The Impact of Hearing Aids on the Cognitive Functions of Postlingually Hearing Impaired Older Adults

Danelia D Kok 31562086

BSc Biomedical Science

BSc Molecular Biology

Murdoch University

Thesis Supervisor:

Dr Dona M P Jayakody

Ear Science Institute Australia

Ear Sciences Centre, School of Surgery, UWA

Responsible Academic:

A/Prof Robert Mead

Biological Sciences and Biotechnology

Murdoch University

November 2015

This thesis is presented for the degree of Bachelor of Science in Biomedical Science with Honours, School of Veterinary and Life Sciences, Murdoch University

Disclosure Statement

This thesis was prepared as part of the requirements for the degree of Bachelor of Science with Honours in Biomedical Science. I declare that this thesis is my own account of my research and contains as its main content of work, which has not been previously submitted for a degree at any other tertiary institution.

ACKNOWLEDGEMENTS

Thank you to my Creator.

I would like to acknowledge the contribution of my primary supervisor Dr Dona Jayakody. You took a naïve student under your wing and developed her abilities. Thank you for the kind words and firm support. I am forever grateful for this opportunity and for your guidance.

I would like to acknowledge the contribution of my fellow researcher and partner in crime (and life) Esmeralda Nel. Thank you for your calming nature and patience. I have learnt so much from you. Your strength continues to inspire me. Lief jou altyd my meisiekind.

I would especially like to thank A/Prof Bob Mead for the many years of counselling whilst at university. Thank you for always believing in me. Thank you to Prof Rob Eikelboom for supporting us from the start and for the countless hours of proof reading and presentation preparations.

I would like to thank my support structure at my family home. Thank you to my Mamma Danelia for the silent hugs of encouragement, my Pa Franswa for his support, and my siblings Herman, Janet and Franswa for your love. Thank you to Lukas, who wiped many tears this year. Thank you to all my friends who adapted their schedules to have coffee.

Thank you to our research assistant Elly Reynolds for your help. Thank you to Angela Liew, Doug Fletcher, Sandra Safstrom, Jacqueline McGregor and the fellow student mentors in our research room. Lastly I would like to thank the Ear Science Institute Australia for this wonderful opportunity. Thank you for allowing us to use your facilities and involving us in your projects.

Finally, thank you to the participants who selflessly volunteered for this study.

Contents

List of Figures

List of Tables

List of Abbreviations

ABS	Australian Bureau of Statistics
AGS	American Geriatric Society
ARHL	Age Related Hearing Loss
AST	Attention Switching Task
BAI	Beck Anxiety Inventory
CANTAB	Cambridge Neuropsychological Test Automated Battery
CAS	Central Auditory System
DASS	Depression Anxiety Stress Scale
DMS	Delayed Match to Sample
DSST	Digit Symbol Substitution Test
FCSRT	Free and Cued Selective Reminding Test
GDS	Geriatric Depression Scale
HAC	Hearing Aid Candidates (Study Group)
HAU	Hearing Aid Users (Study Group)
M	Mean
MMSE	Mini Mental State Exam
MOT	Motor Screening Test
n	Number of participants
NART	National Adult Reading Test
NH	Normal Hearing (Study Group)
PAL	Paired Associates Learning
RTI	Reaction Time
RVP	Rapid Visual Information Processing
SE	Standard Error
STM	Short Term Memory
SWM	Spatial Working Memory
VRM	Verbal Recognition Memory
WHO	World Health Organization

ABSTRACT

Background: The World Health Organisation estimates that 360 million people worldwide suffer from a disabling hearing loss (WHO, 2012). In Australia alone, one in six suffer from hearing impairment, with the incidence increasing to three out of four by the time an individual reaches 70 years of age (Wilson et al., 1999). Age Related Hearing Loss or presbycusis is a common type of hearing impairment in older adults. Hearing loss is known to affect speech perception (Moore, 1996) but is also associated with a higher risk of loneliness (Pronk et al., 2013). The effect of untreated hearing loss on cognitive functions has also been investigated. Reports by Lin et al. (2011 & 2013) indicate that untreated hearing loss is independently associated with accelerated cognitive decline, cognitive impairments in executive function and memory, and an increased risk of incident dementia. **Aims:** This study had two objectives; 1) determine if a significant difference exists between Normal Hearing (NH) and Hearing Aid Candidates (HAC) in mental health scores and cognitive tests of executive function and memory, and 2) investigate whether the use of hearing aids improves these mental health scores and cognitive functions in HAC.

Methods: Testing was conducted at baseline before hearing aid use and three months after fitting of hearing aids. Participants completed a questionnaire on anxiety, stress, and depression as a means to obtain and control for mental state. A battery of computerised tests was used to assess cognitive functions.

Results: A significant difference was found in the test of delayed visual recognition memory matching (DMS) and attention switching (AST) between NH and HAC groups. It appears that a task mediated through the temporal lobe (DMS) is impaired in HAC whereas tasks mediated through the frontal lobe (AST) showed a compensatory mechanism and therefore performance was better in the HAC. Hearing aid use did not affect these scores at three

months, perhaps because three months is not long enough for acclimatisation to occur in the brain. Presbycusis sufferers displayed a higher risk for depression and stress. Hearing aids did not significantly improve this.

Conclusion: More research is needed to specifically identify which cognitive functions are affected by hearing loss to target specific treatments to these areas.

CHAPTER 1: INTRODUCTION

This chapter reviews the current literature and provides (i) an insight to the effects of ageing on hearing and cognition; (ii) an overview of the impact of Age Related Hearing Loss (ARHL) on the hearing system; (iii) a description of the impact of ARHL on speech perception, cognitive function and mental health; (iv) a summary of the treatment for hearing loss; (v) a summary of all the relevant literature and presents hypotheses for investigating relationship between treatment of hearing loss using hearing aids and cognitive functions.

1.1 Age Related Hearing Loss

It is estimated that 360 million people worldwide suffer from a disabling hearing loss (WHO, 2012). In Australia, one in six people suffer from hearing loss (Wilson, 1997; Wilson et al., 1999). Australians over 70 years of age have a three in four chance of suffering from hearing loss (Fig 1). This is a particular concern with Australia's ageing population and it is estimated that by 2050 one in every four Australians will suffer from hearing loss (Wilson et al., 1999).

According to the Australian Bureau of Statistics (ABS, 2012), people over 65 years currently make up around 14% of the Australian population. This is set to increase to 22% by 2061. Australia is faced with an ageing population and therefore the incidence of hearing impairment will increase. In 2006, the Listen Hear report indicated that, hearing loss costs Australia $ 11.75 billion per year (Hear, 2006). The disease burden (loss of wellbeing) was estimated to be an additional $ 11.3 billion in 2005 (Hear, 2006). Almost 160,000 people of working age, were not employed in 2005 due to hearing loss. Hence, ARHL, or Presbycusis is considered a significant public health concern (Hear, 2006).

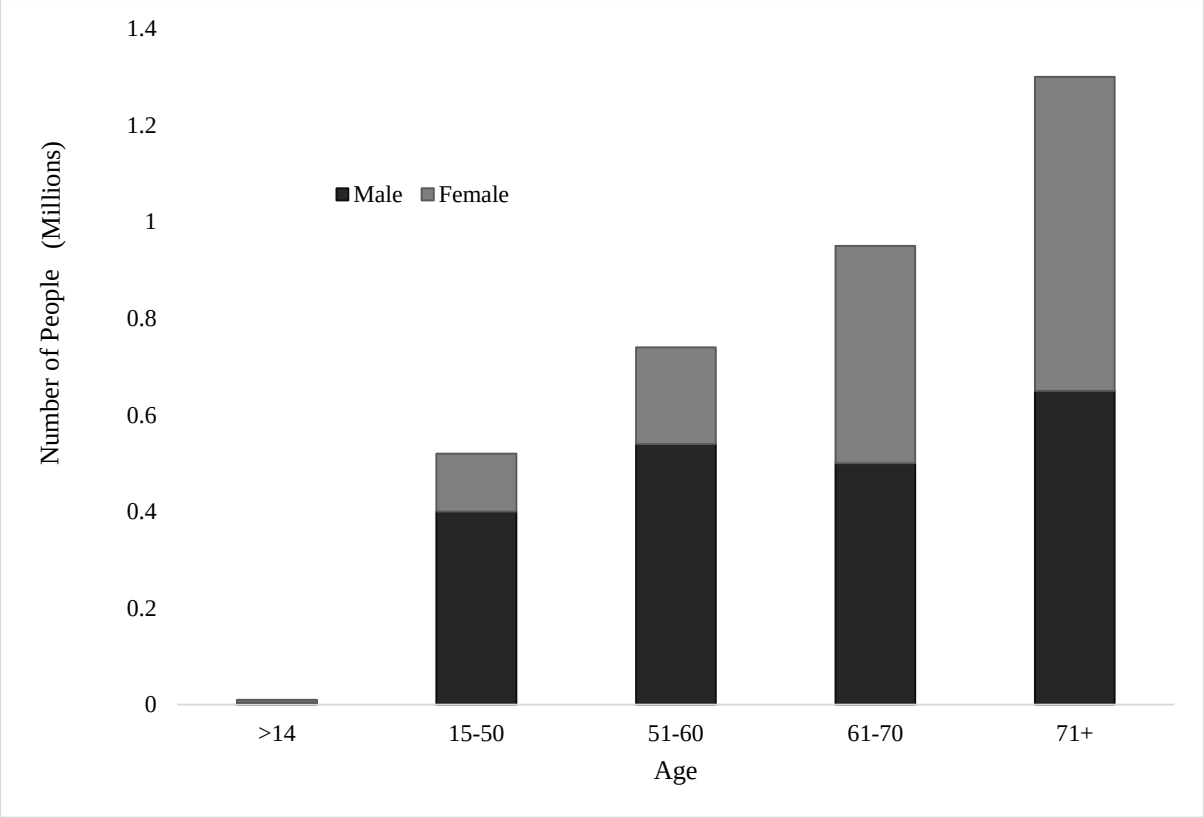

Figure 1*: Prevalence of Hearing Loss in 2005 in Australia. (Hear, 2006; Wilson, 1997; Wilson et al., 1999).*

The severity of the hearing loss can be categorized into mild, moderate, moderately-severe, severe or profound (Katz, 2009). A 26-40 dB loss in hearing is considered to be mild, 41-55dB is moderate, 56-70dB loss is moderately severe, 71-90dB is severe and anything over 91dB lost is considered profound hearing loss (Katz, 2009). A hearing loss is considered to be disabling if the mean thresholds of hearing loss in the better ear are 40dB or over (WHO, 2012).

ARHL is the ageing of the auditory system (Gates & Mills, 2005). It initially affects the higher frequencies which adversely affects communication. A common complaint is "I can hear my wife, but she is mumbling." Voiceless consonants (t, k, p, f, s, and ch) and vowels are misidentified. Sufferers can also confuse words like "map" with "mat" or "someday" with "Sunday" (Huang & Tang, 2010). Communication is adversely affected. The effects of ARHL on the auditory system are described below.

1.2 Effects of ARHL on Auditory and Cognitive Functions

Three levels of information processing occurs when an auditory signals reaches the ear: (1) peripheral hearing awareness is required to perceive the sound, (2) the central auditory system processes the incoming sound signal and transmits the information to the brain, and (3) cognitive operations in the brain decide how the information is useful and if it requires any action (Willott et al., 2001). The effects of ageing on these systems are described below:

1.2.1 Peripheral Auditory System

Many pathological, physiological and neurological changes take place in the peripheral and central auditory system as a part of the ageing process. Age-related changes that take place in peripheral and central auditory systems are summarised in Table 1. Structurally, both outer and middle ear undergo changes but these do not have a significant effect on the function of the ear (Wiley et al., 1999). Most affected by the ageing process is the cochlea, including outer hair cells (OHC) and inner hair cells (IHC) (Gates & Mills, 2005). All of these changes will collectively affect the way sound is perceived by the central auditory system.

Table 1: *Summary of Age Related Changes in the Auditory System (AGS, 2002).*

Region	Changes
External Ear Canal	Walls become thin, epithelium becomes dehydrated, glands lose secretory ability, and cerumen becomes dry.
Middle Ear	Eardrum thickens and loses elasticity, joints show arthritic change
Inner Ear	Hair cells are lost, stiffening of basilar membrane, loss of cochlear neurons, and calcification of auditory structures.

1.2.2 Central Auditory System

Hearing depends on a functioning peripheral system but also the central auditory system (CAS). The CAS is affected by ageing independently of the factors that affect peripheral ageing (Ouda et al., 2015). The auditory cortex suffers from atrophy in ageing. A reduction in neurons situated in the auditory centres of the brain is seen, neurons shrink in size and the cell body becomes smaller (Willott et al., 2003). Most cells are lost in the superior temporal gyrus (Katz, 2009). The capacity for the CAS to process sound hence becomes impaired (Ouda et al., 2015). It is clear that hearing depends on both the peripheral system and the CAS for efficient processing of sound information. Hearing is affected by ageing.

1.2.3 Cognitive Processing

The capability to hold and manipulate temporary information simultaneously is known as the working memory (Baddeley, 1996). The listener needs to detect the overall structure of the information given and what this means to integrate the information logically. As an example, the sentence "*My brother did not attend the wedding as he dislikes the groom*." contains two people (brother and groom) and an action resulting from a dislike. The brain must correctly integrate the parts of the sentence to act on it. When working memory is impaired, complex sentences become difficult to comprehend (Wingfield & Grossman, 2006). Hence, optimal functioning of both auditory and cognitive systems is required for an individual to accurately perceive a speech signal. Baldwin (2009) found that working memory was impaired by hearing loss. The impairment was even greater for older participants and indicated that ARHL affects cognitive processes like working memory.

The effect of hearing loss on brain volume decline was investigated by Lin et al. (2014). It was shown that hearing loss sufferers had accelerated rates of brain volume decline and in specific regions in the right temporal lobe. This increased decline was shown to be

comparable to individuals who develop mild cognitive impairment (Lin et al., 2014). Damage in the posterior lateral temporal cortex (Wernicke's area) has been shown by Goodglass and Wingfield (1998) to be detrimental to language comprehension. We can posit that impairment in the temporal lobe is a feature of ARHL and is detrimental to cognitive processing in language comprehension.

1.3 The Effects of ARHL on Speech Perception and Cognition

There are four processes required for effective communication: (1) hearing as a means to access the auditory world as a passive function, (2) listening both attentionally and intentionally (requiring mental effort), (3) comprehension to decipher the meaning, intent and requirement of the perceived information, and (4) communication, which is the transfer of information between two or more listeners (Kiessling et al., 2003).

In everyday conversations, speech rates range between 140-180 words per minute (Wingfield & Tun, 2001). The brain must identify each individual word as it arrives. The speech is then processed to identify the relationships between the individual words (i.e., actions, objects, and who is involved). Speech is integrated with prior knowledge and new information is received simultaneously. If this process does not occur fluidly, memory is engaged as a back log of processing is created. The person needs to remember new information as the older information is still being processed (Wingfield & Grossman, 2006). The effects of ARHL on this system are described below:

1.3.1 Speech Perception

Speech Perception in Quiet

Damage to the cochlear structures affects the perception of pitch, timbre, and loudness (Moore, 2007). In relation to loudness, people with presbycusis experience recruitment (exaggerated perception of sound levels) resulting in an overall reduction in dynamic range

(Moore, 1996). As a result of recruitment, sounds that fluctuate in amplitude like speech or music are exaggerated (Moore, 2007). Impairment of the outer hair cells decreases its capability to amplify its tasked frequency (Moore, 2007). People suffering from presbycusis may then perceive the same sound at a different pitch in each ear. The cochlea can hence lose its capacity to distinguish between different sound frequencies. So even when sound and noise have different frequencies, the auditory system is unable to differentiate between them (Dillon, 2012). Speech intelligibility is adversely affected due to this impairment (Moore, 2007).

Speech perception in noise

Understanding speech in noisy environments is a complex task which requires perception through peripheral hearing, and processing in the CAS for cognitive use by the brain (Anderson et al., 2013). People suffering from ARHL often experience difficulty in understanding speech in challenging listening environments. The speech-to-noise ratio has to be higher in hearing loss sufferers as spatial separation of the speech and interference is impaired (Moore, 1996). People with normal hearing use the temporal and spectral dips to identify speech in the competing background noise. This process requires a wide dynamic range as seen in normal hearing patients. Due to loudness recruitment which reduces dynamic range, these dips cannot be distinguished in people with sensorineural hearing loss. If the intense part of the sentence is comfortably loud, softer parts may become inaudible. Speech perception becomes challenging as some parts in a sentence cannot be heard and processed (Moore, 1996). Presbycusis impairs the understanding of speech in sound as sufferers cannot distinguish between spectral and temporal dips in competing background noise (Moore, 1996).

1.3.2 The Effects of Age-Related Hearing Loss on Cognition

Hearing loss has been shown to be independently associated with cognitive decline (Lin et al., 2011). The Baltimore Longitudinal Study of Ageing indicated that participants (*n* = 347) performed 6.8 years older in cognitive tests when they had a hearing loss of 25dB. Cognition independently declined to hearing loss in areas of memory and executive function. The study found hearing impaired participants performed poorer on visual memory tests than normal hearing participants. The Free and Cued Selective Reminding test (FCSRT) was used by Lin et al. (2011) and is considered to be sensitive to the changes in the temporal lobe (Fletcher & Henson, 2001). These results suggest that mild to moderate sensorineural hearing loss impacts delayed recognition memory function, particularly if mediated through the temporal lobe.

Another study by Lin et al. (2013) found that hearing loss is independently associated with an acceleration in cognitive decline among older adults. All 1984 participants (*M* =77.4 years) from the Health ABC study underwent audiometric and cognitive testing. All participants were free from prevalent cognitive impairment at baseline. It was found that hearing loss increased the risk for cognitive impairment by 24%. Cognitive decline was accelerated by 30-40% in individuals with hearing loss when compared to normal hearing participants. The study found that baseline hearing loss was linearly associated with increased cognitive decline and increased risk for cognitive impairment.

Early studies by Granick (1976) suggested a ‘clear-cut’ relationship between loss of auditory acuity and loss of cognitive function. The data obtained in this primitive study clearly suggested that hearing loss has a noteworthy role in cognitive decline, particularly in areas of verbal recall.

A study by Verhaegen et al. (2014) investigated the impact of hearing loss on age related declines in verbal short term memory (STM) performance. Verbal STM test were conducted in older and younger participants with the same level of hearing loss. These results were compared to a group of young normal hearing participants. It was shown by the study that young and old participants suffering hearing loss had equal levels of performance in STM test. The two hearing impaired groups, however, performed significantly poorer than the normal hearing group. The study therefore indicates that the effect of hearing loss on STM is not exclusively due to age related factors. The authors concluded that hearing loss is a significant factor in STM decline. Even mild hearing loss was shown to impair STM performance.

A study by Zekveld et al. (2007) did not find an association between hearing loss and impairment on memory and attention tests. The study did not specifically look at an older population (n = 30; M = 53 ± 14 years) and ten of the participants already used hearing aids. The age and IQ of the participants were sufficient to explain the variance in participants. They did, however, suggest that people with hearing loss required greater use of their working memory to compensate for the loss of sound perception. There are four basic hypotheses that aim to explain the relationship between hearing loss and cognitive impairment and decline:

Hypothesis 1: Sensory Deprivation (Cascade)

The first hypothesis relates to the sensory deprivation. It is thought that cognition declines after a prolonged sensory deprivation, (i.e. hearing loss, due to neural atrophy). The 'cascade hypothesis' suggests that hearing loss over an extended period affects cognitive functioning as a result of sensory underload (Sekuler & Blake, 1987). In theory, cognitive function should improve by use of hearing aids as sensory input is restored (Sekuler & Blake, 1987). Hearing loss was independently linked to accelerated volume decline in the temporal

auditory region (Lin et al., 2014). The authors proposed that the degraded hearing signals results in a loss of volume in the auditory processing centre in the brain. This has a cascading effect on the associated memory and cognitive processes which relies on the regions affected by hearing loss (Lin et al., 2014).

Hypothesis 2: Cognitive Overload

The second hypothesis suggests that hearing impairment requires additional brain resources to understand sound input (Wingfield & Grossman, 2006). Due to this re-allocation, fewer resources remain for demanding cognitive processes like executive function and memory (Wingfield & Grossman, 2006). Colangelo et al. (2005) investigated cognitive overload by testing the recollection of words in normal hearing and mild to moderate hearing loss older participants. Participants with a hearing loss recalled significantly less overall words even though it was established that they correctly identified all words. The authors concluded that hearing loss participants required more effort to successfully perceive sound. The extra effort reduces the processing resources available to store the speech signals in memory.

Hypothesis 3: Common Cause

The third hypothesis suggests that cognitive and sensory decline are both age related and therefore a shared factor or 'common cause'. This is explained by degeneration of the central nervous system with age. In a prospective study, 111 women (*M*= 70 years) were randomly selected from the Gerontological and Geriatric Population Study in Gothenburg and the Prospective Population Study of Women. None of the women presented with dementia and all underwent hearing screening and computerised tomography scans of the brain (Tun et al., 2012). The study found that general cortical atrophy was related with high frequency hearing loss in the hearing system. The authors concluded that both the cognitive and sensory systems are affected by ageing and therefore declines in both systems are seen.

Hypothesis 4: Testing Procedures

The last hypothesis relates to the cognitive testing itself. It suggests that poor functioning in tests of cognition is not due to poor cognitive ability but rather the impairment of information received by the brain. The participant is mentally able to complete the task but cannot hear the instruction clearly. They therefore make mistakes which reduces their testing scores (Valentijn et al., 2005).

1.3.3 Effect of Age-Related Hearing Loss on Mental health

Older adults with hearing loss can suffer significantly both emotionally and socially (Kramer, 2005). Depression and loneliness is associated with poorer quality of life, wellbeing and general functioning capacity (Blazer, 2003).

A study by Pronk et al. (2013) investigated the link between baseline hearing status, depression and loneliness. It was a longitudinal study which ran over four years and looked specifically at an older population. A significant association was found between hearing loss and loneliness ($p < .05$). No impact on depression was found. Hearing loss was associated with an increase in social and emotional loneliness (Pronk et al., 2013).

Men are particularly affected by hearing loss due to its associated impact on the relationship with their partner (Dykstra & de Jong Gierveld, 2004). Men tend to experience greater loneliness as they are often closely attached to their partner, whereas females rely on close friends as well. The problem is exacerbated as hearing loss is more often denied in men (Dykstra & de Jong Gierveld, 2004).

A study of 2461 participants (M = 65 years) by Strawbridge et al. (2000) showed that individuals who reported moderate or worse hearing loss were two times as likely to suffer from depression than those who did not report any hearing loss. These results were also found for a decrease in overall health, (i.e., moderate hearing loss decreased mental health). The

authors concluded that hearing loss decreases crucial social engagement and positive mental health. More attention should be given to prevention and early treatment or identification of factors that causes hearing loss. The authors reported that clinicians have an essential role in educating patients on the damaging effects of noise exposure.

1.4 Hearing Loss Treatment

Permanent hearing loss is most often and effectively treated by hearing aids. (Hampson, 2012). Hearing aids assist the wearer by amplifying the sound received by the ear. The hearing aid is programmed to the hearing loss across the speech frequency range. Sound is detected by a microphone in the body of the hearing aid, converted into an electrical signal and amplified. The electrical signals are sent to a receiver/speaker which converts them back into sound. This altered sound signal is then transmitted into the ear canal for processing by the auditory system (van Pletzen, 2012). Hearing aids can reduce environmental and background noise through various sound and speech processing methods.

1.4.1 Hearing Aids and Speech Perception

Hearing aids are designed to increase sound in different frequency regions to ensure that the auditory signals received in the ear are sufficient to compensate for the loss in hearing (Tremblay et al., 2014). The hearing aid alters and amplifies the sound signal. This modified signal is processed in the auditory system. The comprehension of sound relies both on the quality and processing of the signal received by the brain. The brain is therefore essential in the rehabilitation of hearing, and also of cognitive function, as it is responsible for the biological coding, integration and use of the information perceived (Tremblay et al., 2014).

A study by Choi et al. (2011) investigated whether cognitive functions involving speech in background noise could be improved by the use of hearing aids in older adults.

Results indicated that the use of hearing aids in people with hearing loss, positively affected the input of auditory signals into the central auditory system. The authors stated that hearing aids assist the degenerated cognitive function associated with hearing loss.

1.4.2 Hearing Aids and Cognition

Technological advances in hearing aids have focussed on improving the signal-to-noise ratio of speech. A study by Sarampalis et al. (2009) showed that the noise reduction function of hearing aids reduces the cognitive load required to listen to speech. The study showed that additional cognitive resources became available which improved performance on a secondary task. Sarampalis et al. (2009) reported that when study subjects were involved in two simultaneous tasks, a competition for brain resources resulted. The more cognitive demanding task used a greater share of its allocated resources, which decreased what was available for the other task. This was seen through the changes in performance on both tasks. The presence of background noise in the experiments was shown to have a negative effect on listening and cognitive activities. It is posited that people with hearing loss will find it challenging to focus on a conversation in a noisy environment. The authors concluded in saying that the increase in noise-to-sound ratio through hearing aids, not only improves speech intelligibility, but also reduces listening effort (Sarampalis et al., 2009).

If hearing aids are able to reduce listening effort, it can theoretically reduce cognitive overload. Whether this reduction in cognitive overload leads to a reduction in cognitive decline, still remains to be investigated.

1.4.3 Hearing Aids and Mental Health

The mental health benefits of using hearing aids in an older population have been investigated (Acar et al., 2011). Thirty four hearing loss participants over the age of 65 completed a Mini Mental State Exam (MMSE) and Geriatric Depression Scale-short form

(GDS) before receiving hearing aids, and then three months later. All patients displayed significant cognitive and psychosocial improvements after using hearing aids for three months. The authors concluded that hearing aids should be used in elderly people suffering from presbycusis as it improved mental functions and mental state.

A study by Pronk et al. (2013) found that hearing aid use had a protective effect on the loneliness associated with untreated hearing loss. Participants whose hearing continued to decline experienced an increase in loneliness whereas this did not appear in hearing aid participants.

1.5 Summary

Existing literature indicate that untreated ARHL not only affects communication but also cognitive function in older adults (Lin et al., 2014). Hearing loss is independently associated with accelerated cognitive decline and incident dementia (Lin et al., 2013). It is also associated with a reduction in volume in the auditory cortex (Lin et al., 2014). Cognitive areas particularly affected by hearing loss include executive function, and working memory (Baldwin, 2009). Hearing aids have been shown to improve speech in noise (Choi et al., 2011), mental health (Acar et al., 2011) and cognitive load (Sarampalis et al., 2009).

Hearing aids as a means to improve cognitive function in postlingually hearing impaired older adults is still to be further investigated. The present study has been designed to investigate the impact of hearing aids on cognitive function and mental health. Four hypotheses were developed based on the findings of this review:

Hypothesis one**:** Normal hearing participants (NH) will perform significantly better on tests of executive function, working memory and strategy use, verbal recognition memory and sustained attention tasks than hearing aid candidates (HAC).

Hypothesis two**:** NH group will perform significantly better than HAC participants on measures of depression, anxiety and stress.

Hypothesis three: Hearing Aid Users (HAU) will perform significantly better in executive function, working memory and strategy use, verbal recognition and sustained attention tasks than HAC.

Hypothesis four: Hearing Aid Users (HAU) will perform significantly better in depression, anxiety and stress scores after three months of device use.

CHAPTER 2: METHODS

This chapter discusses the methods used to test the hypotheses proposed in the preceding chapter. Ethical approval for this study was obtained from The University of Western Australia Human Ethics Committee. All procedures were undertaken in accordance with this approval.

2.1 Participants

To investigate hypothesis one and two, a group of NH participants and a group of hearing loss participants who were considered hearing aid candidates (HAC) were recruited. For hypothesis three and four, the baseline HAC group was divided into a HAC (still no hearing aid at three months) and first time hearing aid user (HAU) group. This was due to the fact that three participants had not received their hearing aids by the third month and therefore they remained in the HAC category. Nevertheless, the three month HAC data was used as a control group for the HAU. Three groups of participants (normal hearing - NH, hearing aid candidates - HAC, first time hearing aid users - HAU) were therefore recruited for this study through the Lions Hearing Clinics, Subiaco, Western Australia, as well as through local radio advertisements and local newspapers. Each participant received an invitation letter (appendix 1& 2) to participate and an information letter (appendix 3 & 4). Consent forms were signed by all participants prior to taking part in the study (appendix 5). All participants had to adhere to four criteria: i) aged between 45-85 years; ii) native English speakers or have been exposed to Australian English for at least 10 years; iii) never previously worn a hearing aid; and iv) no obvious neurological conditions which could impact completion of the test battery. Demographic details of all three participant groups are summarised in Table 2.

***Table 2**: Demographic Details of the Three Participant Groups*

Description	Number	Mean Age ±SD	Male	Female
Normal Hearing (NH)	8	67.00 ± 4.07	0	8
Hearing Aid Candidates (HAC)	3	69.33 ± 6.81	2	1
First-time Hearing Aid Users (HAU)	6	69.83 ± 4.67	5	1

Prior to taking part in the study, all three participant groups completed a hearing assessment as a part of their standard audiological assessment. The hearing assessments were conducted by a qualified audiologist. The hearing thresholds of the HAC and HAU participants are listed in Table 3. The NH group had bilateral hearing sensitivity thresholds within 20 dBHL across 500 Hz to 8 kHz.

***Table 3:** Hearing Thresholds of Both HAC and HAU Participants.*

				4AFL[1]		**3AHFL[2]**	
0M Group	**3M Group**	**Sex**	**Age**	*Right (dBHL)*	*Left (dBHL)*	*Right (dBHL)*	*Left (dBHL)*
HAC	HAU	M	67	42.50	43.75	85.00	88.33
HAC	HAU	F	70	27.50	26.25	48.33	46.67
HAC	HAU	M	70	46.25	40.00	73.33	70.00
HAC	HAU	M	78	48.75	47.50	76.67	78.33
HAC	HAU	M	64	15.00	36.25	23.33	76.67
HAC	HAU	M	70	25.00	22.50	60.00	45.00
HAC	HAC	F	67	36.25	73.75	30.00	55.00
HAC	HAC	M	64	21.25	20.00	41.67	53.33
HAC	HAC	M	77	26.25	28.75	48.33	55.00

[1] Average Four Frequency Hearing Loss (500Hz, 1 kHz, 2 kHz & 4 kHz)
[2] Average Three High Frequency Hearing Loss (4 kHz, 6 kHz & 8 kHz)

2.2 Equipment and Materials

All three participant groups completed the following assessments:

2.2.1 Depression Anxiety Stress Scale [DASS-21; (Lovibond & Lovibond, 1995)]

DASS-21 is a self-report questionnaire which measures distress along the 3 axes of depression, anxiety and stress. Participants were asked to indicate the presence and severity of depression, anxiety and stress symptoms over the past seven days. Each item on the questionnaire was given a score between 0 and 3 (0: Did not apply to me; 1: Applied to me some of the time; 2: Applied to me to a considerable degree; 3: Applied to me most of the time). Scores from the responses were tallied in the corresponding column of either depression, anxiety, or stress and a total score for depression, anxiety, and stress was obtained (appendix six).

2.2.2 National Adult Reading Test-Revised [NART-R; (Nelson & Willison, 1991)]

This test provides a means of estimating the premorbid intelligence levels of adults suspected of suffering from cognitive decline. The NART-R contains words that minimise the use of common rules of pronunciation. It contains 50 words in order of increasing difficulty. Participants read through the list and errors made were recorded. The NART-R error score is the total number of errors made by the participant (i.e. error score equals 50 minus number of words read correctly). Predicted Verbal IQ = 129- 0.92 (x NART-R error score) is calculated. The verbal IQ score is a predictor for verbal intelligence, and was used as a control the cognition scores generated by the Cambridge Neuropsychological Test Automated Battery (CANTAB) software (see section 3 below).

2.2.3 Cambridge Neuropsychological Test Automated Battery [CANTAB; (Cambridge Cognition, 1996)]

Cognitive functions were assessed using a selection of modules from the Cambridge Neuropsychological Test Automated Battery (CANTAB). Module selection was based on information obtained through the literature review. The modules were chosen to determine if and to what extend aspects of executive function and memory were affected by hearing loss. The software was run on a Dell Inspiron One computer (Windows 8.1, 4 GB RAM, 64bit operating system) with an integrated display which was sensitive to touch. The following modules of the CANTAB test battery were used:

(a) Motor Screening (MOT): Screen for visual, movement and comprehension difficulties. The activity is used to familiarise the participants with the interface. It allows screening for any vision, comprehension or movement problems which can affect the ensuing activities.

(b) Paired Associates Learning (PAL): PAL assessed visual associative learning and memory. Performance in this section is reliant on the temporal lobe, particularly the entorhinal cortex (Owen et al., 1995).

(c) Verbal Recognition Memory (VRM): This task assessed both immediate and delayed memory of verbal information under free recall and forced choice recognition conditions. Recall performance on tests of this type relies on fronto- temporal networks (Fletcher & Henson, 2001), while the recognition phase depends on the hippocampus (Henson et al., 2005).

(d) Rapid Visual Information Processing (RVP): RVP is a continuous performance task, and measures sustained visual attention with a small memory component. Performance of the RVP task has been shown to be associated with activation in brain networks including the frontal and parietal lobes (Coull et al., 1998 & 1996).

(e) Reaction Time (RTI): This task determines working memory capacity by measuring the participant's speed of response to a visual target where the stimulus is either predictable (simple reaction time) or unpredictable (choice reaction time). This activity is based on the 5-choice serial reaction time test (5-CSRT) and tests the frontal/parietal lobe functions (Robbins et al., 2000).

(f) Attention Switching Task (AST): The AST assesses executive function through measuring attentional set- shifting. This activity is designed to measure executive function. Through the comparison of response latencies and errors, a Stroop-like effect can be detected. Trials where both arrow direction and location are congruent, is measured to the trials were they are not congruent. Incongruent tasks place a higher demand on cognitive function. The Stroop test has been shown to activate regions in the frontal cortex (Bench et al., 1993).

(f) Delayed match to Sample (DMS): This task assesses immediate visual matching ability and delayed visual recognition memory matching. The DMS activity is sensitive to changes in the medial temporal lobes, in particular the hippocampus, and frontal lobes (Sahgal & Iversen, 1978). Neuroimaging studies by (Elliott & Dolan, 1999) on primates reported an increased activity in the occipital and parietal cortices for the short delay segments of the DMS task. Temporal and ventrolateral frontal cortices experienced greater activation during the long delay segments of DMS (Elliot and Dolan, 1999). Excision of the temporal lobe in humans in a study by Owen et al. (1995) showed impairment in test of delayed match to sample. Excision of the frontal lobe did not affect DMS in the study.

(g) Spatial Working memory (SWM): This task measures the ability of the participant to retain spatial information for manipulation in the working memory. The task measures heuristic strategy due to its self-ordered nature. Changes in the prefrontal cortex, in particular the

dorsolateral prefrontal cortex, will impair the participants' ability to perform this task (Owen et al.,1990).

2.3 Procedure

Participants attended two test sessions, three months apart. Each test session lasted approximately 1.5 hours. The participants were given breaks to avoid fatigue. All assessments were conducted by a trained researcher. Participants completed the assessments in the following order:

2.3.1 DASS-21 Questionnaire

Participants were asked to go through the 21 questions listed on the questionnaire and circle the most appropriate response. Results were tallied from the responses to produce an overall score in each category of depression, anxiety, and stress.

2.3.2 NART-R

Participants were given a folder containing 50 words with increasing difficulty. One word was listed per page in large font. The participants were asked to read each word aloud at their own pace. They were told that not all words will be familiar, but to try to read them in any case. A score of one point was given for each correct response.

2.3.3 CANTAB

Participants were asked to refrain from drinking caffeine for at least an hour before the testing. The participants were asked to use the index finger of their dominant hand to select the correct response on the touch screen computer. All instructions were given as provided in the CANTAB training manual (Cambridge Cognition, 2004). The participants were given both verbal and written instructions to accompany each test, and specific verbal and written prompts and encouragement were used where indicated. Testing was conducted

in a quiet room with only the participant and researcher. The participants completed the following modules of the CANTAB test battery:

(a) Motor Screening (MOT): A flashing cross appeared in any location on the screen. The participants were asked to tap the middle of the cross (Fig 2). The activity is particularly useful to familiarise the older participants with the touch screen interface. The data from this activity was therefore neither measured nor used.

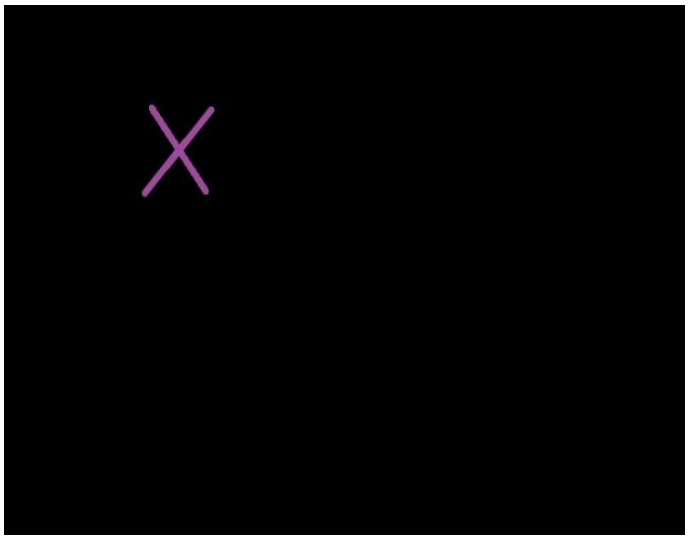

Figure 2: *The MOT screening test.*

(b) Paired Associates Learning (PAL): Six white boxes appeared on the screen with each box opening in a random order. Some or all of the boxes contained a pattern. The participants were required to remember which pattern belonged in which box. A pattern would appear in the middle of the screen and the participants were asked to assign it to the box they thought it belonged to (Fig 3). The program derived a score by measuring the amount of errors made, how many trails were required to allocate the patterns correctly, and how many stages were completed successfully. The total number of errors made was recorded by the software.

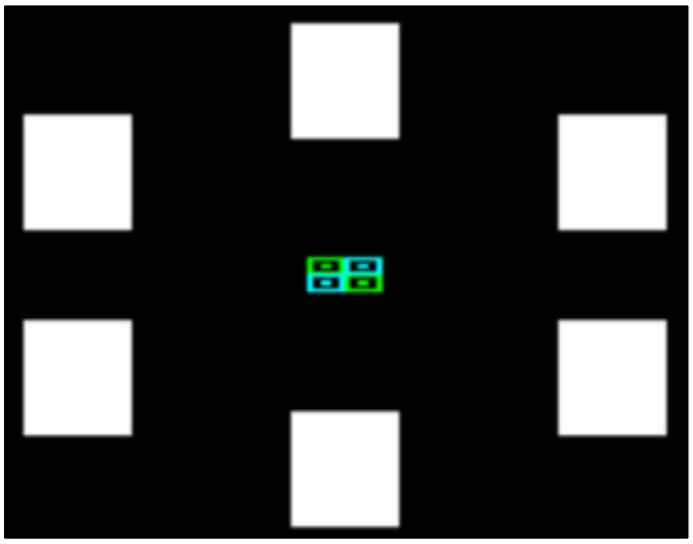

Figure 3: *The PAL test screen showing a pattern in the middle.*

(c)Verbal Recognition Memory (VRM): A list of words appeared on the screen, one after the other. The participants were required to read each word aloud and try to remember it (Fig 4). The participants were not required to remember the order in which the words appeared.

Figure 4: *The VRM presentation phase with words.*

At the end of the list of words, the participants were asked to recall as many words as possible (free recall). In the recognition phase, words appeared on the screen one by one, and the participants were instructed to tap on the 'yes' button if the word was from the previous

list, and 'no' if it was not (Fig 5). This segment was repeated 20 minutes later. The numbers of words correctly recalled and recognised were recorded by the software.

Figure 5: *The VRM recognition phase (and delayed recognition phase) screen with words.*

(d) Rapid Visual Information Processing (RVP): Random digits between one and nine appeared one at a time on the screen. The participants' task was to look for the sequence 3-5-7 in that order and tap a button on the bottom of the screen every time the sequence appeared (Fig 6). In the practice trail, participants received sound feedback on the correct identification of the sequence and if they responded within a given time frame. As the test phase progressed, the participants were also required to look for the sequences 2-4-6 and 4-6-8, in addition to 3-5-7. The target sequences remained on the right hand corner of the screen. The total administration time for this test is seven minutes and therefore required sustained attention. The target detection score (RVP A') and time taken to respond (RVP latency) were recorded by the software.

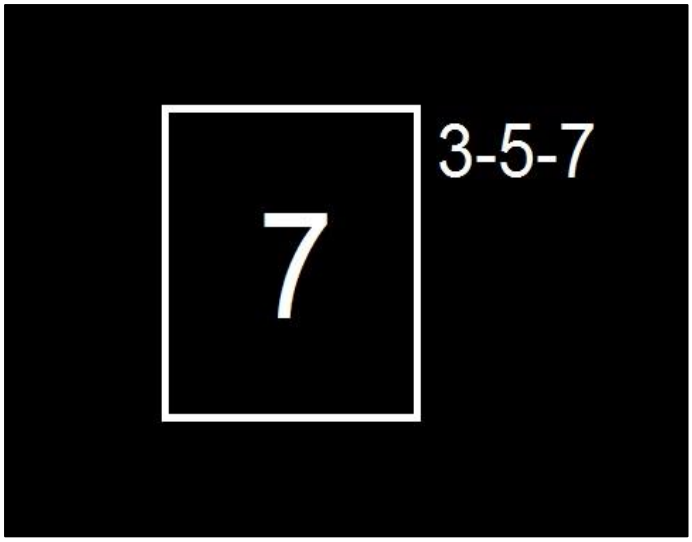

Figure 6: *RVP A' test screen with the sequence 3-5-7.*

(e) Reaction Time (RTI): This test was conducted in two phases. During the first phase, participants were required to press and hold the allocated pad on the bottom of the screen (resting position). When a yellow spot appear inside the white circle on the touch screen, the participants needed to release the pad and touch inside the white circle (Fig 7). The participants were then required to return to the resting position and wait for the yellow spot to flash again. In the second phase, five white circles appeared on the screen (Fig 8). The yellow spot could appear in any of the white circles. The participant's task was to tap in the circle in which the yellow spot appeared and return to resting position. RTI measured speed of responses and movement in single and five choice paradigms. The reaction time (to release pad) and movement time (pad to circle) in the both single and five choice paradigm were recorded.

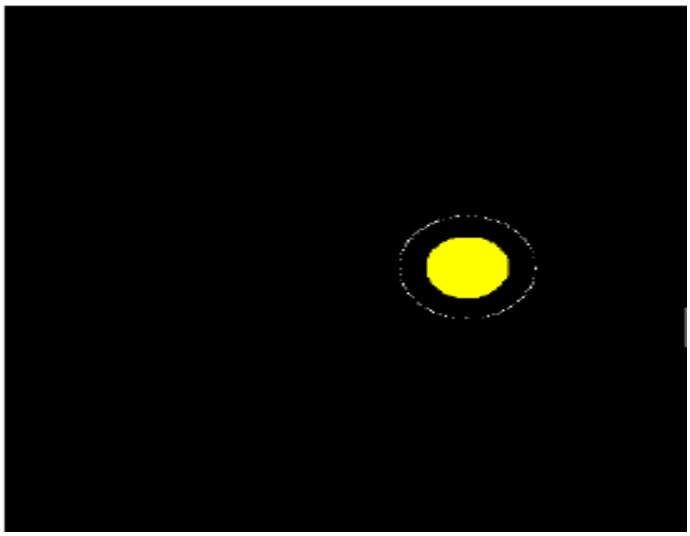

Figure 7: *The RTI task screen for the single-choice stage of the RTI test.*

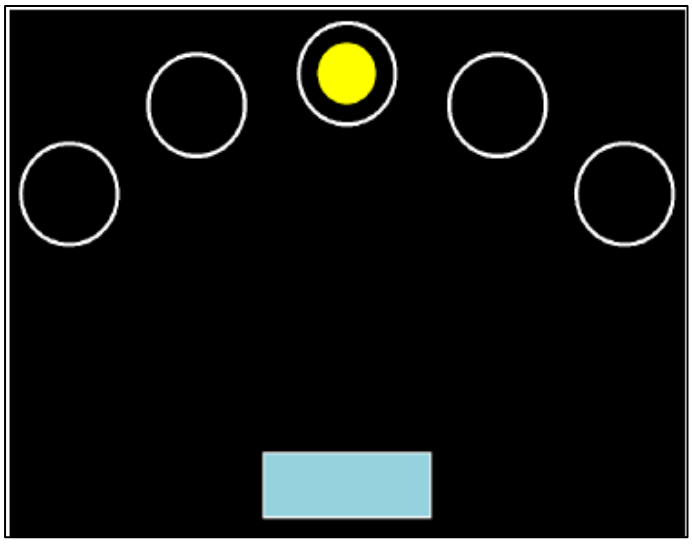

Figure 8: *The RTI task screen for the five-choice stage of the RTI test.*

(f) Attention Switching Task (AST): This task had three parts. In the first part, an arrow appeared on the screen either pointing to the left or to the right. The instruction: "Which DIRECTION" appeared in the top of the screen. The participants were instructed to press the appropriate button for the direction of the arrow (If arrow points left, press left button and vice versa) (Fig 9). In the second part of the test, the instruction "Which SIDE" appeared in the top of the screen. The participants were instructed to ignore the direction of the arrow and press the button that suits the side of the arrow (if arrow is on right side of screen, press right

button). In the last segment, the participants saw a combination of the stimuli that appeared on the first two segments. The instructions could either ask for side or direction of the arrow and the participants were required to read the instructions and respond appropriately. Response latencies (congruent and incongruent) were recorded for each participant.

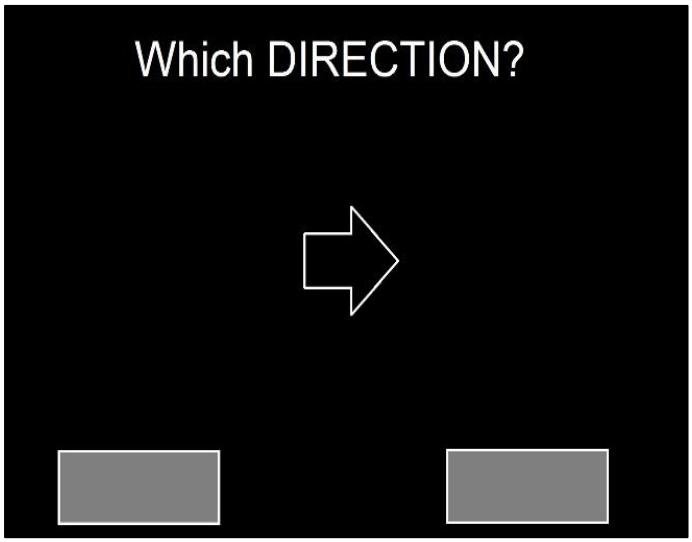

Figure 9: *AST task screen.*

(g) Delayed match to Sample (DMS): A sample pattern appeared in the middle of the screen with four other patterns at the bottom of the screen. One of the four patterns at the bottom of the screen matched to the sample pattern in the middle of the screen (Figure 10). The participant's task was to select one of the four patterns that matched the sample pattern. The patterns were complex in terms of both colour and shape. Each pattern contained four sub elements of different colours. One option was identical to the sample pattern, one was a distraction (novel), one had the shape of the distractor and the colour of the sample, the final option was the reverse. All options had one common quadrant which discouraged encoding strategies. The sample pattern either remained visible (simultaneous trial) whilst the four options were displayed, or disappeared before the four options were made available. The delay between the sample pattern and four options varied in time (0, 4 or 12 seconds). The

signal detection theory was used to measure the probability of an error after a response (correct or incorrect). The percentage of correct responses/matches and the time taken to identify the matching patterns were recorded (Sahgal & Iversen, 1978).

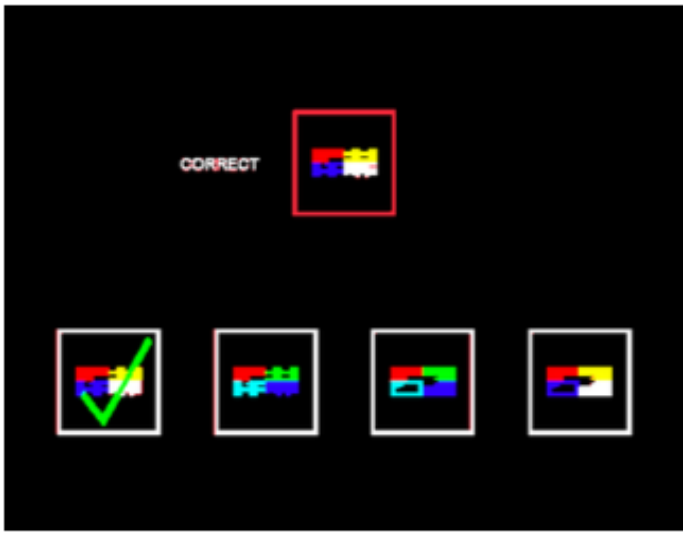

Figure 10: *DMS test screen.*

(h) Spatial Working memory (SWM): A set of coloured boxes appeared on the screen. The participant's task was to find a blue 'token' hidden in of the coloured boxes through the process of elimination and to use the blue tokens to fill up an empty column on the right hand side of the screen (Fig 11). The number of coloured boxes gradually increased from three to eight. The colour and position of the boxes were changed from trial to trial to discourage the use of stereotyped search strategies. The program obtained a score by measuring how many times a participant revisits a box that either has already contained a blue token, or had already been opened and found to be empty in the same segment. The blue tokens were automatically relocated for each test segment, this allows for repeated testing. Strategy use by the participants was recorded by CANTAB as proposed by Owen et al. 1990.

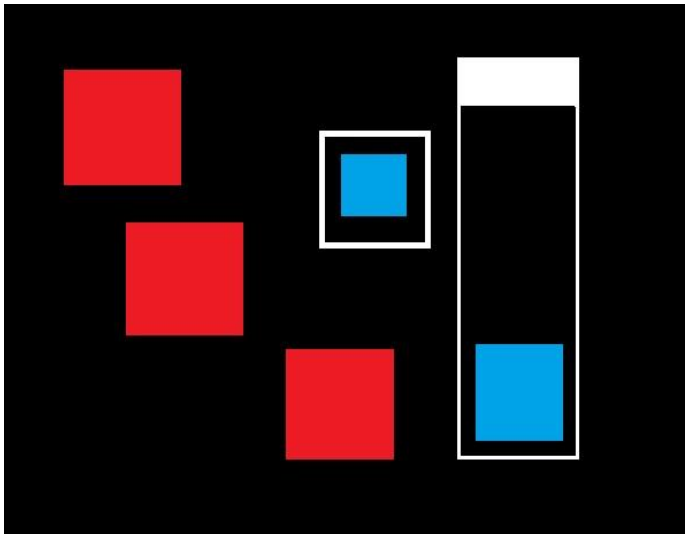

Figure 11: *SWM test screen with three coloured boxes.*

2.4 Statistical analysis

The NART score for each participant was entered into the CANTAB system to control for cognition scores of verbal intelligence. The adjusted scores were exported from the CANTAB system for analysis.

Mean DASS-21 scores were compared between groups through use of the Mann Whitney U non- parametric t-test (IBM SPSS, V.21; IBM Corporation, NY, USA).

CANTAB modules were measured in different units. The non-parametric Mann Whitney U test was used to compare results between the NH and both hearing impaired groups (HAC and HAU) at baseline. Changes at three months were analysed by Wilcoxon Signed Rank test as the data was non-parametric.

SPSS v21 (IBM Corporation, NY, USA) was used for the statistical analysis.

CHAPTER 3: RESULTS

3.1 Hypothesis 1: A significant difference will be observed between NH and HAC on tests of executive function, working memory and strategy use, verbal recognition and sustained attention tasks as measured by the CANTAB test battery.

To test Hypothesis one, mean scores obtained by NH (n =8; M = 67.00 ± 4.07) and HAC groups (n = 9; M = 69.66 ± 4.67) at the baseline for the seven CANTAB test modules [(Paired Associates Learning (PAL), Verbal Recognition Memory (VRM), Rapid Visual Information Processing (RVP), Reaction Time (RTI), Attention Switching Task (AST), Delayed match to Sample (DMS) and Spatial Working memory (SWM)] were compared. The means (*M*) and standard errors (*SE*) of the raw scores for both participant groups are summarised in Table 4.

Table 4: *Baseline CANTAB Scores of NH and HAC participants.*

	NH		**HAC**		
Test	*M*	*SE*	*M*	*SE*	*p value*
PAL Total Errors	37.75	10.85	51.67	9.37	0.321
VRM Free Recall	8.63	0.60	6.67	0.85	0.114
VRM Recog (immediate) *(msec)*	23.25	0.31	22.22	0.62	0.321
VRM Recog (delayed) *(msec)*	23.38	0.38	22.33	0.47	0.059
RVP A'	0.89	0.01	0.91	0.01	0.277
RVP Latency (msec)	578.93	26.92	537.70	29.92	0.277
RTI Five-choice Reaction Time	357.75	14.81	344.06	10.58	0.321
RTI Five-choice Movement Time	365.68	14.32	353.24	10.08	0.423
AST Latency (congruent) *(msec)*	977.32	23.59	800.14	43.90	0.002*
AST Latency (incongruent) *(msec)*	1053.73	27.59	869.53	45.34	0.004*
DMS Delays *(%)* correct	90.83	3.07	70.37	5.00	0.006*
SWM Strategy	34.38	1.43	33.11	2.23	1.000

Note: $p < 0.05$ values are marked with (*).

A nonparametric Mann Whitney U test was conducted to compare the baseline scores between both participant groups on all seven CANTAB test modules. No significant difference was observed between NH and HAC participant groups on PAL total errors, VRM immediate or delayed recognition, RVP A', RVP latency, RTI-five choice reaction time, RTI-five choice movement time, and SWM strategy. A significant difference was observed between NH and HAC groups for AST congruent (U = 6, Z = -2.887, p = 0.002) (Fig 12) and incongruent (U = 7, Z = -2.791, p = 0.004) (Fig 13) and DMS tasks (U = 8.5, Z = -2.689, p = 0.006) (Fig 14).

Attention switching task (AST)

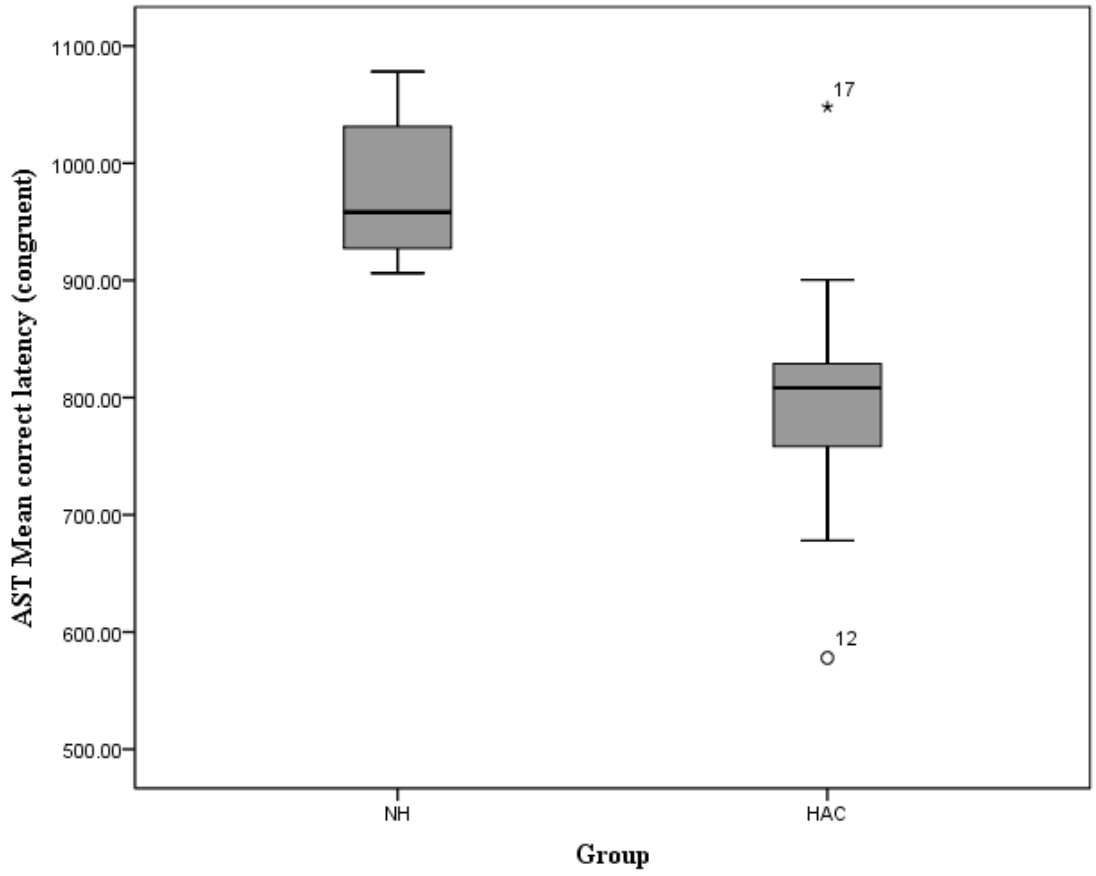

Figure 12: *Boxplot representation of the difference between NH and HAC in the test of AST Congruent. HAC responded quicker. The data shown are medians (thick horizontal line), 50% observations (boxes), range (whiskers) and outliers (open circles).*

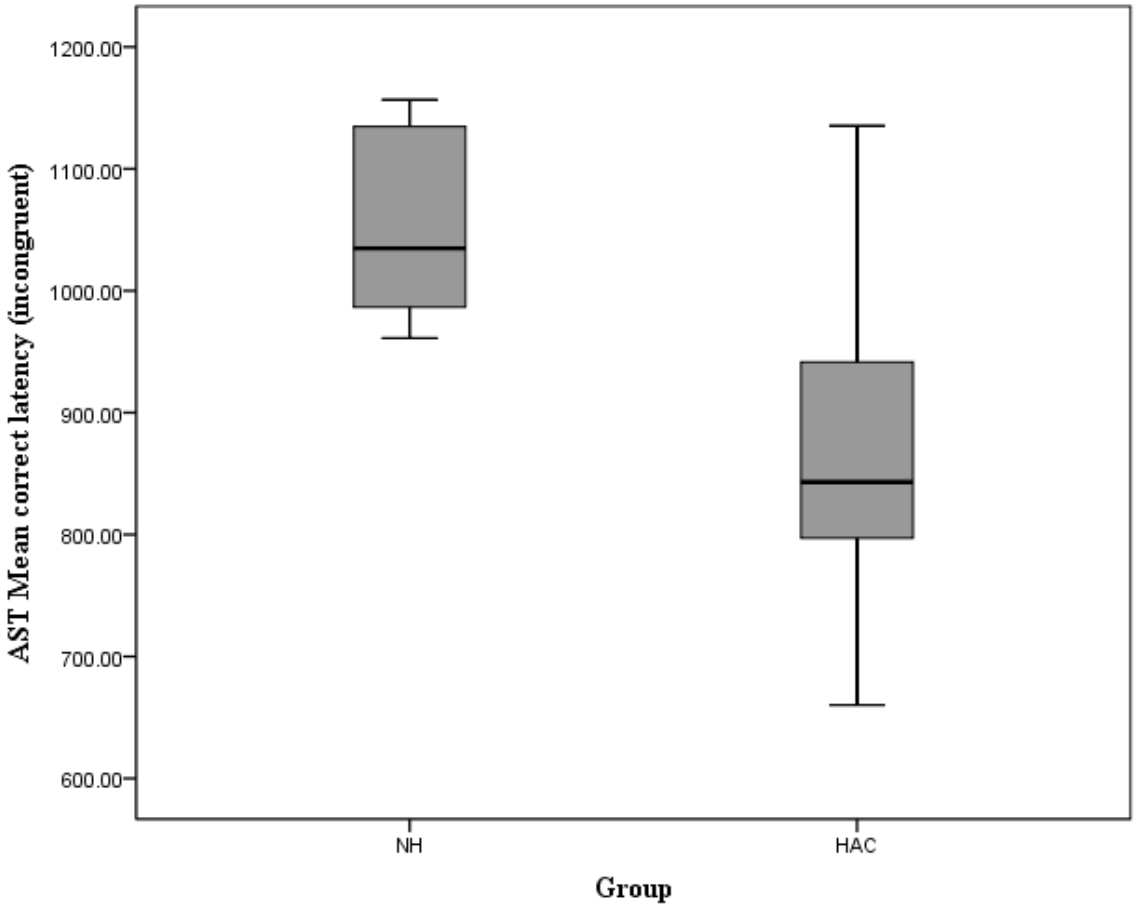

Figure 13: *Boxplot representation of the difference between NH and HAC in the test of AST Incongruent. HAC responded quicker. The data shown are medians (thick horizontal line), 50% observations (boxes), range (whiskers) and outliers (open circles).*

Delayed match to Sample (DMS)

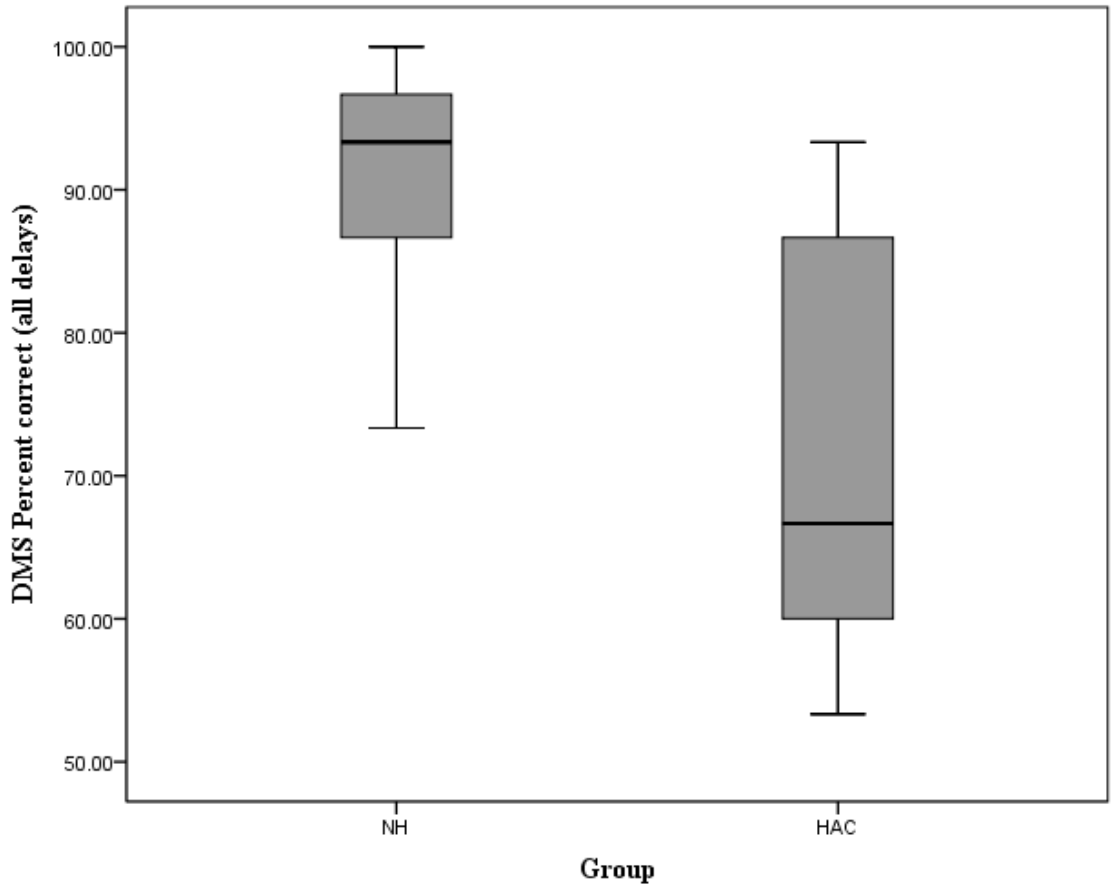

Figure 14: *Boxplot representation of the difference between NH and HAC in the test of DMS delays. HAC had less correct matches. The data shown are medians (thick horizontal line), 50% observations (boxes), range (whiskers) and outliers (open circles).*

3.2 Hypothesis 2: A significant difference will observed between NH and HAC on depression, anxiety and stress scores as measured by DASS-21.

To test Hypothesis two, difference in 0 to 3 months scores obtained by NH (n =8; M = 67.00 ± 4.07) and HAC groups (n = 9; M = 69.66 ± 4.67) for DASS-21 were compared. The means and standard errors of the raw scores for both participant groups are summarised in Table 5.

Table 5: *DASS-21 Baseline Scores for NH and HAC Participants.*

	NH		**HAC**		
Test	*M*	*SE*	*M*	*SE*	*p value*
Depression	0.63	0.32	2.78	1.01	0.046*
Anxiety	2.13	0.40	2.56	1.18	0.481
Stress	2.00	0.65	5.22	0.94	0.021*

Note: $p < 0.05$ values are marked with (*).

A significant difference was found between NH and HAC groups for depression (U = 56.50, Z = 2.060, $p = 0.046$) (Fig 15) and stress (U = 60, Z = 2.237, $p = 0.021$) scores (Fig 16). No significant difference was found between the NH and HAC groups for anxiety scores.

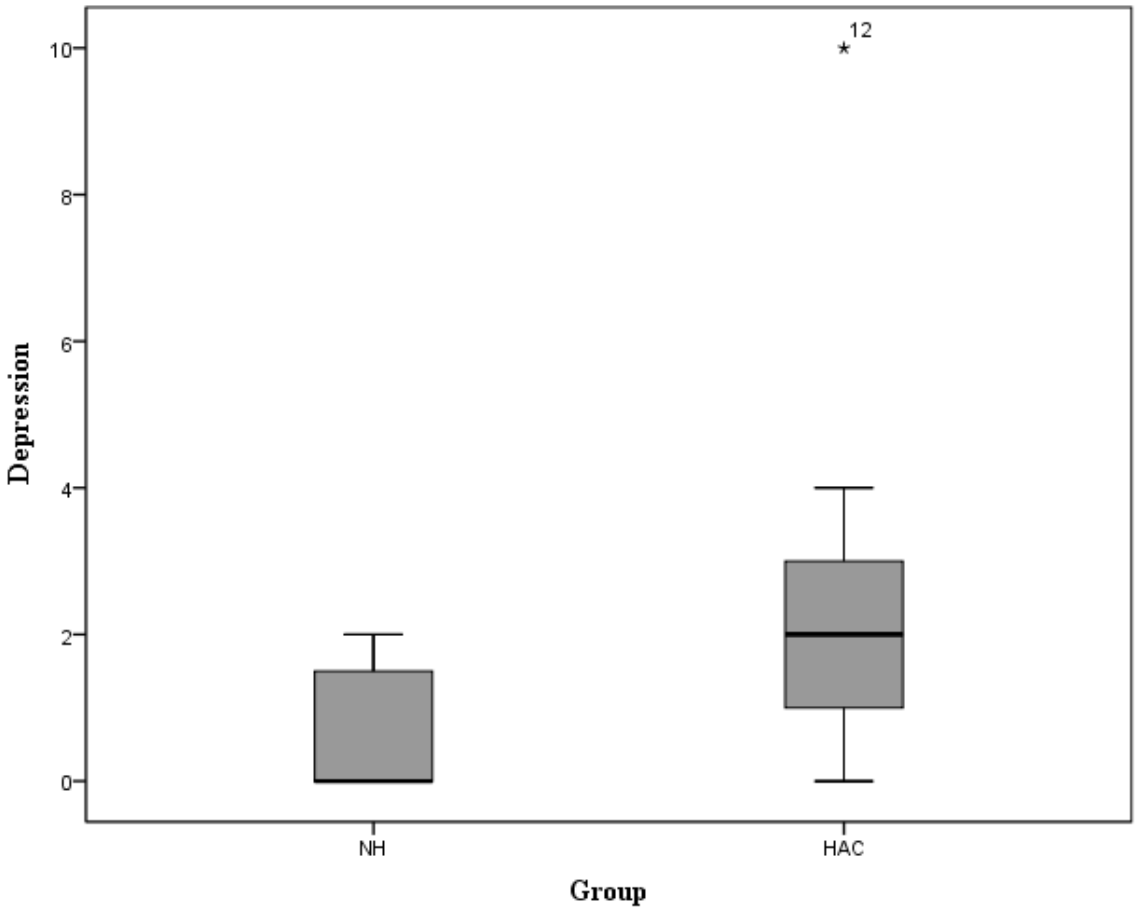

Figure 15: *Boxplot representation of the difference between NH and HAC in Depression Scores. HAC displayed higher scores. The data shown are medians (thick horizontal line), 50% observations (boxes), range (whiskers) and outliers (open circles).*

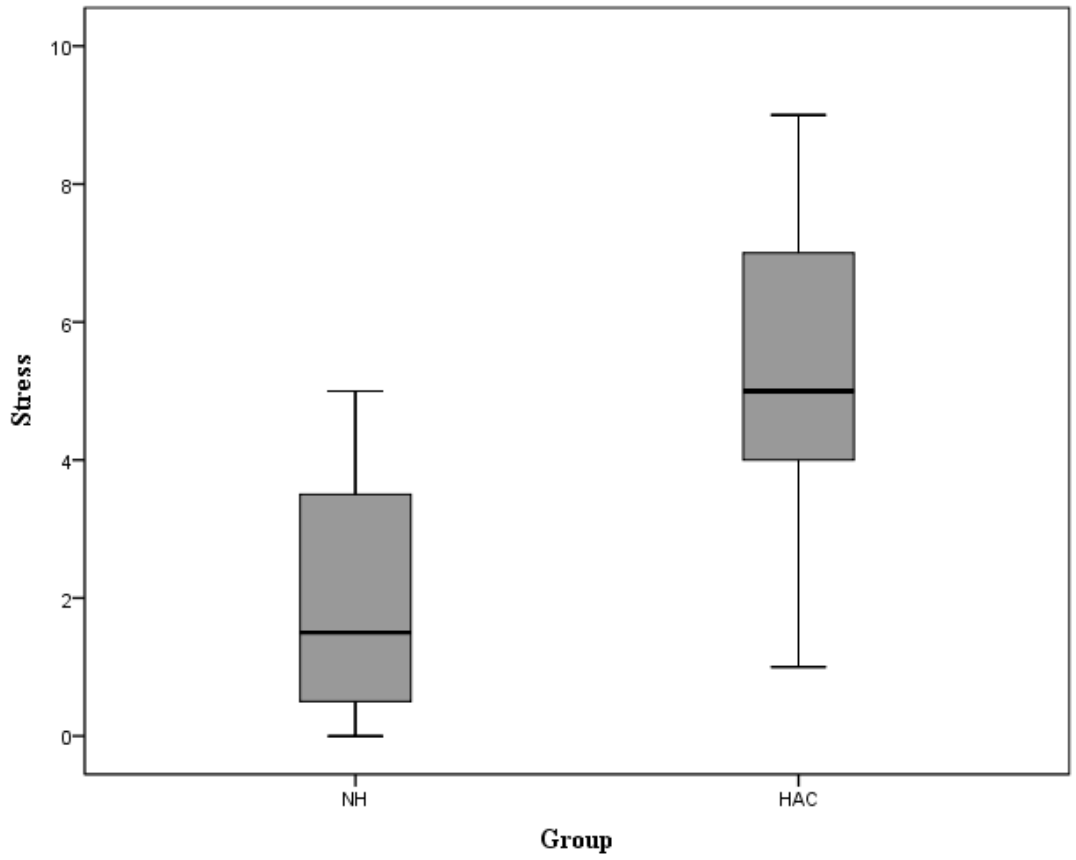

Figure 16: *Boxplot representation of the difference between NH and HAC in Stress scores. HAC displayed higher scores. The data shown are medians (thick horizontal line), 50% observations (boxes), range (whiskers) and outliers (open circles).*

3.3 Hypothesis 3: Hearing Aids will significantly improve the performance in executive function, working memory and strategy use, verbal recognition and sustained attention tasks after three months of using the device in HAU.

To test Hypothesis three, difference in mean scores at baseline and three months for the seven CANTAB test modules obtained by HAU (n = 6; M = 69.83 ± 4.67) and HAC group (n = 3; M = 69.33 ± 6.81) were compared. The means (M) and standard errors (SE) of the raw scores for both participant groups are summarised in Table 6. A nonparametric Wilcoxon Ranked Sign Test was conducted to compare 0 to 3 months differences between HAU and HAC participant groups on all seven CANTAB tests. No significant 0 to 3 months difference was observed between HAU and HAC participant groups on PAL total errors,

VRM immediate or delayed recognition, RVP A', RTI-five choice reaction time and movement time, AST congruent or incongruent, DMS correct or SWM strategy.

Table 6: *CANTAB Scores Obtained by HAC and HAU Participants at 0 and 3 months.*

	HAU				HAC			
	0 Months		3 Months		0 Months		3 Months	
	M	*SE.*	*M*	*SE*	*M*	*SE*	*M*	*SE.*
PAL errors	35.80	7.91	46.00	14.47	40.33	21.40	62.00	12.12
VRM Free recall	7.40	0.60	6.40	0.68	7.33	2.73	5.67	2.33
VRM Recog (immediate)	22.60	0.98	22.00	0.89	22.33	1.20	22.33	1.20
VRM Recog (delayed)	23.20	0.37	22.20	0.66	23.00	0.58	21.67	1.33
RVP A'	0.91	0.02	0.95	0.01	0.90	0.03	0.91	0.00
RVP latency (*msec*)	513.20	17.48	556.59	71.16	447.43	45.15	600.87	49.71
RTI reaction (*msec*)	344.40	20.52	333.50	5.22	351.50	31.59	359.33	7.69
RTI movement (*msec*)	361.07	25.90	339.52	5.31	361.27	28.53	372.05	13.45
AST congruent (*msec*)	833.98	32.66	752.19	30.22	728.76	42.60	863.93	52.05
AST incongruent (*msec*)	885.89	55.38	809.85	25.15	844.20	61.56	966.46	26.17
DMS Delay (%)	85.33	5.33	77.33	6.18	80.00	13.88	62.22	5.88
SWM Strategy	35.60	1.29	33.40	2.20	35.67	0.33	37.67	1.45

3.4 Hypothesis 4: Hearing Aids will significantly improve depression, anxiety and stress scores after three months of device use in HAU.

To test Hypothesis four, mean scores obtained by HAU (n = 6; M = 69.83 ± 4.67) and HAC group (n = 3; M = 69.33 ± 6.81) at baseline and three months for depression, anxiety and stress were compared. The means and standard errors of the raw scores for both

participant groups are summarised in Table 7. DASS-21 scores did not significantly change in either group after three months.

Table 7: *Depression, Anxiety and Stress Scores Obtained by HAC and HAU Participants at 0 and 3 months.*

Test	HAC				HAU			
	0 Months		3 Months		0 Months		3 Months	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Depression	2.80	1.85	2.60	1.08	2.33	0.67	1.33	0.33
Anxiety	3.60	2.04	2.20	0.73	1.33	0.88	0.33	0.33
Stress	4.60	1.29	3.80	0.80	6.00	2.08	4.33	2.19

3.5 Correlations

A Pearson product-moment correlation coefficient was computed to assess the relationship between the age, NART, depression, anxiety and stress scores and AST, DMS, PAL RTI, VRM and, SWM scores of the baseline HAC group. Age did not significantly correlate with any test module in the CANTAB test battery. A significant positive correlation was observed between NART and VRM Recognition (delayed) scores ($r = 0.743$, $p = 0.022$). A significant positive correlation was observed between NART and SWM strategy ($r = 0.752$, $p = 0.019$). A significant positive correlation was observed between depression and anxiety ($r = 0.747$, $p = 0.021$) and between depression and stress ($r = 0.723$, $p = 0.028$).

CHAPTER FOUR: DISCUSSION

This chapter critically evaluates the methods and results presented in the preceding chapters. It also discusses the limitations of the study and provides suggestions for future directions.

4.1 Hypothesis 1: A significant difference will observed NH and HAC on tests of executive function, working memory and strategy use, verbal recognition and sustained attention tasks as measured by the CANTAB test battery.

A significant difference ($p < 0.05$) was found between the NH and HAC groups for the AST and DMS tasks. However, no significant difference was found between NH and HAC groups for visual associative learning (PAL), free recall and recognition memory (VRM), sustained visual attention (RVP), reaction time (RTI), movement time (RTI), and information retention for use in the working memory (SWM) tasks. Hence, hypothesis one was partially accepted in this study.

The AST measures the participants' executive function through attentional set-shifting (Cognition, 1996). AST is based on the Stroop test and relies heavily on the functions of the frontal lobes (Bench et al., 1993). For both AST- congruent and incongruent modules of this task, the HAC group showed a shorter latency than the NH group. The HAC participants therefore responded faster than the NH participants. Similar findings have been reported by Rothpletz et al. (2003). This observation can be explained based on communication characteristics of hearing impaired individuals. For effective communication, hearing impaired individuals rely more heavily on visual cues such as facial expression and lip reading than their normal hearing counterparts (Heming & Brown, 2005). Based on our current findings, it is posited that participants with a mild-moderate sensorineural hearing loss allocate their visual resources more efficiently than those with normal hearing.

The DMS task measures the participant's delayed recognition memory. Delayed recognition memory is reported to be sensitive to the temporal lobe functions (Owen et al., 1995). In this study, the HAC group performed significantly poorer than the NH group. These results agree with Lin's et al. (2011) study, in which he found hearing impaired participants performed poorer on visual memory tests than normal hearing participants. The Free and Cued Selective Reminding test (FCSRT) was used by Lin et al. (2011). The FCSRT is considered to be sensitive to the changes in the temporal lobe (Fletcher & Henson, 2001). Owen et al. (1995) showed that performance in the delay segment of DMS is also reliant on the temporal lobe. These results suggest that mild-moderate sensorineural hearing loss impacts delayed recognition memory function, particularly if mediated through the temporal lobe.

Lack of significant differences obtained in the test of verbal recognition memory (VRM free recall and recognition) did not agree with the findings by Lin et al. (2011) in the Baltimore longitudinal study of ageing. Their study found that hearing loss was significantly associated with lower scores in test of memory (Free Recall). The FCSRT was used by Lin et al. (2011) instead of VRM. The FCSRT is sensitive to changes in the temporal lobe whereas VRM is sensitive to the frontal and temporal lobe (Fletcher & Henson, 2001). If the frontal lobe is implicated in tests of memory, hearing loss does not appear to have an influence. It is suggested that delayed recall memory pertaining to the temporal lobe (FCSRT) is affected rather than verbal recognition memory from the frontal lobe (VRM test). These results can also be explained through correlation analysis results. In our study, the NART score significantly and strongly correlated with recognition (delayed) of VRM at the 0.022 level. An increased verbal IQ predicted a higher VRM score in both recall and recognition phase.

This study's data suggest that mild-moderate sensorineural hearing loss does not affect sustained visual attention (RVP). Similar findings have been reported by Zekveld et al.

(2007). Lack of significant difference observed between NH and HAC group for the visual associative learning (PAL), free recall and recognition memory (VRM), sustained visual attention (RVP), reaction time (RTI), movement time (RTI), and information retention for use in the working memory (SWM) are suggestive that mild- moderate sensorineural hearing loss does not affect all aspects of cognition.

4.2 Hypothesis 2: NH group will perform significantly better than HAC participants on measures of depression, anxiety and stress.

This hypothesis was partially supported by the results of this study. Depression, anxiety, and stress were measured through the use of the DASS-21 questionnaire. A significant difference ($p = 0.046$) was found between NH and HAC groups for depression. It should be noted that even though the HAC group had a significantly higher score for depression, it was still within the range considered as 'normal' for DASS-21 scores. Although mild to moderate hearing loss does not significantly affect depression scores, significant difference in scores observed between two participants groups suggest that hearing impaired participants are at a risk of developing depression compared to NH participants. Strawbridge et al. (2000) reported that participants with moderate or higher hearing loss were twice as likely to suffer from depression. In line with the findings observed in the current study, participants with a mild hearing loss did not have an impact on depression in Strawbridge et al. (2000)'s study. Mild presbycusis does not appear to cause depression; however, we propose that it increases the risk for depression.

A significant difference ($p = 0.021$) was found between NH ($M = 2.00 \pm 0.65$) and HAC ($M = 5.22 \pm 0.94$) for stress. Although a significant difference is observed between these groups, the HAC score is still within the normal range for the DASS-21 questionnaire.

Stress was strongly and significantly correlated with depression [(r (8) = 0.723 p = 0.028)].Stress therefore interacts with depression.

No significant difference in anxiety was found between NH and HAC. Hearing loss does not appear to influence anxiety.

Anxiety had a strong [r (8) = 0.747)] and significant (p = 0.021) correlation with depression. A study by Tambs (2004) found similar results. Their study included an older population with mild- moderate hearing loss in the high frequencies. These results can be compared based on the similarities in participant groups. No study has investigated the impact of presbycusis on depression, anxiety and stress to date. We can posit that mild presbycusis elevates the risk for depression and stress.

4.3 Hypothesis 3: Hearing Aids will significantly improve the performance in executive function, working memory and strategy use, verbal recognition and sustained attention tasks after three months of using the device in HAU.

This hypothesis was not supported by this study. The HAC and HAU groups did not differ significantly in tests of: visual associative learning (PAL), free recall and recognition memory (VRM), sustained visual attention (RVP), reaction time (RTI), executive function – congruent and incongruent (AST), immediate visual matching ability and delayed visual recognition memory matching (DMS), and information retention for use in the working memory (SWM).

The use of hearing aids did not significantly impact VRM after 3 months. The study by Choi et al. (2011) used a test where verbal information is visually presented. This is similar to the VRM is its two phase approach (free recall and recognition). The study found that the use of hearing aids significantly improved the free recall and recognition of the given information after six months. As the study comprised of older participants, (M = 69.5 ± 8.3

years) which is comparable to our study ($M = 69.83 \pm 4.67$), and follows the same testing concept. Hence, it is suggest that testing our participants at six months or later may produce different results.

The HAU did not perform significantly better in SWM task after three months. The study by Zekveld et al. (2007) did not find that the use of hearing aids improves SWM strategy. The study did however have a much wider age range (18-80 years of age) and results can therefore not be correlated to our study. To begin with there was no significant difference between HAC and NH groups at baseline, this could explain the lack of improvement observed in the HAU group after three months of hearing aid use. In our study, HAC participants' NART score significantly and strongly with the ability of the participant to recognise words after a delay in VRM. Increased NART resulted more words being correctly identified.

A significant difference was observed between NH and HAC in the test of delayed match to sample (DMS) at baseline. We therefore anticipated that hearing aids would improve DMS scores. However, HAU participants failed to show any significant improvement in DMS scores after using hearing aids for three months. No other studies have investigated the use of hearing aids as a means to improve cognitive functions mediated through the temporal lobe. However, three months is unlikely to be sufficient to allow for acclimatisation in the auditory system (Willott, 1996). Testing at the six and twelve months may produce different results. Additionally, this study had a small sample size, making it difficult to generalise the findings to the overall population.

The impact of hearing aids on cognition was measured by Lin et al. (2011) using the Digit Symbol Substitution Test (DSST) which is a nonverbal test of psychomotor speed and executive function (Wechsler, 1997). The use of hearing aids was significantly associated

with a higher score of DSST even after adjustment for age, sex, race, education and hearing loss severity. The study had a small number of participants *(n* =13) and did not specifically state that the participants were first time HAU.

A few factors could have contributed to the lack of significant improvement observed in the HAU group in PAL, VRM, RVP, RTI, AST, DMS, and SWM after three months of hearing aid use. The HAU sample size was very small, and those recruited may not represent the population. Tonotopic organization of auditory system undergoes changes following a hearing loss, hence, acclimatisation process takes more than few months for the first time hearing aid users (Willott, 1996). A study by Choi et al. (2011) reported that acclimatisation of the CAS is induced by the use of hearing aids, however, would take up to six months. As the participants in this study were first time hearing aid users, more changes in the above mentioned cognitive functions may be observed after six months of hearing aid use. Furthermore, details on hearing aid use e.g. number of hours HAU group used their hearing aids per day, was not recorded in this study. If participants did not use their hearing aids consistently, the hypothesised changes in cognitive function could not be expected.

4.4 Hypothesis 4: Hearing Aids will significantly improve depression, anxiety and stress scores after three months of device use in HAU.

This hypothesis was not supported by the results of this study. The use of hearing aids did not significantly impact depression, anxiety or stress of the HAU group after three months of hearing aid use. The HAC group did not change significantly after three months either, as should be expected. A cross sectional study by Dawes et al. (2015) found no association between depression and the use of hearing aids. The authors did find that hearing aids were associated with better cognition, but that this relationship was independent of depression. It therefore suggests that any improvements by hearing aids are due to cognitive

factors, rather than removal of the negative mental health impacts of hearing loss. Dawes et al. (2015)

A study by Andersson and Green (1995) used the Beck Anxiety Inventory (BAI) to investigate the impact of hearing aid wear on anxiety in an older age group. Anxiety scores did not correlate with baseline audiometry pure tone thresholds. It did however correlate (r =.31) with self-reported hearing problems. All participants (n = 42, M = 70.60 ± 2.90) had worn hearing aids (M duration = 3.2yrs). Perceived anxiety was more related to self-report hearing problems rather than audiometry pure tone thresholds. The study did, however, only consider a pure tone average in the lower frequencies (0.5, 1, 2, and 3 kHz) whereas this present study specifically focused at presbycusis in the higher frequencies (4, 6 and 8 kHz). These results should therefore be compared with caution.

4.5 Limitations of the study

This study was subject to a number of limitations:

4.5.1. Participants: Small sample size had a significant impact on statistical analysis and interpretation of the results of the study. The study initially recruited a larger group [NH (n =31); HAC (n =12)]. Participants were excluded due to medical reasons, or if they could not successfully and easily complete MOT. Some participants had previously worn hearing aids and were therefore excluded from the study. Recruiting hearing aid candidates proved to be challenging, as fewer than expected people were identified as potential participants, and not all of these made themselves available to the study. In addition, three participants in the HAC group had not received their hearing aids three months into the study, and therefore remained in the HAC group. Details on number of hours hearing aids were worn, was not recorded.

4.5.2. Timeline: Due to constraints of an Honours project, the HAU group could only be tested after three months of using their devices. A longer follow up period may show significant changes in cognition, depression, anxiety and stress.

4.6 Suggestions for future research

1. Recruiting participants from a larger group of hearing clinics will increase the sample size, and the statistical power of the study.

2. Potential participants should be screened e.g. via a telephone interview, before an appointment is made to identify conditions which might make them ineligible for the study (i.e. worn hearing aids before).

3. Assessments of hearing aids users should be made over a longer follow up period to allow better acclimatisation to occur in the auditory system.

4. Collection of data on hearing aid use, including satisfaction with hearing aids and quality of life.

4.7 Clinical Implications

This study has identified a number of items that have clinical implications. The following may help to provide better patient care for the older adults with a hearing loss. Firstly, presbycusis increases the risk for depression and stress. It is therefore important that presbycusis is managed not only from an audiological point of view, but also form a mental health point of view. Secondly, presbycusis affects cognitive tests of memory. It is important that cognitive functions are considered as part of the diagnosis and management plan. Hearing aid users might require further training and information to use their hearing aids effectively and extensively.

REFERENCES

Australian Bureau of Statistics. (2012). *Population Projections, Australia, 2012 (base) to 2101*. (3222.0). Canberra.

Acar, B., Yurekli, M. F., Babademez, M. A., Karabulut, H., & Karasen, R. M. (2011). Effects of hearing aids on cognitive functions and depressive signs in elderly people.*Archives of Gerontology and Geriatrics, 52*(3), 250-252.

American Geriatric Society. (2002). Geriatrics Review Syllabus, 5th Ed., Vols. 1-3 (Vol. 26, pp. 98): Ringgold, Inc. New York, USA

Anderson, S., White-Schwoch, T., Parbery-Clark, A., & Kraus, N. (2013). A dynamic auditory-cognitive system supports speech-in-noise perception in older adults. *Hearing Research, 300, 18-32.*

Andersson, G., & Green, M. (1995). Anxiety in elderly hearing impaired persons. *Perceptual and Motor Skills*, *81*(2), 552-554.

Baddeley, A. (1996). The fractionation of working memory. *Proceedings of the National Academy of Sciences*, *93*(24), 13468-13472.

Baldwin, C. L. (2009, October). Hearing Levels Affect Higher Order Cognitive Performance. In *Human Factors and Ergonomics Society Annual Meeting Proceedings* (Vol. 53, No. 2, pp. 121-125).

Bench, C. J., Frith, C. D., Grasby, P. M., Friston, K. J., Paulesu, E., Frackowiak, R. S. J., & Dolan, R. J. (1993). Investigations of the functional anatomy of attention using the stroop test. *Neuropsychologia*, *31*(9), 907-922.

Blazer, D. G. (2003). Depression in late life: review and commentary. *Journals of Gerontology Series A, 58*(3), 249-265.

Cambridge Cognition. (1996). Cambridge neuropsychological test automated battery (CANTAB). *CeNeS Limited, Cambridge*.

Cambridge Cognition. (2004). CANTAB test administration guide. *Cambridge, UK: Cambridge Cognition*.

Choi, A. Y., Shim, H. J., Lee, S. H., Yoon, S. W., & Joo, E. J. (2011). Is cognitive function in adults with hearing impairment improved by the use of hearing aids?. *Clinical and Experimental Otorhinolaryngology*, *4*(2), 72-76.

Colangelo, M., Cox, L. C., Tun, P. A., Stewart, R. A., Wingfield, A., & McCoy, S. L. (2005). Hearing loss and perceptual effort: Downstream effects on older adults' memory for speech. *The Quarterly Journal of Experimental Psychology Section A, 58*(1), 22-33.

Coull, J. T., Frackowiak, R. S. J., & Frith, C. D. (1998). Monitoring for target objects: activation of right frontal and parietal cortices with increasing time on task. *Neuropsychologia, 36*(12), 1325-1334.

Coull, J. T., Frith, C. D., Frackowiak, R. S., & Grasby, P. M. (1996). A fronto-parietal network for rapid visual information processing: a PET study of sustained attention and working memory. *Neuropsychologia, 34*(11), 1085-1095.

Dawes, P., Emsley, R., Cruickshanks, K. J., Moore, D. R., Fortnum, H., Edmondson-Jones, M., . . . Munro, K. J. (2015). Hearing loss and cognition: the role of hearing aids, social isolation and depression. *PloS one Journal Article, 10*(3).

Dillon, H. (2012). *Hearing Aids*: Thieme Medical Publishers, Inc., New York, USA.

Dykstra, P. A., & de Jong Gierveld, J. (2004). Gender and marital-history differences in emotional and social loneliness among Dutch older adults. *Canadian Journal on Aging/La revue canadienne du vieillissement, 23*(02), 141-155.

Elliott, R., & Dolan, R. J. (1999). Differential neural responses during performance of matching and nonmatching to sample tasks at two delay intervals. *Journal of Neuroscience, 19*(12), 5066-5073.

Fletcher, P. C., & Henson, R. N. (2001). Frontal lobes and human memory: insights from functional neuroimaging. *Brain, 124*(Pt 5), 849-881.

Gates, G. A., & Mills, J. H. (2005). Presbycusis. *The Lancet, 366*(9491), 1111-1120.

Goodglass, H., & Wingfield, A. (1998). The changing relationship between anatomic and cognitive explanation in the neuropsychology of language. *Journal of Psycholinguistic Research, 27*(2), 147-165.

Granick, S., Kleban, M. H., & Weiss, A. D. (1976). Relationships between hearing loss and cognition in normally hearing aged persons. *Journal of Gerontology*, *31*(4), 434-440.

Hampson, R. (2012). Hearing aids. *European Geriatric Medicine, 3*(3), 198-200.

Hear, L. (2006). The economic impact and cost of hearing loss in Australia. *A report by Access Economics Pty Ltd*.

Heming J.E. & Brown L.N. (2005) Sensory temporal processing in adults with early hearing loss. *Brain and Cognition*. 59, 173-182.

Henson, R., Hornberger, M., & Rugg, M. (2005). Further dissociating the processes involved in recognition memory: An fMRI Study. *Journal of Cognitive Neuroscience, 17*(7), 1058-1073.

Huang, Q., & Tang, J. (2010). Age-related hearing loss or presbycusis. *European Archives of Oto-Rhino-Laryngology, 267*(8), 1179-1191.

Katz, J. (2009). *Handbook of clinical audiology* (6th ed.). Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins.

Kiessling, J., Pichora-Fuller, M., Gatehouse, S., Stephens, D., Arlinger, S., Chisolm, T., . . . Holmes, A. (2003). Candidature for and delivery of audiological services: special needs of older people. *International Journal of Audiology, 42*, S92-S101.

Kramer, S. E. (2005). The psychosocial impact of hearing loss among elderly people: A review. In D. S. L. Jones (Ed.), *The impact of genetic hearing impairment* (pp. 137–164). London, United Kingdom: Whurr.

Lin, F. R., Ferrucci, L., An, Y., Goh, J. O., Doshi, J., Metter, E. J., . . . Resnick, S. M. (2014). Association of hearing impairment with brain volume changes in older adults. *NeuroImage, 90*, 84-92.

Lin, F. R., Ferrucci, L., Metter, E. J., An, Y., Zonderman, A. B., & Resnick, S. M. (2011). Hearing loss and cognition in the Baltimore Longitudinal Study of Ageing. *Neuropsychology, 25*(6), 763-770.

Lin, F. R., Yaffe, K., Xia, J., Xue, Q.-L., Harris, T. B., Purchase-Helzner, E., . . . Health, A. B. C. S. G. (2013). Hearing loss and cognitive decline in older adults. *JAMA internal medicine, 173*(4), 293.

Lovibond, P. F., & Lovibond, S. H. (1995). The structure of negative emotional states: Comparison of the Depression Anxiety Stress Scales (DASS) with the Beck Depression and Anxiety Inventories. *Behaviour Research and Therapy, 33*(3), 335-343.

Moore, B. C. (1996). Perceptual consequences of cochlear hearing loss and their implications for the design of hearing aids. *Ear and Hearing, 17*(2), 133-161.

Moore, B. C. (2007). *Cochlear hearing loss: physiological, psychological and technical issues*: John Wiley & Sons. West Sussex. England

Nelson, H. E., & Willison, J. (1991). *National Adult Reading Test (NART)*: Nfer-Nelson.

Ouda, L., Profant, O., & Syka, J. (2015). Age-related changes in the central auditory system. *Cell and Tissue Research, 361*(1), 337-358.

Owen, A. M., Downes, J. J., Sahakian, B. J., Polkey, C. E., & Robbins, T. W. (1990). Planning and spatial working memory following frontal lobe lesions in man. *Neuropsychologia, 28*(10), 1021-1034.

Owen, A. M., Sahakian, B. J., Semple, J., Polkey, C. E., & Robbins, T. W. (1995). Visuo-spatial short-term recognition memory and learning after temporal lobe excisions, frontal lobe excisions or amygdalo-hippocampectomy in man. *Neuropsychologia, 33*(1), 1-24.

Pronk, M., Deeg, D. J. H., & Kramer, S. E. (2013). Hearing status in older persons: a significant determinant of depression and loneliness? Results from the longitudinal aging study amsterdam. *American Journal of Audiology*, *22*(2), 316.

Robbins, T. W., Mehta, M. A., & Sahakian, B. J. (2000). Neuroscience. Boosting working memory. *Science*, *290*(5500), 2275-2276.

Rothpletz, A. M., Ashmead, D. H., & Tharpe, A. M. (2003). Responses to targets in the visual periphery in deaf and normal-hearing adults. *Journal of Speech, Language, and Hearing Research*, *46*(6), 1378-1386.

Sahgal, A., & Iversen, S. D. (1978). The effects of foveal prestriate and inferotemporal lesions on matching to sample behaviour in monkeys. *Neuropsychologia, 16*(4), 391-406.

Sarampalis, A., Kalluri, S., Edwards, B., & Hafter, E. (2009). Objective measures of listening effort: Effects of background noise and noise reduction.*Journal of Speech, Language, and Hearing Research, 52*(5), 1230-1240.

Sekuler, R., & Blake, R. (1987). Sensory underload. *Psychology Today*, *21*(12), 48-51.

Strawbridge, W. J., Wallhagen, M. I., Shema, S. J., & Kaplan, G. A. (2000). Negative consequences of hearing impairment in old age: A longitudinal analysis. *The Gerontologist, 40*(3), 320-326.

Tambs, K. (2004). Moderate effects of hearing loss on mental health and subjective well-being: results from the Nord-Trøndelag Hearing Loss Study. *Psychosomatic Medicine, 66*(5), 776-782.

Tremblay, K. L., Scollie, S., Abrams, H. B., Sullivan, J. R., & McMahon, C. M. (2014). Hearing aids and the brain. *International Journal of Otolaryngology, 2014*, 518967.

Tun, P. A., Williams, V. A., Small, B. J., & Hafter, E. R. (2012). The effects of aging on auditory processing and cognition. *American Journal of Audiology, 21*(2), 344-350.

Valentijn, S. A. M., Martin, P. J. v. B., Susan, A. H. v. H., Bosma, H., Beckers, H. J. M., Ponds, R. W. H. M., & Jolles, J. (2005). Change in Sensory Functioning Predicts Change in Cognitive Functioning: Results from a 6-Year Follow-Up in the Maastricht Aging Study. *Journal of the American Geriatrics Society, 53*(3), 374.

Van Pletzen, H. C. (2012). Hearing aids. *Continuing Medical Education, 30*(9), 334.

Verhaegen, C., Collette, F., & Majerus, S. (2014). The impact of aging and hearing status on verbal short-term memory. *Neuropsychology, development, and cognition.Section B, Aging, neuropsychology and cognition, 21*(4), 464-482.

Wechsler, D. (1997). Technical manual for the Wechsler Adult Intelligence and Memory Scale–. *New York: The Psychological Corporation*.

World Health Organisation. (2012). WHO global estimates on prevalence of hearing loss. *Mortality and Burden of Diseases and Prevention of Blindness and Deafness.* Retrieved from http://www.who.int/pbd/deafness/WHO_GE_HL.pdf

Wiley, T. L., Cruickshanks, K. J., Nondahl, D. M., & Tweed, T. S. (1999). Aging and middle ear resonance. *Journal of the American Academy of Audiology, 10*(4), 173-179.

Willott, J. F. (1996). Physiological plasticity in the auditory system and its possible relevance to hearing aid use, deprivation effects, and acclimatization. *Ear and Hearing, 17*(3), 66.

Willott, J. F., Hnath Chisolm, T., & Lister, J. J. (2001). Modulation of presbycusis: current status and future directions. *Audiology and Neurotology*, *6*(5), 231-249.

Willott, J., & Lister, J. (2003). The aging auditory system: anatomic and physiologic changes and implications for rehabilitation. *Int J Audiol*, *42*, 2S3-2S10.

Wilson, D. H. (1997). *Hearing in South Australia: Disability, impairment and quality-of-life*. University of Adelaide, Department of Community Medicine.

Wilson, D., Walsh, P., Sanchez, L., Davis, A., Taylor, A., Tucker, G., & Meagher, I. (1999). The epidemiology of hearing impairment in an Australian adult population. *International Journal of Epidemiology*, *28*(2), 247-252.

Wingfield, A., & Grossman, M. (2006). Language and the aging brain: patterns of neural compensation revealed by functional brain imaging. *Journal of neurophysiology*, *96*(6), 2830.

Wingfield, A., & Tun, P. A. (2001). Spoken language comprehension in older adults: Interactions between sensory and cognitive change in normal aging. In*Seminars in Hearing* (Vol. 22, No. 03, pp. 287-302). Thieme Medical Publishers, Inc., New York, USA.

Zekveld, A. A., Deijen, J. B., Goverts, S. T., & Kramer, S. E. (2007). The Relationship Between Nonverbal Cognitive Functions and Hearing Loss. *Journal of Speech, Language, and Hearing Research*, *50*(1), 74-82.

APPENDICES

Appendix One: NH Invitation Letter

Invitation letter: The Impact of Hearing Loss on Cognitive Functions in Postlingually Hearing Impaired Adults- Normal Hearing Participants

Dear Participant,

You are invited to participate in a research study. In this study we are evaluating the cognitive/ thinking skills of those who have a hearing loss and compare their results with normal hearing participants.

Please note that none of your personal or audiological information has been given to the researchers and will only be passed on with your written permission. You are also able to withdraw from the study at any point in time without prior notice. The study has ethics approval at the University of Western Australia. More information about the study, inclusion criteria, possible benefits and risks and participant rights can be found in the attached information sheet and consent form.

If you are interested in participating in this study, you will be asked to attend a hearing screening test and a play some computer games on a touch screen computer that will assess your cognitive/ thinking skills. Your involvement has the potential to benefit to those who have a hearing loss.

Please do not hesitate to contact the Ear Science Institute Australia, Hearing Implant Centre should you have any queries regarding this study. Our contact details are:

Phone: 6380 4944
Fax: 6380 4950
Mail: Ear Science Institute Australia, Implant Centre
Suite 2, Level 2
1 Salvado Rd, Subiaco WA 6008

I hope that you will be able to participate in this interesting study, and I look forward for your reply.

Many thanks,

Appendix Two: HL Invitation Letter

Invitation letter: The Impact of Hearing Loss on Cognitive Functions in Postlingually Hearing Impaired Adults- Normal Hearing Participants

Dear Participant,

You are invited to participate in a research study. In this study we are evaluating the cognitive/ thinking skills of those who have a hearing loss and compare their results with normal hearing participants.

Please note that none of your personal or audiological information has been given to the researchers and will only be passed on with your written permission. You are also able to withdraw from the study at any point in time without prior notice. The study has ethics approval at the University of Western Australia. More information about the study, inclusion criteria, possible benefits and risks and participant rights can be found in the attached information sheet and consent form.

If you are interested in participating in this study, you will be asked to attend a hearing screening test and a play some computer games on a touch screen computer that will assess your cognitive/ thinking skills. Your involvement has the potential to benefit to those who have a hearing loss.

Please do not hesitate to contact the Ear Science Institute Australia, Hearing Implant Centre should you have any queries regarding this study. Our contact details are:

Phone: 6380 4944
Fax: 6380 4950
Mail: Ear Science Institute Australia, Implant Centre
Suite 2, Level 2
1 Salvado Rd, Subiaco WA 6008

I hope that you will be able to participate in this interesting study, and I look forward for your reply.

Many thanks,

Appendix Three: NH Information Letter

Information letter for the potential research participants

Project title: The Impact of Hearing Loss on Cognitive Functions in Postlingually Hearing Impaired Adults – Normal Hearing Participants

Primary Investigator: Dr Dona Jayakody,

Ear Science Institute, 1 Salvado Road, Subiaco

Ph: 6380 4900, Email: dona.jayakody@earscience.org.au

Co-investigator: Adjunct Professor Rob Eikelboom,

Ear Science Institute, 1 Salvado Road, Subiaco

Ph: 6380 4900, Email: rob.eikelboom@earscience.org.au

Introduction

You have been invited to participate in a research study which is to be conducted by the Ear Science Institute Australia (ESIA). In this study, we will be assessing your cognitive/ thinking skills. Your participation in this study is entirely voluntary and you have the right to withdraw from the study at any stage without having to give any reasons.

Purpose

In this study we will be investigating the relationship between the hearing loss and cognitive/ thinking skills.

Inclusion criteria:

If you are native Australian English speaker or have been speaking Australian English for more than 10 years, you are invited to take part in this study.

Exclusion criteria:

If you are not in general state of good health, in a dependent relationship, or unable to perform tasks required due to an underlying physical or mental condition.

What will occur during the test?

During the appointment, your cognitive/thinking skills will be assessed by a computerised test. For this task you will be asked to play some games using a touch screen computer. This test will take about 45 minutes to complete. In addition you will also be asked to complete a questionnaire on your daily activities that will provide the research additional information on anxiety and stress.

Possible benefits of participating in this research?

By participating in this study you will be able to find out your cognitive/thinking skills, and increase your awareness of relationship between hearing loss and cognitive thinking skills. These results will be used to help plan your rehabilitation appointments at the clinic. You will also help to further the knowledge in this area, and promote safer practices if some risks to health are identified.

Possible risks of participating in this research?

The risks associated with this research are no different to those that you would expect in attending a hearing test at an audiology clinic. All the testing will be carried out by a trained researcher.

How the results and data will be stored?

All data collected will be stored according to The University of Western Australia protocols. Any personal information will be retained in a secure filing system and a password protected computer to which only the personnel directly involved will have access. No material that could directly identify you will be used in any reports of this study. At the completion of the study, any data required to be kept will be stored securely, and any data not required will be destroyed. Should you withdraw yourself from this study all of your data collected will be withdrawn and destroyed.

Is there any cost involved for the participants?

There will be no cost involved for the participants who attend the hearing screening and cognitive/thinking skills test.

Ethics approval

Approval to conduct this research has been provided by the University of Western Australia, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time.

In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Research Ethics Office at the University of Western Australia on (08) 6488 3703 or by emailing to hreo-research@uwa.edu.au

All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.

What are my rights?

Your participation in this study does not prejudice any right to compensation, which you may have under statute or common law. You are free to withdraw from the study at any time without having to give any reason and any information collected will be destroyed unless otherwise agreed

Further information and Contacts during the study

If you have any questions or concerns now or at any time about the study, your safety or rights, please ask your doctor, or the investigators.

Appendix Four: HL Information Letter

Information letter for the potential research participants

Project title: The Impact of Hearing Loss on Cognitive Functions in Postlingually Hearing Impaired Adults

Primary Investigator: Dr Dona Jayakody,

Ear Science Institute, 1 Salvado Road, Subiaco

Ph: 6380 4900, Email: dona.jayakody@earscience.org.au

Co-investigator: Adjunct Professor Rob Eikelboom,

Ear Science Institute, 1 Salvado Road, Subiaco

Ph: 6380 4900, Email: rob.eikelboom@earscience.org.au

Introduction

You have been invited to participate in a research study which is to be conducted by the Ear Science Institute Australia (ESIA). In this study, we will be assessing your cognitive/ thinking skills. Your participation in this study is entirely voluntary and you have the right to withdraw from the study at any stage without having to give any reasons.

Purpose

In this study we will be investigating the relationship between the hearing loss and cognitive/ thinking skills.

Inclusion criteria:

If you are native Australian English speaker or have been speaking Australian English for more than 10 years, you are invited to take part in this study.

Exclusion criteria:

If you are not in general state of good health, in a dependent relationship, or unable to perform tasks required due to an underlying physical or mental condition.

What will occur during the test?

During the appointment, your cognitive/thinking skills will be assessed by a computerised test. For this task you will be asked to play some games using a touch screen computer. This test will take about 45 minutes to complete. In addition you will also be asked to complete a questionnaire on your daily activities that will provide the research additional information on anxiety and stress.

Possible benefits of participating in this research?

By participating in this study you will be able to find out your cognitive/thinking skills, and increase your awareness of relationship between hearing loss and cognitive thinking skills. These results will be used to help plan your rehabilitation appointments at the clinic. You will also help to further the knowledge in this area, and promote safer practices if some risks to health are identified.

Possible risks of participating in this research?

The risks associated with this research are no different to those that you would expect in attending a hearing test at an audiology clinic. All the testing will be carried out by a trained researcher.

How the results and data will be stored?

All data collected will be stored according to The University of Western Australia protocols. Any personal information will be retained in a secure filing system and a password protected computer to which only the personnel directly involved will have access. No material that could directly identify you will be used in any reports of this study. At the completion of the study, any data required to be kept will be stored securely, and any data not required will be destroyed. Should you withdraw yourself from this study all of your data collected will be withdrawn and destroyed.

Is there any cost involved for the participants?

There will be no cost involved for the participants who attend the hearing screening and cognitive/thinking skills test.

Ethics approval

Approval to conduct this research has been provided by the University of Western Australia, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time.

In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Research Ethics Office at the University of Western Australia on (08) 6488 3703 or by emailing to hreo-research@uwa.edu.au

All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.

What are my rights?

Your participation in this study does not prejudice any right to compensation, which you may have under statute or common law. You are free to withdraw from the study at any time without having to give any reason and any information collected will be destroyed unless otherwise agreed

Further information and Contacts during the study

If you have any questions or concerns now or at any time about the study, your safety or rights, please ask your doctor, or the investigators.

Appendix Five: Consent Form All Participants

Consent form: The Impact of Hearing Loss on Cognitive Functions in Postlingually Hearing Impaired Adults

Approval to conduct this research has been provided by the University of Western Australia, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time.

In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Research Ethics Office at the University of Western Australia on (08) 6488 3703 or by emailing to hreo-research@uwa.edu.au

All research participants are entitled to retain a copy of any Participant Information for and/or Participant Consent Form relating to this research project. Your results will only be used for the purpose of this study and will not be released to your employer or any third party without your consent.

Should you have any queries or concerns about this study, please contact us at:

Phone: 6380 4944, Fax: 6380 4950

Mail: Ear Science Institute Australia, Implant Centre, Suite 2, Level 2, 1 Salvado Rd, Subiaco WA 6008

Should you be interested in taking part in this study, please complete the consent form and return it to Ear Science Institute by reply-paid envelop

Consent Statement

I have read the information provided and any questions

- I have asked have been answered to my satisfaction. I agree to participate in this activity, realising that I may withdraw at any time without reason and without prejudice.
- I understand that all identifiable information that I provide is treated as strictly confidential and will not be released by the investigator in any form that may identify me. The only exception to this principle of confidentiality is if documents are required by law.
- I have been advised as to what data is being collected, the purpose for collecting the data, and what will be done with the data upon completion of the research.
- I understand that I am free to withdraw from the study at any time without having to give any reason and any information collected will be destroyed unless otherwise agreed
- I agree that research data gathered for the study may be published provided my name or other identifying information is not used.

_____ _____

Participant signature Date

Appendix Six: DASS-21 Questionnaire