

**The effect of sleep deprivation on temporal resolution and listening effort of normal hearing young adults**

By

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A dissertation submitted in fulfilment of the requirement for the degree

MA (Audiology)

In the Department of Speech-Language Pathology and Audiology

FACULTY OF HUMANITIES

UNIVERSITY OF PRETORIA

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September 2018

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## **Acknowledgement**

I would like to thank my supervisors Dr Lidia Pottas and Dr Maggi Soer for all the constant support, hard work, assistance and dedication. I could not have done the research without you.

To Prof Bart Vinck and Dr Marien Graham, thank you for your support and guidance with analysing my data.

I would furthermore like to thank my language editor Dr Elsie Naude for making sure my language is up to standard.

To my participants, thank you for making this research possible.

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## **List of Abbreviations**

GIN- Gaps-In-Noise

DIN- Digits-In-Noise

SNR- Signal-to-Noise Ratio

RGDT- Random Gap Detection Test

CAP- Central Auditory Processing

POMS- Profile of Mood States

SRT- Speech Reception Threshold

NSDP- non-sleep-deprived condition

SDP- Sleep deprived condition

SD - standard deviation

TMD- Total Mood Disturbance

### **Formatting**

For the dissertation the APA referencing style was used.



## Abstract

*Background:* Sleep deprivation is often caused by the demands of work, school, and social activities. A considerable amount of research has focused on the effects of sleep deprivation on the motor performances, mood, and cognitive functioning of an individual. The effect of sleep deprivation on the central auditory processes, however, has been insufficiently investigated.

*Objective:* The aim of the study was to determine the influence of sleep deprivation on temporal resolution and listening effort. In addition, the impact of sleep deprivation on mood states was determined to supplement the information obtained regarding listening effort and temporal resolution.

*Method:* A quasi-experimental, within-subject repeated-measures design was implemented. Twenty seven adults between the ages of 18 and 30 years (mean age 22.56) with normal hearing, normal middle ear functioning, and normal central auditory processes were recruited purposively from the University of Pretoria. Participants were tested using the Gaps-In-Noise (GIN) Test, Digits-In-Noise (DIN) Test, Profile of Mood States (POMS), and Listening Effort Test over a time period of three days on four occasions: the evening before and the morning after having had approximately 6 to 8 hours of sleep (NSDP); and the evening before and the morning after having to remain awake throughout the night (SDP). The results of the NSDP and SDP condition were subsequently compared.

*Results:* The percentage of correct scores obtained by the participants on the Listening Effort Test in all five prescribed listening conditions did not significantly increase in the SDP condition. No significant difference was found when comparing the non-sleep-deprived (NSDP) condition with the SDP condition ( $p > 0.05$ ), suggesting that further research is needed to investigate the effect of an increased sleep deprivation period on listening effort. No significant difference was found between the NSDP and the SDP condition ( $p > 0.05$ ) in the average SNR obtained in the DIN Test. Results of the GIN Test indicated that the approximate gap duration thresholds (AGDT) increased significantly and the percentage calculated decreased significantly in the sleep deprived (SDP) condition ( $p < 0.05$ ). A night of sleep deprivation also caused

significantly greater negative disturbances to all the mood states (anger, depression, fatigue, vigour, confusion and tension) as measured by the POMS. Thus, the Total Mood Disturbance appeared to be significantly larger after a night of sleep deprivation ( $p < 0.05$ ).

*Conclusion:* In this study sleep deprivation had an effect on temporal resolution. It also affected the different mood states, such as anger, confusion, fatigue, depression, and vigour, significantly. However, a 24 hour period of sleep deprivation did not seem to affect the results of the Listening Effort Test and the speech perception in noise skills as determined by the DIN Test.

**Keywords:** Sleep deprivation, sleep deprived condition, non-sleep deprived condition, temporal processing, temporal resolution, listening effort, mood states, Gaps-In-Noise (GIN), Profile of Mood States (POMS), Digit-In-Noise (DIN)

# Chapter One: Introduction and orientation

## 1.1. Background

Sleep deprivation is known to decrease work efficiency, public safety, and individual happiness and is often the reason for accidents and disastrous mistakes (Thomas et al., 2000). A lack of sleep is reported to be evident in 20% of the adult population (Goel, Rao, Durmer & Dinges, 2009). Sleep is often affected by the demands of work, school, and social activities, as people often feel that they can spend the time in which they would be sleeping on activities that are more useful or entertaining. Additionally, sleep deprivation appears to be common in certain occupations, such as in medical residency or military occupations (Killgore, 2010). Studies have shown that a lack of sleep significantly affects immune function and memory, as well as endocrine, digestive, and thermal regulation (Arora, Bhat, Raj, Kumar & Kumar, 2014; Stickgold & Walker, 2009). Insufficient sleep also appears to have an influence on cognitive aspects and certain mood states. Mood states such as feelings of fatigue, confusion, depression, irritability and a loss of vigour may be experienced by individuals who suffered a period of sleep deprivation (Goel et al., 2009).

The specific effects of sleep deprivation on the neurophysiology of cortical structures of the brain have been determined in various studies (Liberalesso, D'Andrea, Cordeiro, Zeigelboim, Marques & Jurkiewicz, 2012; Thomas et al., 2000). Research by Thomas et al. (2000) discovered a reduced cerebral metabolic rate for glucose (CMRglu) and neuronal synaptic activity in the cortical and subcortical areas, thalamus, and the prefrontal cortex after 24 hours of sleep deprivation. Further research demonstrated that sleep deprivation has an effect on areas in the temporal lobe, the amygdala, the hippocampus, and the frontal lobe (Liberalesso et al., 2012). These structures are associated with various executive functions such as planning, sequencing, decision making, creativity, language skills, cognitive flexibility, memory, attention, behaviour, and mood state (Babkoff, Zukerman, Fostick & Ben-Artzi, 2005; Killgore, 2010; Liberalesso et al., 2012).

Cognitive areas, such as the temporal lobe, superior temporal gyrus, left inferior frontal gyrus, and the prefrontal cortex are especially important in the context of the current

study, as these are directly associated with auditory processing, particularly auditory temporal processing (Babkoff et al., 2005; Liberalesso et al., 2012). Damaged areas in the temporal lobe are linked to difficulties in the perception of sound and auditory information (Liberalesso et al., 2012). The prefrontal cortex, which is one of the first areas affected by sleep deprivation, can also be linked to temporal processing abilities, more specifically auditory temporal resolution capabilities (Babkoff et al., 2005). Evidence suggests that the left region of the prefrontal cortex is responsible for the perception of rapidly fluctuating verbal and non-verbal auditory stimuli (Belin et al., 1998). Furthermore, it has been found that temporal discrimination of acoustic stimuli is regulated by the superior temporal gyrus and left inferior frontal gyrus (Joanisse & Gati, 2003). In addition, research indicated that 24 hours sleep deprivation influences the interhemispheric transference of auditory information negatively (Liberalesso et al., 2012). These areas are all associated with the comprehension of speech and language, proving its correlation with temporal resolution skills (Babkoff et al., 2005). As these areas are linked to certain auditory processing skills the question might arise what the influence of sleep deprivation is on auditory processing.

Auditory processing of acoustic information is fundamental to receptive language abilities, sound discrimination, lateralisation and localisation, temporal processing, auditory closure and the recognition of auditory patterns (Liberalesso et al., 2012). The effect of sleep deprivation on a specific auditory processing skill, namely temporal processing, has also been indicated (Arora et al., 2014; Fostick, Babkoff & Zukerman, 2014). Temporal processing refers to the ability to process a rapidly altering acoustic signal and is a very important skill for speech recognition, phonological processing, auditory closure, and reading (Fu, 2002; Schulte-Körne, Deimel, Bartling & Remschmidt, 1999; Shinn, Chermak & Musiek, 2009). Arora and colleagues (2014) conducted a study that investigated the effects of acute sleep deprivation on temporal processing and frequency resolution in normal healthy adults who had no psychological and neurological complications. A series of tests including the Gap Detection Test, Temporal Modulation Transfer Function, Duration Discrimination Test and Pitch Discrimination Test was performed, the results of which showed variations between the subjects that were tested before and after the 24 hour sleep deprivation period. Results indicated that in the sleep-deprived group, temporal processing and frequency resolution skills were reduced (Arora et al., 2014). As temporal processing

is an auditory processing skill that incorporates temporal resolution (Kumar, Ameenudin & Sangamanatha, 2012), it is speculated that lack of sleep may affect temporal resolution abilities.

Temporal resolution is an auditory processing skill that allows an individual to detect alterations in sound over time (Stuart, Givens, Walker & Elangovan, 2006). Previous research indicated that sleep deprivation does have an influence on temporal resolution skills (Babkoff et al., 2005; Fostick et al., 2014; Liberalesso et al., 2012). Research by Babkoff et al. (2005) investigating the effects of sleep deprivation on dichotic temporal order judgement as a representative of temporal resolution, provided evidence that a 24 hour period of sleep deprivation can cause a decrease of 28% in auditory temporal resolution measured by the temporal order judgment, which could cause complications in language comprehension. Fostick, Babkoff and Zuckerman (2014) found, furthermore, that the temporal order judgement (TOJ) threshold was lengthened in the sleep deprived population. Furthermore, Liberalesso et al. (2012) measured auditory temporal resolution using the Random Gap Detection Test (RGDT), and compared the results for a group of participants before and after a sleep deprivation period of 24 hours. The results indicated that sleep deprived subjects needed longer intervals to recognise two separate stimuli. These studies provide evidence that sleep deprivation does affect temporal resolution abilities. However, most research conducted on the effects of sleep deprivation on temporal resolution employed the RGDT (Arora et al., 2014; Liberalesso et al., 2012) which is said to test auditory fusion rather than temporal resolution (Parthasarathy, 2006). Research investigating the effects of sleep deprivation on temporal resolution using the Gaps in Noise (GIN) Test, which is regarded as a clinically useful assessment tool for evaluating temporal resolution abilities, is therefore indicated (Musiek et al., 2005).

With regard to the effect of sleep deprivation on speech-in-noise perception, it appears that limited research has been conducted on this topic. Speech perception in noise skills involve the ability to hear speech in the presence of background noise, and this aptitude is related to temporal resolution (Omidvar, Jafari, Tahaei & Salehi, 2013). Temporal resolution abilities allow an individual to separate acoustic stimuli over time, which is critical for speech perception in noise, especially when it has an oscillation amplitude envelope (Kumar et al., 2012; Omidvar et al., 2013). Omidvar et al. (2013)

pointed out that temporal resolution and speech-in-noise perception can be assessed using the same assessment tools, which suggests that the same mechanisms underlie both. The close relation existing between temporal resolution and speech-in-noise perception indicates that speech-in-noise perception may also be influenced by insufficient sleep.

The processing of speech and complex language in the presence of background noise are both challenging listening tasks that require a substantial amount of mental effort and cognitive resources, such as attention, processing speed, and working memory (Degeest, Keppler & Corthals, 2015). This effort can be termed listening effort. As sleep deprivation is known to have a considerable influence on complex language tasks in which high-level processing and attentiveness are prerequisite, it is possible that the amount of listening effort will be increased after a period of sleep deprivation (Liberalesso et al., 2012). Furthermore, auditory processing deficits are directly linked to an increase in listening effort which causes an elevation of mental fatigue, stress, and tension. Listening effort can be assessed using a dual task paradigm. Within a dual task paradigm a primary task is performed, while at the same time attention is also given to the completion of a secondary task. The required mental capacity is expended for the primary task, while for the completion of the secondary task the spare mental capacity is applied (Degeest et al., 2015). Even though no study has been conducted on the effect of sleep deprivation on listening effort, there has been research proving the influence of sleep deprivation on various cognitive resources, such as attention, processing speed, and working memory (Babkoff et al., 2005). These skills are all associated with the amount of effort needed to process auditory information, especially in the presence of background noise (Babkoff et al., 2005; Liberalesso et al., 2012). The assumption is therefore made that an increased amount of listening effort will be required for auditory processing, more specifically temporal resolution and the processing of speech in noise, after a period of sleep deprivation (Hornsby, 2013).

## **1.2. Rationale**

A sizeable body of research has focused on the effects of sleep deprivation on the basic functioning and cognitive performance associated with the daily routines of

individuals (Fostick et al., 2014). Researchers have described how sleep deprivation affects certain aspects of cognitive functioning (Babkoff et al., 2005; Fostick et al., 2014; Killgore, 2010; Liberalesso et al., 2012). However, only limited research has been conducted on certain auditory processing skills, specifically temporal processing or temporal resolution (Arora et al., 2014; Babkoff et al., 2005; Fostick et al., 2014; Liberalesso et al., 2012). To the researcher's knowledge, no researchers have studied the effects of sleep deprivation on temporal resolution, which is measured by the GIN, and on the listening effort, measured by the Listening Effort Test. A question was thus formulated: How does a 24 hour period of sleep deprivation influence the listening effort and the performance on the GIN Test, which measures auditory temporal resolution? The general purpose of this study on listening effort and temporal resolution is also to expand the knowledge regarding the effect of sleep deprivation on linguistic abilities and speech perception abilities, and the possible effect of sleep deprivation on work productivity and quality (Babkoff et al., 2005).

### **1.3. Clarification of terminology**

The following terms were used frequently throughout this dissertation and therefore require definition.

#### **1.3.1. Sleep deprivation**

Sleep deprivation occurs if an individual does not get sufficient sleep. The term typically refers to a deterioration in alertness, in health, and in overall performance, caused by lack of sleep (Abrams, 2015). Acute sleep deprivation can be defined as not sleeping for a period of one or two days. Chronic sleep deprivation refers to the effect of repetitively sleeping less than the number of hours required for optimal sleep every night (Goel et al., 2009; Short & Banks, 2014). In this study the participants were deprived of sleep for a period of 24 hours.

#### **1.3.2. Temporal processing**

Temporal processing refers to the perception of acoustic stimuli over time, specifically the perception of the time related aspects of auditory information (Musiek & Chermak, 2014). Temporal processing incorporates many skills such as temporal integration,

temporal masking, temporal ordering, temporal discrimination and temporal resolution (Kumar et al., 2012).

### **1.3.3. Temporal resolution**

Temporal resolution is the ability to recognise rapid alternations in an acoustic signal over time (Musiek & Chermak, 2014). This skill assists an individual to detect important alterations in speech and is therefore of significance for speech perception (Liberalesso et al., 2012).

### **1.3.4. Speech-In-Noise**

This term is used in the context of the perception of speech and other auditory information in the presence of background noise. The term background noise is used for any sound that prevents or partially prevents an individual from hearing the primary speech signal (Pottas, 2015). An individual's ability to process speech in noise may be impacted by auditory processing deficits, hearing impairments, and factors related to language, attention and other cognitive functions. In addition, musical experience is known to enhance speech perception in noise skills (Musiek & Chermak, 2014).

### **1.3.5. Listening effort**

Listening effort can be defined as the amount of cognitive resources such as attention, processing speed, and working memory that is required for the processing of auditory information in either a quiet or a noisy environment. The amount of listening effort increases when complex auditory information or speech in noise has to be processed (Degeest et al., 2015).

## **1.4. Outline of chapters**

The chapters of the study are all summarised in the following section.

### **1.4.1. Chapter One: Introduction**

The theoretical underpinnings of the effects of sleep deprivation on temporal processing, temporal resolution, and speech in noise skills and listening effort are discussed in this chapter. The rationale and the problem statement are also provided along with a section on the clarification of relevant terminology.



#### **1.4.2. Chapter Two: Methodology**

The methodological framework is discussed in this chapter which includes the aim and objectives, the study design, and the ethical considerations of the study. The description of the participants, the material and apparatus for data collection, the method of data collection, and the reliability and validity are furthermore explained in the chapter.

#### **1.4.3. Chapter Three: Results**

This chapter focuses on the presentation of the results and the outcomes of the study. These are summarised using tables and depicted in figures.

#### **1.4.4. Chapter Four: Discussion of results**

The results of the present study are reinforced and compared to previous findings, and related to the aims and rationale of the study provided in chapters one and two.

#### **1.4.5. Chapter Five: Conclusion and recommendations**

The final chapter summarises the main findings of the present study and reflect on strengths and limitations of the study along with recommendations for future research.

#### **1.5. Summary**

The introductory chapter provided the reader with a discussion of the significance of the research and provided more information on the background of the study. The problem statement and rationale were also addressed in the current chapter. A section on the clarification of the important terminology and an outline of the all the chapters were subsequently presented in this chapter.

## **Chapter two: Methodology**

### **2.1. Introduction**

In this chapter the research aim, research design, and the ethical considerations of the study, the material and apparatus, and procedure of participant selection are described and discussed. The material and apparatus and procedure for data collection, the data analysis procedure and analysis, as well as the reliability and validity of the study are furthermore explained in the chapter. In addition, data collection was obtained in the year of 2017.

### **2.2. Research aim**

The main aim of this study was to determine the influence of sleep deprivation on temporal resolution and listening effort in normal hearing young adults.

### **2.3. Research design**

A quasi-experimental, within-subject repeated-measures design was implemented to collect quantitative data in this study. A quantitative research approach highlights objectivity and analysis of data using numerical and mathematical based methods (Leedy & Ormrod, 2014). With regard to the within-subject repeated-measure design, the participants were exposed to various conditions (sleep deprivation and NSDP condition) and were evaluated at different times of the day (Lee, Kim & Suh, 2003). In a quasi-experimental design, the researcher is able to establish the causality between variables (Leedy & Ormrod, 2014). The participants were assessed in two separate conditions (NSDP condition and SDP condition) and the results obtained were compared. In this study, the effects of the causal variable (sleep deprivation) on temporal resolution and listening effort (the dependant variables) were measured (Lee et al., 2003). The present study aimed to find a solution to a specific problem and can therefore be referred to as applied research (Leedy & Ormrod, 2014). A lack of research has been reported on the effects of sleep deprivation on auditory processing abilities, such as speech-in-noise perception and auditory temporal resolution, and listening effort (Babkoff et al., 2005; Thomas et al., 2000). The current research study focuses on investigating the stated problem by expanding the knowledge regarding the effects of sleep deprivation on auditory processing.

## **2.4. Ethical considerations**

Ethical clearance was obtained from the Research and Ethics Committee of the Faculty of Humanities and the Department of Speech-Language Pathology and Audiology at the University of Pretoria (Appendix A). The following ethical considerations were of value in this study.

### **2.4.1. Autonomy**

Written informed consent to participate in this study was obtained from each participant prior to testing. In the information letter (Appendix C) the overall purpose of the study was explained. Protection against any physical and psychological harm and precautions to ensure the comfort and safety of the participants were also explained in the written consent form. No dangerous or risky procedures were used that could harm the participants (Appendix C). Furthermore, the participants were assured of the right to withdraw from the study at any time (Leedy & Ormrod, 2014).

### **2.4.2. Confidentiality**

Information disclosed during the assessment of each participant remained confidential. Each participant was assigned a code for the purpose of data analysis so that no identifying information about the participant was disclosed (Leedy & Ormrod, 2014). Data obtained from the participant will be stored in an electronic format at the Department of Speech-Language Pathology and Audiology, University of Pretoria for a minimum of 15 years. Participants may also request to view the results obtained.

### **2.4.3. Honesty and plagiarism**

The results of the study were reported honestly and were not misleading. Data was not altered for the purpose of confirming a satisfying conclusion (Leedy & Ormrod, 2014). The documentation of the research study and the research report was the researcher's own original work. The secondary material used was recognized and referenced according to the University of Pretoria's specifications (Leedy & Ormrod, 2014).

#### **2.4.4. Permission from relevant authorities**

A letter (Appendix B) to the Director of Student Affairs of the University of Pretoria requested permission to approach students from the University of Pretoria to act as voluntary participants. The Director of Student Affairs subsequently signed the letter giving the researcher permission to include students as participants in the study.

### **2.5. Participants**

In the following section the participant selection criteria, the material and apparatus, and the procedure for participant selection are discussed.

#### **2.5.1. Sampling method**

The participants in this study were selected according to a purposive convenience sampling method (Bryman & Bell, 2015; Leedy & Ormrod, 2014). Participants were chosen purposively from the University of Pretoria through word of mouth according to specific criteria namely age range, hearing status, and auditory processing abilities.

#### **2.5.2. Participant selection criteria**

The following strict selection criteria were used to ensure optimal validity of the study:

Inclusion criteria:

The participants of the research study were required to present with the following characteristics in order to be included in the study:

- Participants within the age range of 18 and 30 years were selected to participate in the study as this population group is expected to present with normal hearing and auditory processing abilities (Degeest et al., 2015; Sanju, Bohra & Sinha, 2016). According to Sanju et al. (2016), auditory processing abilities begin deteriorating in the middle-aged population (40-60 years). Cognitive functions and the ability to perceive speech in the presence of background noise are also known to start decreasing in the middle aged population and in the older population (Degeest et al., 2015).
- It was essential that all participants presented with normal peripheral hearing (American Association of Audiology [AAA], 2010). Participants had to have normal pure tone thresholds of 0 to 15 dB at 125 Hz to 8000 Hz

(International Standards Organization [ISO], 1998), as a peripheral hearing loss would have affected the reliability of the data gathered (AAA, 2010).

- Additionally, acoustic immittance testing (tympanometry and acoustic reflex measurements) and otoscopy had to produce normal results for the participants. To be included in the study participants had to present with normal Type A tympanograms in both ears (static compliance of 0.3 to 1.7 ml; a tympanometric peak pressure of -100 to 50 daPa and an ear canal volume of 0.6 - 2.0 ml) with ipsilateral acoustic reflex thresholds that range from 70 to 95 dB HL at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz (Kramer, 2014). Normal acoustic immittance results were essential, as abnormal middle ear functioning might influence the pure tone thresholds and auditory processing abilities (Musiek & Chermak, 2014).
- Participants should not present with a CAPD, as an existing CAPD might influence the baseline temporal resolution abilities and the Listening Effort test results (Hornsby, 2013; Liberalesso et al., 2012). The integrity of the central auditory processes of the participants, more specifically binaural integration, was determined by the Dichotic Digit Test in which it was a prerequisite for participants to score 90% or above. The Dichotic Digit Test has a high sensitivity and specificity and was therefore an appropriate test to use in this study to determine if the participants were suitable to be included in the study (Musiek & Chermak, 2014). Samelli and Schochat (2008) used the Dichotic Digits Test as a basic triage of auditory processing in their study.
- Since participants were required to have reported healthy sleeping patterns, individuals with sleep disturbances and chronic sleep problems were identified and excluded from the study (Lee et al., 2003). For this reason, participants were obligated to log their sleeping pattern every day for two weeks prior to the first testing session.

Exclusion criteria:

Participants with the following characteristics were excluded from the study.

- Participants with pure tone thresholds greater than 15 dB were excluded from the study. A peripheral hearing loss affects the central auditory

processes and might affect the participant's speech understanding in the presence of background noise (Degeest et al., 2015; Hicks & Tharpe, 2002).

- Participants who had a history of recurrent otitis media were excluded from the study, as this is a risk factor for a CAPD (Musiek & Chermak, 2014). Otitis media is known to influence CAP as well as speech perception in noise (Groenen, Crul, Maassen & van Bon, 1996). A questionnaire (Appendix D) was used to obtain information regarding participants' possible history of otitis media.
- Individuals with a medical history of neurological abnormalities such as learning disabilities and Attention Deficit Hyperactivity Disorder (ADHD) or head trauma were not accepted as participants, as these conditions are often associated with auditory processing disorders (Samelli & Schochat, 2008; Musiek & Chermak, 2014). The questionnaire (Appendix D) that was completed by each participant provided information on the participant's medical history.
- Participants were not allowed to take any stimulants for a period of 24 hours before the administration of test procedures, since stimulants such as medication, caffeine, alcohol, and nicotine might affect the sleeping pattern and the results of the evaluation (Franke, Lieb & Hildt, 2012; Koelega, 1993; Lieberman, Tharion, Speckman, Shukitt-Hale & Tulley, 2002). Any stimulants the participants took were likewise determined by the questionnaire (Appendix D) which the participants were required to complete.
- Participants were required to comply with the requirements of the Listening Effort Test. Those that were unable to perform the primary and secondary task of the Listening Effort Test were excluded from the study. Participants were furthermore excluded if the score of the baseline secondary task measurement was below 50% (Degeest et al., 2015).
- Participants were not included in the study if they had abnormal visual acuity, as normal visual acuity or corrected normal visual acuity was a requirement for the Listening Effort Test. Normal visual acuity was established through the questionnaire, provided in Appendix D (Degeest et al., 2015).

- Participants were also required not to be exposed to noise 24 hours prior to the commencement of data gathering, as research has shown that individuals exposed to noise might experience a temporary hearing loss, as well as a decrease in speech-in-noise perception and auditory processing (Hope, Luxon & Bamiou, 2013; Kumar et al., 2012).

### **2.5.3. Material and apparatus for participant selection**

A questionnaire developed by the researcher (Appendix D) and completed by each participant allowed the researcher to obtain additional information about the history of hearing loss or middle ear infections, the medical history, current medications, and academic performance.

An otoscope (Welch-Allyn REF 22861) was used to inspect the ear canal and tympanic membrane for any abnormalities such as a foreign body, impacted wax, or perforations.

Acoustic immittance testing was executed using the GSI Tymptstar (Calibrated in January 2017) for the purpose of identifying any middle ear pathologies. The GSI Tymptstar was calibrated in accordance with the SANS 10154-1/2 10182 standards.

Pure tone audiometry was conducted in a sound proof booth using a GSI 61 Welch-Allyn audiometer (Calibrated in January 2017) with Telephonic -50 earphones, to ensure that the participants had normal air conduction thresholds (0 dB HL -15 dB HL).

The Dichotic Digit Test developed by Musiek (1983) can be employed as a basic triage of auditory processing and was used as a screening instrument for possible auditory processing problems (Samelli & Schochat, 2008). The Dichotic Digit Test is known to identify brainstem and cortical lesions and is sensitive to lesions of the interhemispheric fibres (Bellis, 2003). This test was used specifically because of this high sensitivity and specificity for cortical and brainstem lesions (Musiek & Chermak, 2014). The GSI 61 Welch-Allyn audiometer (Calibrated in January 2017) with Telephonic -50 earphones was connected to the Sansui CD210 CD player for the presentation of the stimuli for this procedure.

The Listening Effort Test was performed for the purpose of guaranteeing that all participants could accomplish the primary and secondary task of the Listening Effort Test separately and simultaneously. Comprehensive conditions and procedures of the test are discussed in sections 2.5.4, 2.6.4 and 2.8.3. Participants were excluded from the study if they were unable to reach 50% in the visual memory task and if they were unable to undertake any of the specific tasks of the test. The test was performed in a sound treated room using an Acer E1-572 computer with Proline speakers (Degeest et al., 2015).

#### **2.5.4. Procedures for participant selection**

Potential participants were required to log their sleeping patterns for two weeks prior to the first testing session. Furthermore, they were asked to complete the questionnaire (Appendix D) that served to provide a short background history pertaining to hearing, academic performance, and general background information. This information provided the researcher with essential knowledge about certain aspects, such as a neurological disorder and a middle ear infection, which might influence central auditory test performance (AAA, 2010). Participants who presented with a history of middle ear infection or hearing loss, for example, were excluded from the study as this might influence their test performance. Applicants also signed the informed consent form (Appendix C) prior to participation in the study.

A set of tests including pure tone audiometry, acoustic immittance testing, and the Dichotic Digit Test was then administered to ensure that the hearing, middle ear functioning, and CAP were normal.

Otoscopy was performed first to identify the presence of any abnormalities in the outer ear. Individuals who presented with any visible abnormalities such as a foreign body, impacted wax, or a perforation were not included in the study. Acoustic immittance testing was performed next to ensure that the middle ear was functioning optimally. Tympanometry and ipsilateral acoustic reflex measurements had to indicate normal results (Type A tympanograms in both ears with ipsilateral acoustic reflex thresholds that range from 70 to 95 dB HL at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz) (Kramer, 2014), as abnormalities in the middle ear might influence the hearing and auditory



processing abilities. It was important to execute these procedures as individuals with middle ear pathology, regardless of their pure tone thresholds, had to be excluded from the study (Musiek & Chermak, 2014). If abnormalities were identified, participants were advised to visit a general practitioner for treatment.

Subsequently, pure tone audiometry was administered to determine whether the participant had normal hearing sensitivity. Pure tone air conduction thresholds were obtained in a sound proof booth with supra aural ear phones. Air conduction testing was conducted using the Hughson-Westlake method (Hughson & Westlake, 1944). Participants were excluded from the study if air conduction thresholds were greater than 15 dB at any tested frequency (International Standards Organization [ISO], 1998).

The Dichotic Digit Test was performed by presenting two digits in each of the ears at the same time, which the participant was required to repeat. These digits were presented at an intensity of 50 dB SL (Musiek & Chermak, 2014). The number of digits repeated correctly for each ear constitutes a percentage correct score. A normal hearing adult was considered to have abnormal results when the score in one or both ears was below 90%. Participants were included in the study if they had a score of more than 90% (Musiek & Chermak, 2014).

The Listening Effort Test was performed in a baseline condition and in a dual task condition and consisted of a primary and secondary task. In the baseline condition the primary and secondary task were performed separately for the purpose of determining whether each participant could perform the task. In the primary task, two sequences of five digits were presented at five fixed listening conditions (quiet, Signal to Noise Ratio [SNR] of +2 dB, -2 dB, -6 dB and -10 dB). The participant was required to repeat the digits heard after the presentation of five digits (Degeest et al., 2015). The baseline secondary task, which assesses the visual memory, involved the presentation of five circles on a raster. Five sets of five circles were presented, but only the last two sets were scored. Participants were required to memorise the positions of the five circles and were required to indicate these on a score sheet. The participant should not obtain less than 50% on the baseline visual memory task (Degeest et al., 2015). When the dual task condition was performed the primary and secondary task were performed simultaneously. For each listening condition two sets of five digits and two sets of five

circles on a raster were presented to the participant. Hence, the participant was able to achieve a score out of 10 for the visual memory task and a score out of 10 for the speech recognition task. Participants were instructed to first repeat the digits heard in the primary task before designating the memorised positions of the geometric figures on the score form. Subsequently, the listening effort was calculated (Degeest et al., 2015). If participants were unable to perform the tasks in the Listening Effort Test, they were excluded from the study.

#### **2.5.5. Description of participants**

A set of 27 participants (6 males; 21 females) between the ages of 18 and 30 years (mean age=22.56; SD=1.17) were selected from various faculties (Faculty of Humanity, Faculty of Health Science and Faculty of Engineering, Built Environment and Information Technology) . No participants was excluded from the original 27 participants that were selected. The minimum age was found to be 19 years, while the maximum age was 25 years. All participants were found to be right-handed. Research has been found that the dominant hand can be influential to the hemispheric specialisation. Right-handedness indicates left hemispheric sensitivity to language. The results were thus not influenced by participants having a right hemispheric specialization (Samelli & Schochat, 2008). Further characteristics of the participants are summarised in Table 1.

**Table 1: Characteristics of participants (n=27)**

<b>Characteristics</b>	<b>Number of participants (%)</b>
Male	6 (22%)
Female	21 (78%)
Right handed	27 (100%)
<b>First language</b>	
Afrikaans	14 (52 %)
English	10 (33%)
Setswana	1 (4%)
German	3 (11%)
<b>Level of education</b>	
Undergraduate	10 (37%)
Postgraduate	17 (63%)
<b>Sleep habits</b>	
Good sleeping pattern of 6-8 hours for at least 2 weeks prior to testing	27 (100%)
<b>Other characteristics</b>	
Type A; present ipsilateral reflexes at 70-95 dB HL	Right: 27 (100%) Left: 27 (100%)
<b>Test performance in the participant selection</b>	
Average PTA (mean)	<b>Right:</b> 4.81 dB HL (SD=3.56) <b>Left:</b> 3.64 dB HL (SD=3.24)
Average DDT percentage (mean)	<b>Right:</b> 96.74% (SD=4.71) <b>Left:</b> 98.59% (SD= 3.46)
Performance on the Listening Effort Test (mean)	<b>Visual Memory task percentage :</b> 91.48% (SD=11.67) All participants were able to perform both the primary and secondary tasks separately and simultaneously.

## 2.6. Material and apparatus for data collection

Within this section all the audiometric equipment used for data collection are discussed. The reader will furthermore be introduced to each assessment used for data collection.

### **2.6.1. Audiometric equipment**

For the GIN Test the GSI 61 Welch-Allyn audiometer with Telephonic -50 earphones was connected to the Sansui CD210 CD player so that the GIN Test material which is recorded on a CD could be presented. The GSI Welch-Allyn audiometer was calibrated in January 2017 in accordance with the SANS 10154-1/2 10182 standards. For the DIN Test an Android Smartphone application on a Samsung Galaxy Fame Lite GT-S6790 phone with headphones (Seinheiser HD 201 supra-aural headphones) was utilised. The procedure used to assess listening effort was performed using an Acer E1-572 computer with Proline speakers and was presented through Microsoft Power Point 2013.

### **2.6.2. Gaps-in-Noise (GIN) Test**

The GIN Test is a standardised procedure and was developed by Musiek and his associates for the purpose of assessing temporal resolution abilities (Musiek, Shinn, Jirsa, Bamiou, Baran & Zaidan, 2005). The GIN Test contains one practice list and four test lists out of which two test lists (Test list 1 and 2) were used. Each test list contains a total number of 60 gaps. One test list was appointed to each ear for each testing session. Evidence has indicated that the specificity of the test for identifying CAPD is 94% while the sensitivity was found to be 67% (Musiek et al., 2005). The GIN Test is more likely to detect impairments that are found in the cortical areas rather than those found in the brainstem (Musiek et al., 2005).

### **2.6.3. A smartphone based Digits-In-Noise (DIN) Test**

The smartphone based DIN Test developed by Potgieter, Swanepoel, Myburgh, Hopper and Smits (2016) was conducted to assess the participants' ability to discriminate speech in noise. A sensitivity of 0.91 and a specificity of 0.93 was also established for the identification of hearing impairments with this test (Smits, Kapteyn & Houtgast, 2004). Each participant's performance obtained with the DIN Test was measured in Signal to Noise Ratio. The application stores 120 digit triplets from which a digit triplet is chosen at the beginning of the test. In addition, any digit from 0 to 9 can be selected for a digit triplet. The triplets presented are separated by a 500ms silent interval and individual digits are separated by a 200ms silent interval (Potgieter et al., 2016). The use of digits may be beneficial in a country such as South Africa in

which several different languages are spoken by the population, as it requires very little top down and linguistic perception (Lehohla, 2012; Smits, Goverts & Festen, 2013) . The SNR is calculated using the number of correctly discriminated speech material in a specific noise situation. Evidence has been reported that the SNR is lower in Speech-in-Noise tests when using digits (Smits et al., 2013). The DIN Test is known to assess primarily auditory speech recognition skills as the test does not require extensive processing of the linguistic components (Smits et al., 2013).

#### **2.6.4. Listening Effort Test**

The amount of cognitive processing required for the comprehension and processing of speech is termed the listening effort (Degeest et al., 2015). The procedure designed by Degeest, Keppler and Corthals (2015) at the Ghent University assesses the amount of mental effort used for the perception of auditory information. Thus, the procedure assesses the processing speed, attention, and working memory, which are all known to play a role in the processing and comprehension of auditory information and in the understanding of speech in the presence of background noise (Degeest et al., 2015; Degeest, Keppler & Corthals, 2017). It is very important to include a test that assesses the working memory, processing speed, and attention, as these skills may influence the results of the GIN and the DIN and may be a more sensitive indicator of the influence of sleep deprivation. As discussed in section 2.5.4, the Listening Effort Test is comprised of three conditions, namely two baseline conditions and a dual task condition, and five listening conditions (quiet, SNR of +2 dB,-2 dB,-6 dB and -10 dB). The order in which the five listening conditions and the two baseline conditions and the dual task condition were presented differed in various sets. Each participant was randomly appointed four different sets for each evaluation.

#### **2.6.5. Profile of Mood State (POMS)**

The POMS was developed by McNair, Lorr, and Droppleman (1992) and is a standardised procedure in which the validity of the close relationship between the POMS scales and the mood was established (Nyenhuis, Yamamoto, Luchetta, Terrien & Parmentier, 1999). The POMS, a measurement usually utilised to gauge psychological distress, is a subjective report on the different mood states of the participant, such as anger, confusion, depression, fatigue, vigour, and tension (Curran,

Andrykowski & Studts, 1995; Sandridge, Santiago, Newman & Behrens, 2015). Research has indicated a close relationship between the psychological distress and the cognitive performance of an individual (Saadat et al., 2016). The information provided by the POMS may thus assist in explaining the results obtained from the GIN, DIN and the Listening Effort Test after a period of sleep deprivation.

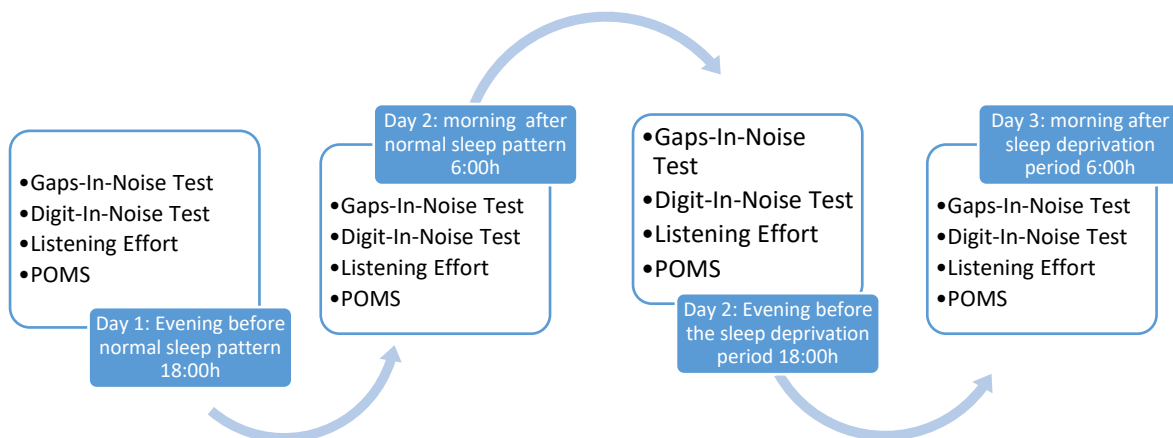
### **2.7. Pilot study**

A pilot study was conducted before the collection of data to determine the duration of testing for planning purposes. It provided the researcher with knowledge about the expertise needed for the specific procedures and gave an indication of how the data should be analysed. The pilot study also enhanced the reliability and validity of the study (Leedy & Ormrod, 2014).

For the pilot study the complete test battery planned for the collection of data was completed on three random participants who consented to participate. It was determined through the pilot study that the whole data collection procedure would take approximately an hour. Furthermore, the researcher was able to attain knowledge on the set up of the different equipment and the scoring of each specific procedure. The pilot study also confirmed that the data should be coded and analysed using Microsoft Excel and the Statistical Software Package (SPSS) version 23. Other than the information attained, it was also determined by the pilot study that the questionnaire and any other procedure planned in the study did not need to be adapted or changed for the success of the study.

### **2.8. Procedures for data collection**

Figure 1 depicts the procedures used for the collection of data over the course of three days.



**Figure 1: Audiometric procedures for the collection of data**

Data was obtained over the course of three days. On day one, the DIN Test, the GIN Test, the Listening Effort Test and the POMS were conducted at 18:00 (pre) and at 6:00 (post) the following morning after participants had slept for approximately 6 to 8 hours (NSDP condition). The same measurements were then employed the evening at 18:00 (pre) before the night's sleep deprivation and the morning thereafter on day 3 at 6:00 (post).

Three participants were selected per session and were kept together overnight in a room at the Department of Speech-Language Pathology and Audiology at the University of Pretoria under the supervision of a researcher. The Head of the Department had given verbal consent regarding the use of a room and the security of the University of Pretoria was informed about these arrangements. During the night, the participants were kept busy with board games, video games, and movies and were provided with non-caffeinated and non-alcoholic snacks and drinks. Participants were also instructed not to take any stimulants that might influence their wakefulness for a period of 24 hours before the administration of test procedures. The group was deprived of caffeine, nicotine, and alcohol to ensure optimal cognitive performance (Lee et al., 2003; Liberalesso et al., 2012). Procedures that were followed are summarised in Figure 1.

The following procedures were followed for the specific tests:

### **2.8.1. Procedure of the Gaps-In-Noise (GIN) Test**

The GIN was conducted in a soundproof booth that complies with the ANSI S3.1 (1999) standards (Katz, Chasin, English, Hood & Tillery, 2015). The order of the test list with which the researcher began was randomised for each testing session. For 50% of the participants testing began with the left ear, while for the other 50% testing commenced in the right ear. Each test list contains broadband noise fragments of six seconds, in which zero to three silent intervals are presented. The silent intervals also known as “gaps” may have a duration of 2, 3, 4, 5, 6, 8, 10, 12, 15 or 20 msec (Musiek & Chermak, 2014). The participants were required to push a button after each gap they detected. The stimuli were presented at 50 dBSL to obtain maximum test performance (Weihing, Musiek & Shinn, 2007). The smallest gap duration identified by the participant, also known as the approximate gap duration threshold (AGDT), can be used to detect a lesion in the central auditory nervous system. In addition to measuring the AGDT, a percentage was calculated from the number of correct responses. Both the AGDT and the percentage were used when scoring the GIN (Musiek & Chermak, 2014). The AGDT for adults should be equal to or above 6 msec, while the percentage calculated is perceived as normal when it is above 54% (Weihing et al., 2007).

### **2.8.2. Procedure of the smartphone based Digits-In-Noise (DIN) Test**

This test can be administered in any room that does not have high background noise levels (Potgieter et al., 2016). Within this test procedure the participant was instructed to listen to various triplets that were presented in varying degrees of noise levels; ergo, the participant was exposed to a range of SNRs. At the beginning of the test procedure the participant was required to select a comfortable intensity level which determined the first triplet chosen in the test. Subsequently, the participant was expected to type the triplet heard into a pop up keypad. When all the digits of a triplet were entered correctly, the SNR was lowered by 2 dB for the next set of digits, but when the participant failed to enter the correct response the SNR was raised by 2 dB. Entering even one incorrect digit of the triplets was considered an incorrect response. Scoring of the DIN was conducted by calculating the average of the SNR of the set of digits demonstrated. The normative value for adults was considered to be a SNR that was smaller than -9.4 dB (Potgieter, Swanepoel, Myburgh & Smits, 2018).



### 2.8.3. Procedure of the Listening Effort Test

The Listening Effort Test comprises three conditions, namely two baseline conditions and a dual task condition. Furthermore, the test consists of a primary and secondary task. In the baseline condition the primary and secondary task were performed separately. The primary task assessed speech comprehension in a quiet and noisy environment, while the secondary task provided more information on visual memory. When administering the primary task, monosyllabic digits from 0-12 were presented at five fixed listening conditions (quiet, SNR of +2 dB, -2 dB, -6 dB and -10 dB). Two series of five digits were presented at each listening condition, and the participants were requested to repeat the digits after the presentation of five digits. Thereafter the researcher marked the correct and the incorrect numbers in a scoring sheet designed by the Ghent University. Scores were then obtained by calculating a percentage of the correct responses out of 10 per listening condition. For the baseline secondary task, five sequences of five blue filled circles at a time were displayed consecutively in a raster on the computer. The participants were required to remember the positions of the circles that appeared on the raster (Figure 2) and were required to indicate the memorised positions on a scoring sheet. Each correct position that was indicated was awarded a point. The participant was able to achieve a maximum amount of 10 points, as only the 4<sup>th</sup> and 5<sup>th</sup> series tested were scored (Degeest et al., 2015).

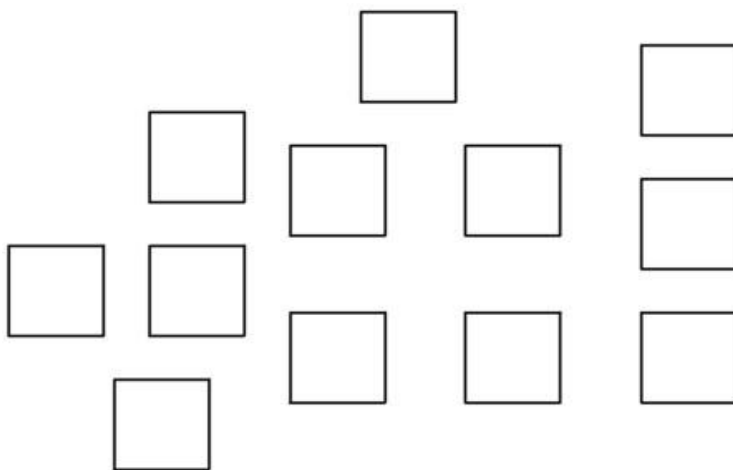


Figure 2: *The raster in which the participants were required to indicate the memorised positions*

Once the primary and secondary tasks had been performed separately, the Listening Effort Test was performed in a dual task condition. Within the dual task condition the

primary and secondary task were performed simultaneously. For each listening condition two sets of five digits and two sets of five circles on a raster were presented to the participant. Hence, the participant was able to achieve a score out of 10 for the visual memory task and a score out of 10 for the speech recognition task. Participants were instructed to first repeat the digits heard in the primary task before designating the memorised positions of the geometric figures on the score form. The results of the Listening Effort Test were calculated using the following formula: Listening Effort= [(score of the visual memory task in the baseline condition - score of the visual memory task in the dual task condition) / score of the visual memory task in the baseline condition] times 100. The formula was multiplied with a 100 to obtain a percentage. The percentage indicates how much listening effort an individual uses to process auditory information. Thus the percentage obtained should be as low as possible (Degeest et al., 2015, 2017).

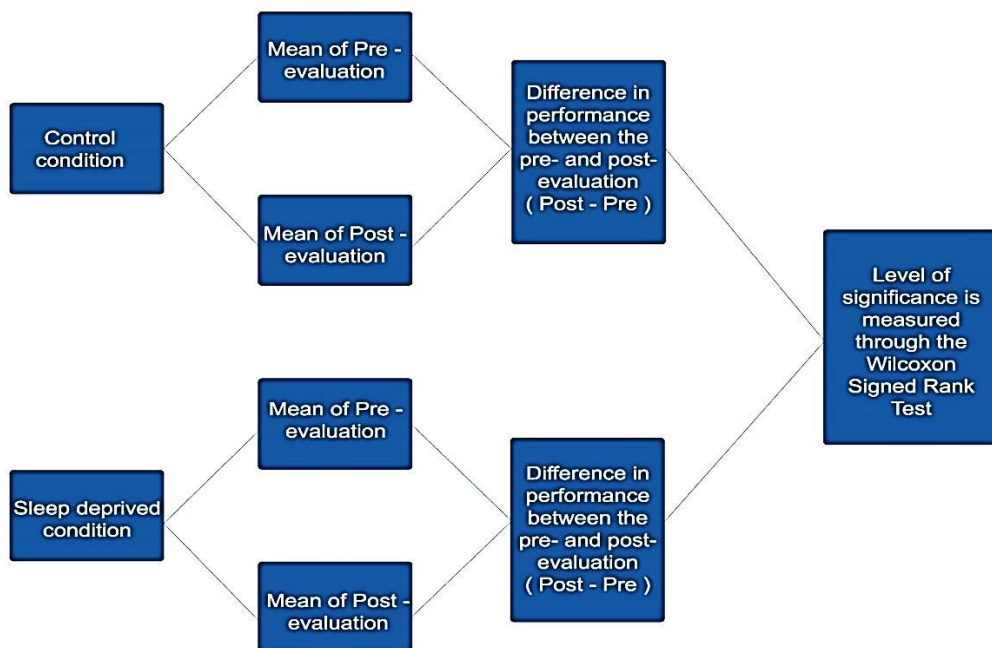
#### **2.8.4. Procedure of Profile of Mood States (POMS)**

This test required the participants to indicate their mood, regarding 65 different mood states, on a 5 point Likert scale (“not at all”, “a little”, “moderate”, “Quite a bit”, “Extremely”). The moods listed on the POMS were categorised into six different subscales (anger, depression, confusion, tension, fatigue, and vigour). Scoring included scores for these subscales and a Total Mood Disturbance score. The Total Mood Disturbance score was calculated by adding together the scores for five of the different subscales, namely anger, fatigue, tension, confusion and depression, and then subtracting the vigour score. The test provided additional information on how different mood states, including fatigue and vigour, were affected by sleep deprivation. The POMS took about three to seven minutes to administer (Curran et al., 1995; Sandridge et al., 2015). The greater the score of the different subscales, namely anger, fatigue, confusion, tension, and depression, the more negative the mood state. The score for vigour, however, is required to be as large as possible in order for it to be a good score (McNair et al., 1992).

#### **2.9. Data processing and analysis procedures**

Data processing consists of the processes of editing, coding, and classifying data in a logical manner so that it can be analysed. In this study, data was initially converted

into a coded format that was stored in a Microsoft Excel sheet (Microsoft Excel 2013). This data was then analysed using the Statistical Software Package (SPSS) version 23 according to a within-subject repeated-measure design. The Wilcoxon Signed Rank test was implemented using non-parametric statistics, as the Shapiro Wilk test indicated that the data was not normally distributed (Tredoux & Durrheim, 2013). All extreme outliers were removed. The value 0.05 was used for the level of significance in all of the tests with the exception of the POMS. Based on the small p-values obtained in the statistical analysis, the value 0.01 was used to determine the level of significance for the results of the POMS to provide stronger evidence (Tredoux & Durrheim, 2013). The level of significance was calculated using the changed performance scores between the pre and post evaluations of both the NSDP condition and the SDP condition (post - pre) (Dimitrov & Rumrill, 2003; Tredoux & Durrheim, 2013). The level of significance was then determined for the difference between the NSDP and SDP condition. Figure 3 is a graphical representation of how the data was analyzed in the study.



**Figure 3: Analysis of data**

Subsequently, a Linear Regression Model was conducted to determine if the POMS results had an influence on the performance obtained on the GIN Test. In the analysis the pre and post evaluations were compared for the NSDP condition and the SDP

condition. After the removal of extreme outliers, all the assumptions for running a Linear Regression Model were met, as the residuals were normally distributed (Tredoux & Durrheim, 2013).

A bivariate causal analysis was implemented so that beneficial results could be achieved in this study. This type of analysis is concerned with identifying the relationship among two variables and how these are influencing each other. In this case the relationship between a night of sleep deprivation and either temporal resolution or listening effort was analysed (Bryman & Bell, 2015). Furthermore, the results of the study were analysed with basic descriptive statistics including mean, range, and standard deviation (SD).

The use of tables and figures provided a more efficient way of representing and depicting the data.

#### **2.10. Reliability and validity**

In order to achieve the purpose of the study, both validity and reliability had to be ensured. Validity can be described as the degree to which the measurements used to obtain data collection are accurately measuring the intended data (Weiten, 2013). Reliability refers to the degree to which the measurements of data collection maintain consistency and accuracy (Weiten, 2013).

Validity in this study was ensured by the administration of standardised, validated measurements namely the GIN and the DIN. Other variables that might warrant validity in the study were the stringent participation selection criteria the study employed. The measurements were conducted in both the NSDP and SDP condition, which ensured an accurate representation of the effects of sleep deprivation.

Reliability was guaranteed by various factors. Most notably, the equipment used was calibrated according to the SANS 10154-1/2 10182. The same test battery was used on each subject in the study which likewise justifies the reliability of the study. Participants also received proper instructions so that they had sufficient understanding

of how they had to respond during the testing, which was related to the accuracy of the results.

### **2.11. Summary**

A detailed description of the method of the study is provided in this chapter. A within-subject repeated-measures design was used to investigate the effect of a night of sleep deprivation on temporal resolution and listening effort. The GIN, DIN, POMS and a procedure designed by Degeest et al. (2015) to assess the listening effort were used in this study.

## **Chapter three: Results**

### **3.1. Introduction**

Sleep deprivation has been known to have negative effects on an individual's cognitive performance and can, therefore, be linked to a poorer quality of work performance and decreased public safety (Thomas et al., 2000; Lange et al., 2009). The present study aimed to shed more light on the effects of sleep deprivation on auditory processing.

This chapter discloses the outcome of the study by presenting the descriptive and inferential statistical analysis of the data collected from the participants. The results of the inferential statistics provide more information on the comparison of the NSDP and SDP condition. The results are presented according to the different procedures used for data collection. This will provide the reader with a detailed review of the effect of sleep deprivation as revealed by the results of the different tests namely Listening Effort Test, GIN Test, POMS Test and DIN Test. Statistical analysis was conducted on data obtained from 27 adults and thus 54 ears. The n-value of the statistical analysis indicates the number of ears used within the study (n=54).

### **3.2. Listening Effort Test**

The participants were assessed the evening before (pre) and the morning after (post) they had to sleep the optimal number of hours (NSDP condition) or had to remain awake throughout the night (SDP condition). The listening effort was calculated using the score obtained from the baseline visual memory and the dual task visual memory task. Furthermore, a percentage for listening effort was calculated for five listening conditions (Quiet; SNR (+2), SNR (-2), SNR (-6) and SNR (-10)) (Degeest et al., 2015, 2017).

Table 2 provides an overview of the means and standard deviations of the scores obtained on the Listening Effort Test in percentage. The data reflects the scores obtained by the participants in the pre and post NSDP and SDP conditions. The table further provides the results of the Wilcoxon test for significance.

**Table 2: Mean (M) and standard deviations (SD) of the listening effort scores (%) for the pre and post evaluations in the NSDP condition and SDP condition (n=54)**

Listening condition	Condition	Pre/Post	Mean (%)	SD	Difference in mean (post-pre)	p-value
Quiet	NSDP	Pre	21.43	19.58	-4.4	0.277
		Post	17.03	16.74		
	SDP	Pre	19.64	18.15	1.36	
		Post	21.00	17.18		
SNR (+2)	NSDP	Pre	16.05	20.45	0.62	0.703
		Post	16.67	17.10		
	SDP	Pre	22.46	21.30	-2.23	
		Post	20.23	23.35		
SNR (-2)	NSDP	Pre	21.46	20.69	1.66	0.899
		Post	23.12	14.83		
	SDP	Pre	23.79	19.87	1.69	
		Post	25.48	15.29		
SNR(-6)	NSDP	Pre	23.82	20.68	2.82	0.146
		Post	26.64	21.35		
	SDP	Pre	23.85	23.77	-2.06	
		Post	21.79	18.76		
SNR(-10)	NSDP	Pre (n=52)	21.19	15.99	2.86	0.014* (Wilcoxon Signed Rank Test) 0.086 (Ancova)
		Post	24.05	17.79		
	SDP	Pre	27.30	19.14	-4.79	
		Post	22.51	20.28		

(\* p<0.05)

The overall results (means and standard deviations) obtained by the participants in the Listening Effort Test in percentage for all five listening conditions pre and post NSDP and SDP condition indicate no observable difference between the two conditions. In two of the listening conditions, namely Quiet and SNR (-2) condition, the participants did seem to have used an increased amount of listening effort in the post SDP condition. In the Quiet listening condition, the mean listening effort score of the post SDP test results obtained by the participants (M=21.00 ± 17.18) is higher than the pre SDP score (M=19.64 ± 18.15), meaning that more listening effort was used by the participants post SDP. The mean listening effort score of SNR (-2) attained by the participants in the post SDP condition was also found to be higher (M=25.48 ± 15.29) compared to the mean of the pre SDP test results (M=23.79 ± 19.87). In three of the

listening conditions, namely SNR (+2), SNR (-6) and SNR (-10), the listening effort score appeared to be lower in the post SDP condition. The lower score indicates that less listening effort was used. Thus, it is observed that especially in the most difficult conditions the listening effort results improve after SDP.

The Wilcoxon Signed Rank Test showed a significant difference between the NSDP condition and SDP condition for only one of the five listening conditions, namely SNR (-10) ( $p > 0.05$ ). Subsequently, the ANCOVA was used for statistical analysis in the SNR (-10) condition only, as there were significant variabilities between the participants' mean responses in the results obtained in the pre NSDP condition ( $M = 21.19 \pm 15.99$ ) and in the pre SDP condition ( $M = 27.30 \pm 19.14$ ). These results indicated that no significant difference was found in the SNR (-10) listening condition between the mean differences attained in the NSDP and SDP condition ( $p = 0.086$ ) on the Listening Effort Test.

### 3.3. DIN Test

During the performance of the DIN Test participants were required to identify digit triplets that were presented in different noise conditions. An averaged score for each SNR was determined for each participant (Potgieter et al., 2017).

The mean Speech Reception Threshold Signal to Noise Ratio (SRT SNR) and the standard deviation during the DIN test in the NSDP and SDP conditions are summarised in Table 3.

**Table 3: SRT SNR's in dB obtained for the DIN (n=54)**

Condition	Pre/Post	Mean	SD	Difference in mean (post-pre)	p value
NSDP	PRE	-11.56	0.64	0.2	0.632
	POST	-11.36	0.64		
SDP	PRE	-11.64	0.69	0.17	
	POST	-11.47	0.80		

(\* $p < 0.05$ )

The mean SRT SNR attained by the participants in the pre ( $M = -11.56 \text{ dB} \pm 0.64$ ) and post ( $M = -11.36 \text{ dB} \pm 0.64$ ) NSDP condition were within close range. Moreover the



mean SRT SNR obtained by the participants in the pre ( $M=-11.64 \text{ dB} \pm 0.69$ ) and post ( $M= -11.47 \text{ dB} \pm 0.80$ ) SDP condition were also within close range.

A statistical analysis by means of the Wilcoxon Signed Rank Test using the mean difference scores of the pre and post test results (post – pre) indicated that there was no significant difference ( $p=0.632$ ) between the NSDP and SDP condition.

### 3.4. GIN Test

The results of the GIN Test consisted of a percentage of correct responses and an AGDT that were calculated per ear. The AGDT refers to the shortest gap duration identified by the participant within a broadband noise fragment. A percentage was also calculated using the number of correctly recognised gaps out of 60 (Musiek & Chermak, 2014).

The mean AGDTs obtained by the participants pre and post NSDP and SDP are depicted in a Figure 4.

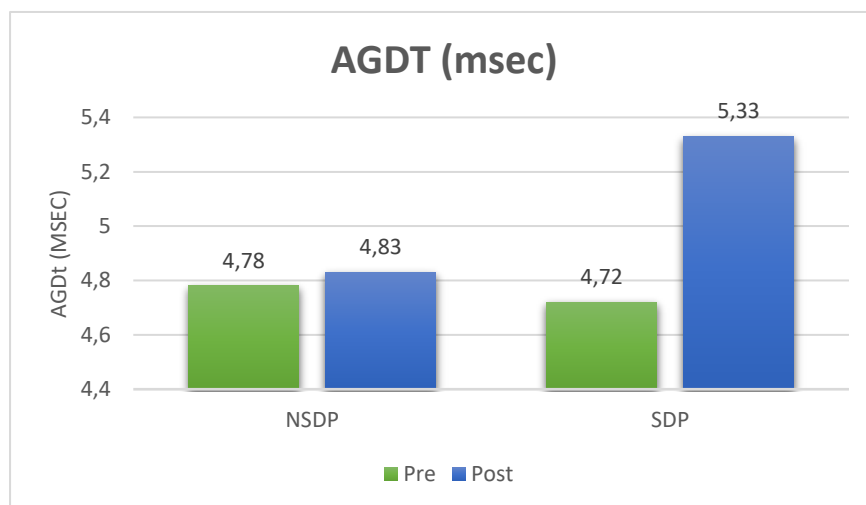
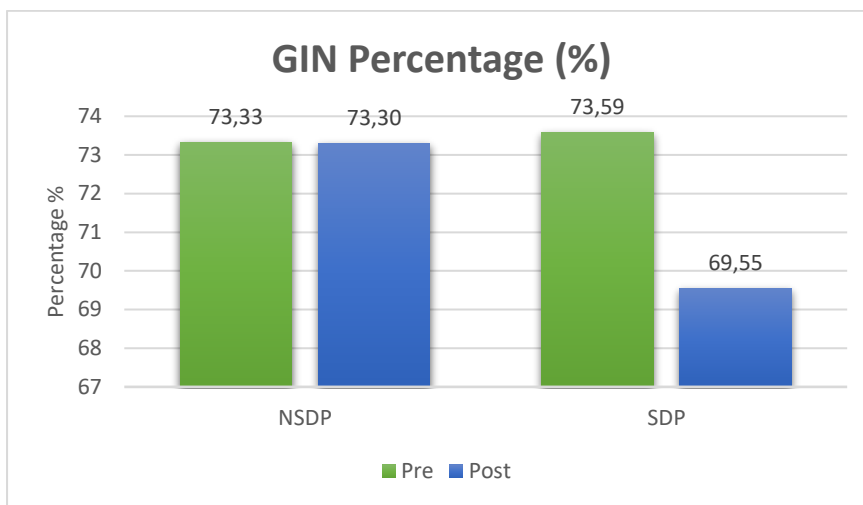


Figure 4: Comparison of the pre and post test results of the mean AGDT: NSDP vs SDP condition ( $n=54$ )

The mean AGDT attained by the participants pre- and post NSDP was observed to be within close range –  $M=4.78 \text{ msec} \pm 1.06$  (pre) and  $M=4.83 \text{ msec} \pm 1.01$  (post) - in comparison to the considerable change in performance demonstrated by the participants in the SDP condition between the pre ( $M=4.72 \text{ msec} \pm 0.86$ ) and post SDP results ( $M=5.33 \text{ msec} \pm 1.38$ ).

When inferential statistics (the Wilcoxon Signed Rank Test) were conducted, a significant difference between the pre and post NSDP/ SDP results (post-pre) was observed when comparing the NSDP condition and the SDP condition  $z(p=0.002)$ .

Figure 5 depicts the mean percentage of correct responses obtained by the participants during the performance of the GIN test in the pre and post NSDP and SDP conditions.



**Figure 5: Comparison of the pre and post test results of the mean percentage of correct responses of the GIN: NSDP vs SDP condition (n=54)**

From Figure 5 it is clear that the mean percentages of correct responses obtained on the GIN Test pre ( $M=73.33\% \pm 8.18$ ) and post ( $M=73.30\% \pm 8.12$ ) NSDP remained within close range. For the SDP condition, however, a difference was seen when comparing the pre ( $M=73.59\% \pm 8.04$ ) and post SDP results ( $M=69.55\% \pm 9.14$ ). After the sleep deprived period participants obtained a noticeably lower percentage, which indicates that their performance deteriorated after sleep deprivation.

To determine if this difference in pre and post SDP results was significantly different from the difference observed between the pre and post NSDP test results, the Wilcoxon Signed Rank Test was performed. A significant difference was found between the results obtained in the NSDP and SDP conditions  $z(p=0.016)$ .

### 3.5. POMS

The POMS, like the other assessments in the study, was conducted the evening before (pre) and the morning after (post) sleeping (NSDP) and being sleep deprived for the whole night (Curran et al., 1995; Sandridge et al., 2015).

Table 4 summarizes the means and standard deviations of the participants' performance pre and post NSDP and SDP. The results of the Wilcoxon Signed Rank Test for significant difference are also provided in the table.

**Table 4: Mean (M) and standard deviation (SD) of all mood states and total mood disturbance (TMD) (NSDP: n=54; Sleep deprivation: n=52)**

Mood State	Condition	Pre/Post	Mean	SD	Difference in mean (post- pre)	P- value
<b>ANGER</b>	NSDP	PRE	3.04	4.13	0.15	0.002**
		POST	3.19	4.56		
	SDP	PRE	2.19	3.18	3.35	
		POST	5.54	5.37		
<b>CONFUSION</b>	NSDP	PRE	6.00	2.88	-0.3	0.000**
		POST	5.70	2.77		
	SDP	PRE	5.54	2.43	3.61	
		POST	9.15	4.35		
<b>DEPRESSION</b>	NSDP	PRE	4.70	4.06	-0.4	0.002**
		POST	4.30	5.97		
	SDP	PRE	3.54	4.69	3.04	
		POST	6.58	5.99		
<b>TENSION</b>	NSDP	PRE	6.56	4.88	-1.41	0.000**
		POST	5.15	4.84		
	SDP	PRE	4.31	4.08	2.31	
		POST	6.62	2.80		
<b>FATIGUE</b>	NSDP	PRE	7.19	3.54	-0.97	0.000**
		POST	6.22	4.71		
	SDP	PRE	5.54	4.53	9.11	
		POST	14.65	5.71		
<b>VIGOUR</b>	NSDP	PRE	12.70	5.25	-2.22	0.000**
		POST	10.48	6.37		
	SDP	PRE	11.46	6.84	-6.04	
		POST	5.42	4.85		
<b>TMD</b>	NSDP	PRE	14.78	15.31	-0.71	0.000**
		POST	14.07	21.15		
	SDP	PRE	9.73	19.21	27.42	
		POST	37.15	20.82		

(\*\*p<0.01)

Participants' mean scores for all the different mood states did not differ noticeably between the pre and post NSDP condition. However, with regard to the SDP condition, results indicated greater negative disturbances of all the mood states (anger, depression, fatigue, vigour, confusion and tension) in the post SDP compared to the pre SDP test results. An increased score in the POMS test results indicates a greater negative mood disturbance. The mean anger scores obtained by the participants were the lowest compared to the rest of the mood states, which means that anger was the least affected by the SDP condition. However, the mean score for anger still appeared to have increased noticeably in the post SDP condition ( $M=5.54 \pm 5.37$ ) compared to the pre SDP results ( $M=2.19 \pm 3.18$ ). When comparing the pre and post SDP results, the mean scores for the fatigue and Total Mood Disturbance (TMD) measures increased the most post SDP. The mean scores of the POMS did not increase post NSDP.

Inferential statistical analysis by the Wilcoxon Signed Rank Test was conducted using the mean difference scores between the pre and post SDP/NSDP results of all six mood sub-scores, namely anger, confusion, depression, tension, fatigue, vigour, as well as the TMD obtained in both the NSDP and SDP condition ( $p<0.01$ ). A highly significant difference was found when comparing the results obtained in the NSDP condition and SDP condition ( $p<0.01$ ). The level of significance that was found for anger and depression between the participants' performance in the NSDP and SDP condition is  $z$  ( $p=0.002$ ), compared to  $z$  ( $p=0.000$ ) for the other mood state scores, indicating that anger and depression were the least affected by sleep deprivation, while fatigue, tension, confusion, and vigour are affected the most.

### **3.6. The influence of the POMS results on the GIN Test results**

As both the POMS and GIN Test results were significantly affected in the SDP condition the question was raised whether the POMS had an influence on the participants' performance in the GIN Test. A Linear Regression Model was used to determine the influence of the POMS Total Mood Disturbance (TMD) on the percentage of correct responses attained in the GIN Test and on the AGDT within the NSDP and the SDP conditions, respectively (Appendix F). These results are summarized in Table 5.

**Table 5: The influence of the POMS TMD on the GIN % and AGDT**

	Condition	Pre/ Post	Unstandardized Coefficient	p-value	R-square
<b>POMS TMD on GIN %</b>	NSDP	PRE	0,157	0,032*	0,086
		POST	-0,119	0,031*	0,087
	SDP	PRE	-0,098	0,079	0,058
		POST	-0,040	0,525	0,008
<b>POMS TMD on AGDT</b>	NSDP	PRE	-0,014	0,129	0,044
		POST	0,014	0,071	0,061
	SDP	PRE	0,014	0,055	0,069
		POST	0,006	0,554	0,007

(\*p<0.05)

From Table 5 it is clear that the POMS TMD could not be considered to be a significant predictor for the GIN percentage in all the evaluations of the SDP condition. However, it is a significant predictor in the pre and post NSDP results ( $p < 0.05$ ). Taking this into account and considering the findings in Table 5 that are significant, for the pre NSDP condition for POMS TMD on GIN percentage, for every one unit that the POMS TMD increased, the GIN percentage increased by 0.157 units. On the other hand, for the post NSDP condition for POMS TMD on GIN percentage, for every one unit that the POMS TMD increased, the GIN percentage decreased by 0.119 units.

With regard to the AGDT, it is evident that the POMS TMD results did not significantly influence the AGDT results pre and post NSDP and SDP ( $p < 0.05$ ) and therefore the mood states of the participants do not need to be taken into consideration in the discussion of results

The small R squared values in all the conditions for both the NSDP and SDP condition further indicate that a slight amount of the variance in the percentage of the correct responses attained by the participants in the GIN Test and in the AGDT was predicted by the POMS TMD.

Further results providing detail on the influence of all the separate POMS mood states on the percentage obtained by the participants in the GIN Test and the AGDT are found in Appendix F.

### **3.7. Summary**

In this chapter the findings regarding the effects of sleep deprivation on temporal resolution and listening effort are discussed. These findings were reported in terms of the different procedures of the study, namely the GIN, DIN, Listening Effort, and POMS Tests. Tables and figures are used to present the results of the study.

## **Chapter four: Discussion of results**

### **4.1. Introduction**

Sleep deprivation may result in a deterioration of cognitive skills. As a result auditory processing skills may be affected which in turn may influence communication ability and work performance (Babkoff et al., 2005; Fostick et al., 2014). Research reports regarding the effect of sleep deprivation on certain aspects such as immune function and memory, endocrine, digestive, and thermal regulation are common. However, reports concerning the effect of sleep deprivation on certain auditory processing skills, such as temporal resolution and listening effort, are limited (Liberalesso et al., 2012). The current study aimed to determine the effect of sleep deprivation on auditory temporal resolution and listening effort by comparing the test results obtained in the NSDP condition to those obtained in the SDP condition. The results are discussed against the background of relevant literature and according to the different procedures that were used for data collection.

### **4.2. Listening Effort and DIN Tests**

There was no significant difference between the results of the Listening Effort and the DIN Tests in the SDP condition and the NSDP condition. It seems that sleep deprivation did not influence listening effort and the processing of speech in the presence of background noise.

The processes involved in and needed for auditory processing and comprehension of speech and the listening effort required include attention, processing speed, and working memory (Degeest et al., 2015, 2017). These aspects, as well as planning, sequencing, decision making, creativity, language skills, cognitive flexibility, and memory are influenced by sleep deprivation (Babkoff et al., 2005; Killgore, 2010; Liberalesso et al., 2012). However, Lee et al. (2003) demonstrated in their study that a 38 hour period of sleep deprivation did not influence complex cognitive functions such as fine perceptual analysis, visual discrimination, and working memory. The current research indicated that these processes were not influenced during the performance of the Listening Effort and DIN Tests. There are several possible reasons why a 24 hour period of sleep deprivation did not have a significant effect on the results of the Listening Effort and DIN Test results.

The period of sleep deprivation is the first factor that is considered in sleep deprivation studies. The results of the Listening Effort and DIN Test may not have been affected in the SDP condition because a 24 hour period of sleep deprivation may not have been enough to have an impact. Previous research reports on the influence of sleep deprivation on cognitive components are not consistent with regard to the amount of sleep deprivation needed to influence the cognitive resources (Chee & Choo, 2004; Killgore, 2010; Lee et al., 2003). Some studies suggest that sleep deprivation may only influence complex cognitive components after a wakefulness period of 36 to 40 hours (Killgore, 2010; Lee et al., 2003), while others suggest that a sleep deprivation period of 24 hours may be enough to cause an impact (Chee & Choo, 2004).

The release of dopamine in the brain is an aspect that could impact the period of sleep deprivation needed to influence auditory processing skills (Liberalesso et al., 2012). Evidence was found of significantly more dopamine being released after a 24 hour sleep deprivation period than in a condition of no sleep deprivation (Liberalesso et al., 2012). The activation of the reward dopaminergic system of the mesocorticolimbic brain reward system maintains arousal and increases motivation towards a cognitive task (Volkow et al., 2008). Participants by virtue of being in the research study may have tried harder to perform better on tasks implying that more dopamine is being secreted. The release of the neurochemical dopamine, especially in the prefrontal cortex, may thus prevent the damaging effects of a 24 hour period of sleep deprivation from reaching its full potential. Therefore, the secretion of dopamine may explain why the listening effort exerted by the participants did not show a significant increase after a 24 hour sleep deprivation period. In addition, it might provide an explanation why a cognitively demanding task such as the DIN Test, which requires the participants to repeat 20 sets of digits, was not significantly affected (Liberalesso et al., 2012).

The age of the participants is another possible reason that the results of the Listening Effort and DIN Tests remained unaffected by a 24 hour period of sleep deprivation. In the current study university students between the ages of 18 and 30 years were selected. It could be conjectured that the population group selected was too young. The results reported by Patrick et al. (2017) appear to corroborate this opinion, as no significant differences regarding working memory and other executive functions were found in a young adult group that were within the same age range as the participants



in the current study. This theory was furthermore supported by Lee et al. (2003) who also used a young adult participant group whose complex cognitive performance was not influenced after a 38 hour sleep deprivation period. Sleep deprivation causes greater activation in brain regions related to inhibition and attention in an older population group (Almklov, Drummond, Orff & Alhassoon, 2014). It appears, therefore, that young adults are able to manage the effect of sleep deprivation better than older adults (Patrick et al., 2017). Based on the research by Almklov, Drummond, Orff and Alhassoon (2014), brain regions related to auditory processing might show a greater influence after a 24 hour period of sleep deprivation in an older population group compared to the young population group selected.

Another reason why the Listening Effort Test results might have remained unaffected in the current study is the fact that high variabilities (SD) were found in the performance of the participants in the Listening Effort Test. In a dual task paradigm the required mental capacity is used for the primary task, while the remaining mental capacity is used for the secondary task (Degeest et al., 2015). McGarrigle et al. (2014) and Gagné et al. (2017) revealed that there is a lack of consistency in the dual task paradigm used to assess listening effort and argued that it is difficult to determine how much attention the participants allocated to each task independently. The participants might have focused more on the secondary visual memory task than on the primary auditory task, especially in the most difficult listening condition (-6dB and -10 dB), regardless of the instructions to prioritise the primary task. The calculation of the Listening Effort was therefore influenced, as the Listening Effort is calculated from the results obtained in the baseline visual memory task and the dual visual memory task. Learned behaviour is another factor to consider that could have caused the high variability in the results of the Listening Effort Test, as each participant's listening effort was assessed on four occasions over the course of three days. The repetition of the same task might have caused the participants to develop a technique to perform better in the task (Hornsby, 2013). Hornsby (2013) also measured listening effort repeatedly using a dual task paradigm and found a gradual improvement in the word recognition task which was believed to be caused by the learning effect. The same pattern was observed in the speech recognition results of the Listening Effort Test in the current study, suggesting that the learning effect could also be an influential factor in this study.

### **4.3. GIN Test**

Significantly higher approximate gap duration thresholds and lower percentages on the GIN Test were obtained after a period of 24 hours of sleep deprivation. These results are consistent with the results of other studies (Babkoff et al., 2005; Fostick et al., 2014; Liberalesso et al., 2012), which found temporal resolution to be affected after a 24 hour period of sleep deprivation. However, these studies made use of other tests such as the temporal order judgement and the RGDT while the current study utilised the GIN Test.

The neurophysiology of the brain structures is a strong determiner of results in auditory processing studies. Sleep deprivation is found to affect the prefrontal cortex activity which is known to be linked to cognitive related activities (Harrison & Home, 2000). As auditory temporal resolution appears to be related to the left inferior and left dorsolateral prefrontal cortex specifically (Babkoff et al., 2005), decreased activity in this area – as a result of sleep deprivation - may have influenced the performance on the GIN Test. This is also in line with research by Chee and Choo (2004) who determined that a 24 hour period of sleep deprivation causes decreased activation in specific areas of the prefrontal cortex.

In addition to the prefrontal cortex, sleep deprivation also affects the cortical and subcortical areas in the brain, specifically in the frontal and the temporal lobe (Liberalesso et al., 2012). These structures are known to be associated with decreased activity in attention; concentration; divergent, innovative, flexible thinking; memory; and processing speed (Babkoff et al., 2005; Harrison & Home, 2000; Killgore, 2010; Pilcher, Band, Odle-dusseau & Muth, 2007) and are thus important in the processing of auditory information (Liberalesso et al., 2012). More specifically attention is linked to the prefrontal cortex, temporal and parietal cortices, the basal ganglia, and the cerebellum. As some of these cortical regions are also linked to the auditory association cortex, the attentional network might be responsible for directly impacting auditory processing skills, namely temporal resolution (Liberalesso et al., 2012). Thus, the significant difference in the results of the participants between the NSDP and SDP condition on the GIN test may be explained by the decreased ability to concentrate and maintain attention sufficiently. These results are confirmed by research of Pilcher et al. (2007) indicating that participants showed a decrease in

performance level on cognitive tasks requiring sustained attention after sleep deprivation.

#### **4.4. POMS**

A significant difference was obtained for all the different mood states when comparing the results of the participants in the NSDP condition to the SDP condition in the POMS results. Similar mean values were obtained for all the different mood states - anger, confusion, depression, fatigue, tension, and vigour (as indicated in Table 4) - between the pre and the post NSDP conditions. These results clearly differed from the results obtained in the SDP condition. Within the SDP condition, participants obtained significantly higher scores in confusion, anger, depression, fatigue, and tension the morning after 24 hours of sleep deprivation. Additionally, the participants' vigour scores were observed to be significantly lower in the post SDP evaluation compared to the NSDP condition.

If one considers the areas in the brain involved, an increased activation of certain cognitive areas is found in sleep deprived individuals. The hippocampus, medial prefrontal cortex, the amygdala, occipital area, and the connectivity between the amygdala and medial prefrontal cortex all appear to be affected and may be linked to the emotional state of an individual (Goel et al., 2009). The significant findings of this study correlate with the results obtained in past research that also used the POMS, where participants were found to be more confused and irritable, and showed increased feelings of fatigue and a loss of vigour after a period of sleep deprivation (Goel et al., 2009; Scott, Mcnaughton & Polman, 2006).

The affected mood states may have an effect on how well participants perform in other cognitive tasks (Saadat et al., 2016). Evidence in this regard has indicated that if participants are found to be more fatigued they may experience increased effort and decreased motivation for the completion of cognitive tasks, which might result in a poorer performance (Saadat et al., 2016). The question was thus raised whether the POMS results had an influence on the participants' performance on the GIN Test, which was determined through the Linear Regression Model. The results of the current study, however, revealed that the POMS TMD could not be considered to be a

significant predictor for the AGDT and the percentage attained in the GIN Test for the participants in the SDP condition. The results of the current study indicated instead that the performance attained on the GIN Test in the SDP condition could not be explained by the results of the POMS, but was rather influenced by other factors as previously discussed.

#### **4.5. Integration of findings**

The results of the present study suggest that a 24-hour period of sleep deprivation may have more influence on auditory temporal resolution and the emotional state of an individual, than on the results of the Listening Effort Test and the DIN Test. The question is therefore raised why the participants' performance on the GIN Test was affected, while their performance in the other cognitive tasks, namely the Listening Effort Test and DIN Tests, remained unaffected. Auditory temporal resolution might be more sensitive to sleep deprivation in contrast to the other skills due to the different nature of the various tasks. To complete the GIN Test, participants were obliged to maintain their attention for a long period, while participants completing the DIN Test and the Listening Effort Test were more actively engaged. The GIN Test is a simple but lengthy test, in which participants were required to wait and respond to a gap presented in six seconds broadband noise fragments. On the other hand, the tasks of the Listening Effort Test were more complex, requiring of the participants to remember certain positions of circles in a raster (visual) and digits presented (auditory) the whole time. The DIN Test is a short test requiring the participant to listen carefully to digits presented in noise. The GIN Test is thus a less engaging task, requiring more active controlled attention and making the ability to sustain attention more difficult. Contrary to the GIN Test, the Listening Effort and the DIN Tests consisted of interesting and engaging tasks in which the participants were able to sustain their attention better (Lee et al., 2003; Pilcher et al., 2007). Evidence showed that sleep deprivation may be more likely to have an effect on monotonous and uninteresting activities, while it appears not to affect the demanding and more interesting cognitive activities to the same extend (Lee et al., 2003).

Cognitive processes, for example working memory, attention, and concentration, are important processes to all tests used in the study. Research results regarding the

effects of sleep deprivation on cognitive processes differ in terms of the number of hours that are needed for sleep deprivation to be influential. There are research studies that suggest that a sleep deprivation period of 24 hours may be sufficient to impact cognitive processes such as attention and working memory (Chee & Choo, 2004; Pilcher et al., 2007), while other studies suggest that working memory may only be influenced after a sleep deprivation period that lasts more than 40 hours (Killgore, 2010; Lee et al., 2003). In this study, however, a 24-hour period of sleep deprivation appeared to have negatively impacted the performance of the participants on the GIN Test, but not the Listening Effort Test and the DIN Tests, indicating that not all cognitive processes are affected equally. The Listening Effort and DIN Tests appear to be tasks that require more working memory, while the GIN Test does not seem to require as much working memory. The results of the current study suggest that some cognitive processes, such as attention and concentration, are more sensitive to a 24-hour sleep deprivation period than other processes, such as working memory (Lee et al., 2003; Pilcher et al., 2007).

#### **4.6. Summary**

In Chapter Four the effect of sleep deprivation on the different tests that were used to assess temporal resolution, the ability to discriminate speech in noise, mood states, and listening effort are discussed. Findings regarding the GIN Test and the POMS were similar to previous research results stating that sleep deprivation does affect temporal resolution and different mood states. Results of the study also revealed that the results of the POMS in this study did not have a significant influence on the results of the GIN Test, especially in the SDP condition.

## **Chapter five: Conclusion and recommendations**

### **5.1. Introduction**

Evidence has shown that sleep deprivation influences cognitive processes such as concentration, attention, and working memory (Babkoff et al., 2005; Killgore, 2010; Liberalesso et al., 2012). These processes are known to play a role in the listening effort and in auditory processing skills such as temporal resolution. Auditory temporal resolution permits an individual to perceive meaningful variations in speech, which is essential for successful verbal communication (Babkoff et al., 2005; Fostick et al., 2014; Liberalesso et al., 2012). Effective communication is an important component of most activities in daily life and may influence work productivity and quality (Lange et al., 2009; Saadat et al., 2016). It is this potentially extensive impact of sleep deprivation that led to the current research.

This chapter concludes the study. The clinical implications of the results, a critical evaluation of the study, and recommendations for future research are provided.

### **5.2. Conclusion of the research study**

The main aim of this study was to determine the effect of sleep deprivation on temporal resolution and listening effort. As previous research indicated that sleep deprivation has an effect on cognitive performance in activities associated with daily life, the assumption was made that sleep deprivation will decrease the scores obtained in the Listening Effort Test, GIN Test, DIN Test, and the POMS.

This study has shown that a 24 hour period of sleep deprivation resulted in a significant difference in the participants' AGDT's and the percentage obtained with the GIN Test. Sleep deprivation also had a significant effect on the emotional state of the participants as evaluated by the POMS. Although performance of the participants on the GIN Test and the POMS was significantly affected, statistical analysis revealed that the POMS is not a significant predictor for the performance of the participants on the GIN Test in the SDP condition. Mood states were therefore not directly influencing performance on the GIN Test. On the other hand, contrary to the conjecture of this researcher, a 24 hour period of sleep deprivation did not have a significant effect on the results of

the Listening Effort Test or the results of the DIN Test used for the evaluation of speech understanding in background noise.

### **5.3. Clinical implications**

The following clinical implications have emerged from this study:

- Sleep deprivation should be taken into consideration in a clinical situation when administering the auditory processing test battery. With the knowledge of the effects of sleep deprivation, clinicians will be more cautious when assessing a patient's listening effort and auditory processing skills such as temporal resolution when there is a possibility that the patient is sleep deprived. Questions regarding sleeping habits should be included in the case history.
- This study may have contributed to increasing awareness of the influence of sleep deprivation on an individual's task performance in everyday functioning. Auditory temporal resolution is essential for the interpretation of a rapidly changing auditory stimulus. It is known to be associated with linguistic skills and may impact the ability to communicate efficiently (Babkoff et al., 2005; Liberalesso et al., 2012). This study has proven, in addition, that sleep deprivation heightens the emotional states of an individual. Heightened emotional states are known to impact the ability to communicate effectively, to empathise, and to make decisions (Saadat et al., 2016). The results of the present study can serve to raise awareness that jobs involving long working hours and high job demands may cause an individual to suffer from sleep deprivation, which may lead to the detrimental effects described above (Lange et al., 2009).
- The study emphasizes the value of the GIN Test as a clinical tool. It is a test that can be used with ease and is easily interpreted. The GIN test furthermore makes use of stimuli with a low linguistic load and is thus a valid tool for the multicultural and multilinguistic SA context.
- A test such as the Listening Effort Test needs to be used and interpreted with caution, as large variabilities were found in the results of the Listening Effort Test. McGarrigle et al. (2014) discussed the complexity of the dual task paradigm, pointing out that measuring the attention an individual gives to a specific task might be challenging. During the dual task paradigm instructions

are given prior to commencing with the task to focus on the primary task and to use residual resource capacity for the completion of the secondary task. However, test subjects may focus on the secondary task rather than on the primary task and the calculation of the Listening Effort Test might thus be influenced. This argument is supported in a research review by Gagné, Besser and Lemke (2017).

#### **5.4. Critical evaluation of the study**

A critical evaluation of the research project is crucial in order to interpret the findings of research within the framework of its strengths and limitations.

##### **5.4.1. Strengths of study**

- Reliable and valid measurements, namely the GIN Test, DIN Test, and POMS were utilised in the study ensuring validity in the study design.
- Stringent participant criteria allowed the researcher to acquire meaningful results and ruled out other factors that could have affected the dependent variables. This ensured furthermore that all the participants had the same characteristics.
- The study made use of a strict testing regime. The consistent use of the same times in the study was considered a strength, as it rules out the fact that the different times of the day as well as the circadian rhythm could have affected the dependent variables.
- The use of a pilot study benefited the study, as it allowed the researcher to gain additional knowledge about the duration of testing for planning purposes and on the expertise needed for the specific procedure.

##### **5.4.2. Limitations of study**

- The procedure used to evaluate listening effort is a newly developed test that needs further investigation (Degeest et al., 2015, 2017). A large variability in performance was found in the results achieved by the participants during the administration of the Listening Effort Test in both test conditions. The reason for these variabilities might be linked to the test-retest reliability, test procedures, and the learning effect.



- This study used a small study sample (n=27) and the results can thus not be generalised to the larger population.
- The number of hours of sleep deprivation was also a limitation in this study. A 24 hour period without sleep might not have been enough to influence certain cognitive components involved in the Listening Effort and DIN Tests.
- Previous research has indicated that students tend to sleep less than the suggested optimal number of hours. As a result a student population group might be more resilient to the negative consequences of sleep deprivation (Lee et al., 2003; Patrick et al., 2017; Pilcher et al., 2007). The results of this study indicated that the age of the participants could have had an influence on the effect of sleep deprivation, especially on the results of the DIN and Listening Effort Test.
- Sleep logs are subjective in nature and are based on what is reported.

### **5.5. Future research**

These results reveal the opportunities for further research regarding the following:

- High variabilities in the performance on the Listening Effort Test were found within the current study. As no previous research study has focused on the test retest reliability of this specific test, further research in this area is needed to explain the high variability in performance.
- The Listening Effort Test is still a new test. The results in hand indicate that future research needs to be done on how the cognitive components, such as working memory, processing speed, and attention, are related to listening effort.
- The present research study has indicated that sleep deprivation does have an effect on auditory temporal resolution. Temporal resolution is involved the perception of rapidly altering auditory stimuli and is thus linked to the perception of speech. As previous research indicated that temporal resolution might be connected to performance on linguistic tasks (Babkoff et al., 2005), further research is needed to investigate the specific linguistic abilities that may be affected by sleep deprivation.
- The results indicated that a 24 hour period of sleep deprivation might not have been sufficient to influence the results of the Listening Effort and the DIN Tests. Some research studies have shown that sleep deprivation may only be

influential after a 36 to 40 hours period of sleep deprivation. Thus, research investigating the effects of sleep deprivation on the Listening Effort Test and temporal resolution should be conducted with a sleep deprivation period that is equal to or greater than 36 to 40 hours (Killgore, 2010; Lee et al., 2003).

- Based on the study by Patrick et al. (2017), the selected population group in the present study might have been able to handle the damaging effects of sleep deprivation better than a population group that is older than 30 years. Future research could investigate the effects of sleep deprivation on listening effort and temporal resolution in an older population group (Patrick et al., 2017).

### **5.6. Final comment**

The current study provided new information on the effect of sleep deprivation on temporal resolution and the Listening Effort Test, and highlighted the need for further research in this area. It further revealed possibilities for future research.

*“Research is formalised curiosity. It is poking and prying with a purpose”*

*Zora Neale Hurston*

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# Appendices

## Appendix A: Ethical clearance letter



4 October 2017

Dear Ms Niebuhr

**Project:** The effect of sleep deprivation on temporal resolution and listening effort of normal hearing young adults  
**Researcher:** B Niebuhr  
**Supervisors:** Drs L Pottas and M Soer  
**Department:** Speech-Language Pathology and Audiology  
**Reference Number:** 13019709 (GW20170907HS)

Thank you for the application that was submitted for ethical consideration.

I am pleased to inform you that the above application was **approved** by the **Research Ethics Committee** on 28 September 2017 and by the Dean of Humanities on 3 October 2017. Data collection may therefore commence.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. Should the actual research depart significantly from the proposed research, it will be necessary to apply for a new research approval and ethical clearance.

We wish you success with the project.

Sincerely

**Prof Maxi Schoeman**  
**Deputy Dean: Postgraduate Studies and Ethics**  
**Faculty of Humanities**  
**UNIVERSITY OF PRETORIA**  
**e-mail: tracey.andrew@up.ac.za**

cc: Dr L Pottas (Supervisor)  
Dr M Soer (Co-supervisor)

## **Appendix B: Letter of permission from relevant authorities**



June 2017

**Attention: Dr Matete Madiba**  
**DIRECTOR: Department of Student Affairs**

Dear Dr Matete Madiba,

**REQUEST FOR PARTICIPANTS IN AN INSTITUTION**

I am a Master's student in Audiology at the University of Pretoria, I will be investigating how a 24 hour sleep deprivation period influences the temporal resolution (the ability to detect alterations in sound over time) and listening effort of normal hearing young adults.

**Title:** The effect of sleep deprivation on temporal resolution and listening effort of normal hearing young adults

**Aim:** The main aim is to determine the influence of sleep deprivation on temporal resolution and listening effort. This research on listening effort and temporal resolution will expand the knowledge on how sleep deprivation is often the cause for impaired linguistic abilities and speech perception deficiencies, which may impact the work productivity and quality.

**Design and procedure:** A quasi-experimental, within-subject repeated measures design was selected. The aim is to purposively approach different students who are willing to undergo a 24 hour sleep deprivation period.

**Participants:** A set of 30 participants who range between 18 and 30 years will be selected through snow-ball participant selection using word of mouth. Participant selection criteria will include good sleeping habits and no history of auditory processing disorders or learning difficulties. The participants will be requested to visit the Department of Speech-Language Pathology and Audiology; where, upon arrival, they will be asked to fill in a questionnaire on their hearing status, academic performance and general background information. After the completion of the questionnaire a set of tests will be administered to ensure that hearing and auditory processing of sound is normal. Following this process the participants will be required to return to the department on a different date. On this day a set of tests evaluating the temporal resolution and listening effort will be performed as a baseline measurement in the evening which will then be repeated the morning of the following day after they had a normal sleep pattern. The same set of tests will be performed the evening of the same day before having to remain awake continuously throughout the night. Participants will be required to spend the night at the Department of Speech-Language Pathology and Audiology and will be provided with video games, board games, card games and movies. Thereafter the set of tests will be repeated the following morning to measure the effects on hearing and processing of sound. Participants that fall asleep during the 24 hour sleep deprivation will be excluded from the study with no negative consequences.

**Ethical considerations:** Their participation will only take place after they have consented to and fully understood the terms of the study. They will have full authority to withdraw from participating


in the study at any given time. All identifying information will be kept confidential and anonymous. Data collected will be stored for 15 years for research purposes.

**Risk and benefits:** There are no risks and benefits associated with this research study.

Should you require further information, kindly contact me at:  
Bianka- 076 039 5172 and bianca.niebuhr@gmail.com

Your attention regarding this matter is highly appreciated.

Yours sincerely



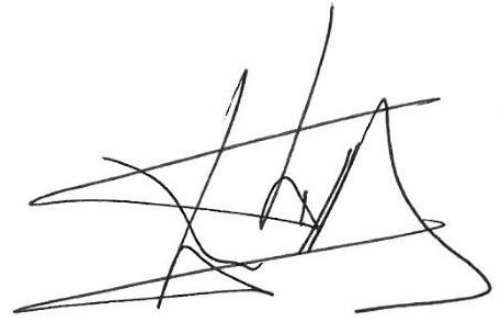
Bianka Niebuhr  
Researcher/ student



Dr L. Pottas  
Supervisor



Dr M. Soer  
Supervisor



Prof. BMHE Vinck  
Head of the Department

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**PERMISSION FOR THE USE OF STUDENTS FROM THE UNIVERSITY OF  
PRETORIA IN RESEARCH**

Herewith, I Dr Matete Madiba give permission for the students from the University of Pretoria to be used as voluntary subjects in the research titled: *The effect of sleep deprivation on temporal resolution and listening effort of normal hearing young adults*

↳ subject to the faculty's  
ethical clearance.



Dr Matete Madiba  
DIRECTOR: Department of Student Affairs

Date: 26/6/17

## **Appendix C: Information brochure and consent**





UNIVERSITEIT VAN PRETORIA  
UNIVERSITY OF PRETORIA  
YUNIBESITHI YA PRETORIA

Faculty of Humanities

Department of Speech-Language Pathology and Audiology

Dear Participant,

### **REQUEST FOR PARTICIPATION IN RESEARCH STUDY**

I am a Master's student in Audiology at the University of Pretoria, I will be investigating how a 24 hour sleep deprivation period influences the temporal resolution (the ability to detect alterations in sound over time) and listening effort of normal hearing young adults.

Sleep deprivation is often caused by the demands of work, school and from the society, as people often feel that they can spend the time in which they sleep on activities that are more useful or entertaining. Much research has been conducted that focuses on the effects of sleep deprivation on the motor performances, mood and cognitive functioning of an individual. However, the effect of sleep deprivation on the central auditory processes still needs to be further investigated as there is a dearth of published research that has been found in this regard. This research on listening effort and temporal resolution will expand the knowledge on how sleep deprivation is often the cause for impaired linguistic abilities and speech perception deficiencies, which may impact the work productivity and quality. The study will create awareness on the extent of the effects of sleep deprivation and its causes.

Participation in this study requires that you visit the Department of Speech-Language Pathology and Audiology at the University of Pretoria. Upon arrival you will be asked to complete a short background history pertaining to hearing, academic performance and general background information. A set of tests will be administered to ensure that hearing and auditory processing of sound is normal. You will then be required to return to the department on a different date. On this day a set of tests evaluating temporal resolution and listening effort will be performed as a baseline measurement in the evening which will then be repeated the morning of the following day after you had a normal sleeping pattern. The same set of tests will then be performed the evening of the same day before having to remain awake continuously throughout the night. Thereafter the tests will be repeated the following morning to measure the effects on hearing and processing of sound. You will be expected to spend the night in a room at the Department of Speech Language Pathology and Audiology and will be provided with movies, video games, card games and board games. Participants that fall asleep during the 24 hour sleep deprivation period will be excluded from the study with no negative consequences.

Participation in this study is completely voluntary and you may withdraw from the study at any time without any negative consequences. Participation in this study does not pose any risk for participation.

All identifying information of participants will be kept confidential and anonymous. The data will be kept for 15 years for archiving and research purposes before being destroyed. The data obtained will be available to my supervisors Dr. Pottas and Dr. Soer, as well as the Head of Department of Speech-Language Pathology and Audiology, Prof. Vinck. All the relevant results will be compiled in a research report, which will be available at the University of Pretoria. Participants may also request to view the results obtained.

By signing the informed consent, you agree to the following:

- Staying awake continuously for 24 hours
- Not using any of the following stimulants for a period of 24 hours before testing: Foods and beverages containing caffeine, such as coffee and tea, Coca Cola or any soft drink containing caffeine, such as Redbull and Monster energy drinks, alcohol, smoking and no use of medication that influences the sleep pattern.

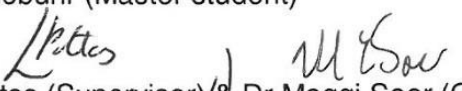
If you require any additional information, you are welcome to contact me at 076 039 5172.

Your participation will be greatly appreciated.

Yours Sincerely,



Bianka Niebuhr (Master student)



Dr. L. Pottas (Supervisor) & Dr Maggi Soer (Co-supervisor)



Prof. Bart Vinck

HEAD OF THE DEPARTMENT OF SPEECH-LANGUAGE PATHOLOGY AND AUDIOLOGY.

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**INFORMED CONSENT: The effect of sleep deprivation on temporal resolution and speech-in-noise skills of normal hearing young adults**

Should you consent to the requirements of this study:

Please complete the following

I \_\_\_\_\_ hereby acknowledge and agree to the above conditions about this study and agree that my clinical data will be used for research purposes at the Speech-Language Pathology and Audiology Department.

Signature

Date

\_\_\_\_\_

\_\_\_\_\_

## Appendix D: Questionnaire

## Questionnaire

Thank you for agreeing to participate in our research study.  
Please answer the questionnaire as truthfully and accurately as possible.

### Section A: Demographical Information

1. Participant number: \_\_\_\_\_
2. Code (initials): \_\_\_\_\_
3. Gender

Female	
Male	

4. Date of Birth \_\_\_\_\_
5. Age \_\_\_\_\_
6. Cellphone number \_\_\_\_\_
7. Are you right-handed or left-handed? \_\_\_\_\_

8. First Language

Afrikaans	
English	
IsiNdebele	
IsiXhosa	
IsiZulu	
Sepedi	
SeSotho	
Setswana	
SiSwati	
XiTsonga	
Other	

### Section B: Medical History

1. Do you have a history of

Ear infections	
When?	

2. Do you experience difficulty to hear?

<b>Yes</b>	<b>No</b>

If yes please specify:

All the time	
Hearing in the background noise	

3. Have you experienced

Trauma to the head	
--------------------	--

Epileptic seizure	
Injury due to any accident	

4. Are you on any medication

<b>Yes</b>	<b>No</b>

If yes please specify \_\_\_\_\_

5. Do you have difficulty with your eye sight?

<b>Yes</b>	<b>No</b>

If yes, has it been corrected?

<b>Yes</b>	<b>No</b>

**Section C: Academic History**

1. Highest level of education

Grade 10	
Grade 11	
Grade 12	
Current student	
Graduate degree	

2. Academic performance

Did you experience any difficulty in school with:	<b>Yes</b>	<b>No</b>
Reading?		
Writing?		
Spelling?		
Following instructions?		
Completing assignments or tasks in the relevant time?		

**Section D: Sleep habits**

1. Do you experience any chronic sleep disturbances?

<b>Yes</b>	<b>No</b>

2. What are your regular sleeping hours? \_\_\_\_\_

## Appendix E: Data storage form



**Declaration for the storage of research data and/or documents**

I/ We, the principal researcher(s) Bianka Valerie Niebuhr  
and supervisor(s) Dr L. Pottas; Dr M. Soer  
of the following study, titled The effect of sleep deprivation on temporal resolution  
and listening effort of normal hearing young adults

will be storing all the research data and/or documents referring to the above-mentioned study in the following department: Department of Speech-Language Pathology and Audiology

We understand that the storage of the mentioned data and/or documents must be maintained for a minimum of 15 years from the commencement of this study.

Start date of study: 1. March 2017  
Anticipated end date of study: 1. December 2017  
Year until which data will be stored: 2032

Name of Principal Researcher(s)	Signature	Date
Bianka Valerie Niebuhr	<i>Niebuhr</i>	17/06/2017

Name of Supervisor(s)	Signature	Date
ME SOER	<i>M Soer</i>	19/06/2017
L. Pottas	<i>L Pottas</i>	19/6/2017

Name of Head of Department	Signature	Date
PROF. DR. B H M E LINCH	<i>[Signature]</i>	19/6/2017

## Appendix F: Result of Linear Regression Model



## POMS on GIN percentage

Mood State	Condition	Pre/Post	Coefficient	p-value	R square
<b>ANGER</b>	NSDP	PRE	0,307	0,264	0,024
		POST	-0,620	0,015*	0,109
	SDP	PRE	-0,579	0,034*	0,084
		POST	-0,358	0,137	0,044
<b>CONFUSION</b>	NSDP	PRE	-0,042	0,916	0,000
		POST	-0,688	0,105	0,050
	SDP	PRE	-0,156	0,742	0,002
		POST	0,232	0,365	0,016
<b>DEPRESSION</b>	NSDP	PRE	0,727	0,007*	0,130
		POST	-0,119	0,551	0,007
	SDP	PRE	0,041	0,845	0,001
		POST	0,228	0,294	0,022
<b>TENSION</b>	NSDP	PRE	0,281	0,225	0,028
		POST	-0,714	0,002*	0,163
	SDP	PRE	-0,487	0,077*	0,059
		POST	-0,529	0,249	0,026
<b>FATIGUE</b>	NSDP	PRE	0,675	0,032*	0,085
		POST	-0,190	0,453	0,011
	SDP	PRE	-0,419	0,102	0,051
		POST	-0,294	0,190	0,034
<b>VIGOUR</b>	NSDP	PRE	-0,172	0,426	0,012
		POST	0,245	0,186	0,033
	SDP	PRE	0,314	0,068	0,063
		POST	0,313	0,280	0,023
<b>TMD</b>	NSDP	PRE	0,157	0,032*	0,086
		POST	-0,119	0,031*	0,087
	SDP	PRE	-0,098	0,079	0,058
		POST	-0,040	0,525	0,008

\*p<0.05

## POMS on AGDT

Mood State	Condition	Pre/Post	Coefficient	p-value	R square
<b>ANGER</b>	NSDP	PRE	-0,039	0,267	0,024
		POST	0,074	0,043*	0,076
	SDP	PRE	0,097	0,006*	0,135
		POST	0,067	0,066	0,066
<b>CONFUSION</b>	NSDP	PRE	0,045	0,373	0,015
		POST	0,076	0,216	0,029
	SDP	PRE	0,039	0,534	0,007
		POST	-0,043	0,273	0,024
<b>DEPRESSION</b>	NSDP	PRE	-0,065	0,070	0,062
		POST	0,010	0,737	0,002
	SDP	PRE	0,013	0,640	0,004
		POST	-0,033	0,309	0,021
<b>TENSION</b>	NSDP	PRE	-0,030	0,312	0,020
		POST	0,074	0,032*	0,085
	SDP	PRE	0,082	0,023*	0,095
		POST	0,036	0,604	0,005
<b>FATIGUE</b>	NSDP	PRE	-0,073	0,073	0,060
		POST	0,025	0,483	0,010
	SDP	PRE	0,057	0,092	0,054
		POST	0,052	0,128	0,046
<b>VIGOUR</b>	NSDP	PRE	0,014	0,618	0,005
		POST	-0,041	0,123	0,045
	SDP	PRE	-0,024	0,305	0,020
		POST	-0,032	0,468	0,011
<b>TMD</b>	NSDP	PRE	-0,014	0,129	0,044
		POST	0,014	0,071	0,061
	SDP	PRE	0,014	0,055	0,069
		POST	0,006	0,554	0,007

\*p<0.05