, congenital arteriovenous fistula, dehiscent jugular bulb, or acquired arteriovenous shunt (Folmer et al., 2004).

Tinnitus is a defining feature of some otologic conditions, such as Ménière's disease and vestibular schwannoma. Patients with Ménière's disease may have tinnitus characterised by low-frequency pitch matches (Douek & Reid, 1968) and significantly higher severity and annoyance (Stouffer & Tyler, 1990). Tinnitus has also been reported to be present in 73% of patients with vestibular schwannoma (Moffat, Baguley, Beynon, & Da Cruz, 1998). Pathologies such as semicircular canal dehiscence and glomus tumours also warrant specialist otolaryngology investigation (Brantberg et al., 2001; Waldvogel, Mattle, Sturzenegger, & Schroth, 1998).

Objective forms of tinnitus can arise from structural disorders such as temporomandibular joint dysfunction, or chronically patent Eustachian tube (Folmer et al., 2004). Contractions of the stapedius or tensor tympani muscle, and palatal myoclonus may cause clicking or low-pitched buzzing tinnitus (Folmer et al., 2004; Fox & Baer, 1991).

In such cases where there is a causative disease underpinning the tinnitus which likely involves comorbid or contributing issues, therapy should be considered in the wider context of treatment; potentially with a multidisciplinary approach (Baguley, Williamson, & Moffat, 2006).

2.5.3 *Counselling Approaches*

Counselling is an important part of tinnitus management and should address the patient's difficulties, with emphasis on the emotional aspect of tinnitus (Tyler & Baker, 1983). Counselling is included in many treatment options/packages, including: Cognitive Behavioural Therapy, Tinnitus Retraining Therapy, and Neuromonics (Wong & Hickson, 2012). More than just providing information, the most important components of a successful counselling program are changing thoughts, changing behaviour, and understanding an individual patient's needs (Tyler, 2006).

2.5.3.1 *Directive and Non-directive Counselling*

There are two major approaches to counselling, which can be referred to as non-directive and directive (Clark & Martin, 1994; Hodgson & Katz, 1994). Non-directive counselling is client-centric, focusing on emotional support and empowering the individual to better cope with future problems, while directive counselling seeks to solve the problem through educating and communicating information to the client (Henry, 2007).

2.5.3.2 *Informational Counselling*

Most therapy approaches provide information about tinnitus to help patients better understand their symptoms and reassure them of the nature of their tinnitus, which (if unknown) can feed into the distress caused by it (Tyler, 2006). Tyler (2006) provides a useful table summarising general categories of information that is usually provided to tinnitus patients in informational counselling. These include: understanding hearing loss, learning about the prevalence, causes and effects of tinnitus to demystify the condition, and exploring treatment options for hearing loss

and tinnitus (Tyler, 2006). Other approaches also include discussions around habituation and attention (Hallam, 1989; Hallam, McKenna, & Tyler, 2006).

2.5.3.3 Cognitive Behavioural Therapy

Cognitive Behavioural Therapy (CBT) (Craske, 2010) aims to identify negative behaviours and modify adaptation, with an aim towards helping a patient habituate to their tinnitus signal. This goal is based on the finding that for those people with chronic tinnitus who have successfully habituated to the noise, they are subsequently not significantly distressed by it. CBT arises from its similar uses in chronic psychological conditions such as: depression, anxiety, pain syndromes and insomnia (Morin & Barlow, 1993; Philips & Rachman, 1996). The therapy aims to re-orient an individual's thoughts, emotions and coping strategies (Andersson & Kaldo, 2006). A recent Cochrane Review with Level 1 evidence (Martinez-Devesa, Perera, Theodoulou, & Waddell, 2010) identified eight randomised controlled trials with sufficiently similar methodology and measures to enable a meta-analysis (total n = 468). The primary outcome measure investigated was subjective tinnitus loudness. Analyses of pooled data of four studies (n = 171) comparing CBT treatment to a waitlist control group found no difference in subjective tinnitus loudness between the groups post-treatment. The secondary measures were self-perceived of quality of life and depression. Pooled data from six of the eight studies included, revealed a significant positive treatment effect for self-rated depression and tinnitus severity. Overall, the review concluded that CBT has positive effects on patients with bothersome tinnitus (Martinez-Devesa et al., 2010), though the studies included in their review did not have long-term follow up data. Their findings are consistent with the results of a meta-analysis by Hesser, Weise, Rief, and Andersson (2011).

2.5.3.4 Acceptance and Commitment Therapy

Acceptance and commitment therapy (ACT) (Hayes, Strosahl, & Wilson, 1999) was designed as an alternative psychotherapy that focuses on behavioural effectiveness, with the aim to help patients through distressing circumstances. ACT emphasises acceptance of internal experiences and mindfulness, rather than attempting to control or change the patient's negative or distressing thoughts and emotions (Hayes, Luoma, Bond, Masuda, & Lillis, 2006; Hayes et al., 1999). Research on CBT has revealed significant influences of acceptance in the treatment and outcomes of chronic medical conditions (Hayes et al., 2006; McCracken, 2011).

Westin, Hayes, and Andersson (2008) developed the Tinnitus Acceptance Questionnaire (TAQ) and conducted a longitudinal self-report questionnaire study ($n = 77$) using the TAQ, the Acceptance and Action Questionnaire (Hayes, Strosahl, Wilson, Bissett, & Pistorello, 1996), and the THI (Kuk et al., 1990). The findings showed that acceptance had a mediating role in depression, quality of life and tinnitus distress (Westin, Hayes, et al., 2008).

Westin et al. (2011) compared 10 weekly 1 hour sessions of ACT with Tinnitus Retraining Therapy (TRT) in a randomised controlled trial. Results showed that those in the ACT group ($n = 21$) experienced significant improvements in tinnitus impact, and problems with sleep and anxiety, compared to a waitlist control group ($n = 22$). The ACT group also reported significantly greater improvements in tinnitus impact and sleep problems compared to the TRT group at post-treatment, at the 6-month and 18-month follow-up intervals. At the 6-month follow-up, 54.5% of the ACT group demonstrated clinically-significant and reliable changes in tinnitus impact compared to 20% for the TRT group. Process analyses revealed that increases in acceptance mediated the primary outcomes in the group receiving ACT.

Hesser et al. (2012) compared an internet-delivered ACT protocol (n = 33) to an established CBT protocol (n = 27) for the treatment of tinnitus. A high percentage of clinically significant change in tinnitus distress was found for both groups at the post-treatment, 8-week follow-up and 1-year follow-up intervals, compared to controls (n = 32). As there were no significant differences between the ACT and CBT group, the authors concluded that ACT was a worthwhile alternative to the traditional CBT.

Hesser et al. (2014) sought to examine the mediation pathways in ACT and CBT, by comparing the effects of internet-delivered ACT and internet-delivered CBT on tinnitus impact. Sixty-seven tinnitus patients were randomly allocated to one of the two therapies. Mediation analyses revealed that a small degree of suppression of tinnitus-related thoughts, as measured by the TAQ suppression sub-scale, was a significant mediator for patients in the ACT group, but not the CBT group. However, the difference in mediated pathway between treatments did not reach typically accepted level of significance ($p = 0.06$, two-tailed) (Hesser et al., 2014). Activity engagement also mediated outcomes equally for both groups. These findings suggest that only the improvements in the ACT group were influenced by changes in acceptance, rather than suppression of tinnitus-related thoughts and feelings (Hesser et al., 2014).

As ACT has emerged as a fairly recent trend in tinnitus management, no systematic reviews have yet been conducted. However, evidence from longitudinal questionnaire studies and randomised controlled trials indicate that ACT certainly has potential merits in improving tinnitus related outcomes (Hesser et al., 2012; Westin, Östergren, & Andersson, 2008; Westin et al., 2011).

2.5.4 *Treatment Packages*

2.5.4.1 *Tinnitus Retraining Therapy*

Tinnitus Retraining Therapy (TRT) consists of a combination of tinnitus masking and directive counselling, which is a form of informational counselling explaining to patients how tinnitus arises (Jastreboff, 2007). This form of counselling seeks to teach, rather than gain patient feedback or input (Henry, 2007). TRT aims to recondition the mechanisms of the nervous system to habituate the brain to the tinnitus signal (Henry, 2007). A Cochrane Review (Phillips & McFerran, 2010) identified a study by Henry et al. (2006) which trialled this method by comparing TRT with partial masking alone, in veterans. After 3 months of treatment, a significantly beneficial effect was observed in the masking group as reflected by THQ scores (Kuk et al., 1990). However, further improvement was not observed at the 6, 12, and 18-months reassessment intervals (Henry et al., 2006). In contrast, TRT provided tinnitus sufferers with improved symptoms for up-to 18 months. It is worth noting that that roughly one-quarter of the participants used HAs which may be a methodological confounder, as amplification may have likely been beneficial in relieving tinnitus (Henry et al., 2006). Therefore, a separate analysis of HA users and non-users may shed light on the effects of amplification (Wong & Hickson, 2012).

2.5.4.2 *Neuromonics*

Neuromonics involves a combination of masking and/or partial masking (depending on the phase of treatment), using spectrally-modified music with informational counselling (Davis, Paki, & Hanley, 2007). The approach incorporates the addition of partial masking via broadband noise during phase 1 of treatment and if the patient is ready, removes this additional masking support during phase 2 of treatment. The goal of Neuromonics is to promote desensitization and

adaptation to patients' tinnitus perception in a way that is tolerable. Davis, Wilde, Steed, and Hanley (2008) compared patients who received Neuromonics treatment (n = 22) compared to those who participated in a counselling group with (n = 15) and without (n = 13) also receiving a broadband noise stimulus. There were two Neuromonics groups: Group 1 (n = 13) who were instructed to set the stimulus volume to a level that masked their tinnitus as far as comfortable, and Group 2 (n = 9) who were instructed to set the volume so that their tinnitus was covered half that time (Davis et al., 2008). At the end of 6 months of treatment, most (86%) of the Neuromonics group achieved the minimum criterion for clinical success, which was defined as reduction in tinnitus disturbance by at least 40% (per the TRQ score)—compared to 47% of participants allocated to the counselling + noise group, and 23% of the counselling-only group (Davis et al., 2008). Data for Neuromonics Group 1 and Group 2 were pooled for analysis as it was discovered that many patients had deviated from the prescribed instructions, and so there was little difference in treatment applied between the groups (Davis et al., 2008). There was also no difference in TRQ between the groups post-treatment (Davis et al., 2008). The Neuromonics group received significantly greater reduction in tinnitus disturbance compared to the counselling + noise and counselling-only groups (Davis et al., 2008).

A study by Goddard et al (2009) found significant improvement in TRQ scores after 8 months of Neuromonics treatment. A major limitation of this study were the large number of participants who dropped out (n = 14), compared to the 15 participants who completed the treatment (Goddard, Berliner, & Luxford, 2009). The efficacy of the counselling and masking components was also unclear.

2.5.4.3 Biofeedback, Relaxation Training and Hypnosis

Other treatment approaches include biofeedback, relaxation training and hypnosis (Wong & Hickson, 2012). A review by Dobie (1999) reported no clear effect of biofeedback and relaxation training on alleviating tinnitus. An issue in isolating the effects of hypnosis is that it is often applied in conjunction with psychotherapy (Dobie, 1999). Ross, Lange, Unterrainer, and Laszig (2007) conducted a study of 393 tinnitus patients over a 28-day period, all whom were administered hypnosis as well as: informational counselling, relaxation training and sound therapy using music. Though a reduction in tinnitus distress was found via the Tinnitus Questionnaire (Hiller & Goebel, 1992), the effects could not be attributed to any single component of the therapies applied (Ross et al., 2007).

2.6 Attention

Attention is an unifying term encompassing a variety of psychologic concepts (Styles, 2006). Shiffrin (1988, p. 739) refers to attention as “aspects of human cognition that the subject can control...and to all aspects of cognition having to do with limited resources or capacity, and methods of dealing with such constraints.” It is generally agreed upon that attention has a limited capacity, and the allocation of focus on what is attended to, can be controlled in some instances (Styles, 2006).

2.6.1 Attention: A Brief History

The rise of attention research began during World War II when it became important for military staff to attend to, and react efficiently to multiple sources and types of information arriving at the

same time perceptually (Styles, 2006). This prompted researchers to investigate the limitations of cognitive performance (Styles, 2006). Welford (1952) showed that when two signals were presented in quick succession and the participant was required to immediately respond to both, the reaction time to the second stimulus was dependent on the elapsed time between the two signals presented. A decrease in the elapsed time (stimulus onset asynchrony) corresponded with increased reaction time to the second stimulus, which Welford (1952, p. 2) termed the “psychological refractory period”, suggesting that processing for one stimulus must be complete before the next stimulus can be processed.

Most of the early attention experiments examined the visual domain (Styles, 2006), which Broadbent (1971) explained was due to the ability to instantly shift our focus to where our visual gaze falls. However, this is not as easily and efficiently facilitated for our ears. Therefore, investigation of attention to auditory stimuli tends to shed light on central or neural processing, rather than on contributions of controlled mechanical movements that can determine our visual or auditory field (Scharf, 1998).

2.6.2 Overview of Attention Models and Theories

With the progression of attention research, different models and terminologies have evolved, many of which no longer enjoy widespread use. The models and subsets of attention presented in this overview are intended to provide the reader with a brief introduction to some of the prevailing models and forms of attention, rather than functioning as an exhaustive summary. For more information, readers may wish to consult: (Moray, 1969; Näätänen, 1992; Pashler, 1998; Styles, 2006)

There are several types of attention for different circumstances that are encountered. The defining features of the different types of attention relate to the intensity (or difficulty) of the task, and the selectivity or the attentional focus required (van Zomeren & Brouwer, 1994). Selectivity and intensity factors associated with attention-based tasks can be manipulated, and the effect of variations in selectivity and intensity can shed light on one's attention limitations (van Zomeren & Brouwer, 1994). Sustained attention and alertness reflect the intensity factor, while selective and divided attention reflect the selectivity factor (van Zomeren & Brouwer, 1994).

Sustained attention is the ability to focus on a task for a continuous length of time without deviation (Davies, Jones, & Taylor, 1984). Studies of sustained attention are primarily interested in three different features, 1) "Time-on-task effects", 2) "Intra-individual variability", and 3) "Lapses of Attention" (van Zomeren & Brouwer, 1994, p. 173). Time-on-task effects account for reduced performance over time as a result of loss of attention, with effects expected to arise after 15 minutes of a continuous task. Intra-individual variability describes the fluctuation of an individual's performance throughout the course of the task (van Zomeren & Brouwer, 1994). Examination of variability can compare performance between time blocks of equal duration, and can consider both the quality and efficiency of responses (van Zomeren & Brouwer, 1994). Finally, attentional lapse refers to reductions in performance efficiency typically lasting a few seconds, which can occur as a missed response, or increased reaction time (van Zomeren & Brouwer, 1994).

Alertness describes the readiness to respond to task demands and preservation of responsiveness during lengthy tasks (Posner & Boies, 1971). Alertness is reported to be affected by circadian rhythms, with low levels occurring with rest, and higher levels associated with wakeful states

(Sturm & Willmes, 2001; van Zomeren & Brouwer, 1994). A sudden increase in alertness is termed arousal, which is also referred to as the orienting reaction. Arousal is considered a reflex as it occurs without conscious control (van Zomeren & Brouwer, 1994) and prepares an animal or organism to respond to its environment (Luria, 1973).

Divided attention is the processing and reaction to two or more separate concentration demands simultaneously, requiring more than one mental operation to be running at once (Davies et al., 1984). This is often referred to as multi-tasking. Divided attention differs from selective attention, as all stimuli are relevant (i.e. targets) and require attention and reaction (Eysenck & Keane, 2005; van Zomeren & Brouwer, 1994). Divided attention assessments typically employ a dual task paradigm (Sturm, Willmes, & Orgass, 1997).

Alternating attention has been described in research literature as the attentional process in which focus is required to shift between different cognitive demands (Sohlberg & Mateer, 1987), and also the process of facilitating the exchange of attention between different stimuli (Turken & Swick, 1999).

This study focuses on selective attention which is the ability to selectively focus on a target stimulus while simultaneously filtering distractions (van Zomeren & Brouwer, 1994). Selective attention is also referred to as focused attention in the literature (van Zomeren & Brouwer, 1994). This will be discussed in more detail in the following sections.

2.6.3 *Selective Attention*

Selective attention is typically examined in the auditory and visual domains, each with unique features of stimulus manipulation (van Zomeren & Brouwer, 1994). As this study focuses on auditory selective attention, the findings of some of the notable experiments and assessment approaches for this domain are summarised in the following sections.

2.6.3.1 *Auditory Selective Attention*

2.6.3.1.1 *Selective Auditory Attention Models and Theories*

Driver (2001) described selective attention as the process which drives our experience to be dominated by one thing over another. The ability to select and focus on relevant auditory information over less-relevant information has been the emphasis of a large body of research since the 1950s (Driver, 2001). Early investigations were focused on determining the stage at which distractors were removed from further processing (Driver, 2001). Some researchers argued that this occurred at an early stage of information processing, while others believed that more thorough processing occurred before rejection (Driver, 2001). There is ongoing research investigating how attention may be allocated or affected when cognitive or mental reserves are subjected to various task demands (Styles, 2006).

A key theory, considered influential in the field of attention research, is the “Cocktail Party” effect, which arose from experiments involving dichotic and diotic speech stimuli (Cherry, 1953, p. 976; Cherry, 1982). These experiments aimed to investigate the perceptual processes behind the ability to recognise and discriminate speech, which allow people to identify individual voices in complex cocktail party situations (Cherry, 1953).

Many classic experiments used a selective attention listening task where two different verbal passages were presented simultaneously, usually dichotically via headphones, and participants were asked to shadow (verbally repeat) the passage heard in the nominated ear (Cherry, 1953). Researchers sought to determine the variances between the passages that were important for participants to selectively shadow effectively, and what participants typically recalled about the non-target passage (Driver, 2001). It appeared that for effective shadowing, a defined physical difference between the passages was required, for example, very different voices, or voices coming from different locations (Broadbent, 1958; Driver, 2001; Poulton, 1956). Participants appeared to remember very little about the non-target passage when questioned retrospectively (Cherry, 1953; Moray, 1959).

Donald Broadbent's filter theory, presented in a landmark book (Broadbent, 1958), explained cognitive processing with a computer metaphor. He drew parallels between the attentional processing of humans, and the central processing hardware within computers (Broadbent, 1958). In the first phase, physical properties of sound (e.g. pitch, temporal and spatial characteristics) were thought to be extracted in a parallel processing fashion. The next phase processed more complex psychological properties, such as the meaning of the words. This latter phase was theorised to be protected from sensory overload by a selective filter which only allowed through stimuli that possessed a certain physical property (Broadbent, 1958).

2.6.3.1.2 Selective Auditory Attention Assessment Approaches

Auditory selective attention can be assessed with dichotic listening tasks (van Zomeren & Brouwer, 1994). Two different signals are presented to the left and right ears simultaneously via

headphones, with one ear is assigned as the target, and the other ear as the distractor, which is to be ignored (van Zomeren & Brouwer, 1994). The complexity of the task can be manipulated by changing the similarity of the target and distractor signals (van Zomeren & Brouwer, 1994).

The Coordinate Response Measure (CRM) is a communication performance task adapted from similar tasks by Moore (1981) (Bolia, Nelson, Ericson, & Simpson, 2000). The sentences used in the CRM phrases contain a call signal, followed by a colour-number combination embedded within a carrier phrase. An example of a typical sentence would be 'Ready Charlie, go to red four now,' where Charlie is the call signal, and red-four is the colour-number combination (Bolia et al., 2000). For the task, listeners are allocated a call signal, and respond by selecting the colour and number combination articulated by the appointed speaker, whose sentence included the nominated call signal (Bolia et al., 2000). Dependent measures of the performance task include the percentage of time the correct call signal is detected, the percentage of correctly identified colour-number combinations, and the associated reaction times (Bolia et al., 2000). As the listener must be able to discriminate the call signal from various simultaneously spoken call signals, the percentage of correctly selected colour-number combinations can be interpreted as an index of a listener's ability to selectively attend to a single auditory stream while ignoring irrelevant streams (Bolia et al., 2000). The phrases are relatively free of contextual clues and bias, which ensures that variations in performance can be attributed to specific controlled factors, as opposed to contextual indications (Bolia et al., 2000). The CRM paradigm was developed to incorporate factorial permutations of the eight call signs (arrow, baron, Charlie, eagle, hopper, laker, ringo, tiger), four colours (blue, green, red, white), and the numbers (ranging from one to eight) generating 256 phrases in total (Bolia et al., 2000). All phrases were recorded by each of

the eight talkers (four males and four females, age 18-26), giving a total of 2048 phrases (Bolia et al., 2000). Humes et al. (2006) examined age effects on auditory attention by administering the CRM corpus in a single-talker-competition paradigm. Participants were a group of 10 young normal hearing listeners, and a group of 13 elderly hearing impaired listeners. The elderly group performed significantly worse on eight out of the nine divided attention tasks, and worse on only three of the nine selective attention tasks. Overall performance for both groups was worse on the divided attention tasks due to its increased demands on memory (Pashler, 1998). Variation in performance within the elderly group was related to memory, as assessed by a digit span memorisation task, but not associated with age or hearing loss (Humes et al., 2006).

Coughlin's (2004) doctorate thesis examined speech identification performance using the CRM in one-talker interference conditions that increased in complexity. Audibility was ensured across the main speech frequencies of 250 – 4000 Hz. There were four groups of participants: two elderly hearing impaired groups (one aged 65-75 years, the other group aged 76 - 86 years), as well as two, young, normal-hearing groups (Coughlin, 2004). Despite acoustic matching of the young normal-hearing control group to the elderly hearing-impaired groups, speech recognition performance was significantly better in the young participant group (Coughlin, 2004). Individual differences in performance among the elderly were found to be associated with age and level of education (Coughlin, 2004).

The Stroop test, developed from the Stroop effect (Stroop, 1935) requires participants to state the colour of a set of colour-words, to state the colour of a set of colour-words, some of which are congruent, and some incongruent, with the target word's ink colour. The Stroop effect refers to the difference in reaction times between naming the target colour word in congruent and

incongruent trials. It is thought to test central executive control as the incongruent trials require suppression of the more prominent response (i.e. to name the word rather than the colour of the word) (Botvinick, Braver, Barch, Carter, & Cohen, 2001).

2.6.4 *Attention and Tinnitus*

Attentional mechanisms may also influence how permanently fixed in the central auditory system the phantom auditory signal becomes (Hazell, 1995). Some hypotheses suggest that in individuals who attend to their tinnitus, adaptive changes occur centrally which help to preserve the phantom sound (Hazell, 1995). Tinnitus has been frequently linked to reduced cognitive function (Jacobson et al., 1996; Wilson et al., 1991).

There are anecdotal reports of individuals with tinnitus having difficulties with mental concentration (Sanchez & Stephens, 1997; Tyler & Baker, 1983), and many tinnitus impact questionnaires query the patients' ability concentrate or focus (Meikle et al., 2012; Newman et al., 1996; Wilson et al., 1991). A review by Banbury, Macken, Tremblay, and Jones (2001) concluded that task-irrelevant sounds interrupted selective attention and had a large effect on cognitive performance. From this, one can draw parallels to the potential effects on cognition that tinnitus may have.

In our everyday sensory-laden environments, much of the information processing in our brain occurs involuntarily—without our conscious control (Näätänen, 1992). The selective exclusion of repetitive and redundant stimuli from further processing promotes optimal information processing (Venables, 1964). This ability of the CNS to prevent or constrain responses to

repetitive or irrelevant sensory input is described as sensory gating (Boutros, Korzyukov, Jansen, Feingold, & Bell, 2004). This is a critical and protective mechanism preventing higher cortical centres from being inundated with irrelevant information (Møller et al., 2011; Venables, 1964).

Neuroimaging studies have shown altered brain connectivity in tinnitus patients through functional magnetic resonance imaging (fMRI) (Maudoux et al., 2012) and positron emission tomography scans (Schecklmann et al., 2013). Husain et al. (2015) used fMRI to examine auditory and visual attention processing in participants with hearing loss and tinnitus (n = 14), compared to age-matched control groups with matched hearing loss (n = 11) and normal hearing (n = 12). Participants performed a short-term memory task with conditions of varying loads. The auditory condition of the task used non-speech sounds while the visual condition used unfamiliar Korean letters. Similar behavioral responses were observed across all groups, modalities and tasks. However, the response of the attention network was reduced in the tinnitus group compared to the control groups for both task loads, with a greater effect for the high load condition. Interestingly, for the visual modality, the tinnitus group demonstrated increased response for the attention network for both memory loads compared to the control groups.

Cuny et al. (2002) examined mechanisms of involuntary attention comparing attention performance in participants with left (n = 10) and (n = 10) right unilateral tinnitus, bilateral tinnitus (n = 10), left (n = 10) and right (n = 10) unilateral tinnitus simulated controls, and control participants (n = 10). Unilateral tinnitus participants were more accurate for stimuli directed to the tinnitus ear versus the contralateral ear, while there was no difference between the tinnitus and non-tinnitus ears in the simulated tinnitus group (Cuny et al., 2002). These findings support

the theory of attentional bias in the tinnitus ear, suggesting that directing attention away from the tinnitus ear may be more difficult (Cuny et al., 2002).

Hallam et al. (2004) examined a common complaint among tinnitus sufferers that noises affect their ability to concentrate. This was assessed using self-report questionnaires and cognitive tasks measuring performance in single and dual-task conditions. The tasks assessed: sustained attention, reaction time, verbal fluency, immediate memory, and delayed memory (Hallam et al., 2004). Participants were tinnitus patients of audiology clinics (n = 43), a non-tinnitus group with hearing impairment (n = 17), and non-clinical volunteers without tinnitus or noticeable hearing loss (n = 32) (Hallam et al., 2004). The tinnitus group had significantly slower response times for a dual-task condition, and also performed more poorly on verbal fluency (Hallam et al., 2004). No significant differences were found for performance on the other tasks (Hallam et al., 2004). Tinnitus patients also reported significantly more problems on the Cognitive Failures Questionnaire (Broadbent, Cooper, FitzGerald, & Parkes, 1982), compared to the control group (Hallam et al., 2004). The authors suggested that reduced cognitive adeptness in tinnitus patients was linked to the regulation of attentional processes, consistent with the habituation model.

Andersson (2002a, p. 197) introduced the concept of the “changing-state” character of tinnitus, in that the nature of the tinnitus sound may underpin some of the tinnitus distress and cognitive interruption reported by many tinnitus sufferers. Therefore, he sought to examine this in three separate experiments. In the first experiment, tinnitus (n = 20) and healthy control (n = 20) participants completed a digit symbol test under three different conditions: silence, masking, and intermittent making. The tinnitus group performed worse in the intermittent masking condition than the masking condition, but there was no difference between the silence and masking

conditions. The control group performed worse on the intermittent masking condition when compared to both of the other conditions. The second experiment applied simulated tinnitus to control participants while completing the digit symbol task in the same conditions again, which revealed no changing-state effect. In the third experiment, tinnitus and control participants completed a serial recall test, of greater difficulty than the digit symbol test, under the same three conditions. The results indicated that the tinnitus group performed slightly worse than the controls, but intermittent masking had no effect this time. The authors explained the seeming disparity between the first and third studies to be attributed to the difference in difficulty of the tasks. They also found that the tinnitus participants were often able to direct their attention from the tinnitus (Andersson, 2002a), contrary to theories based on tinnitus presence causing attention disruption or attention-capture (Delb et al., 2008; Rossiter et al., 2006; Stevens et al., 2007)

Goodwin and Johnson (1980a) found that reaction times to auditory stimuli were significantly shorter in the hearing-impaired tinnitus participants compared normal-hearing controls at the tinnitus frequency, but not other frequencies.

2.6.4.1 Auditory Selective Attention and Tinnitus

Research has shown that tinnitus can impact selective attention (Andersson et al., 2000), with patients reporting difficulties with concentrating due to their tinnitus (Andersson et al., 1999). Auditory selective attention can be indexed through the measurement of endogenous event-related potentials, and has been documented to be abnormal in individuals with schizophrenia, who sometimes describe an inability to well-order thoughts due to sensory overload (Freedman et al., 1996). As it is commonly agreed that the persistence of chronic tinnitus may be attributed to

impaired cortical processing (Eggermont & Roberts, 2004), the pathophysiology of tinnitus has been investigated by assessing early arousal and attention in tinnitus sufferers using electrophysiological measures (Jacobson et al., 1996; Vanneste et al., 2010; Walpurger et al., 2003). Electrical activity occurring in structures within the brain can be measured via electrodes placed on the scalp, with measurements displayed on an electroencephalogram, or EEG (Luck, 2005). The EEG contains multiple sources of neural activity which can be extracted using averaging techniques to reveal responses associated with specific sensory, cognitive, or motor events (Luck, 2005).

Jacobson et al. (1996) conducted an experimental study in which participants were instructed to attend to and respond to, a target stimulus intermittently presented in one ear, while ignoring signals presented in the other ear. The magnitude of an index of early selective auditory attention, the negative-difference (Nd) waveform, was enhanced in participants with bothersome tinnitus and high frequency hearing loss, compared normal hearing controls (Jacobson et al., 1996). It was thought that if the presence of continuous bothersome tinnitus causes increased selective attention, there would be involuntary attentional bias.

As tinnitus has been found to influence auditory processing, Acrani and Pereira (2010) examined whether tinnitus was related to other sound processing abilities, including temporal resolution and selective attention. Normal hearing participants with continuous bilateral tinnitus ($n = 15$) and without tinnitus ($n = 30$) completed the Speech in Noise Test, Dichotic Digits Test and Gaps in Noise test. No differences were found between the groups or between the ears, indicating that tinnitus did not interfere with selective attention and temporal resolution for this particular study.

Research suggests that the distracting effects of tinnitus can affect performance on working memory and attention tests (Rossiter, Stevens, & Walker, 2006). Stevens et al. (2007) used the Stroop test (Stroop, 1935) to examine selective attention in tinnitus sufferers (n = 11) compared to a control group (n = 11). Reaction times were averaged for trials and the tinnitus group had a significantly slower time than the control group, even when hearing loss, anxiety and depression were accounted for with covariate analyses (Stevens et al., 2007). These findings were interpreted to support an interaction between tinnitus and an underlying selective attention deficit (Stevens et al., 2007).

Heeren et al. (2014) investigated attentional processes in tinnitus patients (n = 20) and healthy matched controls (n = 20), using the Attention Network Test (Fan, McCandliss, Sommer, Raz, & Posner, 2002). For the selective attention sub-test, accuracy and reaction time were examined, and no significant differences were found between the groups for the orienting (selective attention) abilities, but the tinnitus group did perform significantly poorer for executive control (Heeren et al., 2014). The findings for the study suggested that while the alerting and orienting processes were preserved for their cohort, top-down executive control of attention was compromised (Heeren et al., 2014).

Spiegel et al. (2015) evaluated a novel approach to tinnitus management which combined attention training with audio, visual, and somatosensory stimulation. Participants (n = 18) with primarily unilateral tinnitus were randomly allocated to receive 20 daily sessions of either integration or attention diversion training. The integration training attempted to reduce the perception of tinnitus by linking it to multisensory stimuli to provide a 'source' for the tinnitus, while the attention diversion training delivered stimuli to the non-tinnitus side. A small but

statistically significant reduction in TFI and TSNS scores were observed in both groups, as well as improved attentional abilities. There was no difference in tinnitus improvement between the training groups. These findings demonstrated that short-interval multisensory attention training reduced unilateral tinnitus, with results uninfluenced by the side receiving the stimuli, though the clinical significance was undetermined.

In a feasibility study, Wise et al. (2015) developed and assessed the feasibility of *Terrain*, a game-based auditory attention and localization task customised to an individual's tinnitus perception. Players attended to nominated target sounds while ignoring distracters. Eight participants with chronic tinnitus and bilateral hearing loss completed 30 minutes of training per day for 20 days, and were psychoacoustically assessed via the game software, for tinnitus pitch and loudness daily. Significant reductions in THI scores were observed. The study found that an attention training method was feasible and a potentially promising tool for tinnitus treatment.

2.7 Memory

2.7.1 Memory: A Brief History

Memory can be described as the process by which information is encoded, stored, and retrieved (Wegner, 1987). The idea that memory storage may consist of two or more components rather than a single system is long held (Baddeley, 1986). William James (1890, pp. 643, 648) proposed memory as a composite of “primary memory” which contains information and ideas that are present in the mind, and “secondary memory”, a more lasting form. Hebb (1949, 2009) proposed a neurophysiological distinction between short- and long-term memory. It was suggested that short-term memory may involve temporary electrical circuits, while long-term memory was

based on permanent changes in neural links (Hebb, 1949, 2009). This concept was supported by Brown (1958) and Peterson and Peterson (1959) who found that decay in ability to recall even small amounts of information occurred rapidly without rehearsal. These proposals marked the beginning of active research into models of memory.

2.7.2 *Overview of Memory Models and Theories*

The difference between impaired long-term memory and unaffected short-term plus working memory (Milner, 1966) or vice-versa (Shallice & Warrington, 1970), for patients with brain damage, led to the conceptualization of memory consisting of a sequence of storage systems (Atkinson & Shiffrin, 1968). Atkinson and Shiffrin (1968) proposed the information-processing model, which would go on to be highly influential and known as the “modal model” (Baddeley, 2007, p. 3). This model described memory in terms of information flowing through a system with staggered sensory stores with inputs, processing, and outputs (Atkinson & Shiffrin, 1968; Baddeley, 2007). Environmental inputs are detected by the different sensory nodes, and if the information is attended to, it will enter the short-term store (STS) (Atkinson & Shiffrin, 1968). From there, control processes regulate the flow of information to the long-term store (LTS) as well as retrieval (Atkinson & Shiffrin, 1968, p. 90). According to this model, long-term learning would be dependent upon both the STS and LTS.

However, it soon became apparent that there were holes in this model, as patients with STS deficits did not always show impaired long-term memory or general cognitive dysfunction (Shallice & Warrington, 1970). Another issue was that Atkinson and Shiffrin (1968) assumed that the length of time information was held in the STS increased the probability of transferal to

LTS. Craik and Lockhart (1972, p. 671) published their “Levels of Processing” hypothesis, which proposed that depth of information processing, by encoding richness of meaning, rather than holding time in the STS or number of rehearsals, had greater impact on long-term learning.

Sensory information was thought to flow through a series of perceptual processes, before the finite capacity short-term memory, after which the perceptual information would finally enter long-term memory reserves (Baddeley, 2010).

Short-term memory, working memory, and long-term memory are more commonly known as the main types of memory (Cowan, 2008). Short-term memory is defined as the temporary storage of small quantities of information over short periods of time (Baddeley, 2010). There is a limited capacity, with recall limited to a period of several seconds to a minute, without rehearsal (Baddeley, Thomson, & Buchanan, 1975; Broadbent, 1958). Miller (1956, p. 349) conducted experiments showing short-term memory store was 7 ± 2 meaningful items, or “chunks”. Other estimates of capacity have been lower (Gilchrist, Cowan, & Naveh-Benjamin, 2008). The ability to remember and recollect a series of digits, such as a telephone number, is thought to be contingent on short-term memory. Therefore, digit span tasks are commonly used to assess short-term memory. As the digit sequence grows longer, the short-term memory reserves capable of processing the information should theoretically diminish, thereby affecting performance. Chunking increases memory capacity by processing a long string of information into smaller meaningful items (Miller, 1956). For example, a nine-digit phone number can be memorised in groups of three digits. The conception of working memory arose from short-term memory (Baddeley, 2010), and will be discussed in detail in the next sections.

Long-term memory is the final stage in Atkinson and Shiffrin's (1968) model. In contrast to short-term memory, the long-term memory capacity can store vast amounts of perceptual information indefinitely, which is thought to be maintained by changes in neural connections spread throughout the brain (Bliss & Collingridge, 1993; Costa-Mattioli & Sonenberg, 2008). Long-term memory can be divided into explicit memory and implicit memory (Cohen & Squire, 1980). Explicit memory, also known as declarative memory, requires conscious thought recollection of previous experiences and information (Schacter & Graf, 1986). It can be further separated into episodic and semantic memory (Tulving, 1986). Implicit memory is also known as procedural memory, which is an automatic memory not requiring conscious or intentional effort that is enabled by previous experience (Lewandowsky, Dunn, & Kirsner, 1989).

2.7.3 *Working Memory*

Working memory is the dynamic system that transitorily holds and processes newly arriving cognitive information, usually over a brief time period (e.g. seconds) (Baddeley, 2002; Deco & Rolls, 2005).

Baddeley and Hitch (1974) proposed a three-component model of working memory comprised of a central executive controller with temporary storage systems which became known as the "visuospatial sketchpad" (Baddeley, 1986, p. 71) and the "articulatory loop" (Baddeley, 1986, p. 75) or "phonological loop" (Baddeley & Hitch, 1994, p. 486). Though the term working memory had been used previously by Miller, Galanter, and Pribram (1986), Baddeley and Hitch (1974) opted to use the term to emphasise its functional role, rather than a storage reserve like short-term memory. A fourth component, "the episodic buffer", was later added (Baddeley, 2000, p. 417).

The role of the central executive was proposed to monitor and manage the operation of the temporary storage systems. Rather than functioning as a memory store, it was concerned with directing and prioritizing attentional processes (Baddeley, 1986). The phonological loop was theorised to process: language-based information, articulatory control processes and the phonological store (Baddeley, 2007). The phonological store was thought to transitorily hold information in speech-based form for 1 - 2 seconds (Baddeley, 2007). Spoken words would enter the store directly while the written form must first be converted into articulatory code before admission into the phonological store (Baddeley, 2007). Rehearsing information from the phonological store would theoretically help to retain information in working memory, and is the process by which we are able to remember phone numbers. The visuo-spatial sketch pad was proposed to be the storage system that integrated visual and spatial information into a single representation (Baddeley, 2007). The latest addition, the episodic buffer, was theorised to serve as an interface between the components and LTM; to allow access to the LTM (Baddeley, 2007). This influential model shaped the current understanding of working memory and is supported by evidence from studies in healthy children and adults (Alloway, Gathercole, & Pickering, 2006; Kane et al., 2004), as well as patients with brain lesions (Jonides, Lacey, & Nee, 2005).

Working memory is compromised in many conditions including dementia (Collette, Van der Linden, & Salmon, 1999), attention deficit hyperactivity disorder (Pasini, Paloscia, Alessandrelli, Porfirio, & Curatolo, 2007), and schizophrenia (Fleming, Goldberg, Gold, & Weinberger, 1995).

Dalton, Santangelo, and Spence (2009) investigated whether working memory had a role in reducing interference of auditory distractors, and found greater distractor interference occurring under high compared to low working memory load.

2.7.3.1 Working Memory Assessment Approaches

In experimental psychology and cognition, working memory is typically assessed with tasks that require storage and processing otherwise known as, complex span tasks (Hill et al., 2010). As the central executive coordinates multiple processes, this function is assessed with complex memory tasks where the participant processes and stores increasing quantities of information until recall errors are made. The sentence span task (Daneman & Carpenter, 1980) requires listeners to comprehend the sentence presented, and also recall the last word of the sentence, thereby assessing ongoing attention and storage, respectively. Working memory capacity in this task is defined as the number of sentences that are correctly comprehended with the last word correctly recalled in sequence. This can be adapted as reading span (participant reads the sentence), or listening span (sentences presented verbally). Other tests include counting span (Bull, Espy, & Wiebe, 2008), operation span (Turner & Engle, 1989), and backward digit span (Wundt, 1912).

The Digit Span forward and reverse sub-tests can be traced back over 100 years ago, published in Wilhelm Wundt's An Introduction to Psychology (Wundt, 1912). In the forward condition, the listener is given a sequence of numbers and asked to repeat the numbers sequentially, immediately after they are presented. This task is meant to index short-term memory (Draine, 2015). In the reverse condition, the listener repeats back the number sequence in reverse order. The backward digit span test has become the prevailing method of assessing working memory capability (Ramsay & Reynolds, 1995) and remains in use in several psychological test batteries, including the Wechsler Adult Intelligence Scales, where the digit span score combines the total number of digits that are correctly recalled in both conditions (Wechsler, 2008). Though the

recitation of the number sequence in forward and reverse order utilises different cognitive processes (Reynolds, 1997), Wechsler (1944) noted that the separate subtest resulted in too narrow a range of performance scores, therefore choosing to combine the scores.

2.7.4 *Working Memory and Tinnitus*

Tinnitus has been linked to reduced cognitive function (Jacobson et al., 1996; Wilson et al., 1991), including the domain of working memory (Hallam et al., 2004). According to Hallam et al. (1984) individuals with chronic tinnitus have failed to effectively habituate to the tinnitus signal, are continually orienting to the tinnitus and remain in a state of arousal. As attention is constantly directed at the tinnitus, the working memory capacity is therefore affected. This should mean decreased working memory span, slower reaction time(s), and greater difficulty with more complex dual-task conditions (Rossiter et al., 2006). Rossiter et al. (2006) examined auditory working memory using a verbal version of the Reading Span test (Daneman & Carpenter, 1980) in a group of chronic tinnitus sufferers (n = 19), and a control group (n = 19) matched with regards to the experimental group according to: age, level of education, occupation, and score on the National Adult Reading Test (NART) (Nelson & Willison, 1991). A significant difference was observed, which suggested that working memory was affected in individuals with chronic tinnitus, even when verbal intelligence was accounted for (Crawford, Parker, Stewart, Besson, & Lacey, 1989). Further analyses factoring anxiety as a covariate, showed that anxiety levels did not account for the difference in working memory ability (Rossiter et al., 2006).

Andersson, Edsjö, Kaldo, and Westin (2009) examined the effect of continuous and intermittent masking on performance related to an auditory serial recall task in a tinnitus sample, compared to

a control group matched for age, gender and education level. The serial recall task featured random lists of consonants which the participants were asked to write down following presentation (Andersson et al., 2009). During the task, white noise masking stimuli (constant or intermittent) or no sound trials took place (Andersson et al., 2009). Overall, the experiment revealed no difference in performance between the groups. The different background sound conditions also had no effect. The masking conditions did not differentially impact on performance between the groups, which did not meet the experimenter's expectation that the tinnitus group would perform worse during the intermittent masking condition (Andersson et al., 2009). However, the study assumed that masking would have a similar effect as tinnitus. It did not account for individual differences in tinnitus perception or consider application of a tinnitus-like (e.g. tonal) signal.

As previously described in Section 2.6.4, Hallam et al. (2004) examined attentional and memory process as part of their investigation into the complaint of concentration difficulties in tinnitus sufferers. Participants were tinnitus patients of audiology clinics ($n = 43$), a non-tinnitus group with hearing impairment ($n = 17$), and non-clinical volunteers without tinnitus or noticeable hearing loss ($n = 32$). The authors hypothesised that presence of tinnitus would put additional pressure on the central executive as it would require monitoring and suppression of the constant tinnitus signal, with greater effects demonstrated under more complex and demanding task conditions. The test battery included tasks assessing visual vigilance, reaction time, and delayed forward digit recall, which were administered under dual-task conditions. The secondary tasks were verbal fluency and memory tests, or engaged articulatory suppression. For the test of visual vigilance, participants were required to repeat the word "Boko" aloud throughout the task, which

was intended to occupy cognitive resources in the phonological store. The three groups performed similarly on single and dual-task conditions, which did not support the notion that cognitive interference is attributed to the presence of tinnitus occupying and limiting the capacity of the phonological store. Of the two reaction time tasks, there was no difference in performance between the groups on the five-choice, serial reaction time task (thought to measure concentration), in both single and dual task conditions. Differences were observed for the variable fore-period reaction time task, which was coupled with a verbal fluency task. Both the tinnitus and hearing-impaired group performed more poorly than the normal hearing control group, with the tinnitus group demonstrating poorer results than both groups. For the delayed forward digit recall task, the tinnitus group was poorer at recalling the first and second digits of the sequence, when the task was coupled with another memory task. No significant differences were found for performance on the other tasks.

2.8 Hearing Loss and Cognitive Aging

Hearing loss is estimated to affect nearly two-thirds of adults over the age of 70 (Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011) and has become accepted as a part of the natural ageing process. It has been suggested that hearing loss may accelerate cognitive ageing (Lin et al., 2013), and that more timely and directed management of hearing loss could potentially slow cognitive decline (Wayne & Johnsrude, 2015). Dementia has a huge impact on an individual's quality of life, as well as burdening family and society (Prince, Albanese, & Guerchet, 2014). As the prevalence of dementia is on the trajectory to double every 20 years due to an ageing world population, improving understanding and prevention of cognitive decline and dementia has become an important public health priority (Ferri et al., 2005; Prince et al., 2014).

Hearing loss has been suggested to be independently correlated with reduced cognitive function and dementia (Lin, Metter, et al., 2011). Reduced social engagement and sensory stimulation in individuals with hearing loss have also been cited as possible mediators for this relationship (Ives, Bonino, Traven, & Kuller, 1995; Uhlmann, Larson, Rees, Koepsell, & Duckert, 1989). Lin et al. (2013) conducted a longitudinal cohort study of 1984 older adults (mean age 77.4 years) who enrolled in the prospective, observational Health ABC study which commenced in 1997–98. At baseline, participants had Modified Mini-Mental State (3MS) scores ≥ 80 (indicative of no cognitive impairment). They received audiometric testing in year 5 of the Health ABC study, and were followed for 6 years. Hearing levels were obtained at baseline (Year 5) using the PTA of the better hearing ear hearing thresholds from 0.5 – 4 kHz (Lin et al., 2013). Cognitive testing was done in years 5, 8, 10, and 11 and involved administration of the 3MS (which measures global function and has components for orientation, concentration, language, praxis, and memory) and the Digit Symbol Substitution test (DSS—a non-verbal test measuring psychomotor speed and executive function). The criteria for cognitive impairment were 3MS scores < 80 or a decline in 3MS > 5 (Lin et al., 2013). They found that participants with hearing loss at baseline (PTA > 25 dB, $n = 1162$) had increased rates of decline for 3MS and DSS scores, at 41% and 32% greater, respectively, compared to normal hearing participants (Lin et al., 2013). Hearing loss was associated with a 24% increased risk of incident cognitive impairment, with the risk of incident cognitive impairment and rate of cognitive decline linearly related to baseline hearing loss severity (Lin et al., 2013).

2.9 Purpose of the Study

This study sought to characterise and compare auditory selective attention and working memory ability in individuals with tinnitus with healthy, non-tinnitus controls, and investigate the relationship between cognitive abilities, self-perceived tinnitus impact on functional life, and tinnitus severity. As stated earlier, selective attention and working memory have been linked to tinnitus, and previous studies suggest that these cognitive abilities may be reduced in individuals suffering from tinnitus (Andersson et al., 1999; Hallam et al., 2004; Jacobson et al., 1996; Stevens et al., 2007; Wilson et al., 1991). The few studies which have directly compared behavioural auditory selective attention and auditory working memory abilities between tinnitus participants and a matched control group have yielded inconsistent findings (Acrani & Pereira, 2010; Andersson et al., 2009; Andersson & McKenna, 2006; Mohamad et al., 2015; Rossiter et al., 2006; Stevens et al., 2007). There is also little research on how auditory selective attention and working memory abilities interact with other features of tinnitus experience. It is important to more closely examine and compare the relationship between these cognitive processes and tinnitus, as a major hurdle in developing novel and effective tinnitus therapies is our incomplete understanding of the field cognition as a whole, despite emerging technology and theories (Baguley et al., 2013; Langguth, Kreuzer, Kleinjung, & De Ridder, 2013). Tinnitus remains an incurable symptom (Møller et al., 2011). It is hoped that this study can help identify interactions between tinnitus and cognitive issues that may inform treatment approaches for individuals with tinnitus, and help further the direction of future tinnitus research.

2.9.1 *Aims and Hypotheses*

Based on previous studies, the main study hypothesis was that individuals with tinnitus would show reduced auditory selective attention (ASA) and reduced working memory, digit span abilities compared to individuals without tinnitus (Hallam et al., 2004; Rossiter et al., 2006; Stevens et al., 2007). The present study sought to answer the following research questions:

1. Would the ASA scores be significantly different (worse) when comparing the tinnitus and control groups?
2. Would the digit span scores which index working memory, be significantly different (worse) when comparing the tinnitus and control groups?

Secondary hypotheses were that poorer performance on the ASA and digit span tasks would be related to more severe or distressing tinnitus, and negative tinnitus impact would be contributed to by poorer emotional state. The specific study questions for correlation analyses within the tinnitus group were as follows:

1. Would there be correlations between tinnitus questionnaires employed, identifying greater tinnitus severity and (worse) ASA performance?
2. Would there be correlations between tinnitus questionnaires employed, identifying greater tinnitus severity and (worse) digit span performance?

3 Methods

3.1 Participants

3.1.1 A Priori Power Analysis

An a priori analysis was completed to determine sample size and was influenced by the aim to detect effect size of $d = 1$, an alpha-level of .05 and a power level of .80. Given these factors, a total of 17 participants with tinnitus, and 17 control participants were sought for the study.

3.1.2 Recruitment Strategies

Tinnitus participants were recruited through advertisements displayed in the reception waiting room and clinical areas at the University of Canterbury audiology clinic (Appendix 1), on the Hearing Association noticeboards and in their newsletter, in Age Concern Canterbury's *Keeping On* community newsletter, and on University and community noticeboards (including local supermarkets and public libraries). Potential tinnitus and control participants who met the study criteria were also identified through the University of Canterbury audiology clinic database. Those who had given permission to be contacted for future research were sent an information pack for participation in the study (Appendix 2). Once the tinnitus participants were obtained, non-tinnitus participants were sought to serve as age, sex and hearing loss-matched controls. Tinnitus participants received a \$10 fuel voucher for their participation.

3.1.3 Inclusion Criteria

All participants taking part in the study were required to meet the following criteria:

- Be age 18 to 85 years. This age range was informed by findings from Cox, McCoy, Tun, and Wingfield (2008) who examined monotic auditory processing in older adults (n = 45) who ranged from 66 to 85 years (mean = 74.4, standard deviation (SD) = 4.9). Correlational analyses found that age did not independently contribute to differences in performance on the tasks, with the exception of the pitch pattern sequence, an auditory processing test.
- Have average speech frequency (500 Hz, 1 kHz, 2 kHz) pure tone air conduction hearing thresholds no greater than 25 dB HL. This hearing sensitivity criterion was informed by findings by Cox et al. (2008) that showed older adults with low and high frequency hearing loss performed worse in certain monotic auditory processing tests than those with high frequency hearing losses only. Participants in the low/high frequency hearing loss group had mean speech frequency PTA ranging from 25 to 35 dB HL (mean = 28.4, SD = 2.9).
- Have normal bone conduction thresholds (no conductive hearing loss).
- Be comfortable completing a computer-based assessment task presented in an English format.
- Not prescribed or currently taking any medications likely to affect attention, memory or emotional state.

Additionally, tinnitus participants also met the following criteria:

- Presence of tinnitus in one or two ears lasting six months or longer (i.e., chronic tinnitus).

- Score of 25 or greater on the Tinnitus Functional Index (TFI) (Meikle et al., 2012) to ensure sufficient tinnitus to avoid a ‘floor effect’ with respect to data outcomes and results.
- Describe tinnitus perception/experience that is not pulsatile in nature, potentially indicative of vascular involvement.
- Have normal loudness sensitivity (lacking hyperacusis or hypersensitivity to loud sounds others find easily tolerable).

3.2 *Questionnaires and Behavioural Testing*

3.2.1 *Questionnaires*

The Tinnitus Sample Case History Questionnaire (TSCHQ) (Langguth et al., 2007) and Tinnitus Functional Index (TFI) (Meikle et al., 2012) were administered to determine preliminary eligibility for tinnitus participants. Following qualification of initial candidacy, participants also completed the Tinnitus Severity Numeric Scale (TSNS) (The Tinnitus Research Initiative, 2009) and the Tinnitus Handicap Inventory (THI) (Newman et al., 1996). Although never designed as an outcome measure, the THI has historically been used in this manner internationally. By incorporating it, international comparisons could be made. The Depression, Anxiety, Stress Scale (DASS) (Lovibond & Lovibond, 1996) was administered to determine emotional state. From an Australian cohort (n = 395), DASS mean, median and (SD) scores characterising results were: depression = 4.31, 1, (7.00), anxiety = 2.85, 1, (4.63) and stress = 7.61, 5, (8.07) (Crawford, Cayley, Lovibond, Wilson, & Hartley, 2011). The Mini Mental State exam (MMSE) (Folstein & Folstein, 1975), a basic cognitive screening test, was used to gauge memory, capability for

attention and calculation, ability to understand and follow instructions in English, and to rule out possible dementia involvement in all participants. MMSE scores of 24 - 30 rule out cognitive impairment, scores of 18 - 23 are suggestive of mild cognitive impairment and scores 0 - 17 are indicative of referral for severe cognitive concerns (Rovner & Folstein, 1987).

3.2.2 *Audiological Assessment*

Otoscopy and tympanometry was also performed for all participants to determine the condition of the ear canal. Pure-tone audiometry via air conduction was tested from 250 Hz to 8 kHz (250 Hz, 500 Hz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, 8 kHz) and bone conduction was tested at 500 Hz, 1 kHz, 2 kHz and 4 kHz where air conduction thresholds exceeded 15 dB HL. Air and bone conduction masking was performed as required. Tinnitus participants were additionally tested at 9 kHz, 10 kHz, 11.2 kHz, 12.5 kHz, 14 kHz, and 16 kHz. Thresholds were obtained using the modified Hughson-Westlake descending method of limits procedure (Hughson & Westlake, 1944). Participants who met the audiological criteria proceeded with the tinnitus characterization, auditory selective attention and working memory assessments.

3.2.3 *Tinnitus Assessment and Characterisation*

Individual tinnitus characterization procedure obtained the pitch, loudness and minimum masking levels (MMLs) of tinnitus.

3.2.3.1 Tinnitus Pitch-Match

Tinnitus pitch match (tF) was obtained by presenting two consecutive comparison pure-tones to the test ear (Henry & Meikle, 2000). A 2AFC method was used to determine which tone was considered to be the better tinnitus pitch-match. The procedure was repeated until the best possible tinnitus pitch-match was determined. Octave confusion was checked by presenting a tone one octave below the first match and rechecking tF.

3.2.3.2 Tinnitus Loudness-Match

Tinnitus loudness-match was attained by the presentation of the tinnitus pitch in an ascending technique. Steps of 5 dB were used initially, to gain a rough estimate of intensity. The procedure was then repeated twice using 2 dB step sizes, and an average loudness match from the three values was calculated. The tinnitus sensation level (dB SL) was derived by subtracting the tinnitus pitch-match frequency's threshold level from the calculated tinnitus loudness-match.

3.2.3.3 Tinnitus Minimum Masking Level

The minimum masking level was determined by presenting narrowband noise at the tinnitus frequency. An ascending technique, initially using 5 dB step size was employed to gain an estimate of the intensity level required to just reduce the tinnitus magnitude (partial masking). Participants were instructed to indicate the level at which the masking stimulus subjectively began to 'blend' with their tinnitus, making it difficult to differentiate between the two. The procedure was repeated a further two times, using 2 dB step sizes. The average was calculated from the intensity levels obtained.

3.2.4 *Selective Attention Assessment*

The experiment was presented dichotically using the Millisecond Inquisit 4 software web license (Draine, 2015). The auditory selective attention (ASA) task used the coordinate response measure CRM corpus (Bolia et al., 2000) as described in Humes et al. (2006). ASA was measured with a listening task which involved the identification of words in sentences spoken by one nominated target talker while a second talker produced a very similar competing sentence. The structure of each sentence was identical, with each sentence using the form “Ready (call sign), go to (color) (number) now.” There were eight different call signs (arrow, baron, Charlie, eagle, hopper, laker, ringo, tiger), four different colours (blue, green, red, white), and eight numbers (1 – 8). The assessment corpus incorporated every combination of the eight call signs, four colors and eight numbers, resulting in 256 possible phrases for each talker. Two talkers (1 male and 1 female) were presented, yielding a possible 512 phrase combinations in total. The auditory selective attention corpus was presented via headphones, with the intensity level set to a level found to be subjectively well-audible yet comfortable.

The instructions appeared onscreen for the participants to read (Figure 3-1, Figure 3-2). Instructions were also verbally reinforced by the researcher administering the assessment, to ensure task understanding.

To study people's ability to focus their attention while hearing conflicting information we will present you with **TWO** phrases that contain conflicting information. The phrases will be played at the **SAME TIME**.

Each of those phrases are similar to:

“Ready *CHARLIE* go to *BLUE EIGHT* now”

↓
Call signal

↓
Color

↓
Digit

Each sentence contains a **CALL SIGNAL** (e.g. "Charlie") and information about a **COLOR** (e.g. "Blue") and a **digit** (e.g. "8").

Each sentence has its own call signal, its own color and its own digit. They are *never* the same.

Press <Enter> to go back Press <Spacebar> to continue

Figure 3-1. Dichotic listening task on-screen instructions. Millisecond Inquisit 4 Lab (Draine, 2015).

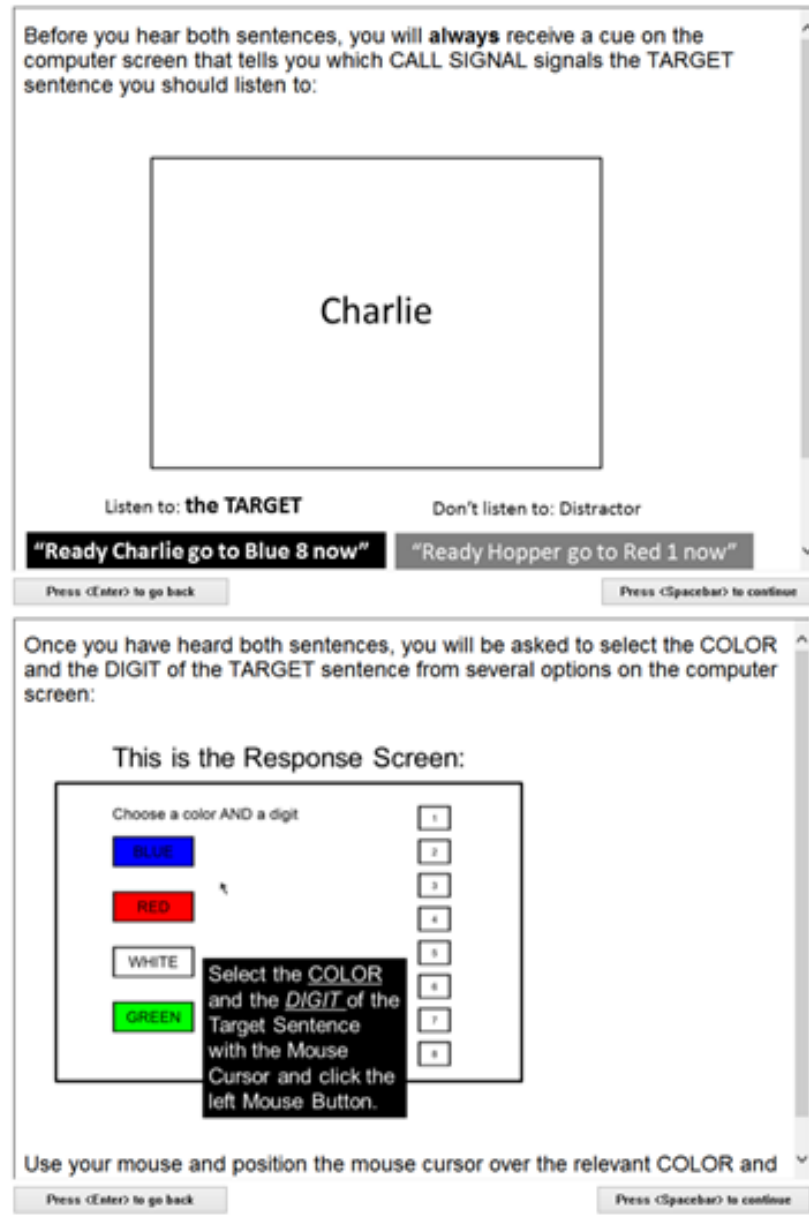


Figure 3-2. Dichotic listening task on-screen instructions. Millisecond Inquisit 4 Lab (Draine, 2015).

The listener first received an onscreen cue to inform them of the call signal of the target speaker they should focus on. The test scenario then commenced. Once the speakers had finished, the listener was asked to select the colour and digit spoken by the designated target speaker.

Participants first completed a block of 32 practice sequences, where onscreen feedback was provided, indicating whether their colour and number selections were correct. As this block served as a practice opportunity for participants, the results were not recorded. After this familiarisation and practice phase, participants commenced with the 64 sequence, recorded blocks.

3.2.5 *Working Memory Assessment*

Working memory was assessed using a digit span task administered with Millisecond Inquisit 4 software web (Draine, 2015). Digit span was the maximum number of digits that were correctly recalled after listening to a series of digits (Baddeley, 1986). Digit span was assessed for forward and backward recall order. Participants were instructed to type the digits presented and remembered, in a box onscreen. Forward recall was assessed first, with a short practice provided to familiarise participants with the procedure before the recorded assessment began. The practice item for forward recall was a three digit sequence, which if the participant responded correctly, the actual assessment would subsequently begin. The practice item for reverse recall was a two digit sequence. If the participant entered the sequence in forwards order, they would be reminded to type in reverse order. The onscreen instructions are shown in Figure 3-3.

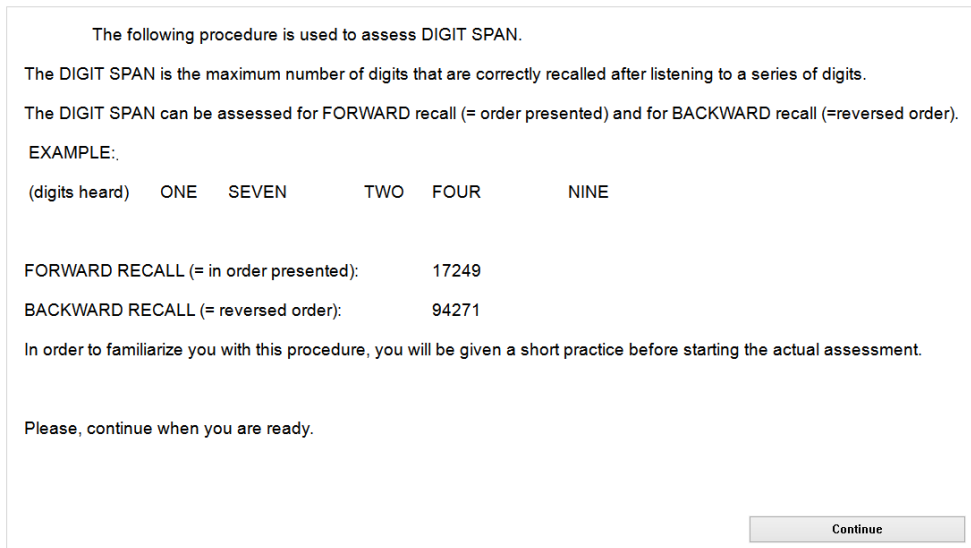


Figure 3-3. Digit Span task on-screen instructions. Millisecond Inquisit 4 Lab (Draine, 2015).

3.3 *Equipment*

3.3.1 *Audiometric and Tinnitus Assessment*

Otoscopy was performed using a Welch Allyn™ otoscope. Audiometric and tinnitus assessments were performed via a Grason-Stadler GSI 61 Clinical Audiometer. Transducers used for air conduction thresholds were either ER-3A insert earphones or TDH-39P supra-aural headphones, and Sennheiser HDA 200 for high frequency audiometry. Bone conduction thresholds were obtained with a Radioear Type B-71 bone vibrator, placed on the mastoid bone of the test ear. Tympanometry was performed using the Clarinet Inventis Middle Ear Analyzer. Calibration of instruments was in compliance with the NZAS guidelines and met either ANSI S3.7-1995 (R2003) or IEC 60645-1 (2001) standards. Audiometric and tinnitus characterization data were collected in an approved sound-treated booth (AS ISO 8253.1, 2009).

3.3.2 *Selective Attention and Working Memory*

Auditory selective attention and working memory assessments were administered using Millisecond Inquisit 4 Web software (Draine, 2015) on a HP Envy laptop computer using Sennheiser HD 280 pro 64 Ω headphones, with the appropriate frequency bandwidth. The auditory selective attention assessment is as described in Humes et al. (2006), as detailed above.

3.4 *Data and Statistical Analysis*

Participant data was recorded in Microsoft Excel 2010 and analysed using IBM Statistical Package for the Social Sciences (SPSS) Version 23 software. A priori and post hoc power analyses were computed using G*Power software (Faul, Erdfelder, Lang, & Buchner, 2007). Descriptive statistics were used to characterise the ASA, working memory, and emotional state of the two groups, obtaining the mean and standard deviation for each variable.

3.4.1 *Between-groups Comparisons*

As the data distributions were non-parametric in nature and contained outliers, the Mann-Whitney U test was used to determine whether significant differences existed between the tinnitus and control groups. After these initial analyses were performed, participants with outlying scores for the ASA measures, digit span measures, and DASS scale, identified with box plot diagrams were removed from the data set. The rationale was to increase the power to detect differences by removing the effects of outliers contributing to random error. As this resulted in uneven numbers, further participants were removed on the basis of age and hearing loss in attempt to form well-matched groups. Partial correlation analyses accounting for age, sex, and hearing loss were then performed.

3.4.2 *Tinnitus Group Interactions*

Descriptive statistics were used to characterise the questionnaire data in the tinnitus group. Bivariate correlation analyses were computed to measure the amount of variability in one variable that was shared by another.

3.5 *Ethical Considerations*

Ethical approval was granted by the University of Canterbury Human Ethics Committee on 12/10/2015 (Reference # 2015/12/LR) (Appendix 3). This study did not require approval from the New Zealand Health and Disability Ethics Committee. All procedures conducted during this study were in accordance with the details of the ethics application. Informed consent forms (Appendix 4) were signed by all participants.

4 Results

4.1 *Participants*

Twenty-eight tinnitus participants entered the study and 20 completed the study. Two were unavailable for the second phase of testing (one participant moved, contact could not be made with the other) and were subsequently dropped from the study. One participant elected to withdraw from the study after completion for reasons unknown. One participant could not operate the computer-based attention and memory tasks. Two were excluded due to hearing loss thresholds exceeding the study criteria. A further two participants were excluded for medication use that could likely affect cognitive task performance.

Twenty-three control participants entered the study and 22 completed the study. One participant was excluded during the session due to medication use suspected to affect cognitive function and potentially, task performance.

4.1.1 *Participant Demographics*

Twenty participants in the tinnitus group completed the study (14 females, 6 males). The age of the tinnitus participant group ranged from 21 to 70 years, with a mean age of 56 (SD = 12) years. Twenty-two control participants completed the study (12 females, 10 males). The age range of the participants was 22 to 75 years, with mean age of 51 (SD = 17). Age did not differ significantly between the groups, $U = 252.5$, $z = 0.820$, $p = 0.412$, $r = 0.013$. Sex did not differ significantly between the groups, $U = 186.0$, $z = -1.018$, $p = 0.309$, $r = -0.157$.

4.2 Audiometry

Mean hearing thresholds for the tinnitus and control groups are shown in Figure 4-1. Hearing thresholds were significantly different between the groups. This meant that for both ears, the tinnitus group had significantly worse hearing thresholds compared to the control group. For the right ear the frequency-specific, significant differences were as follows: 1000 Hz ($p = 0.02$), 2000 Hz ($p = 0.047$), 3000 Hz ($p = 0.012$), 4000 Hz ($p = 0.026$) and 6000 Hz ($p = 0.003$). For the left ear the frequency-specific, significant differences were as follows: 250 Hz ($p = 0.021$), 500 Hz ($p = 0.006$), 1000 Hz ($p = 0.032$), 2000 Hz ($p = 0.003$), 3000 Hz ($p = 0.012$), 4000 Hz ($p = 0.015$) and 6000 Hz ($p = 0.034$).

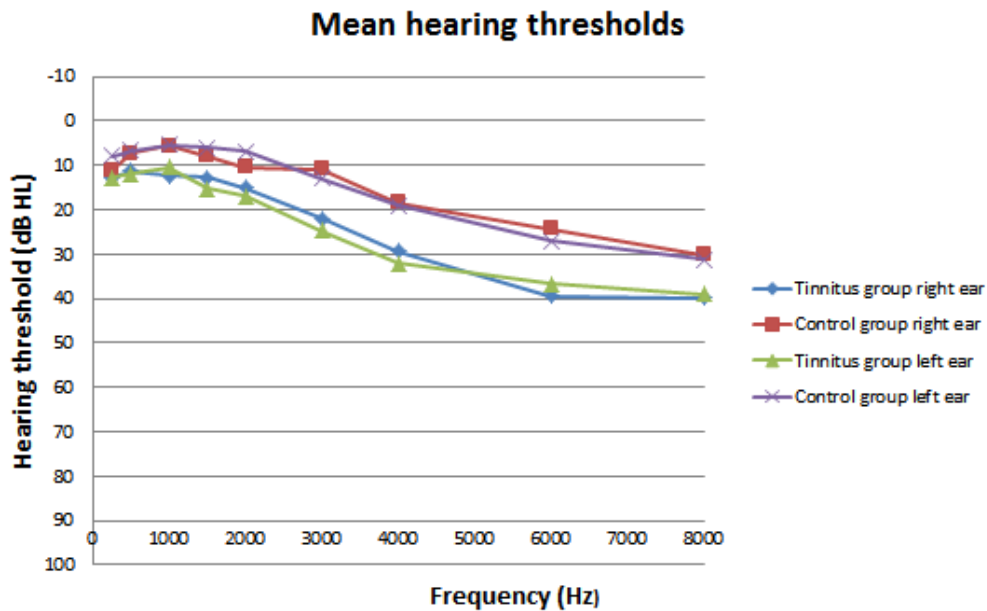


Figure 4-1. Mean hearing thresholds for the tinnitus ($n = 20$) and control ($n = 22$) groups.

Individual hearing thresholds for the tinnitus and control groups are shown in Figures 4-2 and 4-3 respectively.

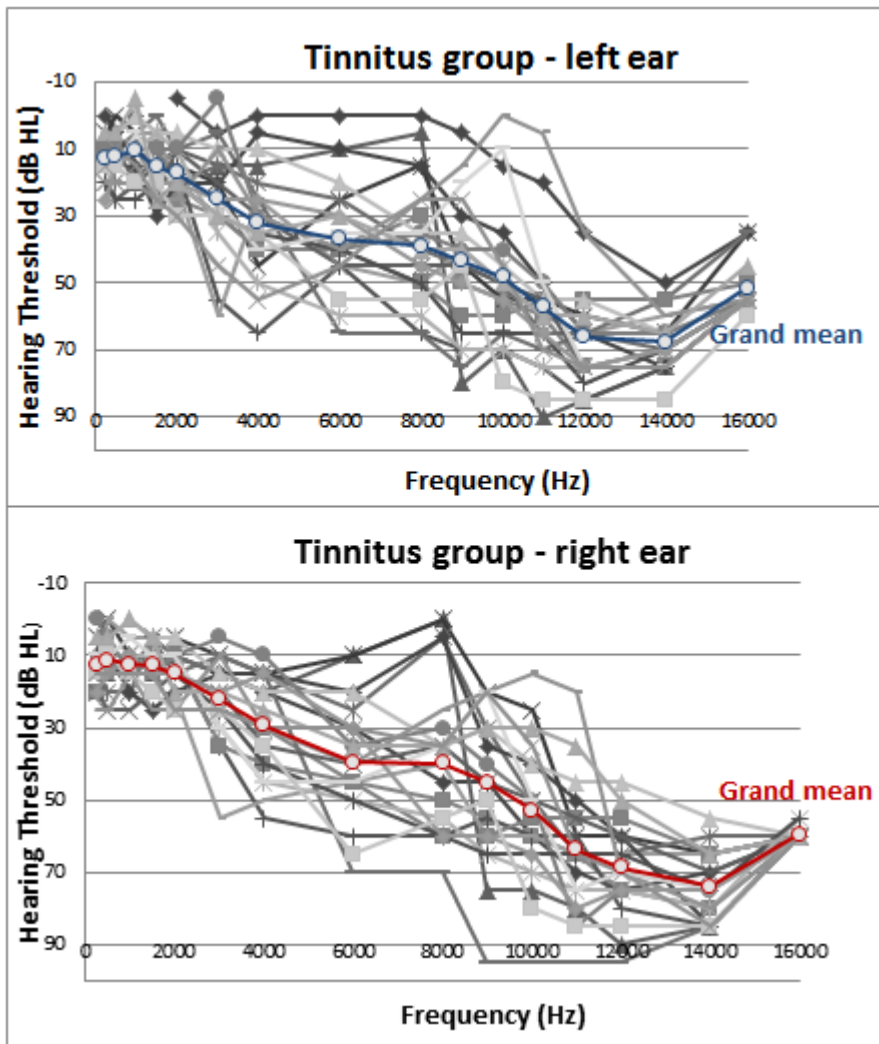


Figure 4-2. Mean (coloured lines) and individual (grey lines) hearing thresholds for the tinnitus group (n = 20) in the left ear (top graph) and right ear (bottom graph).

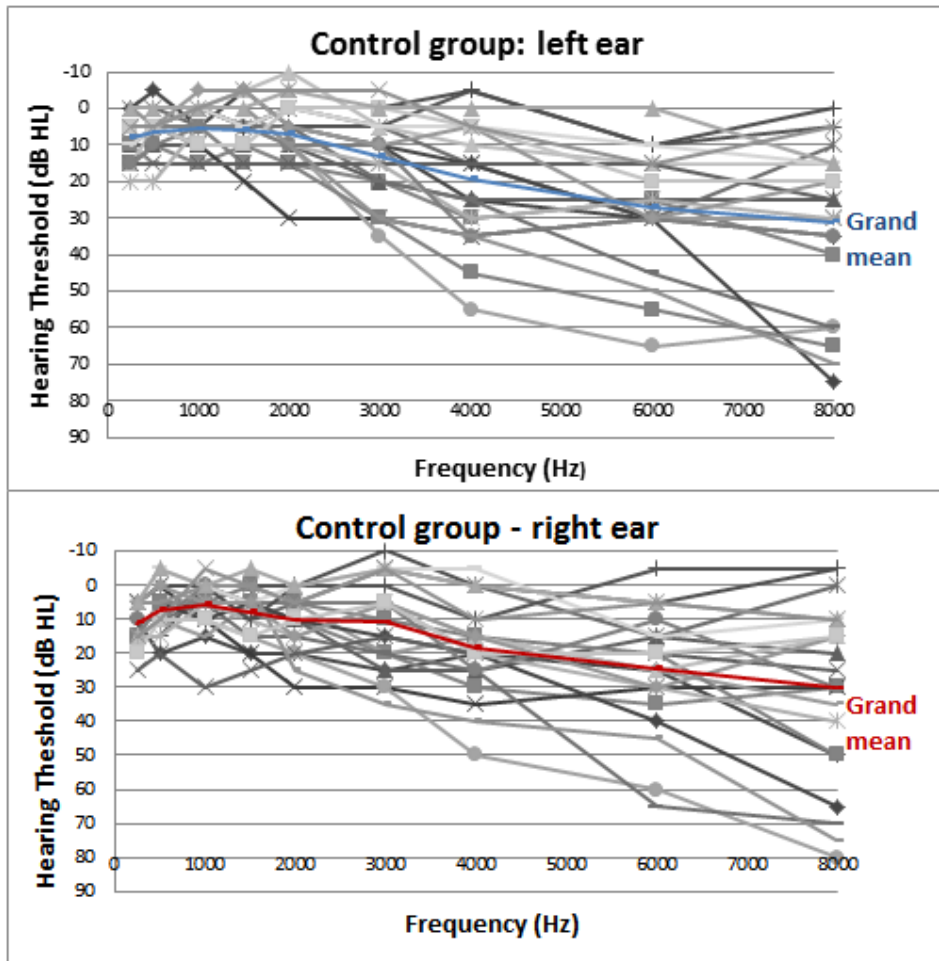


Figure 4-3. Mean (coloured lines) and individual (grey lines) hearing thresholds for the control group (n = 22) in the left ear (top graph) and right ear (bottom graph).

4.3 Tinnitus Characteristics

4.3.1 Tinnitus Onset and Duration

Regarding the initial onset of tinnitus, participants were asked via the TSCHQ (Langguth et al., 2007), “Initial onset: When did you first experience your tinnitus?” The reported durations are shown in Table 4-1 below.

Table 4-1. Percentage (%) of participants (n = 20) in each tinnitus duration category.

| <i>Tinnitus duration</i> | <i>Percentage of participants (%)</i> |
|-----------------------------------|---------------------------------------|
| ≤ 1 year | 0 |
| > 1 year, to ≤ 2 years | 10 |
| > 2 years, to ≤ 5 years | 20 |
| > 5 years, to ≤ 10 years | 20 |
| > 10 years, to ≤ 20 years | 25 |
| > 20 years | 25 |
| Participant Unsure, other answers | 0 |

The onset of tinnitus was reported to be gradual for 60% of participants (n = 12), and abrupt for 35% (n = 7). One participant was not sure/could not remember, accounting for 5% of the sample. Other than having no participants with tinnitus duration of one year or less, the distribution of tinnitus duration in the current study is similar to that of the Oregon Health Sciences University sample (Meikle, Johnson, Griest, Press, & Charnell, 1995).

As per the TSCHQ (Langguth et al., 2007), participants were also queried about any events related to the initial onset of their tinnitus. Most participants (55%) were unsure or did not know the cause of their tinnitus. Nine participants (45%) attributed the onset of tinnitus to a specific cause or circumstance. The highest percentages of known, suspected causes were change in hearing (15%) and noise exposure (15%). One participant attributed both stress and a loud blast of sound as the instigators. These suspected tinnitus aetiologies are listed below in Table 4-2.

Table 4-2. Percentage (%) of tinnitus participants (n = 20) with each main suspected tinnitus aetiology.

| <i>Suspected cause</i> | <i>Percentage of participants (%)</i> |
|----------------------------------|---------------------------------------|
| Change in hearing | 15% |
| Noise | 15% |
| Stress | 5% |
| Neck being in unnatural position | 5% |
| Head trauma | 5% |
| Aspirin use | 5% |
| Unsure/unknown | 55% |

4.3.2 *Tinnitus Localization*

All participants perceived tinnitus bilaterally or centrally. For the cases of bilateral tinnitus, six participants reported their tinnitus was worse for the left ear/side, and three participants reported it was worse for the right.

4.3.3 *Tinnitus Pitch*

Tinnitus pitch-matching was performed with tinnitus participants to frequencies from 250 Hz to 16 kHz for the left and right ears separately. 8 kHz was chosen by 30% of participants as the closest tonal match to their tinnitus in the right ear, and 25% for the left ear. The percentage (%) tinnitus pitch matches across the different frequency ranges are shown in Figure 4-4.

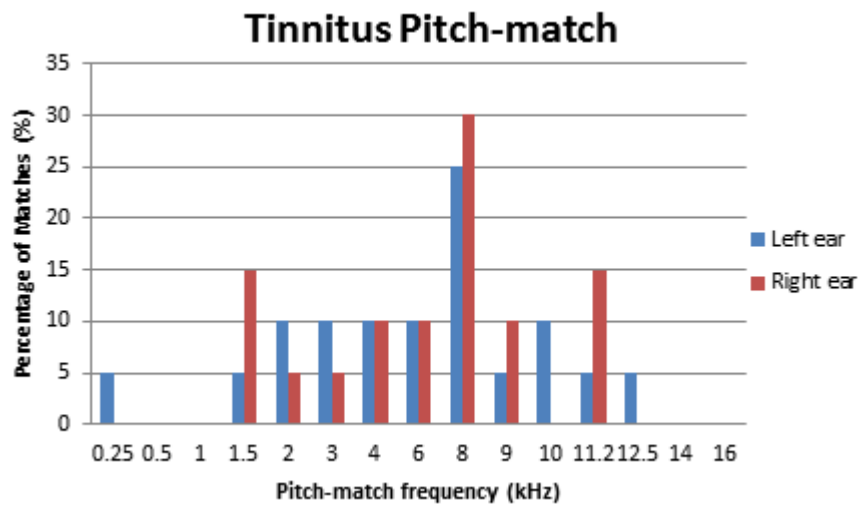


Figure 4-4. Tinnitus pitch-matches for the left (blue) and right (red) ears by percentage (%) (n = 20).

4.3.4 Tinnitus Loudness-Matching

Sixty-five percent and 80% of participants matched their tinnitus to a loudness level of 9 dB SL or less in the left and right ears respectively. Tinnitus loudness-matches are shown in Figure 4-5 below.

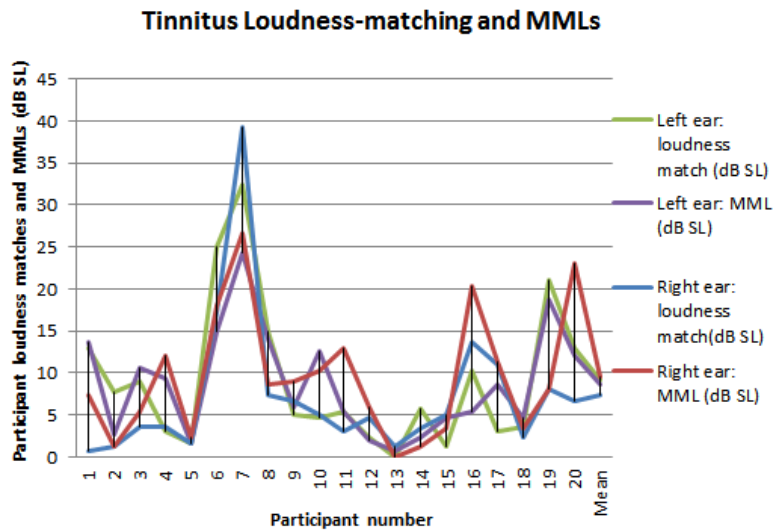


Figure 4-5. Individual and mean tinnitus loudness-matches (dB SL) and minimum masking levels (MML) (dB SL) (n = 20).

4.3.5 Tinnitus Minimum Masking Level

The mean (\pm SD) minimum masking level for partial masking was 9.53 ± 7.53 dB SL for participant's right ear, and 8.72 ± 6.35 dB SL for participant's the ear. Minimum masking levels for each participant are shown with the tLm in Figure 4-5 above.

4.4 Tinnitus Functional Index

In the present study, only participants who presented with a score of 25 or more out of a possible 250 for the TFI were included as scores below 25 indicate mild tinnitus with little need for intervention (Meikle et al., 2012). The mean (\pm SD) overall score of those included in the study was 101.4 ± 44.6 . TFI scores ranging from 25 – 50 indicate subjective tinnitus that is causing a greater, negative effect on functional life and potentially warranting the need for intervention. Scores greater than 50 suggest qualification for intervention (Henry et al., 2014). In the present

study, four participants had scores between 25 and 50, seven scored between 50 and 100, and nine scored over 100—indicating tinnitus was a very big problem, affecting functional life quality.

The TFI sub-scale and overall scores are displayed in Figure 4-6 below.

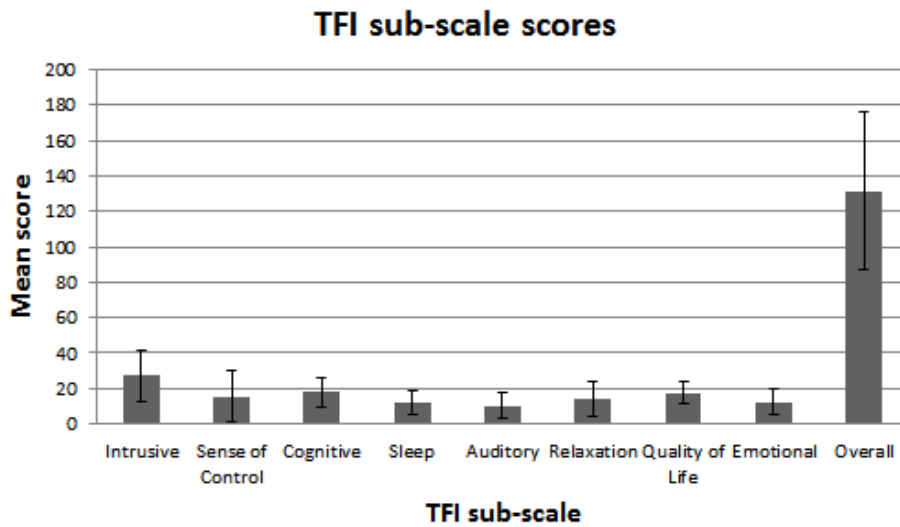


Figure 4-6. Tinnitus Functional Index mean overall score and sub-scale scores (n = 20). The error bars represent standard error.

4.5 Tinnitus Handicap Inventory

A majority of participants (50%) experienced Grade 2, mild tinnitus, according to the THI (Newman et al., 1996). The percentage of participants experiencing each THI grade of tinnitus is depicted in Figure 4-3. The mean (\pm SD) score was 23 ± 14 out of a possible 100.

Table 4-3. Number and percentage (%) of participants (n = 20) in each Tinnitus Handicap Inventory grade.

| <i>Tinnitus Handicap Inventory grade</i> | <i>Number of participants</i> | <i>Percentage of participants (%)</i> |
|---|-------------------------------|---------------------------------------|
| Grade 1 : Slight or no handicap (0-16) | 7 | 35 |
| Grade 2: Mild handicap (18-36) | 10 | 50 |
| Grade 3: Moderate handicap (38-56) | 3 | 15 |
| Grade 4: Severe handicap (58 – 76) | 0 | 0 |
| Grade 5: Catastrophic handicap (78 – 100) | 0 | 0 |

4.6 Tinnitus Severity Numeric Scale

The mean scores for each component of the TSNS are shown in Table 4-4 below. Each component had a maximum score of 10.

Table 4-4. Mean (SD) scores for each Tinnitus Severity Numeric Scale component (n = 20).

| <i>Tinnitus Severity Numeric Scale component</i> | <i>Mean score (SD)</i> |
|--|------------------------|
| Problem | 1.5 (0.8) |
| Loudness | 5.25 (0.8) |
| Uncomfortable | 4.9 (1.7) |
| Annoying | 5.0 (2.2) |
| Ignore | 5.2 (2.3) |
| Unpleasant | 4.95 (2.3) |

4.7 Depression, Anxiety, Stress Scale

The mean scores for each scale of the DASS questionnaire and the overall score for the tinnitus (n = 20) and control (n = 22) groups are shown in Table 4-5 below. The distributions of scores are shown in Figure 4-7.

Table 4-5. Depression, Anxiety and Stress Scale (DASS) mean (SD) sub-scale and overall scores (tinnitus, n = 20; control, n = 22).

| <i>DASS Scale</i> | <i>Tinnitus group mean score (SD)</i> | <i>Control group mean score (SD)</i> |
|-------------------|---------------------------------------|--------------------------------------|
| Depression | 2.05 (1.99) | 2.18 (1.68) |
| Anxiety | 1.75 (1.62) | 3.41 (3.84) |
| Stress | 5.50 (4.29) | 7.36 (5.07) |
| Total | 9.30 (6.27) | 12.95 (8.74) |

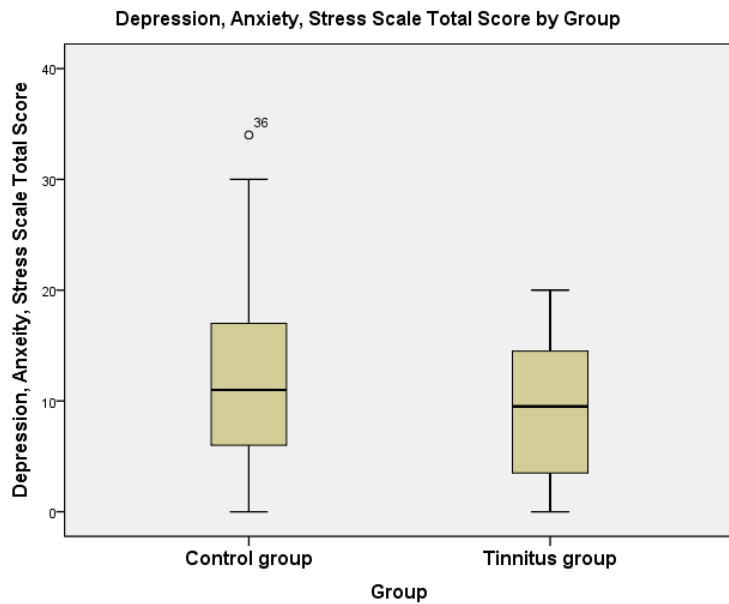


Figure 4-7. Distribution of Depression, Anxiety and Stress Scale total scores for the tinnitus (n = 20) and control (n = 22) groups. The middle line of each box represents the median value, while the outer lines represent the lower and upper quartile values. The extending lines represent the upper and lower extreme values for that variable. The open circle indicates an outlier.

4.8 Mini Mental State Exam

All participants had recommended scores for the MMSE screening tool, indicative of no marked cognitive involvement, and sufficient English language capacity. Scores were 28 or above out of a possible 30 points for all participants. Mean (\pm SD) scores were 29.4 ± 0.75 for the tinnitus group and 29.3 ± 0.78 for the control group. The distribution of scores is shown in Figure 4-8 below. Scores of 24 and above are considered as normal, with no indication of obvious cognitive impairment likely (Folstein & Folstein, 1975).

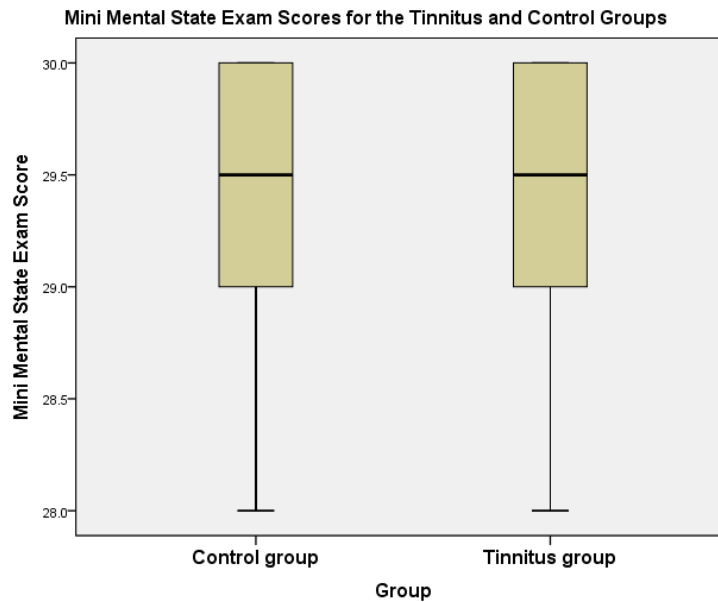


Figure 4-8. Distribution of Mini Mental State Exam scores for the tinnitus ($n = 20$) and control ($n = 22$) groups. The middle line of each box represents the median value, while the outer lines represent the lower and upper quartile values. The extending lines represent the upper and lower extreme values for that variable.

4.9 Between-groups Comparisons

4.9.1 Auditory Selective Attention

The mean (\pm SD) overall percentage correct was 82.4% (\pm 13.5%) for the tinnitus group, and 80.6% (\pm 14.6%) for the control group. The ASA % correct, mean dichotic digit reaction times, and overall dichotic reaction times for each group are displayed in Table 4-6.

Table 4-6. Selective attention task overall percentage (%) correct and mean reaction times for the tinnitus (n = 20) and the control (n = 22) groups.

| <i>Variable</i> | <i>Tinnitus group mean (\pmSD)</i> | <i>Control group mean (\pmSD)</i> |
|--|---|--|
| Overall percentage correct (%) | 82.4 (\pm 13.5) | 80.6 (\pm 14.6) |
| Mean reaction time dichotic digit (ms) | 1265 (\pm 496) | 1254 (\pm 443) |
| Mean reaction time overall (ms) | 2260 (\pm 511) | 2320 (\pm 766) |

Boxplot graphs showing the distribution of scores for ASA % correct and mean overall and digit reaction times are displayed in Figure 4-9 and 4-10 below.

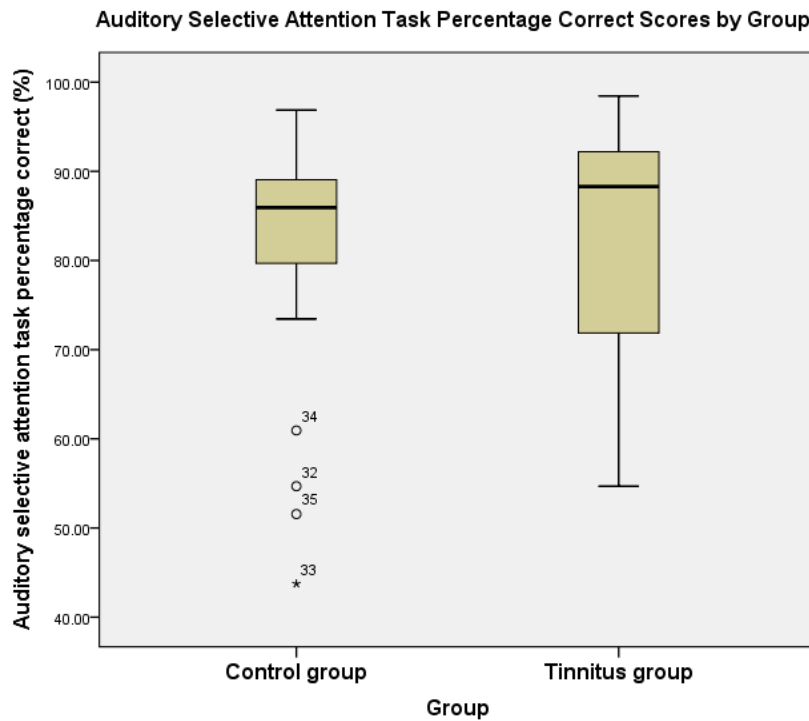


Figure 4-9. Boxplot graph of auditory selective attention percentage correct scores for the tinnitus (n = 20) and control (n = 22) groups. The middle line of each box represents the median value, while the outer lines represent the lower and upper quartile values. The extending lines represent the upper and lower extreme values for that variable. The open circles indicate outliers, and the asterisk indicates an extreme outlier.

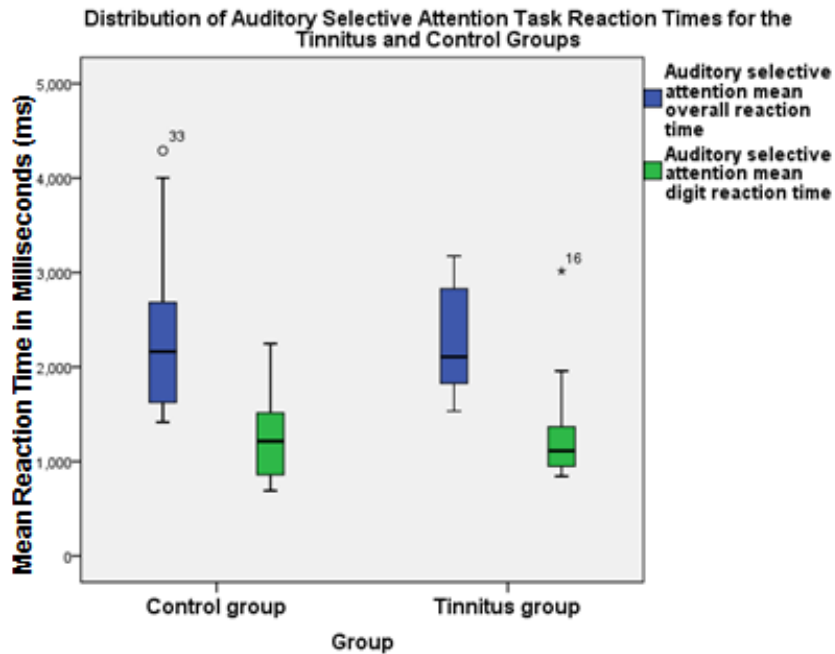


Figure 4-10. Boxplot graph of auditory selective attention mean overall and digit reaction times for the tinnitus (n = 20) and control (n = 22) groups. The middle line of each box represents the median value, while the outer lines represent the lower and upper quartile values. The extending lines represent the upper and lower extreme values for that variable. The open circle indicates an outlier, and the asterisk indicates an extreme outlier.

There were no significant differences in overall percentage correct, mean digit reaction time, or mean overall reaction time between the tinnitus and control groups. The Mann-Whitney U test for between-groups analyses for non-parametric data are shown in Table 4-7 below.

Table 4-7. Mann-Whitney U test results for between-groups analysis of auditory selective attention measures.

| <i>Variable</i> | <i>Test statistic (U)</i> | <i>Significance (2-tailed)</i> | <i>Z-score</i> | <i>Effect size (R)</i> |
|--|---------------------------|--------------------------------|----------------|------------------------|
| Overall percentage correct (%) | 252.5 | .412 | .821 | .127 |
| Mean reaction time dichotic digit (ms) | 220.0 | 1.000 | .000 | .000 |
| Mean reaction time overall (ms) | 227.0 | .860 | .176 | .027 |

4.9.2 Working Memory

The mean (\pm SD) for each digit span measure for the tinnitus and control groups are shown in Table 4-8 below.

Table 4-8. Mean (\pm SD) and range of scores for the digit span measures for the tinnitus (n = 20) and the control (n = 22) groups.

| | <i>Tinnitus group mean (\pmSD)</i> | <i>Control group mean (\pmSD)</i> |
|----------------------------|---|--|
| Forwards recall two-error | 6.45 (\pm 1.54) | 6.91 (\pm 1.27) |
| Forwards recall maximum | 7.05 (\pm 0.89) | 7.09 (\pm 1.27) |
| Backwards recall two-error | 5.55 (\pm 1.15) | 5.23 (\pm 1.48) |
| Backwards recall maximum | 6.00 (\pm 1.34) | 6.14 (\pm 1.28) |

The mean scores for each group are also displayed in Figure 4-11 for comparison.

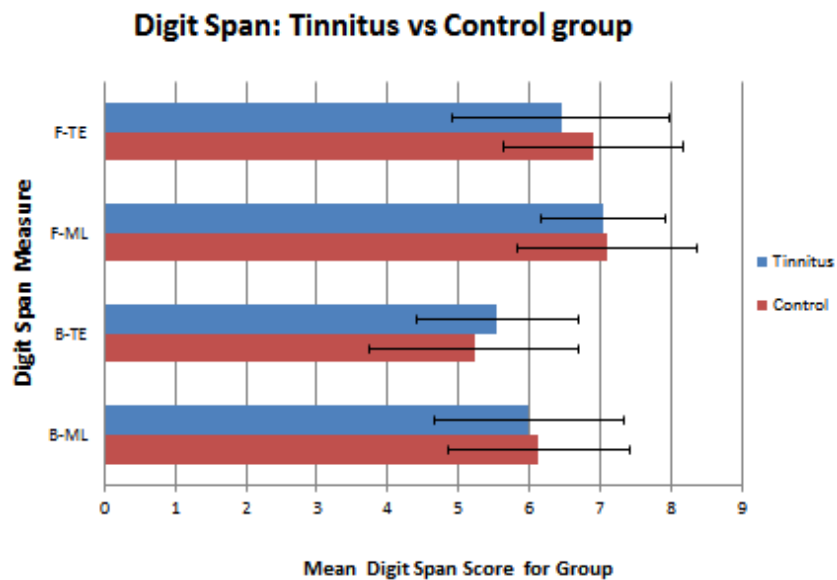


Figure 4-11. Comparison of digit span measures for tinnitus and control group participants. The blue bars represent the mean scores for the tinnitus group (n = 20), and the red bars represent mean scores of the control group (n = 22). F-TE represents the forward recall two-error score, F-ML represents forward recall maximum length, B-TE represents backward recall two-error, and B-ML represents backward recall maximum length. The error bars represent standard error.

The boxplot distribution of digit span scores for both groups are displayed in Figure 4-12.

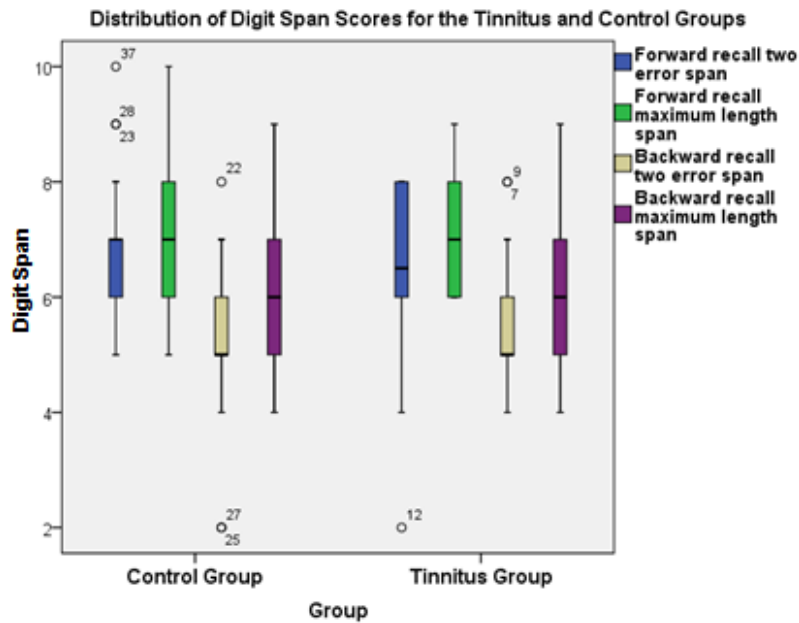


Figure 4-12. Boxplot graph of digit span scores for the tinnitus (n = 20) and control (n = 22) groups. The middle line of each box represents the median value, while the outer lines represent the lower and upper quartile values. The extending lines represent the upper and lower extreme values for that variable. The open circles indicate outliers.

There were no significant differences between the tinnitus and control groups for any digit span measures. The Mann-Whitney U test for between-groups analyses for non-parametric data are shown in Table 4-9 below.

Table 4-9. Mann-Whitney U test results for between-groups analysis of digit span measures.

| Variable | Test statistic (U) | Significance | Z-score | Effect size (R) |
|---------------------------|--------------------|--------------|---------|-----------------|
| Forward recall two-error | 199.5 | .593 | -.535 | -.0825 |
| Forward recall maximum | 220.0 | 1.000 | .000 | .000 |
| Backward recall two-error | 238.0 | .637 | .472 | .0728 |
| Backward recall maximum | 207.0 | .735 | -.338 | -.052 |

4.9.3 Depression, Anxiety, Stress Scale

There were no significant differences between the tinnitus and control groups for the overall DASS score, or sub-scale scores. The Mann-Whitney U test results are shown in Table 4-10 below.

Table 4-10. Mann-Whitney U test results for between-groups analysis of the Depression, Anxiety and Stress Scale's overall and sub-scale scores.

| <i>Variable</i> | <i>Test statistic (U)</i> | <i>Significance</i> | <i>Z-score</i> | <i>Effect size (R)</i> |
|----------------------------|---------------------------|---------------------|----------------|------------------------|
| Depression sub-scale score | 197.0 | 0.554 | -0.592 | -0.0913 |
| Anxiety sub-scale score | 173.5 | 0.232 | -1.195 | -0.184 |
| Stress sub-scale score | 171.5 | 0.220 | -1.226 | -0.189 |
| DASS total score | 173.0 | 0.236 | -1.186 | -0.183 |

4.9.4 Mini Mental State Exam

MMSE scores did not differ significantly between the groups, $U = 223.5$, $z = 0.097$, $p = 0.923$, $r = 0.015$.

4.9.5 Partial Correlations for Formed Groups

Exclusion of participants who had outlying scores for the ASA measures, digit span measures, and DASS scale, as identified with box plot diagrams, resulted in a total of 14 tinnitus participants and 11 control participants. To form two equal groups, three tinnitus participants were removed, with selection based on age and hearing loss, to form matched groups. The final groups were 11 tinnitus and 11 control participants, with mean (\pm SD) ages of 52 ± 12 , and 48 ± 17 years respectively. Mann-Whitney U analyses revealed that age was not significantly different between the groups ($p > 0.05$). Sex distribution was also similar, with 3 males and 8 females in the tinnitus group, and 2 males and 9 females in the control group. Hearing loss could not be

matched across all audiometric frequencies in the left and right ears, with significant differences remaining at 500 Hz ($p = 0.047$) and 2000 Hz ($p = 0.034$) in the left ear indicated by the Mann-Whitney U test. Partial correlations were performed on the matched groups ($n = 11$ in each group), accounting for age, sex, and hearing loss. No significant relationships were found between tinnitus presence and auditory selective attention and digit span measures (Table 4-11).

Table 4-11. Correlation analyses between tinnitus presence ($n = 22$) and auditory selective attention and working memory measures, accounting for age, sex and hearing loss.

| <i>Variable</i> | <i>Tinnitus</i> | | |
|------------------------------|--|-------------------------|------|
| | Correlation | Significance (2-tailed) | |
| Auditory Selective Attention | Overall percentage correct (%) | -.211 | .789 |
| | Mean reaction time dichotic digit (ms) | .138 | .862 |
| | Mean reaction time overall (ms) | .222 | .778 |
| Working Memory | Forwards recall two error | -.492 | .508 |
| | Forwards recall maximum | -.090 | .910 |
| | Backwards recall two error | -.236 | .764 |
| | Backwards recall maximum | -.505 | .495 |

4.10 Tinnitus Group Interactions

4.10.1 Correlations between Task Performance and Tinnitus Severity

Numeric Scale Factors

Spearman's correlation analyses revealed no significant relationship between any of the auditory selective attention measures and the Tinnitus Severity Numeric Scale factors ($p > 0.05$) (Table 4-12).

Table 4-12. Bivariate correlations between auditory selective attention (ASA) measures and the Tinnitus Severity Numeric Scale (TSNS) sub-scales: Problem, loud, uncomfortable, annoying, ignore, and unpleasant for the tinnitus group, $n = 20$ for all analyses. RT denotes reaction time.

| | | TSNS- 1 ¹ | TSNS- 2 | TSNS- 3 | TSNS- 4 | TSNS- 5 | TSNS- 6 |
|-----------------------------|-------------------------|-------------------------|------------|------------|------------|------------|------------|
| ASA % correct | Correlation coefficient | .034 | -.233 | .069 | .149 | .118 | -.083 |
| | Sig. (2-tailed) | .887 | .323 | .774 | .530 | .619 | .728 |
| Mean RT dichotic digit (ms) | Correlation coefficient | .088 | -.109 | .104 | .143 | -.014 | -.150 |
| | Sig. (2-tailed) | .714 | .647 | .662 | .548 | .954 | .529 |
| Mean RT overall (ms) | Correlation coefficient | .183 | -.108 | .120 | .088 | .011 | -.138 |
| | Sig. (2-tailed) | .439 | .652 | .616 | .713 | .964 | .561 |

¹(1) How much of a problem is your tinnitus at present? (2) How STRONG or LOUD is tinnitus at present? (3) How UNCOMFORTABLE is your tinnitus at present, if everything around you is quiet? (4) How ANNOYING is your tinnitus at present? (5) How easy is it for you to IGNORE your tinnitus at present? (6) How UNPLEASANT is your tinnitus at present?

There were significant negative relationships between the forward recall maximum length span and the TSNS scale response to 'How uncomfortable is your tinnitus at present if everything around you is quiet?', $r_s = -.614$, $p = 0.004$, and 'How annoying is your tinnitus at present?', $r_s =$

-.566, $p = 0.009$. All other correlations between the digit span measures and the TSNS factors were not significant ($p > 0.05$) (Table 4-13).

Table 4-13. Bivariate correlations between the Tinnitus Severity Numeric Scale (TSNS) sub-scales: Problem, loud, uncomfortable, annoying, ignore, unpleasant, and the digit span measures in the tinnitus group, $n = 20$ for all analyses. ** $p < 0.01$

| | | <i>TSNS-1</i> ¹ | <i>TSNS-2</i> | <i>TSNS-3</i> | <i>TSNS-4</i> | <i>TSNS-5</i> | <i>TSNS-6</i> |
|------|-------------------------|----------------------------|---------------|---------------|---------------|---------------|---------------|
| F-TE | Correlation coefficient | -.183 | -.235 | -.386 | -.330 | -.176 | -.127 |
| | Sig. (2-tailed) | .441 | .319 | .093 | .156 | .458 | .593 |
| F-ML | Correlation coefficient | -.260 | -.386 | -.614 | -.566 | -.432 | -.306 |
| | Sig. (2-tailed) | .268 | .093 | .004** | .009** | .057 | .189 |
| B-TE | Correlation coefficient | -.262 | -.374 | -.312 | -.264 | -.176 | -.253 |
| | Sig. (2-tailed) | .264 | .104 | .180 | .260 | .459 | .281 |
| B-ML | Correlation coefficient | -.352 | -.322 | -.228 | -.252 | -.061 | -.243 |
| | Sig. (2-tailed) | .128 | .167 | .334 | .283 | .798 | .303 |

¹(1) How much of a problem is your tinnitus at present? (2) How STRONG or LOUD is tinnitus at present? (3) How UNCOMFORTABLE is your tinnitus at present, if everything around you is quiet? (4) How ANNOYING is your tinnitus at present? (5) How easy is it for you to IGNORE your tinnitus at present? (6) How UNPLEASANT is your tinnitus at present?

4.10.2 Correlations between Task Performance and Tinnitus Functional Index and Tinnitus Handicap Inventory Scores

There were no significant relationships between the ASA measures and the TFI or THI overall scores (Table 4-14).

Table 4-14. Bivariate correlations between auditory selective attention (ASA) measures and the Tinnitus Functional Index and Tinnitus Handicap Inventory overall scores for the tinnitus group, n = 20 for all analyses.

| | | <i>Tinnitus Functional Index overall score</i> | <i>Tinnitus Handicap Inventory overall score</i> |
|-----------------------------------|----------------------------|--|--|
| ASA % correct | Correlation coefficient | .136 | .304 |
| | Sig. (2- tailed) | .569 | .192 |
| Mean RT dichotic digit (ms) | Correlation coefficient | .057 | .234 |
| | Sig. (2- tailed) | .811 | .320 |
| Mean RT overall (ms) | Correlation coefficient | .081 | .241 |
| | Sig. (2- tailed) | .733 | .306 |

When considering the digit span assessments, there was a significant negative relationship between the forward recall maximum length span and the overall TFI score, $r_s = -.536$, $p = 0.015$, but not with the overall THI score. All other correlations between the ASA measures and the TFI and THI scores were not significant ($p > 0.05$) (Table 4-15).

Table 4-15. Bivariate correlations between digit span measures and Tinnitus Functional Index and Tinnitus Handicap Inventory overall scores in the tinnitus group, n = 20 for all analyses. F-TE represents the forward recall two-error score, F-ML represents forward recall maximum length, B-TE represents backward recall two-error, and B-ML represents backward recall maximum length. *p < 0.05

| | | <i>Tinnitus Functional Index overall score</i> | <i>Tinnitus Handicap Inventory overall score</i> |
|------|-------------------------|--|--|
| F-TE | Correlation coefficient | -.352 | -.107 |
| | Sig. (2-tailed) | .128 | .655 |
| F-ML | Correlation coefficient | -.536 | -.416 |
| | Sig. (2-tailed) | .015* | .068 |
| B-TE | Correlation coefficient | -.417 | -.239 |
| | Sig. (2-tailed) | .068 | .310 |
| B-ML | Correlation coefficient | -.213 | -.122 |
| | Sig. (2-tailed) | .367 | .609 |

4.10.3 *Correlations between Task Performance and Depression, Anxiety, Stress Scale Scores*

There were no significant relationships between the DASS scale scores and the ASA measures ($p > 0.05$) (Table 4-16), or the digit span measures ($p > 0.05$) (Table 4-17).

Table-16. Bivariate correlations between auditory selective attention (ASA) measures and Depression, Anxiety, Stress Scale scores (DASS) for the tinnitus group, n = 20 for all analyses. RT denotes reaction time.

| | | <i>Depression Sub-scale Score</i> | <i>Anxiety Sub-scale Score</i> | <i>Stress Sub- scale Score</i> | <i>DASS total score</i> |
|-----------------------------------|----------------------------|---|--|------------------------------------|-----------------------------|
| ASA % correct | Correlation coefficient | -.062 | -.184 | -.086 | -.152 |
| | Sig. (2-tailed) | .697 | .245 | .590 | .336 |
| Mean RT dichotic digit (ms) | Correlation coefficient | .027 | .123 | -.071 | .004 |
| | Sig. (2-tailed) | .868 | .436 | .657 | .982 |
| Mean RT overall (ms) | Correlation coefficient | .098 | .186 | .003 | .088 |
| | Sig. (2-tailed) | .538 | .238 | .983 | .578 |

Table 4-17. Bivariate correlations between Digit Span measures and Depression, Anxiety, Stress Scale scores in the tinnitus group, n = 20 for all analyses. F-TE represents the forward recall two-error score, F-ML represents forward recall maximum length, B-TE represents backward recall two-error, and B-ML represents backward recall maximum length. *p < 0.05

| | | <i>Depression Sub-scale Score</i> | <i>Anxiety Sub- scale Score</i> | <i>Stress Sub- scale Score</i> | <i>DASS total score</i> |
|------|-------------------------|---|-------------------------------------|------------------------------------|-----------------------------|
| F-TE | Correlation coefficient | -.167 | .091 | -.016 | -.038 |
| | Sig. (2-tailed) | .290 | .565 | .919 | .813 |
| F-ML | Correlation coefficient | -.053 | .177 | .063 | .072 |
| | Sig. (2-tailed) | .737 | .262 | .692 | .649 |
| B-TE | Correlation coefficient | -.270 | -.011 | -.053 | -.114 |
| | Sig. (2-tailed) | .084 | .944 | .741 | .473 |
| B-ML | Correlation coefficient | -.180 | .113 | .113 | .033 |
| | Sig. (2-tailed) | .254 | .475 | .476 | .835 |

4.10.4 *Correlations between Depression, Anxiety, Stress Scale Scores and Tinnitus Functional Index and Tinnitus Handicap Inventory Scores*

There was a significant positive relationship between the DASS stress sub-scale score and the TFI overall score, $r_s = 0.448$, $p = 0.048$, but not with overall THI score. All other correlations between the DASS scale scores and the TFI and THI overall scores were not significant ($p > 0.05$) (Table 4-18).

Table 4-18. Bivariate correlations between Depression, Anxiety, Stress Scale (DASS) scores and Tinnitus Functional Index and Tinnitus Handicap Inventory overall scores in the tinnitus group, n = 20 for all analyses. *p < 0.05

| | | <i>Tinnitus Functional Index overall score</i> | <i>Tinnitus Handicap Inventory overall score</i> |
|----------------------------------|----------------------------|--|--|
| Depression sub-scale score | Correlation coefficient | .189 | .308 |
| | Sig. (2-tailed) | .425 | .186 |
| Anxiety sub-scale score | Correlation coefficient | .024 | -.004 |
| | Sig. (2-tailed) | .920 | .988 |
| Stress sub- scale score | Correlation coefficient | .448 | .254 |
| | Sig. (2-tailed) | .048* | .281 |
| DASS total score | Correlation coefficient | .299 | .136 |
| | Sig. (2-tailed) | .200 | .567 |

Further correlation analyses between the DASS stress sub-scale score, and TFI and THI sub-scales were computed, revealing significant, positive relationships between stress and the TFI Emotional ($r_s = 0.511$, $p = 0.021$), Intrusion ($r_s = 0.500$, $p = 0.025$), and Control ($r_s = 0.561$, $p = 0.010$) sub-scales. There were no significant relationships between the stress scale and the THI Functional, Emotional, or Catastrophic sub-scales ($p > 0.05$).

4.10.5 *Correlations between Tinnitus Characterisation Measures and Questionnaire Scores*

There were no significant relationships between the tLMs and MMLs and overall THI and TFI scores (Table 4-19).

Table 4-19. Bivariate correlations between tinnitus loudness matches (tLM) and minimum masking levels (MML) and Tinnitus Functional Index and Tinnitus Handicap Inventory overall scores in the tinnitus group, n = 20 for all analyses.

| | | | <i>Tinnitus Functional Index overall score</i> | <i>Tinnitus Handicap Inventory overall score</i> |
|-----------|-----|-------------------------|--|--|
| Right ear | tLM | Correlation coefficient | .081 | .311 |
| | | Sig. (2-tailed) | .735 | .182 |
| | MML | Correlation coefficient | -.061 | .097 |
| | | Sig. (2-tailed) | .798 | .684 |
| Left ear | tLM | Correlation coefficient | .040 | -.054 |
| | | Sig. (2-tailed) | .867 | .820 |
| | MML | Correlation coefficient | .018 | .130 |
| | | Sig. (2-tailed) | .940 | .586 |

The tLMs and MMLs were significantly correlated for both the right ($r_s = 0.720$, $p < 0.01$) and left ($r_s = 0.789$, $p < 0.01$) ears.

5 Discussion

The present study aimed to characterise and compare auditory selective attention and working memory ability in individuals with tinnitus, with healthy, non-tinnitus controls. It also sought to investigate the relationship between cognitive abilities, self-perceived tinnitus impact on functional life, and severity of tinnitus. Auditory selective attention and working memory were assessed using a short battery of computerised dichotic listening, and digit span tasks, respectively. The DASS was administered to examine emotional state; and behavioural tinnitus data included tinnitus characterisation assessment data (loudness match, minimum masking level), and questionnaire data via the: TSNS, TSCHQ, THI and the TFI. The Mann-Whitney U test was used to determine differences between tinnitus and non-tinnitus controls in the whole sample, and partial correlation analyses were used to determine differences between smaller matched groups within the sample while accounting for age, sex, and hearing loss. Finally, bivariate correlation analyses were computed to investigate interactions within the tinnitus group.

5.1 *Main Findings*

The present study revealed no difference between the tinnitus and control groups for any of the ASA task measures, digit span measures, or DASS scores, indicating that ASA, working memory, and emotional state are not influenced by chronic tinnitus for this particular study sample. This finding remained after all participants with outlying data were removed from the analyses. However, significant negative correlations were found for the tinnitus group and certain digit span measures. There was a negative correlation between the forward recall maximum

length scores (the task determining the maximum length of numbers recalled in forward order) and TSNS sub-scales indexing tinnitus discomfort $r_s = -.614$, $p = 0.004$, annoyance $r_s = -.566$, $p = 0.009$, as well as the TFI overall score, $r_s = -.536$, $p = 0.015$. The DASS stress sub-scale was found to be significantly correlated with the TFI overall score, $r_s = 0.448$, $p = 0.048$, and three TFI sub-scales indexing tinnitus' influence on functional life: emotional impact ($r_s = 0.511$, $p = 0.021$), daily life intrusion ($r_s = 0.500$, $p = 0.005$) and locus of control ($r_s = 0.561$, $p = 0.010$). The implications of these findings will be discussed in more detail below.

5.2 *Between-groups Comparisons*

5.2.1 *Cognitive Performance*

The non-significant findings for cognitive task performance are in contrast with a previous study by Rossiter et al. (2006) who administered a reading span test to a group of tinnitus sufferers and a matched control group ($n = 19$ in each group). Their analyses revealed a significant difference in average span scores for tinnitus sufferers (3.0) compared with the control group (3.61) ($p < 0.05$). The test of working memory used by Rossiter et al. (2006) was comparable to the digit span measures used in the present study, particularly the backward recall condition. The second part of the Rossiter et al. (2006) experiment found that when participants were required to divide attention between tasks with increasing difficulty, the tinnitus group had longer reaction times and reduced accuracy compared to the control group when the assessment condition became the most difficult (Rossiter et al., 2006). This part was comparable to the ASA dichotic listening task in the present study, which did not find reduced accuracy or reaction times for the tinnitus group.

It is also worth noting the dichotic listening task used in the present study was also potentially assessing sustained attention as well selective attention, as it took approximately 15 to 20 minutes to complete (van Zomeren & Brouwer, 1994).

5.2.2 *Emotional State*

The control group appeared to score more highly on self-reported depression, anxiety and stress (Total DASS score = 12.95 (SD 8.74)), but this did not reach significance, despite the control group's mean DASS anxiety sub-scale score being above the DASS-recommended mean (Control group's anxiety sub-scale = 3.41 (SD 3.84)). As there were no correlations between the DASS scores and performance on the ASA and digit span tasks, equivalent self-reported depression, anxiety and stress between the groups may not have any impact on task performance. However for the tinnitus group, the DASS stress sub-scale was found to be significantly correlated with the TFI overall score, $r_s = 0.448$, $p = 0.048$. The tinnitus group had less overall self-reported depression, anxiety and stress comparatively (Tinnitus group's total DASS score = 9.30 (SD 6.27)), and the tinnitus group's stress sub-scale was below the DASS-recommended mean (Tinnitus group's stress sub-scale = 5.50 (SD 4.29)). But, the results may suggest that for those with tinnitus, even very modest affective contributions may negatively affect subjective impressions about tinnitus' impact on functional life.

5.3 *Potential Influence of Tinnitus Duration and Severity*

A majority of participants in the present study have had tinnitus for a long duration. Seventy percent of participants had tinnitus lasting 5 years or more, and 50% had it for 10 years or

more. In the Rossiter et al. (2006) study, 10 participants had experienced tinnitus for more than 5 years, and the minimum duration was 9 months. It may be that the individuals in the present study have habituated to their tinnitus to an extent, though there was no correlation between tinnitus duration and ASA % correct. Further, Rossiter et al. (2006) sought participants with constant, moderate-to-severe tinnitus, using the TRQ (mean 36.39). For the present study, the THI questionnaire responses suggest the majority of participants had no more than mild tinnitus, but the mean (\pm SD) TFI score of 101.4 ± 44.6 out of a possible 250, indicated tinnitus was a very big problem. This revealed some discrepancy between the results obtained from the two questionnaires, though they were strongly related, $r_s = 0.684$, $p = 0.001$. It may be due to the fact that the TFI was designed to measure outcome, whereas the THI was never designed to account for this (Meikle et al., 2012). Fackrell, Hall, Barry, and Hoare (2015) reported a strong correlation of $r = 0.82$ between the two questionnaires in a sample of 294 participants. A difference in tinnitus severity may influence task performance, as one would expect less severe tinnitus would not be as intrusive. The study by Rossiter et al. (2006) did not formally test hearing, relied on self-report, and did not match hearing loss between the two groups. As the studies sampled the overall tinnitus population differently, findings cannot be generalised, which may explain the contrary results found.

5.4 Inconsistencies in the Tinnitus and Cognition Literature

Reviews of the literature surrounding tinnitus and impaired cognitive function by Andersson and McKenna (2006) and Mohamad et al. (2015) found inconsistent evidence of a marked difference in cognitive abilities in tinnitus sufferers. Andersson and McKenna (2006) outlined a model

suggesting that the influence of tinnitus on information processing may follow an inverted U-function. For low-demand tasks, tinnitus may have a disruptive effect, leading to poorer performance, while for moderately demanding tasks, processing is focused on the task and the tinnitus is effectively ignored, thereby having little effect on performance (Andersson & McKenna, 2006). For higher demand tasks, tinnitus may impact on performance once more. This model offers some explanation for the discrepancy between the tinnitus patients' common self-reported cognitive deficits (Sanchez & Stephens, 1997; Tyler & Baker, 1983), and the lack of consistent experimental data supporting this. Andersson (2002a) suggested that variation in differences in performance between the tinnitus and control groups between experiments could be attributed to varying task difficulty, and found that the tinnitus participants were often able to direct their attention from the tinnitus (Andersson, 2002a). The difficulty of tasks employed in the present study may be of moderate difficulty, with participants able to focus on the task, and effectively block out any disruptive effects of their tinnitus.

Similarly, Andersson et al. (2009) did not find a difference between the tinnitus and matched control group on auditory serial recall tasks performed under various masking conditions. The authors offered a possible explanation that the tinnitus patients who had mildly distressing forms of tinnitus, were able to temporarily suppress their tinnitus and thereby effectively control their attention whilst completing the tasks; based on findings from studies showing that tinnitus could be consciously blocked from perceptual awareness (Andersson et al., 2006; Westin, Östergren, et al., 2008). Some participants in the present study may also fall into this category, as a majority of had no greater than Grade 2 'mild' tinnitus per the THI questionnaire.

5.5 *Tinnitus Group Interactions*

Tinnitus loudness matches and minimum masking levels were not related to overall THI or TFI score. There were no significant relationships between the tLMs and MMLs in relation to the overall THI and TFI scores, consistent with previous findings that loudness matches are not typically congruent with subjectively reported severity and distress (Henry & Meikle, 1996; Vernon et al., 1990). Further, the TFI questionnaire was always completed before the onsite assessment session, while the THI was usually completed during session.

Some participants commented that their tinnitus on the day of testing was not typical of their usual experience, i.e. louder or quieter. This would affect the tinnitus characterization assessments which represented only a snapshot of the participants' tinnitus perception, and may have also influenced task performance.

5.5.1 *Task Performance and Tinnitus Severity*

The F-ML span had a significant, negative relationship associated with the level of discomfort and annoyance caused by tinnitus, per the TSNS questionnaire. The forward condition of the digit span assessments challenges short-term rather than working memory (Draine, 2015), suggesting that tinnitus participants who were more annoyed with their tinnitus, have poorer short-term memory. A possible explanation for this interaction may be that these participants found these aspects of their tinnitus more immediately intrusive and distracting, making it more difficult to hold items in short-term memory. The relationship between the F-ML and the 'ignore' sub-scale for the TSNS did not reach significance, $r_s = -.432$, $p = 0.057$, suggesting that F-ML was sensitive to the TSNS 'uncomfortable' and 'annoying' sub-scales, but not to the 'ignore'

sub-scale. It is possible that an interaction for the 'ignore' and other TSNS sub-scales may have reached significance with a greater sample size. No significant relationships between the F-TE span and the other TSNS sub-scales were found. This may be due to the F-ML span reflecting a lesser-degree of difficulty and therefore, only indexing more distressing aspects of tinnitus (discomfort and annoyance).

Along the same lines, there was a significant negative relationship between F-ML and TFI overall score ($r_s = -.536$, $p = 0.015$). This may reflect that greater TFI scores, indicative of greater, negative tinnitus life impact, may adversely affect performance in tasks requiring preserved short-term memory. However, this effect was not seen with the THI, as per the THI overall scores ($r_s = -.416$, $p = 0.068$).

5.5.2 *Tinnitus and Short-term Memory*

The interactions between tinnitus and short-term memory support previous studies demonstrating atypical neural short-term memory indicators for individuals with tinnitus, as compared to controls (Husain et al., 2015; Husain, Pajor, et al., 2011). Husain, Pajor, et al. (2011) employed fMRI to examine neural activity using a passive listening task and an active discrimination task in: tinnitus participants with bilateral hearing loss ($n = 8$), participants with bilateral hearing loss only ($n = 7$), and normal hearing non-tinnitus participants ($n = 11$). While behavioural performance for the discrimination task was similar between the groups, the imaging results revealed reduced engagement in the parietal and frontal lobes in the tinnitus group relative to the hearing loss group, and reduced response for frontal lobe activation compared to the normal hearing control group. These findings suggested alterations to the attention and short-term

memory networks in individuals with tinnitus that could not be attributed to hearing loss alone. In a similar study, Husain et al. (2015) similarly used fMRI to compare visual and auditory selective processing in tinnitus participants with hearing loss (n = 12), a hearing loss-matched control group (n = 11), and a normal hearing control group (n = 14). Short-term memory tasks under low and high cognitive loads were employed. Similar to the previous experiment (Husain, Pajor, et al., 2011), engagement of the attention network was reduced in the tinnitus group compared to the control group for both conditions in the auditory domain, with negative effects on attention more pronounced under the high task load; but behavioural performance essentially unaffected. The authors suggested that lack of behavioural difference may be due to insufficient engagement of the attention network using the discrimination task, but it may have also been limited by the study's relatively small sample size. Participants in both studies (Husain et al., 2015; Husain, Pajor, et al., 2011) had Grade 1 or Grade 2 tinnitus severity per the THI, indicating slight or mild tinnitus impact, similar to participants from the present study. While the fMRI neuroimaging technique provides good spatial resolution, it is limited by temporal smearing, which prevents the establishment of accurate temporal relationships (Gevins, Cutillo, & Smith, 1995).

5.5.3 *Tinnitus Severity and Emotional State*

A significant positive relationship was found between the DASS stress sub-scale score and the TFI overall score, and the emotion, intrusion, and control sub-scales ($p < 0.05$). All other correlations between the DASS overall and sub-scale scores and the TFI and THI overall and sub-scale scores were not significant. It is well-documented that tinnitus is related to negative emotional states (Halford & Anderson, 1991; Langguth, Landgrebe, Kleinjung, Sand, & Hajak,

2011; Mucci et al., 2014; Udipi, Uppunda, Mohan, Alex, & Mahendra, 2013; Zielińska-Bliźniewska & Olszewski, 2009). As we excluded participants who were pharmacologically treated for psychiatric and mood disorders, individuals with clinical depression and anxiety were excluded, which may partially explain the lack of relationship between tinnitus and depression and anxiety in the present study.

The severity and distress of tinnitus perception can vary (Kiefer, Schauen, Abendroth, Gaese, & Nowotny, 2015; Penner, 1983; Shulman, 2004; Stouffer & Tyler, 1990). Participants completed the TFI and TSCHQ before attending the assessment session where their tinnitus was characterised and the selective attention and working memory tasks were assessed. This was completed up to 7 months prior for some participants. During the testing session, some participants reported that their tinnitus was different from what they typically experience (either more or less prominent, depending on the individual). As the THI and TSNS questionnaires were completed during the same session as the ASA and digit span assessments, they may better reflect the participants' tinnitus experience at the time of testing.

5.6 Computerised Assessments

5.6.1 Caveats for Computerised Assessments

Classic dichotic listening tasks assessing auditory selective usually required participants to respond by verbally reciting what they heard (Cherry, 1953). Similarly, auditory digit span tasks also typically request verbal recall (Wechsler, 2008; Wundt, 1912). The current experiment required participants to use a computer mouse to navigate the cursor on screen to select the correct answer, or to use the keyboard to type in the digits. This created additional variables

which may influence the results recorded. The ASA task measures reaction time which was highly influenced by the speed and ease with which participants are able to manipulate the computer mouse. Though all participants who completed the study were comfortable and familiar with using a computer mouse, differences in familiarity could still impact greatly on reaction time. As the digit span tasks required participants to type the number sequence on a laptop keyboard, computer familiarity also became a factor. Unfamiliarity may impact on the speed the participants were able to type out the sequence, which potentially contributed to increased elapsed time after hearing the sequence. Unfamiliarity could also increase the number of typing errors. In cases where the error was noticed before the participant continued on to the next question, the correct digit sequence was often forgotten due to short-term memory limitations.

The requirement of computer proficiency and adequate typing skills have been cited as some of the key concerns of administering computer-based assessments (Gallagher, Bridgeman, & Cahalan, 2002; Wang & Kolen, 2001). In light of the continuing development and popularity of computer technology, Noyes and Garland (2008) conducted a literature review examining the equivalence of computer-based assessments compared to their paper-based counterparts. In many cases, traditional paper-based tasks have been adapted to computer-based versions with little consideration for the implications (Noyes & Garland, 2008). Collerton et al. (2007) compared the acceptability and feasibility of paper-based and computer-based cognitive tasks assessing the attention and verbal memory domains in 85 year old participants ($n = 81$) in a randomised trial. Participants found the computer-based cognitive tasks less difficult and stressful, and more acceptable compared to the paper-based tests ($p < 0.05$). The task assessors

were also less likely to rate participants as distressed during the computer-based testing. It is important to note that the computer-based tasks selected for the study required participants to respond using either 'YES' or 'NO' buttons, therefore requiring minimal computer skills.

5.6.2 *Support for Computerised Assessments*

Although administering computer-based assessments introduces potential issues, pervasive healthcare is becoming increasingly prevalent (Arnrich, Mayora, Bardram, & Tröster, 2010). Pervasive healthcare is the application of computing technology to complement existing healthcare models, enabling health to be more available and accessible for the general public (Korhonen & Bardram, 2004). Applications of the model have been recently trialled for tinnitus diagnostics and management, from the *TrackYourTinnitus* mobile application (Pryss, Reichert, Herrmann, Langguth, & Schlee, 2015) to *Terrain*, the game-based tinnitus management tool (Wise et al., 2015), both of which are in early trial stages, but show promise for contributing to the existing methods of tinnitus management.

5.7 *Study Limitations*

5.7.1 *Power to Detect Effect Size*

The present study had several limitations. While the sample size of 20 tinnitus participants and 22 control participants met the requirement of 17 participants in each group to achieve significance at $\alpha = 0.05$ level, power = 0.8 and $d = 1.0$, a meaningful difference may be below $d = 1.0$ which is considered a large effect size (Cohen, 1988). As the standard deviation of the datasets were large, a large magnitude of difference between the groups was required for a

difference to be detected. Although opinions on the use of post-hoc power analysis are divided (Fagley, 1985; Levine & Ensom, 2001), as it is claimed to have no influence on the conclusions that be drawn from the findings of a study (Lenth, 2007), it was computed retrospectively to examine power in the present study. Post-hoc power analyses revealed that the study sample size would need to increase dramatically (more than triple) to detect significant differences between-groups for the effect size observed. With the existing sample size, the study was not sufficiently powered to detect smaller effect sizes between the groups. Based on the results obtained in the present study, increased sample size may reveal more compelling evidence regarding potential links between short-term memory and tinnitus' functional life impact. It may also lend further support for links between tinnitus' functional life impact and stress.

5.7.2 Matched Participant Groups

5.7.2.1 Hearing Loss Differences

Each of the groups comprising the total sample were not adequately matched. Although a concerted effort was made to ensure the participant groups were well-balanced for age, gender, and hearing loss; due to experimental and control participants excluded for hearing loss exceeding the eligibility threshold, medication which could potentially affect performance, and availability of participants, this resulted in the two groups being unbalanced with regards hearing loss. Hearing levels were significantly different between the groups at all frequencies tested, with the tinnitus group having significantly different (worse) hearing thresholds compared to the control group. This was the case for all of the frequencies assessed, with the exception of 250 Hz and 500 Hz for the right ear. This meant there was more low-frequency hearing impairment for the left ear for the tinnitus group (see Section 4-2). Though all participants had average speech

frequency (500 Hz, 1 kHz, 2 kHz) thresholds of less than 25 dB HL as informed by findings by Cox et al. (2008) (Section 3.1.3), a possible impact of low-frequency involvement cannot be ruled out. In the Cox et al. (2008) study, the study groups were characterised as having only high frequency hearing loss, also had average speech-frequency hearing losses up to 21.7 dB HL, which was exceeded by four participants in the present study in one or more ears. Overall, those University of Canterbury (UC) research candidates who consented to participating had milder forms of hearing loss when compared to the Cox et al. (2008) study. Matching for hearing loss is an important consideration as hearing loss itself can impair cognitive function (Pearman, 2000; Rönnberg, 2003). Though the formed groups were better-matched for hearing loss, removal of all participants with outlying scores resulted in a significant reduction of group size.

Previous research has shown support for a link between hearing loss and cognitive decline (Lin et al., 2013). Considering these earlier findings, the tinnitus group from the present study was expected to have poorer performance on the cognitive tasks, influenced by the significant difference in hearing loss—however, this was not the case. There were no significant differences between the tinnitus and control groups for the ASA task measures or the digit span measures. Perhaps, the degree of difference between hearing thresholds between the groups in the present study, although significant, was not sufficient to impact the cognitive-based results for the tinnitus participants overall. Or could it be possible that, the way cognitive decline is expressed in those with co-morbid tinnitus and hearing loss, is different to those with hearing loss only?

5.7.2.2 Age Differences

There was also some imbalance in the distribution of age in the total sample. Though this did not reach significance, all five control participants in the 20-29 year age group performed above the grand mean for the control group for the selective attention task. There was only one participant from this younger age range in the tinnitus group. Correlation analyses found that age was significantly related to reaction times on the ASA task, but not the ASA % correct scores. This benefited the control group, rather than the tinnitus group. It is possible that the difference arose because younger participants may be more familiar/comfortable with using a computer, therefore achieving faster reaction times.

5.7.3 Other Potential Confounders

Another possible confounder of the findings that was not accounted for, was the intelligence and aptitude of the participants. It is possible that performance for the tasks were also influenced by these factors, which could have been estimated through administering more comprehensive intelligence and aptitude assessments such as: The Montreal Cognitive Assessment (MoCA) (Cognitive test) (Nasreddine et al., 2005), the National Adult Reading Test (Intelligence test) (Nelson & Willison, 1991), or the Kaufman Brief Intelligence Test (Kaufman & Kaufman, 2004). Participants could also be matched for the level of education attained, and current occupation status (Rossiter et al., 2006). Coughlin (2004) found that individual differences in performance for elderly participants were associated with level of education. The MMSE was used for the present study to screen for dementia, but it is not as sensitive or specific in detecting milder forms of cognitive impairment as the MoCA (Freitas, Simões, Alves, & Santana, 2013).

Administering more sensitive and specific assessments may provide a wider range of scores that are more meaningful; enabling more accurate analyses of potential variables in conjunction with the attention and memory tasks.

A potential confounder for the present study was the sampling bias. Of the 20 tinnitus participants who completed the study, 16 had expressed interest in participating in research or responded to study advertisements, and 4 were clients of the UC Audiology Clinic who accepted an invitation to participate. Of the 22 control participants, 13 were personal contacts of the researcher, 7 were clients of the UC Audiology Clinic who accepted the invitation to participate, and 2 responded to study advertisements. The difference in the ways that participants were ultimately recruited may have introduced biases such as motivation. As a larger proportion of tinnitus entered the study of their own accord, it is possible that they had higher interest and motivation during the assessments, compared to the control participants who were mostly personally invited in some form. Eysenck and Keane (2005) noted the lack of consideration of personal motivation as a weakness in attention-based studies, as performance is also reliant on personal aim and the willing allocation of attention.

Another issue was that participants were aware of the study aims to compare performance between tinnitus sufferers and non-sufferers, and that the basis of the study was that past evidence indicated that different ASA and working memory abilities may be associated with tinnitus. This may have resulted in participants to either being more highly-motivated, and thus potentially perform better, or self-fulfilling the hypothesis by performing more poorly. Both groups could have been affected by forms of the self-fulfilling prophecy phenomenon, known widely as the Pygmalion effect and the Golem effect (Rosenthal & Jacobson, 1968).

5.7.4 *Additional Considerations*

A majority (85%) of participants in the present study had Grade 2 ‘mild’ tinnitus per the THI questionnaire, which differs from the tinnitus population of other studies which sampled individuals with more severe tinnitus. Although it is possible that those suffering from more severe forms of tinnitus may perform more poorly on ASA and working memory tasks administered, correlation analyses revealed that tinnitus severity per the TSNS, TFI and THI questionnaires were not correlated with any of the ASA measures, and only the TFI score was negatively related to the F-ML score. However, the mean TFI score of 101.4, out of a possible total score of 250, indicated tinnitus was associated with a substantial functional life impact for the tinnitus group participants from the present study. The present study also highlighted the differences between the TFI and the THI in terms of grading tinnitus’ subjective, functional life impact and handicap—and the ability to make meaningful comparisons between the TFI and THI. Each was designed with different purposes in mind; quantifying the functional life impact of tinnitus and outcome measurement provision (Meikle et al., 2012) and quantifying handicapping aspects of tinnitus (Newman et al., 1996). Despite reported strong correlations between the two questionnaires (Fackrell et al., 2015), this study did not show as strong a relationship. Perhaps this highlights the importance of selecting tinnitus questionnaires carefully and considering the current evidence base, when doing so.

5.8 *Future Directions*

Limitations of the present study include the sample size and the uneven matching of groups. Therefore, future studies should have a larger sample size, and employ targeted recruitment to ensure groups are well-matched with regards to demographic variables such as age, hearing loss,

and level of education attained. As bias in sampling was another issue in the present study, future studies may wish to consider different incentives to encourage participant involvement, to overcome aspects of sampling and volunteer bias. The merits of blinding the experiment so the participants are unaware of the study aims and hypotheses may also be worth considering (Karanicolas, Farrokhyar, & Bhandari, 2010).

6 Conclusion

The prevalence of tinnitus is estimated to be 6.0 % in the New Zealand population aged ≥ 14 years, which increases with age (Wu, Searchfield, Exeter, & Lee, 2015). A smaller proportion of individuals who experience tinnitus regard it as a problem (Coles et al., 1984). For those with clinically significant tinnitus, it can lead to reduced quality of life (Halford & Anderson, 1991). There is a need to improve knowledge and understanding related to tinnitus before novel management strategies can be developed and explored. The present study aimed to determine whether differences existed in selective auditory attention, working memory, and emotional state between tinnitus sufferers and tinnitus non-sufferers. This study found no difference in selective auditory attention, working memory, and emotional state between participants with subjectively bothersome tinnitus and healthy non-tinnitus controls. However, the results from those participants with tinnitus suggested a negative impact of tinnitus severity on short-term memory processes. The findings also appear to lend further support to the relationship between tinnitus and stress. Future research with better-designed studies, providing a clearer understanding of the underlying cognitive processes serving short-term memory as it relates to tinnitus, and enabling international comparisons to be considered, are recommended.

7 References

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Appendix 1: Participant Recruitment Advertisements

Appendix 1A. Tinnitus Participant Recruitment Advertisement



ADULT TINNITUS VOLUNTEERS: WE NEED YOUR HELP!

Do you want a free hearing and tinnitus assessment? Are you curious about your cognitive ability?

We are seeking participants for a tinnitus research project at the University of Canterbury which is being undertaken to improve the assessment and management of tinnitus. The project will be conducted by Siena Jiang, Master of Audiology student, under the supervision of Dr Kim Wise, lecturer of Audiology, Department of Communication Disorders.

For this study, you will initially be asked to complete some questionnaires relating to your tinnitus and its effect(s) on your daily life (15 min). These questionnaires will help us learn more about tinnitus in general and assist with study candidacy. Those eligible to participate will be invited for a free hearing and tinnitus assessment session (60-75min) at the University of Canterbury Speech and Hearing Clinic on Greyke Rd. If you are eligible, you will be invited to attend a second session (30–45 min) where you will take some computer assessments which will test your auditory selective attention and working memory, for which you will be receive a \$10 fuel voucher. You will also be given a copy of your hearing and tinnitus assessment results.

If you are interested in more information, please contact:

Siena Jiang
Ph: 0220129101
siena.jiang@pg.canterbury.ac.nz


Dr Kim Wise
Ph: 03 364 2987 extn. 45571
kimberly.wise@canterbury.ac.nz

Approved by the University of Canterbury Human Ethics Committee (Ref # 2015/12/LR)

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| Tinnitus Research Project Contact: Siena Jiang, 022 0129101, Siena.jiang@pg.canterbury.ac.nz | Tinnitus Research Project Contact: Siena Jiang, 022 0129101, Siena.jiang@pg.canterbury.ac.nz | Tinnitus Research Project Contact: Siena Jiang, 022 0129101, Siena.jiang@pg.canterbury.ac.nz | Tinnitus Research Project Contact: Siena Jiang, 022 0129101, Siena.jiang@pg.canterbury.ac.nz | Tinnitus Research Project Contact: Siena Jiang, 022 0129101, Siena.jiang@pg.canterbury.ac.nz | Tinnitus Research Project Contact: Siena Jiang, 022 0129101, Siena.jiang@pg.canterbury.ac.nz | Tinnitus Research Project Contact: Siena Jiang, 022 0129101, Siena.jiang@pg.canterbury.ac.nz |
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Appendix 1B. Control participant recruitment advertisement

WANT A FREE HEARING TEST?
WE ARE LOOKING FOR VOLUNTEERS



UC
 UNIVERSITY OF
 CANTERBURY
Te Whare Wānanga o Waitaha
 CHRISTCHURCH NEW ZEALAND

We are seeking volunteers for a research project at the University of Canterbury which aims to improve the assessment and management of tinnitus. The project will be conducted by Siena Jiang, Master of Audiology student, under the supervision of Dr Kim Wise, lecturer of Audiology, Department of Communication Disorders.

We are currently seeking volunteers who:

- Do not suffer from tinnitus (occasional tinnitus is fine)
- Are age 18-85 years
- Do not have any conditions affecting attention, memory or emotional state
- Are not on any medications affecting attention, memory or emotional state
- Are comfortable using a computer

You will be asked to attend ONE session at the University of Canterbury Speech and Hearing Clinic on Creyke Rd, Ilam, and complete:

- A hearing test (30 minutes)
- A listening and attention task (15 minutes)
- A working memory task (10 minutes)
- A brief questionnaire about your emotional state (5 minutes)
- A mental state screening exam (5 minutes)



If you are interested in more information, please contact:

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 Ph: 0220129101
 siena.jiang@pg.canterbury.ac.nz

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|--|--|--|--|--|--|--|
| Tinnitus Research Project Contact: Siena Jiang, 022 0129101, Siena.jiang@pg.canterbury.ac.nz | Tinnitus Research Project Contact: Siena Jiang, 022 0129101, Siena.jiang@pg.canterbury.ac.nz | Tinnitus Research Project Contact: Siena Jiang, 022 0129101, Siena.jiang@pg.canterbury.ac.nz | Tinnitus Research Project Contact: Siena Jiang, 022 0129101, Siena.jiang@pg.canterbury.ac.nz | Tinnitus Research Project Contact: Siena Jiang, 022 0129101, Siena.jiang@pg.canterbury.ac.nz | Tinnitus Research Project Contact: Siena Jiang, 022 0129101, Siena.jiang@pg.canterbury.ac.nz | Tinnitus Research Project Contact: Siena Jiang, 022 0129101, Siena.jiang@pg.canterbury.ac.nz |
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Appendix 2: Participant Information Sheets

Appendix 2A. Tinnitus Participant Information Sheet

Department of Communication Disorders
College of Science
Tel: +64 3 364 2431
Fax: +64 3 364 2760
www.cmds.canterbury.ac.nz



Do individuals with bothersome tinnitus have different auditory selective attention and working memory abilities?

Information Sheet for Tinnitus Participants

I am a Master of Audiology student undertaking a thesis project to determine whether individuals with tinnitus have different auditory selective attention and working memory abilities, as compared to individuals without tinnitus. Tinnitus has been linked to reduced cognitive function and many tinnitus patients report concentration difficulties as a result of their tinnitus. Research suggests that the distracting effects of tinnitus can affect performance on working memory and attention tasks. There is a need for further research to investigate the relationship between self-reported tinnitus and performance on cognitive tasks. It is hoped that the findings of this project will provide greater insight into the mechanisms of tinnitus, leading to a possible improvement in the management of tinnitus clinically.

The factors which will be investigated include degree of hearing, tinnitus severity, level of depression, anxiety and stress, subjective characteristics of the tinnitus, and auditory selective attention and working memory abilities.

If you are interested in participating in this project, we will ask you to first complete two questionnaires relating to your tinnitus, to help determine initial study candidacy. These questionnaires are expected to take 10-15 minutes. Questionnaire responses may be clarified via a brief phone call or email. If you are determined to be a suitable candidate, a hearing test and tinnitus assessment at the University of Canterbury Speech and Hearing Clinic will be scheduled. These assessments are expected to take 30 - 45 minutes and aid in finalising eligibility for involvement in the project as a research participant. If eligible, you will be asked to complete some computerised auditory selective attention and working memory tasks.

Auditory selective attention will be assessed with a listening task where different signals will be presented to each ear simultaneously through headphones, and you will be asked to attend to an assigned sound and report on it. For the working memory task, you will hear a string of numbers, and be asked to recall them in forward and reverse order. We will also administer a Mini-Mental state exam to screen for cognitive decline and understanding of basic instructions in all participants, as well as some further questionnaires relating to your tinnitus and its effects on your daily life. This second part will take around 45 minutes. You will receive a copy of your hearing test results to take away with you, and have the opportunity to discuss any questions regarding your hearing with the researcher. For full completion of the study, you will also receive a \$10 fuel voucher to contribute to your travel costs.

It is entirely your own decision to participate in this study. A set of documents (Consent form, Tinnitus Functional Index Questionnaire, and Tinnitus Case History Questionnaire) will have been provided to you along with this Information Sheet. Please complete the questionnaires and return them to the researcher via email or NZ post. You may sign and return consent form in a similar manner or bring it to the hearing and tinnitus assessment session, if eligible for this part of study. There are no documented risks associated with study participation. Questionnaire endorsement and the computerised assessment are common, non-invasive research procedures, well-documented in the prevailing research literature.

Participation is voluntary and you have the right to withdraw at any stage during the study without providing a reason or rationale. If you withdraw, any information relating to you collected prior to thesis submission will be withdrawn, should this remain practically achievable.

All potentially identifying information is removed. All data will be either sent via secure postal mailing or secure electronic data transfer. If posting hard copies, data will be stored in a locked filing cabinet in a locked room in the Communication Disorders department at the University of Canterbury. Data transferred electronically will be stored in a password protected computer in a locked room in the Communication Disorders department at the University of Canterbury—as per secure data storage protocols employed by the University of Canterbury.

Individuals with access to the data will consist of the researcher and supervisor involved in this study. All paper and/or computerised or electronic data is stored in a secured, locked facility and will be destroyed after a period of 5 years, per University of Canterbury research protocols and Human Ethics research recommendations. The data will be used for a Master of Audiology thesis which will be a public document on the UC library database.

The results of the project may be published in a professional peer-reviewed research journal. If you would like a copy of the project results, please tick the appropriate box on the consent form.

This project is being carried out as a requirement for the Master of Audiology programme by myself, Siena Jiang, under the supervision of Dr Kim Wise. We will be pleased to discuss any questions or concerns you may have about participation in the project, at any time.

This project has been reviewed and approved by the University of Canterbury Human Ethics (Ref # 2015/12/LR) Committee and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz), phone: + 64 3 364 2987.

We sincerely thank you for taking the time to consider being involved in this project. If you agree to participate, please return the questionnaires by return post or email, and bring the completed the consent form with you to your hearing and tinnitus assessment session.

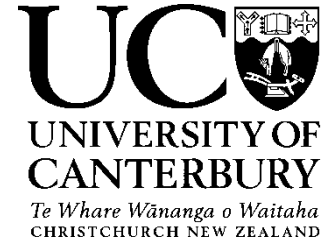
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Appendix 2B. Control Participant Information Sheet

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The factors which will be investigated include degree of hearing, level of depression, anxiety and stress, and auditory selective attention and working memory abilities.

If you are interested in participating in this project, we will ask you to provide a copy of your most recent hearing test (if you have one). If your hearing levels meet our study criteria, you will be invited to attend a session at the University of Canterbury Speech and Hearing Clinic which will include a hearing assessment and a series of computerised assessments. The computerised assessments will include a selective attention and a working memory task. Auditory selective attention will be assessed with a listening task where different signals will be presented to each ear simultaneously through headphones, and you will be asked to attend to an assigned signal and report on it. For the working memory task, you will hear a string of numbers, and be asked to recall them in forward and reverse order. We will also administer a Mini-Mental state exam to screen for cognitive decline and understanding of basic instructions in all participants, as well as a standardised questionnaire to assess your emotional state. These assessments are expected to take 1 – 1.5 hours in total. You will receive a copy of your hearing

test results to take away with you, and also have the opportunity to discuss any questions regarding your hearing with the researcher.

It is entirely your own decision to participate in this study. A consent form will have been provided to you along with this Information Sheet, which you may sign and return by post or when you attend your session. There are no documented risks associated with study participation. Questionnaire endorsement and the computerised assessment are common, non-invasive research procedures, well-documented in the prevailing research literature.

Participation is voluntary and you have the right to withdraw at any stage during the study without providing a reason or rationale. If you withdraw, any information relating to you collected prior to thesis submission will be withdrawn, should this remain practically achievable.

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Appendix 3: Ethics Approval Letter UC HEC



HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2015/12/LR

12 October 2015

Siena Jiang
Department of Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Siena

Thank you for your request for an amendment to your research proposal "Do individuals with bothersome tinnitus have different auditory selective attention and working memory abilities compared to non-tinnitus controls? – an exploratory study" as outlined in your email dated 9 October 2015.

I am pleased to advise that this request has been considered and approved by the Human Ethics Committee.

Yours sincerely

A handwritten signature in black ink, appearing to read 'L. MacDonald'.

Lindsey MacDonald
Chair, Human Ethics Committee

Appendix 4: Participant Consent Form

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www.cmds.canterbury.ac.nz



Do individuals with bothersome tinnitus have different auditory selective attention and working memory abilities?

Consent form for Participants

I have been given a full explanation of this project and have had the opportunity to ask questions.

I understand what is required of me if I agree to take part in the research.

I understand that participation is voluntary and I may withdraw at any time without providing a reason or rationale. Withdrawal of participation will also include the withdrawal of any information I have provided.

I understand that any information or opinions I provide will be kept confidential to the researcher and the researcher's supervisor and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.

I understand that all data collected for the study will be kept in locked and secure facilities and in password protected electronic forms will be destroyed after five years.

I understand the risks associated with taking part and how they will be managed.

I understand that I am able to receive a report of the findings of the study by ticking the box below.

I understand that I can contact the researcher, Siena Jiang (email: siena.jiang@pg.canterbury.ac.nz, cellphone: 64220129101) or supervisor Dr Kim Wise (kimberly.wise@canterbury.ac.nz) by phone on 03 364 2987 extension 45571 for further information. This project has been reviewed and approved by the University of Canterbury Human Ethics Committee (Ref # 2015/12/LR). If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

Please tick the box below if you would like to:

Receive a copy of the final report

Email or postal address: _____

By signing below, I agree to participate in this research project:

Name: _____

Signature: _____ Date: _____

Siena Jiang
Master of Audiology student

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