

**The impact of short-term sleep deprivation on listening  
effort and P300 responses.**

**By**

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*Dada, this is for you.*

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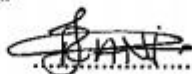
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# Table of Contents

Tables.....	vi
Figures.....	vii
List of Abbreviations.....	viii
Abstract.....	ix
Outline of Chapters.....	x
Chapter 1.....	1
Introduction.....	1
Chapter 2.....	8
Method.....	8
2.1 Introduction.....	8
2.2 Research aim.....	8
2.3 Research design.....	8
2.4 Ethical considerations.....	9
2.4.1 Permission and Ethical Clearance.....	9
2.4.2 Informed consent.....	9
2.4.3 Confidentiality and Non-Maleficence.....	10
2.5 Participants.....	10
2.5.1 Sampling.....	10
2.5.2 Participation selection criteria.....	10
2.5.3 Materials, apparatus, and procedures for selection of participants.....	12
2.5.4 Description of participants.....	14
2.6 Materials and apparatus for data collection.....	14
2.6.1 Profile of Moods States (POMS).....	14
2.6.2 Listening Effort Test (LE).....	15
• <i>Single- Task Evaluation</i> .....	15
• <i>Dual- Task Evaluation</i> .....	17
2.6.3 P300 Assessment.....	18
2.7 Procedures for data collection.....	20
2.7.1 Participant instructions.....	21
2.7.2 Assessment Protocol.....	21
2.7.3 Pilot study.....	24
2.8 Data analysis.....	24
2.9 Reliability and Validity.....	26
2.10 Summary of chapter.....	27

Chapter 3 .....	28
Results .....	28
3.1 Introduction.....	28
3.2 Profile of Mood States (POMS).....	28
3.3 Listening Effort (LE) .....	31
3.4 P300 Assessment.....	33
3.5 Summary of chapter .....	35
Chapter 4 .....	36
Discussion .....	36
4.1 Introduction.....	36
4.2 Profile of Mood States (POMS).....	36
4.3 P300 Assessment.....	38
4.4 Listening Effort (LE) .....	39
4.5 Summary.....	45
Chapter 5 .....	46
Conclusion.....	46
5.1 Introduction.....	46
5.2 Conclusion of findings.....	46
5.3 Study limitations.....	47
5.4 Clinical implications .....	48
5.5 Recommendations for further research .....	48
5.6 Final comments .....	49
References.....	50
Appendices.....	59
Appendix A:.....	60
Ethical Clearance Form: Faculty of Humanities .....	60
Appendix B:.....	62
Institution Permission: Department of Student Affairs .....	62
Appendix C:.....	66
Informed Consent .....	66
Appendix D:.....	70
Participant Questionnaire .....	70
Appendix E:.....	73
Profile of Mood States Questionnaire .....	73

## Tables

Table 1: Inclusion and exclusion criteria for participation selection.....	11
Table 2: Material and apparatus for selection of participants.....	12
Table 3: Target and non-target parameters.....	19
Table 4: Instructions provided to participants prior to data collection.....	21
Table 5: Mean, standard deviation and p-value for the different mood states in the POMS in control and experimental conditions comparing evening and morning sessions (n=27).....	30
Table 6: Mean, standard deviation and p-value for the listening effort (LE) required for listening situations in control and experimental conditions comparing evening and morning sessions (n=27).....	33
Table 7: Mean, standard deviation and p-value for P300 latency and amplitude in the control and experimental conditions comparing evening and morning sessions (n=27).....	34

## Figures

Figure 1: Example of the grid participants were expected to fill.....	16
Figure 2: Example of averaged P300 waves.....	20
Figure 3: Procedure for data collection.....	22
Figure 4: Procedure for statistical analysis. ....	25
Figure 5: Mean difference scores in Profile of Mood States (POMS) between evening and morning sessions for both control and experimental conditions. (Error bars indicate +/- 1 standard error [SE]; TMD = total mood displacement) (n=27).....	29
Figure 6: Mean difference percentages in listening effort (LE) between evening and morning sessions for both control and experimental conditions. (Error bars indicate +/- 1 standard error [SE]; SNR = signal- to-noise ratio) (n=27).....	32

## **List of Abbreviations**

CAP- Central auditory processing

LE- Listening effort

ERP- Event-related potential

EEG- Electroencephalogram

fMRI- functional magnetic resonance imaging

SNR- Signal-to-noise ratio

POMS- Profile of Moods States

TMD- Total mood displacement

## **Abstract**

*Objective:* The present study aimed to determine the impact of 24-hour sleep deprivation on listening effort and P300 responses in a group of young university students.

*Method:* A quasi-experimental, within-subject, repeated measures design was employed. Twenty-seven young students aged between 19 and 25 years (M: 22.56, SD: 1.16) underwent four assessments over a period of three days. Assessments were conducted during the mornings (6:00) and evenings (18:00), starting with the evening baseline assessment prior to the normal sleep routine. Sleep deprivation of 24 hours was undertaken from the morning of day two. On the morning of day three, experimental measurements were obtained under sleep deprivation conditions. The assessments comprised of the Profile of Mood States (POMS) questionnaire, dual-task paradigm LE test, and P300 using an odd-ball stimulus protocol.

*Results:* A statistically significant difference ( $p < 0.01$ ) was obtained for the POMS assessment before and after the sleep deprivation condition, with increased measures of fatigue and decreased vigour, confirming subjective fatigue after sleep deprivation. P300 responses also displayed a statistically significant increase in response latency and decrease in amplitude after sleep deprivation ( $p < 0.05$ ). However, the LE test demonstrated no statistically significant differences ( $p > 0.05$ ) amongst all listening situations after sleep deprivation.

*Conclusion:* The results demonstrated that the participants' mood states, according to the POMS, were displaced. A cognitive decline was experienced in relation to the higher executive functions associated with the P300 assessment as evidenced by the change in latency and amplitude. Despite this, it was evident from the LE evaluation that less LE was used after sleep deprivation in the majority of the listening situations. It is possible that LE was unaffected by the detrimental influence of sleep deprivation. Other possible reasons for the unexpected results, namely the influence of the amount of sleep deprivation, population choice, the LE task combination, setting of priority during LE test, and intra-subject variables, were discussed.

**Key words:** sleep deprivation, mood states, listening effort, event-related potentials, P300 responses.

## **Outline of Chapters**

*Chapter 1 (Introduction):* This chapter provides background information regarding the basics of LE assessment and P300 responses. The background information assists in establishing a rationale for the current study, which is included in this chapter.

*Chapter 2 (Method):* This chapter provides information on the methodology utilised to conduct data collection for this research study. This chapter includes the research aim, research design, ethical considerations, participant information, materials and procedures for selection of participants and data collection, and reliability and validity of the research study. Information on how data analysis was conducted is provided in this chapter.

*Chapter 3 (Results):* This chapter provides information regarding the results obtained from the different assessments. It further discusses the descriptive and inferential statistics obtained from the statistical analysis conducted.

*Chapter 4 (Discussion and Limitations):* This chapter discusses the results obtained from the different assessments, making use of supporting literature.

*Chapter 5 (Conclusion):* This chapter concludes the information obtained from the results of this research study. Limitations regarding the research study, clinical implications, recommendations for further research and final comments are included in this section.

## **Chapter 1**

### **Introduction**

Sleep deprivation is a common and an increasing problem in the present generation of workers and students. Minimum recommended hours of sleep are typically not attained, due to heavy workload and deadlines imposed upon workers and students (Patrick et al., 2017). Social commitments may also lead to a build-up on the lack of sleep already present (Patrick et al., 2017). Studies have shown that sleep is not only essential for the cognitive and other aspects of performance necessary to carry out daily tasks, but is actually crucial for survival (Alhola & Polo-Kantola, 2013; Engle-Friedman, 2014; Liberalesso et al., 2012).

Numerous health problems, including cardiac and weight implications, may arise as a result of lack of sleep (Engle-Friedman, 2014). When an individual is sleep deprived, the body is not able to utilise the limited energy available in order to maintain normal body temperatures. Hence, body temperature rises as a result of the body's inability to thermo-regulate in order to save energy during sleep deprivation (Alhola & Polo-Kantola, 2013; Engle-Friedman, 2014). An increase in energy expenditure and food consumption is seen as another ramification of sleep deprivation, as an individual's body is unable to store energy and control its consumption (Engle-Friedman, 2014). Metabolic processes within cell bodies are affected and consequently, energy provision is low. Cell death is highly possible with increased sleep deprivation due to reduced energy production (Alhola & Polo-Kantola, 2013; Engle-Friedman, 2014). Blood pressure and cortisol secretion is also seen to increase owing to an activation of the sympathetic nervous system as a result of sleep deprivation (Alhola & Polo-Kantola, 2013; Liberalesso et al., 2012).

Bodily and mental processes require regeneration and recovery from varied activities, and this also takes place during sleep (Engle-Friedman, 2014; Verweij et al., 2014). An individual is expected to obtain a minimum of six to eight hours of sleep a day (Kadambi, Lovelace, & Beyette, 2013). This amount of rest provides the body with sufficient time to restore the energy that was used for daily tasks. However, a controversy exists regarding the number of hours a person is able to function optimally after sleep deprivation. Literature argues that individuals undergoing sleep deprivation for 45-46 hours presented with a clear cognitive decline, whereas, others reported that

a period of 24 hours was sufficient to cause cognitive deterioration (Goel, Rao, Durmer, & Dinges, 2009; Lee, Kim, & Suh, 2003; Patrick et al., 2017).

Acute or short-term sleep deprivation is defined as 24 hours of sleep deprivation. Mid-term or total short-term sleep deprivation is considered as less than or equal to 45 hours of lack of sleep, whereas total long-term sleep deprivation is more than 45 hours of lack of sleep (Alhola & Polo-Kantola, 2013; Goel et al., 2009). Delayed cognitive performances and increased mental effort are mediated through slowed responses and brief moments of inattentiveness as a result of sleep deprivation (Alhola & Polo-Kantola, 2013). This is evident when a sleep deprived individual is tested on tasks assessing reaction speed and vigilance (Alhola & Polo-Kantola, 2013; Killgore, 2010). Increased sleep deprivation leads to a variation in mood states, cognition and motor performances associated with specific brain regions (Alhola & Polo-Kantola, 2007; Goel et al., 2009).

Specific brain regions, for example the prefrontal cortex which incorporates most of the cognitive processes involving attention, concentration, creativity, task switching, temporal resolution, and memory, are affected by sleep deprivation (Alhola & Polo-Kantola, 2013; Engle-Friedman, 2014). These cognitive processes, known as higher executive functions, were seen to display a reduction in activation when exposed to increasing hours of sleep deprivation (Goel et al., 2009; Patrick et al., 2017). In order to accomplish task switching, a person applies effort to adjust to novel demands, especially to obtain information embedded in conversation and in constantly altering environments (Engle-Friedman, 2014). However, when a person is sleep deprived, this processing is compromised as it requires diverse levels of attention and other cognitive capacities that are not easily compensated for and typically readily available to the prefrontal cortex (Engle-Friedman, 2014; Goel et al., 2009). As a result of this decrement in cognitive processing, there is a decline in the participants' overall performance in tasks that are normally deemed to be achievable but have become unattainable (Engle-Friedman, 2014).

In spite of the compromised cognitive processes, other studies found that the aforementioned higher executive functions associated with the prefrontal cortex, amongst others, are not generally affected after 24-hours of sleep deprivation (Goel et al., 2009; Jackson, Croft, Kennedy, Owens, & Howard, 2013b; Killgore, 2010; Lee

et al., 2003; Patrick et al., 2017). The unaffected higher executive functions were theorised to be the result of individual variability, which increases with lack of sleep and the number of hours the individual underwent sleep deprivation. The individual differences include self-motivation, compensatory strategies, and a learning effect, all of which are noticeably implemented with increased exposure to sleep deprivation (Alhola & Polo-Kantola, 2013; Goel et al., 2009; Lee et al., 2003; Patrick et al., 2017). It was also evidenced that the effects of sleep deprivation on cognitive processes are usually overlooked as a result of the unavailability of assessments which are sensitive to cognition and the inconsistent data analysing techniques available (Alhola & Polo-Kantola, 2013; Goel et al., 2009; Liberalesso et al., 2012). Increased sleep deprivation is, therefore, suspected to have an impact undetected by most cognitive assessments which are insensitive to the higher executive functions, including temporal resolution and selective attention (Goel et al., 2009).

Temporal resolution, an important aspect of central auditory processing (CAP), is also a function associated with the prefrontal cortex (Liberalesso et al., 2012). Central auditory processing is the process through which the neurocognitive physiological and chemical mechanisms in the brain respond to auditory stimuli. These processes take place in the auditory cortex, and are associated with language comprehension, lateralisation, localisation, and sound discrimination, amongst other aspects (Liberalesso et al., 2012). Several functions associated with CAP also depend on alertness and concentration, both of which are known to be affected by sleep deprivation (Goel et al., 2009; Liberalesso et al., 2012). This in turn alters the neurobiological bases involved, such as frontal and temporal lobe functioning, through which impairment of the cognitive functions involving attention and sound perception associated with those two areas, respectively, become evident (Liberalesso et al., 2012). Therefore, a decline in CAP performance is expected as a result of sleep deprivation (Arora, Bhat, Raj, Kumar, & Kumar, 2014).

Numerous cognitive processes are utilised to execute daily functions, especially in demanding situations, and CAP (amongst other processes) plays an important role in ensuring cognitive success and successfully accomplishing tasks (Liberalesso et al., 2012; Patrick et al., 2017). These highly demanding situations typically involve competing background noise in the presence of a primary auditory stimulus, where the individual is required to multi-task, with additional processing resources (attentional,

cognitive, etc) allocated to the auditory task. The involvement of these extra resources is an indication that the situation has become effortful to achieve a high-level performance on the listening task. This exertion is known as listening effort (LE) (Gagné, Besser, & Lemke, 2017).

Listening effort is believed to involve diverse cognitive functions found in the prefrontal cortex, including working memory, processing speed, selective attention and comprehension of spoken language, all of which are important for speech recognition in noise (Degeest, Keppler, & Corthals, 2015; Engle-Friedman, 2014; Lemke & Besser, 2016). Working memory refers to the ability to retain auditory information temporarily while processing it, thus allowing the listener to relate the auditory information to the already existing comprehensive knowledge of spoken language (Killgore, 2010; Lemke & Besser, 2016). The ability to process information at a nimble rate is crucial, because natural speech is instinctively fast running. The rapid and ongoing interaction between the auditory and cognitive processes allows an individual to follow and process the fast running speech exchanged in conversations (Lemke & Besser, 2016). The aforementioned process requires active attention to auditory stimuli in order to carry out tasks. Meanwhile, selective attention involves the ability to focus attentively on a specific characteristic of a stimulus and demonstrate inattentiveness to the other characteristics present (Killgore, 2010; Phillips, 2016). Central auditory processing aids the individual to pay attention to the main stimulus in the presence of competing background noise and simultaneously process the information, thereby demonstrating selective attention to specific auditory stimuli (Liberalesso et al., 2012). These cognitive processes may lead to an increase in processing load when an individual is exposed to effortful situations such as those with high amounts of background noise, in turn increasing LE (Gagné et al., 2017; Lemke & Besser, 2016).

Listening effort is measured in three ways: subjectively through self-reports, through behavioural measures, or objectively through physiological measures. Self-report measures include questionnaires or scales that the listener is requested to complete. The questionnaires tend to report on fatigue and the perceived effort a patient experiences or endures after being exposed to a demanding situation (McGarrigle et al., 2014). The Profile of Mood States (POMS) questionnaire has been used as a means to determine the vigour and fatigue a person experiences, which are different

aspects of perceived listening (Sandridge, Santiago, Newman, & Behrens, 2015). It has been found that the fatigue experienced increases over time as a result of increased LE (Sandridge et al., 2015). It is important to note that this method measures personal experience and is purely subjective, depending on the perception and emotions of an individual. (Gagné et al., 2017; Lemke & Besser, 2016; McGarrigle et al., 2014).

Behavioural measures are subdivided into single-task and dual/multi-tasking paradigms (Gagné et al., 2017; Lemke & Besser, 2016; McGarrigle et al., 2014). Single-task paradigms make use of a speech recognition task primarily as a means to measure LE (Houben, van Doorn-Bierman, & Dreschler, 2013; McGarrigle et al., 2014). This is performed by either verbal recognition (repetition) or through mechanical recognition (pressing a button, writing main words) to speech stimuli (Houben et al., 2013; MacPherson & Akeroyd, 2014; McGarrigle et al., 2014). The single-task paradigm incorporates response time as a measure of increased effort when an individual is exposed to the task in varying levels of background noise (Houben et al., 2013; McGarrigle et al., 2014). The single-task paradigm relies on the concept that the increased response time as a result of effort is depicted as a reduction in phonological processing. This in turn is believed to be influenced by the competency of the working memory readily available from exposure to the effortful task (McGarrigle et al., 2014).

The dual-task paradigm requires a participant to perform two tasks concurrently. Dual-task paradigms measure the allocated attention and involves the response to a speech recognition task, as well as an assessment of cognition (memory, tactile recognition or visual recognition). Based on literature concerning LE, it is believed that the listener presents with limited cognitive resource capacity which is effectively and equally distributed amongst several mental operations (Gagné et al., 2017; McGarrigle et al., 2014). When a listener is presented with the dual-task paradigm, it is speculated that the most taxing task will consume copious amounts of resources and result in a decrement in the performance of the second task (Gagné et al., 2017; McGarrigle et al., 2014). This reduction in performance is considered a reflection on the amount of effort expended on the primary task of the dual-tasks, thus bringing about the overall LE perceived (Gagné et al., 2017). The dual-task paradigm is theorised to provide listeners with a more naturalistic and realistic situation, through resembling the act of multi-tasking and task switching experienced in everyday life (McGarrigle et al., 2014).

As various task forms have been used in different literature to assess LE, it is clear that a consensus has not been reached regarding a valid and reliable method to assess LE. This may be due to the varied sensitivity of the tasks utilised in relation to specific cognitive functions (Gagné et al., 2017; McGarrigle et al., 2014). However, it is theorised that a word category recognition task and a visual-pattern recognition task are an appropriate test combination to assess LE through the dual-task paradigm (Gagné et al., 2017; McGarrigle et al., 2014). The uncertainty regarding the task function with regard to the specific cognitive processes involved, pose a concern as not all task combinations assess the same cognitive functions to an accurate extent. Therefore, no change in the LE expended was evident in the research reported (Goel et al., 2009).

Changes related to LE in the central nervous system have also been observed using various physiological measures, including functional magnetic resonance imaging (fMRI), event-related potentials (ERP) and electroencephalography (EEG). An EEG was found to provide a clinician with temporarily-precise markers of mental processing, and insight into aspects of cognitive processing possibly involved in LE (McGarrigle et al., 2014). The ERPs associated with LE include pupillometry, skin conductance and P300 (Goel et al., 2009; McGarrigle et al., 2014).

The P300 is an auditory-evoked ERP providing neurophysiological means of analysing higher cerebral functions associated with cognition, attention, information processing and working memory (Ray et al., 2012). This ERP is a positive peak wave presented post-stimulation at approximately 300 ms (Didoné et al., 2016). The P300 is considered an endogenous electrophysiological response, as it functions as an independent response to an internal cognitive “occurrence”. This auditory-evoked potential requires active listening, and is therefore, suitable for assessing cognitive processing (McCullag, Weihing, & Musiek, 2009; Polich, 2011). Physiological measures are also believed to identify the effort experienced through increased activation of the autonomic nervous system which in turn assesses arousal and the responses to LE (Bertoli & Bodmer, 2014).

The P300 waveform consists two of subcomponents, P3a and P3b, which are generated by the frontal and temporal/parietal lobes, respectively (Polich, 2011; Tsolaki, Kosmidou, Hadjileontiadis, Kompatsiaris, & Tsolaki, 2015). The frontal lobe is

accountable for early attention stemming from working memory processes, whereas the temporal/parietal lobes are involved in maintaining working memory processes as well as attention and memory (Tsolaki et al., 2015). Most of these cognitive processes are seen to be involved in LE assessment and in CAP functions (Degeest et al., 2015; Engle-Friedman, 2014; Lemke & Besser, 2016; Liberalesso et al., 2012). P300 is believed to be directly affected by tonic exercise, drugs (caffeine, nicotine and alcohol), age, dexterity, genetic traits and, most pertinently, fatigue (Polich, 2011). Boonstra, Stins, Daffertshofer, and Beek (2007) found that P300 responses are delayed in sleep deprived adults, which is also indicative of reduced auditory processing speed and possibly represents a cognitive decline (Boonstra, Stins, Daffertshofer, & Beek, 2007; Kadambi et al., 2013; Lee et al., 2003).

In conclusion, sleep deprivation is believed to affect the various cognitive processes associated with the prefrontal cortex including CAP and memory that are regularly utilised when performing an activity (Alhola & Polo-Kantola, 2013; Engle-Friedman, 2014; Goel et al., 2009; Jackson et al., 2013a; Killgore, 2010; Lee et al., 2003; Patrick et al., 2017). Sleep deprivation is also known to bring about individual factors which possibly alter the effectiveness of cognitive functions with increased exposure to lack of sleep (Alhola & Polo-Kantola, 2013; Goel et al., 2009; Lee et al., 2003; Patrick et al., 2017). As previously noted in literature, the P300 and LE assessments present overlapping reports on the cognitive processes of the prefrontal cortex which are involved in and affected by sleep deprivation (Alhola & Polo-Kantola, 2007; Engle-Friedman, 2014; Goel et al., 2009; Jackson et al., 2013a; Killgore, 2010; Lee et al., 2003; Patrick et al., 2017). Therefore, it was hypothesised that, as a result of sleep deprivation, a normal hearing individual will experience increased LE due to the added cognitive demands now placed on the individual to complete the task, while these increased cognitive demands also affecting P300 responses. Presently, research has not established the use of the dual-task paradigm for LE in sleep deprived normal-hearing young individuals. This study aimed to provide insight into the cognitive demands related to sleep deprivation when assessing LE and P300 responses.

## **Chapter 2** **Method**

### **2.1 Introduction**

This chapter aims to provide a comprehensive description of the research design employed to determine the impact of sleep deprivation on listening effort (LE) and P300 responses. The aim of the current study is presented, followed by a discussion of the ethical considerations, study participants, and data collection and analysis procedures.

### **2.2 Research aim**

The aim of this study was to determine the effect of short-term sleep deprivation (24 hours) on listening effort and P300 responses in young adults.

### **2.3 Research design**

A prospective, comparative, quasi-experimental, within-subject research design was utilised to ensure that accurate and impartial data was obtained. A prospective design was used to investigate the possibility of a future outcome (the impact of sleep deprivation) on an event (sleep deprivation) (Creswell, 2009; Kumar, 2011; Leedy & Ormrod, 2015). A comparative design assisted in comparing the results of the assessments for two conditions and sessions for each participant (Creswell, 2009; Kumar, 2011). The quasi-experimental design assisted in evaluating the effect of sleep deprivation on LE and P300 responses as this design employs a baseline assessment through which follow-up responses can be obtained (Creswell, 2009; Kumar, 2011; Leedy & Ormrod, 2015). The quasi-experimental design does not make use of randomization in group allocation.

For the purposes of this research study, four measurements were collected over three days of assessments, confirming the employment of a repeated measures design. All participants were placed under experimental conditions (24-hour sleep deprivation) as well as control conditions (24 hours with normal sleep). The effects on each individual participant were assessed independently and performance after control condition was compared to performance under experimental condition. In this study, the control and experimental conditions were introduced in a consecutive time frame (Creswell, 2009; Leedy & Ormrod, 2015).

A quantitative design was employed due to its clear-cut, structured and rigid nature. This, in turn, established accuracy in measurements and classification of results providing quantitative data (Creswell, 2009; Kumar, 2011; Leedy & Ormrod, 2015).

## **2.4 Ethical considerations**

Ethical guidelines ensure that researchers proceed according to the regulations and follow their responsibilities as a practitioner. The study procedures adhered to the requirements of testing human participants under the Declaration of Helsinki Principles (World Medical Association, 2013). In order to ensure that appropriate and moral services were provided, the following ethical aspects were considered (Health Professions Council of South Africa [HPCSA], 2008; South African Speech- Language and Hearing Association [SASLHA], 2011; World Health Organisation [WHO], 2011; World Medical Association, 2013).

### **2.4.1 Permission and Ethical Clearance**

Ethical clearance was obtained from the Research and Ethics Committees of the Faculty of Humanities of the University of Pretoria (Appendix A). Permission was obtained from the Department of Student Affairs at the University of Pretoria, to engage with students and request their participation in the study (Appendix B).

### **2.4.2 Informed consent**

According to World Medical Association (2013) and WHO (2011), ethical guidelines stipulate the need to obtain informed consent from each participant. In the current investigation the informed consent form requested biographic details, and provided information on what the study involved (Appendix C).

Participants were made aware of the aims and purposes of the study in written format. It was ensured that the participants were not deceived in any manner and were made fully aware of what the study entailed, along with what was required of them. Participants were also provided with an opportunity to request clarification in case of any uncertainty. A full explanation was provided regarding the purpose and rationale behind the questionnaire (Appendix D) and tests, as well as the intentions behind the results collected. Contact details of the researcher and supervisors were provided in the informed consent letter should participants require further assistance, have any questions about the study, or should other related issues arise (SASLHA, 2011). The

participants were granted the option to withdraw participation at any given time without any repercussions (World Health Organisation, 2011; World Medical Association, 2013). The information letters stipulated that no risks were involved with regard to partaking in the study. The participant was requested to sign the provided information letter thereafter, consenting participation and willingness to adhere to the study requirements (HPCSA, 2008; SASLHA, 2011; WHO, 2011; World Medical Association, 2013).

### **2.4.3 Confidentiality and Non-Maleficence**

Participants were ensured confidentiality regarding personal information that was disclosed to the researcher. No harm was inflicted on the participant. Individuals consenting to the study were ensured that the researcher acted in the best interest of the participant (HPCSA, 2008; SASLHA, 2011; WHO, 2011; World Medical Association, 2013). Although the researcher was aware of the participant's identity, participant identification was correspondent to an alpha-numeric code for data recording, analysis and reporting (HPCSA, 2008; SASLHA, 2011; WHO, 2011; World Medical Association, 2013).

## **2.5 Participants**

### **2.5.1 Sampling**

A purposive, non-probability sampling approach was implemented (Creswell, 2009; Leedy & Ormrod, 2015). With the aid of a purposive approach, the sample selected assisted the researcher to obtain the most reliable results possible. This is because it allowed for the selection of participants in accordance with strict selection criteria to meet the needs of the study (Creswell, 2009; Kumar, 2011; Leedy & Ormrod, 2015).

### **2.5.2 Participation selection criteria**

Twenty-seven participants were considered and selected based on specific inclusion and exclusion criteria such as: age group, medical status, and cognitive abilities.

Table 1 provides the inclusion and exclusion criteria adhered to by the researcher for the recruitment of participants.

**Table 1: Inclusion and exclusion criteria for participation selection**

Inclusion criteria	Rationale
<p><b>Age group:</b> <b>18- 30 years</b></p>	<p>Cognitive processing, specifically temporal processing, is affected by the aging process. Listening effort has also been found to increase with age. In order to avoid possible cognitive decrement as a result of age, a younger population was selected (Bao et al., 2013; Degeest et al., 2015; Lemke &amp; Besser, 2016).</p>
<p><b>Normal middle ear functioning (American Academy of Audiology [AAA], 2010; Jerger, 1970; Lidén, 1969)</b> <b>Type A tympanograms which can be defined as:</b></p> <ul style="list-style-type: none"> <li>○ ear canal volume of 1.0 to 1.4 ml,</li> <li>○ static compliance between 0.3 ml and 0.7 ml</li> <li>○ middle ear pressure ranging from -50 daPa to +50 daPa.</li> <li>✓ Y-226 Hz tympanograms: Admittance (Y) tympanograms were measured using a 226 Hz probe tone.</li> </ul> <p><b>Ipsilateral Acoustic Reflex present at 1000Hz.</b></p>	<p>Central auditory processing is affected by middle ear pathologies. It is argued that the absence of a discernible pattern in central processing may, in fact, represent the influences of middle ear pathology (AAA, 2010). Therefore, normal middle ear function was necessary to prevent alterations from the results obtained (AAA, 2010).</p>
<p><b>Normal hearing (ISO 389-1, 1998) ≤15dBHL across all octave frequencies.</b></p>	<p>Listening effort was found to increase in the presence of hearing loss as a result of cognitive decrement and added effort. Therefore, normal hearing was required (Degeest et al., 2015; Hornsby, 2013).</p>
<p><b>Normal Central Auditory Processing (Musiek, Gollegly, Kibbe, &amp; Verkest-Lenz, 1991; Samelli &amp; Schochat, 2008)</b> <b>Dichotic Digits Test- 95%</b></p>	<p>Subjective reports claim that abnormal auditory processing leads to an increase in LE (Hornsby, 2013). Therefore, normal CAP was necessary. Abnormal auditory processing was found to affect P300 waves (Hall, 2015).</p>
<p><b>Normal baseline results on LE test (Degeest et al., 2015)</b> <b>80%- speech-recognition task</b> <b>50%- visual memory task</b></p>	<p>This ensures that each participant was capable of fully completing the task, thus, a reference of 80% or more in the quiet listening condition (speech recognition task) and 50% (visual memory task) was required (Degeest et al., 2015).</p>
<p><b>Normal vision or corrected-to-normal vision (Self-Reported and tested- The Near Vision Test)</b></p>	<p>To ensure that vision will not bring about external discrepancies in the results of the secondary visual memory task, normal vision or corrected vision had to be reported by each participant as well as assessed through the use of the Snell Letters (Degeest et al., 2015).</p>
<p><b>Good sleeping patterns (Self-Reported)</b> <b>At least 6- 8 hours of sleep.</b></p>	<p>Reduced hours of sleep impacts cognitive processes and performance. Central auditory processing and multi-tasking is also affected by lack of sleep (Arora et al., 2014; Kadambi et al., 2013; Liberalesso et al., 2012; Lo, Ong, Leong,</p>

	Gooley, & Chee, 2015; Ray et al., 2012). In order to rule out bad sleeping patterns as a variable, participants were requested to report on their sleeping habits by providing a sleep log of 2 weeks prior to testing.
<b>Exclusion criteria</b>	<b>Rationale</b>
<b>Learning disabilities</b>	Learning problems may affect performance in auditory processing measurements, depicting affected cognition. Accordingly, any participant with a learning disability was excluded from the study (Musiek & Chermak, 2014; Ray et al., 2012).
<b>Neurological/cognitive/psychiatric disorders</b>	Potential participants with any indication of cognitive impairment or neurological disorders which may influence CAP abilities were excluded from this study (ASHA, 2005; Degeest et al., 2015; Liberalesso et al., 2012; Ray et al., 2012).
<b>Sleeping disorders</b>	Sleep disorders are found to impact biological and behavioural processes, and are linked to psychiatric functions. Sleep disorders induce changes in the wave morphology of electrophysiological tests. Hence, any participant that reported any bad sleeping patterns or had been diagnosed with a sleeping disorder was excluded from the study (Arora et al., 2014; Liberalesso et al., 2012; Ray et al., 2012).
<b>History of Head injuries</b>	Head injuries may result in cognitive impairments, which in turn affect CAP abilities and LE. On this account, any participant reporting any head injuries that took place at any point was excluded from the study (ASHA, 2005).

The criteria were adhered to throughout data collection and were applied during recruitment of participants prior to signing the information letters.

### 2.5.3 Materials, apparatus, and procedures for selection of participants

The following apparatus and materials (Table 2) were used to conduct the necessary assessments in order to determine the candidacy of the potential participants.

**Table 2: Material and apparatus for selection of participants**

<b>Material and Apparatus</b>	<b>Rationale</b>
<b>Questionnaire</b>	A questionnaire (Appendix D) was used to obtain the case history information of each participant in terms of auditory abilities and overall health, as well as educational history. The questionnaire aided the researcher in ruling out participants based on the participation selection criteria set in place. <b>Procedure:</b> A questionnaire was handed to each participant upon arrival to obtain the case history information.
<b>Otoscope</b>	A Welch Allyn otoscope was utilised to examine the ear canal and the tympanic membrane of both ears.

	<p><b>Procedure:</b> The otoscope assisted in visually determining the condition of the outer ear (ear canal and tympanic membrane) in both right and left ears.</p>
<b>Tympanometer</b>	<p>The GSI Tymptstar (date of calibration: 11/01/2017) was used to obtain immittance and acoustic reflex measurements. The immittance and acoustic reflex assessment is an objective test intended to measure the middle ear function of both ears.</p> <p><b>Procedure:</b> The type of tympanogram for both ears of each participant was attained, as well as their ear canal volume, static compliance and middle ear pressure. Acoustic reflex threshold was acquired ipsilaterally at 1000 Hz.</p>
<b>Clinical Audiometer</b>	<p>GSI 61- clinical audiometer (date of calibration: 11/01/2017) at the University of Pretoria's Speech-Language Pathology and Audiology Department was used to determine ear specific hearing sensitivity.</p> <p><b>Procedure:</b> All participants were tested in a sound proof booth and were expected to present with hearing thresholds within the normal ranges (up to 15dB HL). Tones ranging in frequencies (125 Hz- 8000 Hz) were presented through headphones. Pure tone audiometry was conducted to obtain frequency specific information and to determine the level of hearing each participant presented across all octave frequencies.</p>
<b>Dichotic Digits Test (Musiek et al., 1991)</b>	<p>The Dichotic Digits test (DDT) is an auditory processing test used to assess binaural integration skills. Binaural integration is the process of analyzing and synthesising various inputs presented to both ears simultaneously (Musiek et al., 1991). The Dichotic Digits Test is known to be sensitive in the detection of central auditory lesions (brainstem and cortical lesions) (Musiek et al., 1991), making it an effective triage in examining CAP disorders (Samelli &amp; Schochat, 2008).</p> <p><b>Procedure:</b> The Dichotic Digits Test was used to eliminate auditory processing difficulties once normal hearing was identified. The test analyses dichotic listening skills through the use of pre-recorded spoken digits from 1 to 10, wherein two random digits were presented to each ear, simultaneously. The participants were requested to repeat all the numbers presented, regardless of the order (Samelli &amp; Schochat, 2008). In order to detect their CAP status, the participants were expected to obtain 95% or more (Musiek et al., 1991; Samelli &amp; Schochat, 2008). The tests were scored on a mark sheet and represented as percentages.</p>
<b>Near Vision Test (Sloan, Rowland, &amp; Altman, 1952)</b>	<p>The visual test assesses near vision abilities through the use of Snellen letters. This assessment ensured normal vision or corrected-to-normal visual acuity of each participant. The near vision test also confirmed that the participant did not have difficulties in viewing the visual recognition task (Degeest et al., 2015).</p> <p><b>Procedure:</b> Each participant was placed in front of the Snellen letters at a distance of 40.6 cm away from the chart. In order to be deemed with normal near visual acuity, a participant was expected to correctly read out 3/5 letters from the 8<sup>th</sup> line on the chart.</p>
<b>Baseline- Listening Effort Assessment (Degeest et al., 2015)</b>	<p>Listening effort was assessed using a dual-task condition. However, it was necessary to obtain a baseline so as to ensure that completion of the tasks is possible by the participant. This paradigm consisted of two tasks composed of a speech-recognition task (primary task) and visual memory task (secondary task) (Degeest et al., 2015). The primary task was composed of monosyllabic digits from 0-12 in English. The secondary task was composed of geometric figures with blue filled circles on a computer screen, where a series of 5 sets of figures was displayed (Degeest et al., 2015).</p>

**Procedure:**

The primary (speech recognition) task and secondary (visual memory) task was presented separately to each participant in a random order to ensure that conditioning effect did not take place. This took place in a sound controlled, quiet room. The single-tasks were presented on a laptop with a speaker connected. A series of five spoken digits was played in the presence of steady-state noise of different signal-to-noise ratios (+2dB, -2dB, -6dB, -10dB) and a quiet listening condition. This was presented over speakers, where the participant was placed 90 cm away at 45° and 315° azimuth. During the visual memory task, the participants were asked to keep track of the position of the figures and record them on a scoring sheet after the series is complete. The figures were displayed on a computer screen in front of the participant at eye level, at a distance of 70 cm. In order to ensure their participation in the study, each participant was required to obtain 80% or more in the speech-recognition task (quiet listening condition), and another requisite was to obtain a minimum of 50% in the visual memory task.

The procedures described above took place during the first day of testing, prior to the commencement of data collection. This ensured that all participants had normal middle ear functioning, along with normal hearing and normal auditory processing abilities.

#### **2.5.4 Description of participants**

A total of 27 participants (21 females and six males) were assessed within the age range of 19 to 25 years (M: 22.56, SD: 1.16). Students from tertiary education institutes were recruited as participants, and all participants were fluent in the English language. The participants reported good sleeping behaviours, and presented with normal hearing.

#### **2.6 Materials and apparatus for data collection**

The following materials and apparatus were utilised during testing sessions for data collection.

##### **2.6.1 Profile of Moods States (POMS)**

A 65-item questionnaire (Appendix E), developed by McNair, Lorr and Droppleman (1971), was used to assess fatigue and vigour. The questionnaire consists of a list of words/statements (adjectives) that describe feelings people have. The test requires participants to indicate their emotional state at that point in time by rating on a scale of one (not at all) to five (extremely) how well they do or do not relate to the described feeling. Six mood states are assessed, namely tension, depression, anger, fatigue, confusion, and vigour.

The POMS is analysed to indicate the total mood displacement (TMD) the participant experiences. The TMD is calculated as:

*Total Mood Displacement*

$$= (Tension + Depression + Anger + Fatigue + Confusion) \\ - Vigour$$

The TMD score parameters normally range from -32 to 200. The larger the TMD score, the more tension, depression, anger, fatigue and confusion was experienced in relation to vigour by the participant at the time of the assessment (McNair, Lorr, & Droppleman, 1971). The test was printed out on paper, and each participant rated their emotions during every testing session. The responses were later entered into an online version of the test in order to calculate the TMD.

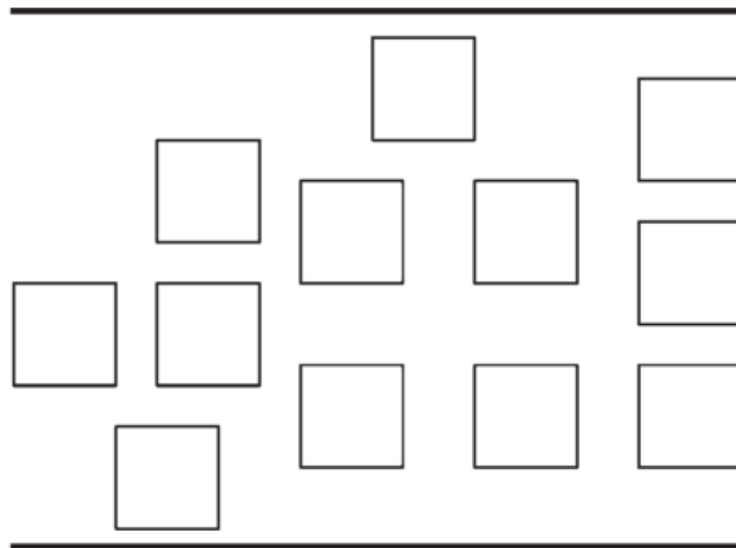
### **2.6.2 Listening Effort Test (LE)**

The LE test used in this study was developed by Degeest et al. (2015), and is based on a dual-task paradigm. Both single- and dual-task conditions were administered in random order per session based on the different sets available. Randomisation was performed to obtain accurate results of the participants' actual LE in comparison to their single-task assessments (Degeest et al., 2015). This LE test was further adapted to fit the needs of this particular study. The test was translated from the Flemish version developed and used by Degeest et al. (2015) to English in order to accommodate the South African population used in this research study. The test included single-task assessments, namely visual memory and speech-recognition tasks, which were administered individually, and the dual-task assessment, where the visual memory and speech recognition tasks were administered simultaneously. This test was presented on a laptop, and testing took place in a sound proof booth with a desk and chair set in positions which remained unchanged for all assessment sessions.

#### *Single-Task Evaluation*

The single-task assessment included a visual memory task and a speech-recognition task which were implemented individually. The visual memory task consisted of a series of geometric figures of five blue filled circles displayed on a grid, presented successively in intervals of one second. The blue filled circles were displayed from a laptop screen, while the participant was seated at eye level from a distance of 70cm

away. This distance was confirmed at each assessment session by the researcher using a measuring tape. The task required the participant to remember the different placements of the circles on the grid and to indicate the positions on a scoring sheet after each series was completed. The participants were expected to fill out the grid depicted in the image below (Figure 1) on the scoring sheet. A similar grid was presented on the laptop screen where the geometric circle series was displayed.



**Figure 1: Example of the grid participants were expected to fill.**

The second single-task assessment involved a speech-recognition task comprising of English monosyllabic digits ranging from one to 12, excluding seven and 11. The digits were presented under five different listening situations with steady-state noise ranging from +2dB signal-to-noise ratio (SNR) to -10dB SNR [+2dB, -2dB, -6dB, -10dB] and a quiet listening situation. The test was played through calibrated speakers connected to the laptop, with the participant placed at a 45° and 315° azimuth, at a distance of 90 cm away. This distance was also confirmed by the researcher. The laptop was calibrated using a Sound Level Meter model NL- 52 (calibration date: 04/04/2017), determining an overall output of 65dB SPL. The sound level meter measured the output of the laptop when the speakers were set to full volume. Following the prior measurement, the laptop volume was then adjusted accordingly. Implementation of this measuring procedure ensured an overall output of 65 dB SPL. Therefore, the generation of the SNR is based upon the set level of 65 dB SPL. An example of generating a variant condition is as follows:

To generate a +2 dB SNR output, the 2 dB will be added to the 65 dB SPL (65 dB+ 2dB= 67 dB), thus providing an output of 67 dB. In the opposite situation, a -2 dB SNR output would results in a reduction of 2 dB from the previously determined 65 dB SPL (65 dB – 2 dB), providing an output of 63 dB.

### *Dual-Task Evaluation*

The dual-task condition consisted of both visual memory and speech-recognition assessments that were administered simultaneously (dual-task). During the dual-task assessment, both the digits in varying SNR conditions and the five blue filled circles were presented concurrently. When a digit was presented, the placement of one geometric circle was shown simultaneously. The participant was requested to pay close attention or to mainly focus on the digits rather than the geometric circles. The LE is based on the concept that when an individual is placed under a cognitively demanding situation, the second task performance will decline as a result of reduced spare cognitive capacity. Therefore, participants are given instructions to focus on the primary task to measure the deterioration in performance on the secondary task. Participants were requested to repeat the perceived digits aloud to the researcher. Thereafter, they were expected to indicate the positions of the circles on the grid (Degeest et al., 2015).

The LE test provides a measurement of performance on the secondary task (visual memory) during the dual-task condition. Any deterioration is seen as a result of reduced capacity available from the primary speech recognition task. In order to determine the participant's LE, the following formula was used:

$$LE = 100 \times \frac{[Baseline (visual memory) - dualtask condition(visual memory)]}{Baseline (visual memory)}$$

Listening effort was measured as a percentage. The percentage was determined by means of comparing the result of the visual memory task of the dual-task assessment to the visual memory task of the single-task assessment. The higher the percentage, the more effort was used for that listening condition (Degeest et al., 2015; Degeest, Keppler, & Corthals, 2017).

### 2.6.3 P300 Assessment

The standard, auditory odd-ball paradigm was used to obtain P300 waveforms, with two different tone bursts being presented, one target and the other non-target (Ray et al., 2012). The Bio-logic Navigator Pro System (version: 7.2.1) auditory evoked potential system was used for this research study.

A two channel electrode montage was used with electrodes placed on the ipsilateral mastoid (Mi) and high forehead (Fz), with a ground electrode on the low forehead (Fpz). The two channel montage is routinely recommended for clinical use (Didoné et al., 2016; Hearing, 2013; Interacoustics, 2015). Although not appropriate for site of lesion testing, the choice of electrode montage was selected as this would be frequently used for clinical purposes and was appropriate for within participant comparisons using binaural routing of stimuli in the present study. The skin areas where the electrodes were placed were cleaned using NuPrep skin abrasive gel. The electrophysiological test utilised Ag-AgCl electrodes. The cup electrodes were filled with Ten20 conductive paste, and were then secured with the aid of Micropore tape. The frequent and infrequent tones were presented through EarTone ABR insert earphones.

The EarTone insert earphone was calibrated first in peak-to-peak equivalent sound pressure level (ppeSPL) using a sound level meter, condenser microphone, and an oscilloscope. Calibration for the insert earphone took place according to the specifications of the manufacturer (3M Company, 2010; Natus Medical Incorporated, 2017). The sound level meter was attached to an HA2 coupler. A response of the activation was obtained and evaluated based on the oscilloscope reading (3M Company, 2010; Sielemann, 2007). The insert earphones were then placed on the HA2 coupler. The stimulus was played through the insert earphones and another response was evaluated based on the oscilloscope reading (3M Company, 2010; Natus Medical Incorporated, 2017; Sielemann, 2007). The amplitude of the stimulus was then adjusted accordingly until a peak-to-peak amplitude was obtained resembling the previously determined amplitude by the sound level meter (Natus Medical Incorporated, 2017). Amplitudes were adjusted according to frequency specific values for each test. The same procedure was applied to the second channel (3M Company, 2010; Natus Medical Incorporated, 2017).

The Bio-logic Navigator Pro System makes use of ppeSPL which is then converted to normal hearing threshold level in decibels (dBnHL). This conversion is achieved through the use of correction factors which are: 250 Hz= 5; 500 Hz= 0; 750 Hz= 0; 1000 Hz= 0; 2000 Hz= 5; 4000 Hz= 0; 8000 Hz= -10.

The following parameters (Table 3) were utilised during the P300 assessment: (Didoné et al., 2016; Ray et al., 2012).

**Table 3: Target and non-target parameters**

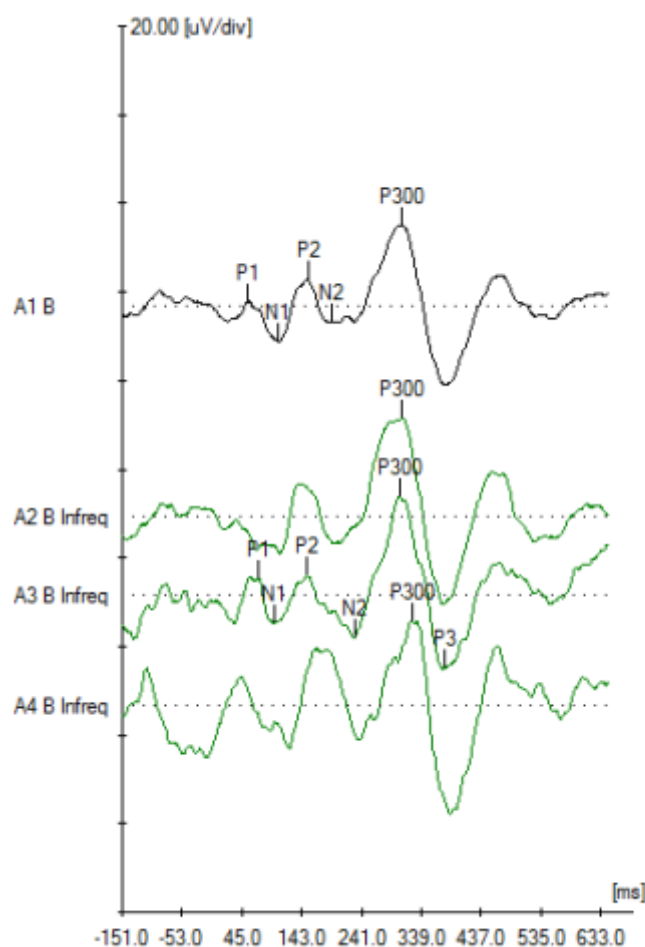
Non-target Stimulus	Target Stimulus
<u>Intensity</u> - 70 dB SPL <u>Sensitivity</u> - 100 µV <u>Frequency</u> - 2000 Hz <u>Stimulus type</u> - Toneburst <u>Ramping</u> - -Rise/Fall: 10 cycles- 10 ms - Plateau: 80 cycles – 80 ms - Total: 100 cycles <u>Stimulus Rate</u> - 0.9/ sec <u>Low Frequency Filter</u> - 1.0 Hz <u>High Frequency Filter</u> - 30.0 Hz	<u>Intensity</u> - 70 dB SPL <u>Sensitivity</u> - 100 µV <u>Frequency</u> - 1000 Hz <u>Stimulus type</u> - Toneburst <u>Ramping</u> - -Rise/Fall: 5 cycles- 5 ms - Plateau: 40 cycles- 40 ms - Total: 50 cycles <u>Stimulus Rate</u> - 0.9/ sec <u>Low Frequency Filter</u> - 1.0 Hz <u>High Frequency Filter</u> - 30.0 Hz

During the recording of the P300 evoked responses, the participant was seated comfortably on a chair inside a sound proof booth. Participants were requested to refrain from excessive blinking, keep their eyes open and relax their shoulders. A mental stimulating exercise was presented to the participants, where they were requested to count the number of times the target stimulus was presented, by writing it on a sheet of paper. It is important to note that engagement between the participant and the researcher took place in between traces. These practices ensured that the participant maintained a maximum state of alertness throughout the test.

The participant's response was then noted at the end of each trace (Didoné et al., 2016; Ray et al., 2012). Each trace consisted of approximately five target stimuli with a break in between repeated traces. During the break, the participant was asked how many target stimuli were perceived (Didoné et al., 2016; Ray et al., 2012). A minimum of three traces were then averaged. The target to non-target stimuli ratio was 20:80 (Didoné et al., 2016; Ray et al., 2012).

The P300 latency was calculated as the highest peak between 200 ms and 400 ms (Didoné et al., 2016) as agreed upon by two experienced audiologists. The response amplitude was calculated by subtracting a representative average of the amplitude of the pre-stimulus period from the base to the proceeding peak of the P300 wave (Hall, 2015).

Figure 2 provides an example of which waves were selected and how averaging took place for one participant. The wave labelled A1 is the representative averaged wave. This average wave was obtained from averaging waves A2, A3 and A4.



**Figure 2: Example of averaged P300 waves.**

## **2.7 Procedures for data collection**

The following procedures were employed for every session during data collection.

### 2.7.1 Participant instructions

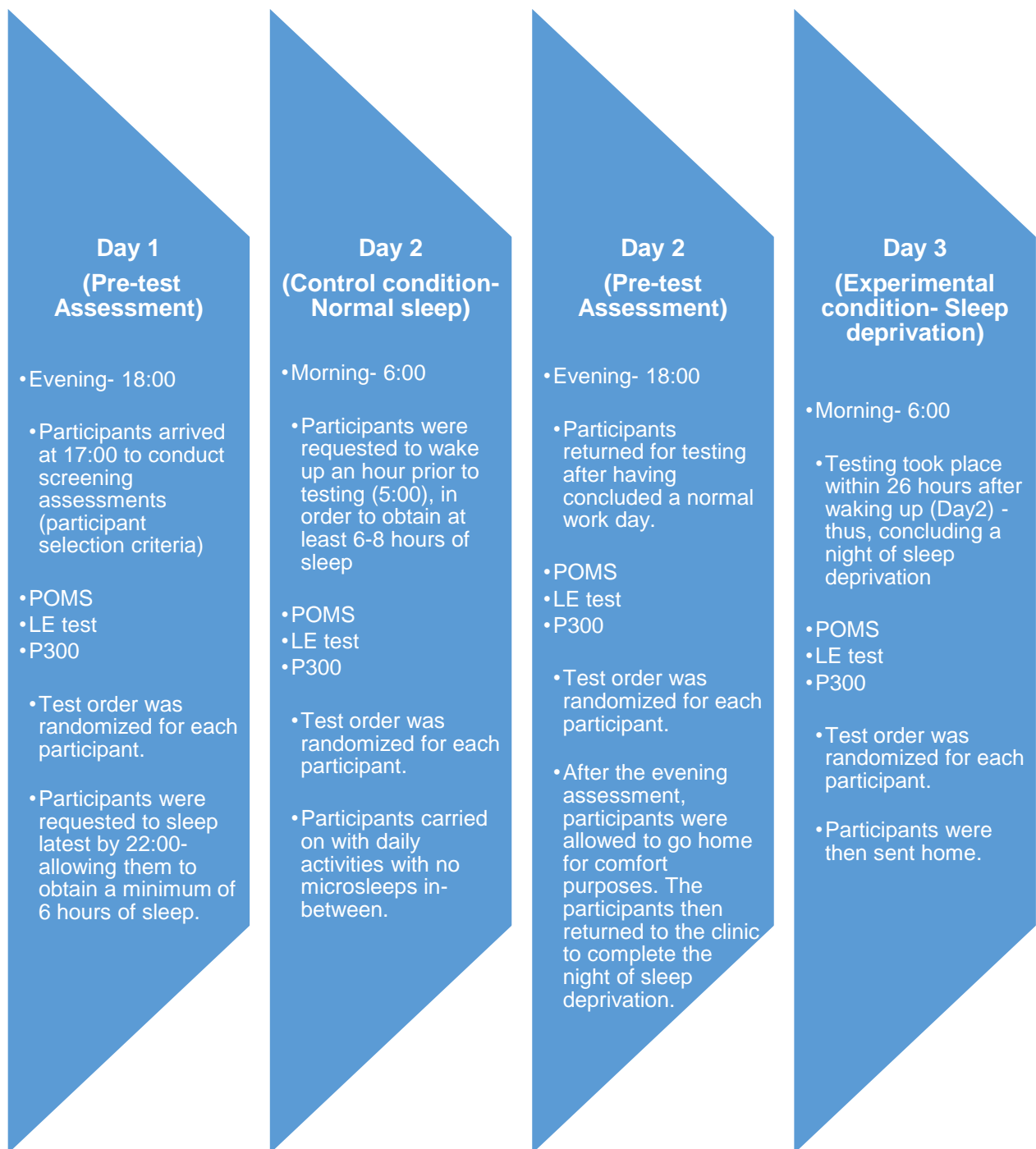
Participants underwent four assessments over a period of three days. Strict instructions were provided to the consenting participants. The participants were informed of what was expected of them, specifically, the restrictions and instructions to adhere to 24 hours prior to testing and throughout the three-day assessment period. Table 4 depicts the instructions that were provided to the participants.

**Table 4: Instructions provided to participants prior to data collection.**

Instructions	Rationale:
Avoidance of drugs that may impair cognition, auditory processing and sleeping patterns.	Such medication has been found to result in changes in wave forms of the P300, as well as the ability to process information (American Speech-Language-Hearing Association, 2005; Arora et al., 2014; Kadambi et al., 2013; Liberalesso et al., 2012; Polich, 2011; Ray et al., 2012).
Avoidance of alcohol, nicotine, and other stimulants such as caffeine.	Wave forms of the P300 are affected by the use of stimulants, and stimulants have been reported to impact the processing of information (Arora et al., 2014; Hedges & Bennett, 2014; Kadambi et al., 2013; Liberalesso et al., 2012; Martin, Davalos, & Kisley, 2009; Polich, 2011; Ray et al., 2012).
Refrain from exerting physical and mental strain (example: exercising, excessive studying, pulling an “all-nighter”, etc.) 24-hours prior to testing	This will increase levels of fatigue, which in turn affects cognitive decisions (Arora et al., 2014; Kadambi et al., 2013; Liberalesso et al., 2012; Polich, 2011). P300 latencies are also seen to increase as a result of such exertion (Ray et al., 2012)

### 2.7.2 Assessment Protocol

The following assessment protocol (Figure 3) was adhered to for data collection:



**Figure 3: Procedure for data collection**

Participants were assessed four times over three days. The present research study obtained assessments under a control condition and an experimental condition. During the control condition, the participants were assessed during a normal sleep cycle, where six to eight hours of slumber was acquired. The experimental condition consisted of the participants remaining awake from the time they awoke, to approximately the same time the next day, acquiring a 24-hour sleep deprivation state.

Strict times for testing were followed to minimise the confounding effects of the individual participants' circadian rhythm variation, which is directly influenced by exposure to light (Engle-Friedman et al., 2003; LeGates, Fernandez, & Hattar, 2014). When a circadian shift occurs, it is believed to present a deficit in learning and memory (LeGates et al., 2014). A circadian shift is identified as a change in the light or dark cycle of the day. This is usually affected by seasonal changes resulting in re-synchronisation of the circadian rhythm to the new time change (Engle-Friedman et al., 2003; LeGates et al., 2014). Specifically, such alterations in light conditions act as an antidepressant on behavioural effects as a result of seasonal changes and increased nocturnal times (Alhola & Polo-Kantola, 2013; LeGates et al., 2014). It is noteworthy that individual circadian rhythms were not formally controlled through retinal ganglion cells and melanopsin (LeGates et al., 2014). Therefore, this study attempted to reduce the effect of inter-participant differences by adhering to strict testing times and specified sleeping times which were provided in the instructions during the assessment period. Testing took place at 6:00 (morning assessment/ post-test) and 18:00 (evening assessment/ pre-test) for the morning and evening, respectively (Engle-Friedman et al., 2003; LeGates et al., 2014). These times were selected as sunlight was already present at the times of testing, and testing times did not impact daily activities. Each session consisted of obtaining responses of the participants for the POMS, LE and P300 assessments.

The study followed a specific test battery and randomised order of assessments for the three testing days with each participant. Participants were tested on the evening of their day one as a means of obtaining the pre-test assessment score. Participants were instructed to sleep at 22:00 and to wake up at 5:00 for the morning assessment of day two. On the morning of day two, assessments were conducted to obtain the participants' results under normal sleep cycle conditions (control condition).

After the morning session of day two, participants were allowed to carry on with daily activities, such as class and work, on the condition that the instructions given were adhered to. On the evening of day two, another pre-test assessment was obtained. Participants were then again allowed to break for comfort purposes, including showering and eating, after which they were requested to meet back at the clinic at a selected time. On the evening of day two, sleep deprivation (experimental condition)

was implemented during which the participants' activities were overseen by the researchers to ensure that no micro-sleep attacks occurred. The participants were allowed to engage in board games and computer games, and to watch movies. After the night of sleep deprivation, the participants were then tested on the morning of day three.

### **2.7.3 Pilot study**

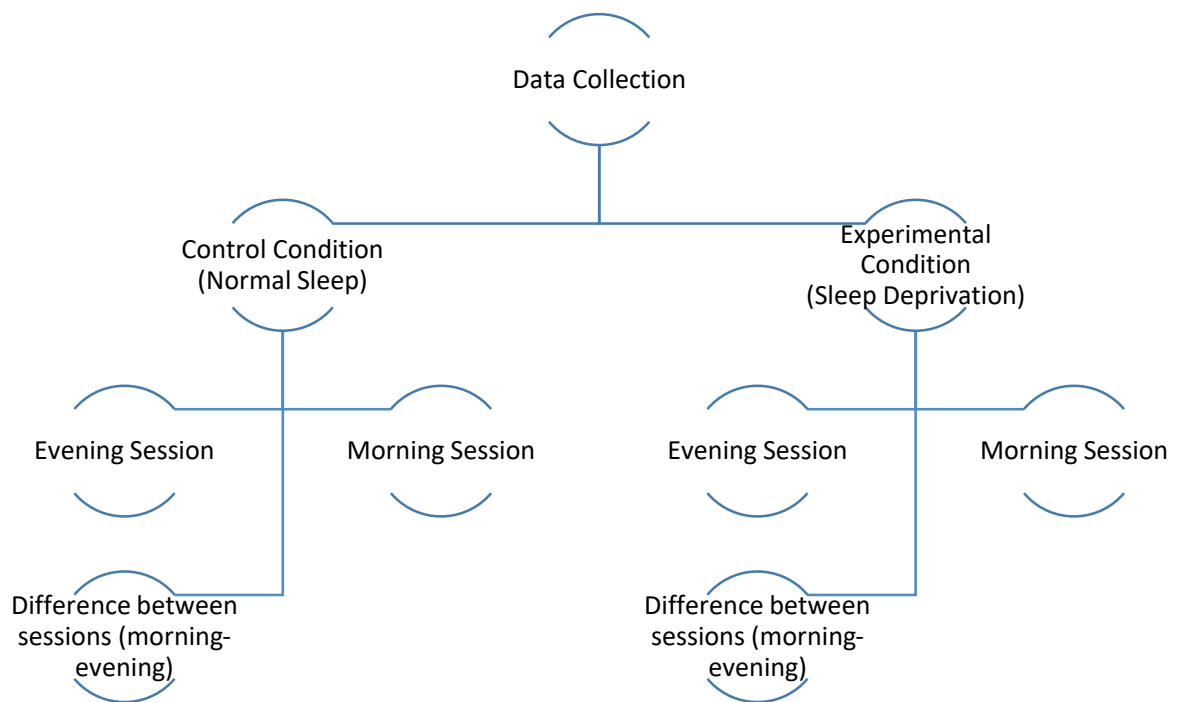
A pilot study was conducted prior to the commencement of data collection. This assisted the researcher in familiarising with the assessment procedures and ensured feasibility. The pilot study consisted of all the assessments: POMS, LE and P300.

The pilot study was conducted on the LE test due to the language adjustment made from the Flemish test assembled by Degeest et al. (2015) to the English version implemented for the purposes of this research study. The test was administered on ten normal hearing students from the University of Pretoria. The same procedures were applied for the pilot study as described in the section on data collection.

Changes were not necessary, and therefore the proposed protocol and procedures were used throughout data collection.

### **2.8 Data analysis**

The Statistical Package for the Social Sciences (SPSS) version 24 data analysing software was used to perform data analysis for this study. The data captured was transcribed on a Microsoft Excel Sheet to enable ease of storage and analysis. In order to perform data analysis, the data was used to compare each individual participant's control results to the results the participant obtained under the experimental condition. Descriptive and inferential statistics described the mean, standard deviation, and significant difference for the different POMS mood states, the percentage LE for the different listening situations, and the P300 latency and amplitude values of the responses. The format depicted in Figure 4 was used to conduct statistical analysis of the data that was collected.



**Figure 4: Procedure for statistical analysis**

Information from all four sessions from the three days of assessment was obtained and captured. Each participant's results were collected for both control and experimental conditions, specific to the evening and morning sessions. In order to conduct descriptive analysis, each individual session's values were utilised. During the analysis of inferential statistics, difference values were used. These difference values were obtained from both evening and morning sessions for each control and experimental condition separately. The evening session values were subtracted from the morning session values, presenting difference values for each condition.

$$\textit{Difference value} = \textit{morning session} - \textit{evening session}$$

This difference analysis was applied and conducted for all the tests: POMS, LE and P300, and their respective sub-tests.

The Shapiro-Wilk test was used to identify whether the data was normally distributed ( $p > 0.05$ ) or non-normally distributed ( $p < 0.05$ ) (Durrheim & Tredoux, 2004). Non-parametric and parametric statistics were used to evaluate the relationship between the repeated measures for both control and experimental conditions. Outliers were

accounted for and removed from the tests: POMS (one participant was removed from the anger state, one participant was removed from the depression state and one from the tension state), LE (SNR: one participant was removed from the [-10 dB SNR]) and P300 (no outliers were encountered).

## **2.9 Reliability and Validity**

The validity of a measuring instrument refers to the extent to which the tool actually measures what it intends to, whereas reliability is defined as the accuracy and consistency of the measure itself (Leedy & Ormrod, 2015).

With the recent and increasing interest in the concept of LE, a study by Degeest et al. (2015) was published using the dual-task paradigm in Flemish, where accurate use of the test was demonstrated. This was evidenced by the correlation analysis performed on the speech recognition task for both single- and dual-task conditions (Degeest et al., 2015, 2017). Another study conducted by the same authors was also published using a similar LE test (Degeest et al., 2017). However, the present study made use of a tool more appropriate to the South African population, namely a version which was translated from Flemish to English by the authors themselves. In order to become familiar with the test and to determine the feasibility of the assessment with regard to duration, a pilot study was conducted on ten students from the University of Pretoria. The assessment tool for the LE test required calibration of the laptop prior to commencement of the tasks. This was performed prior to the pilot study, therefore increasing the reliability of the tool.

The POMS scores were assessed through an objective calculator on the website, providing a reliable and valid confirmation of the results obtained. The POMS also underwent a pilot study prior to the commencement of data collection determining the feasibility of the assessment and its duration, and allowing the researcher to become familiar with the test.

The P300 waveform interpretations were agreed upon by two consenting and experienced audiologists, increasing the reliability of the results obtained. Calibration of the Bio-logic equipment was conducted in the beginning of the year, ensuring up-to-date software. Interaction between each participant and the researcher was maintained throughout the P300 assessment. This interaction established participant awareness throughout the test. In order to calculate the P300 wave for an assessment

during a session, an average of three repeatable waves was obtained. Thereafter, the latency and amplitude values were calculated for that wave. This averaged wave verified that a representative waveform from was obtained from the various waves collected.

It is noteworthy that behavioural and neurophysiological assessments were conducted in a sound-proof booth, ensuring that other background noises would not alter the results obtained. During the sleep deprivation evening all the participants were monitored by the researcher, who ensured that naps did not take place and that the instructions were adhered to.

### **2.10 Summary of chapter**

This chapter provided in-depth information regarding the measures and procedures employed in order to conduct the present research study. The instructions adhered to by the participants were included and the format of data collection was provided.

## **Chapter 3** **Results**

### **3.1 Introduction**

In this section, the outcomes obtained for the POMS, LE and P300 assessments will be analysed and discussed in light of the different aims of this research study.

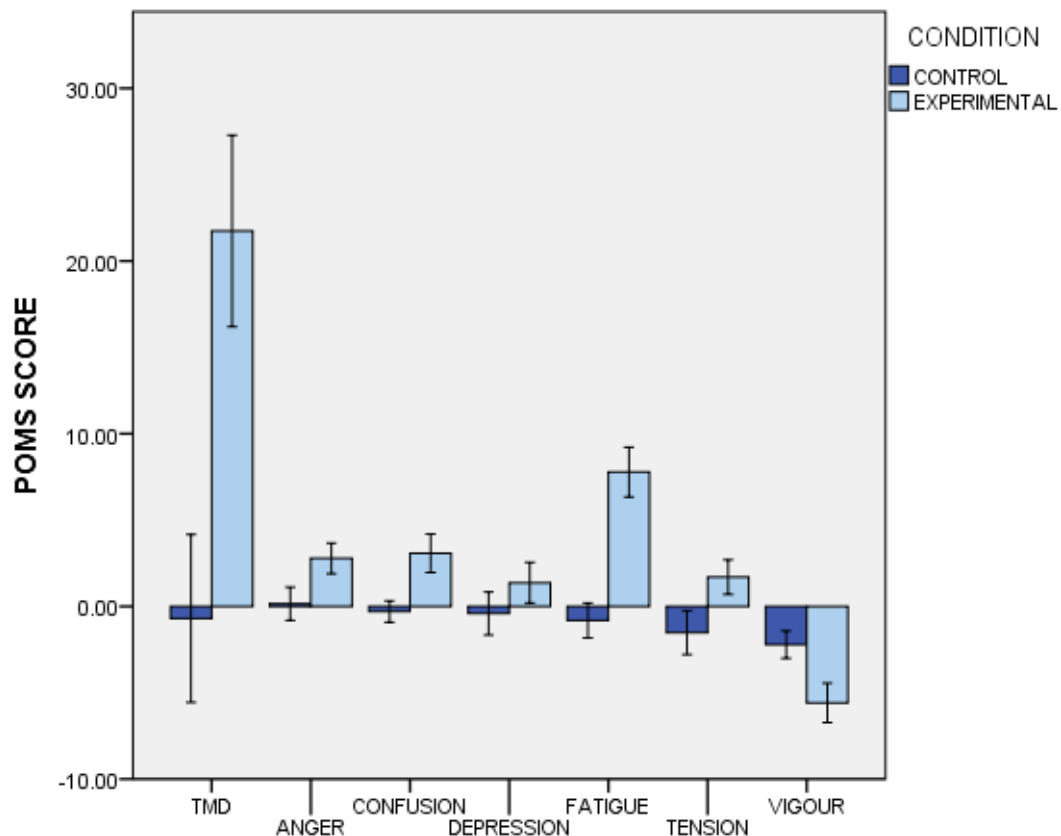
The participants were assessed four times over three days, during which the POMS, LE assessment and P300 responses were collected and evaluated for each participant. This allowed the researcher to compare the results obtained under the control condition (normal sleep) to the results obtained under the experimental condition (sleep deprivation), and thereby to evaluate the impact of sleep deprivation.

### **3.2 Profile of Mood States (POMS)**

A 65- item questionnaire was used to assess fatigue and vigour. Six mood states were assessed, namely tension, depression, anger, fatigue, confusion, and vigour, and the final mood score was calculated as the Total Mood Displacement (TMD).

The difference scores per condition were calculated from the evening and morning sessions for each mood state. Statistical evaluation of these scores were carried out using a Paired T-test for the majority of the POMS categories, except for the anger and confusion mood states, where the data distribution showed a non-normal distribution (Shapiro-Wilk test,  $w = 0.83- 0.97$ ,  $p < 0.05$ ). The differences in anger and confusion mood states were evaluated using the Wilcoxon Signed Rank test.

Figure 5 presents the POMS mean difference scores between the evening and morning sessions for the control and for the experimental conditions.



Error Bars: +/- 1 SE

**Figure 5: Mean difference scores in Profile of Mood States (POMS) between evening and morning sessions for both control and experimental conditions. (Error bars indicate +/- 1 standard error [SE]; TMD = total mood displacement) (n=27).**

An increase in the score for most of the mood states was apparent during the control condition in comparison to the experimental condition, excluding the vigour mood state. A large TMD ( $M = 26.56$ ,  $SD = 24.24$ ) was evident in the experimental condition with a low TMD score ( $M = -0.70$ ,  $SD = 25.26$ ) in the control condition. A low vigour score ( $M = -2.22$ ,  $SD = 4.13$ ) was observed in the control condition, whereas an even lower vigour score ( $M = -6.11$ ;  $SD = 5.38$ ) was apparent in the experimental condition. This change in vigour scores represent a decrease from the control condition to the experimental condition. The highest score ( $M = 9.19$ ,  $SD = 5.60$ ) is evident for the state of fatigue in the experimental condition. The fatigue score in the control condition was relatively low ( $M = -0.81$ ), with an approximately a similar variation in individual scores ( $SD = 5.26$ ).

Table 5 presents in-depth statistics with regard to the POMS for both evening and morning sessions in the control and experimental conditions.

**Table 5: Mean, standard deviation and p-value for the different mood states in the POMS in control and experimental conditions comparing evening and morning sessions (n=27).**

POMS-States	Mood	Condition	Session	TMD	Anger	Confusion	Depression	Fatigue	Tension	Vigour
<b>Mean (SD)</b>	Control Condition		Evening	14.78 (15.46)	3.04 (4.16)	6.00 (2.91)	4.70 (4.09)	7.07 (3.66)	6.67 (4.88)	12.70 (5.30)
			Morning	14.07 (21.35)	3.19 (4.60)	5.70 (2.80)	4.30 (6.03)	6.26 (4.73)	5.15 (4.88)	10.48 (6.44)
			Difference Values	-0.70 (25.26)	0.15 (4.98)	0.30 (3.22)	-0.41 (6.48)	0.81 (5.26)	-1.52 (6.60)	-2.22 (4.13)
	Experimental Condition		Evening	11.44 (21.01)	2.74 (4.25)	5.67 (2.50)	4.15 (5.62)	5.70 (4.56)	4.56 (4.24)	11.44 (6.80)
			Morning	38.00 (21.09)	5.55 (5.32)	9.67 (5.07)	6.48 (5.96)	14.90 (5.80)	6.70 (2.81)	5.33 (4.83)
			Difference Values	26.56 (24.24)	2.81 (4.75)	4.00 (5.08)	2.33 (5.78)	9.19 (5.60)	2.15 (4.94)	-6.11 (5.38)
<b>p- value<sup>†</sup></b>				0.001**	0.027*	0.001**	0.010**	0.000**	0.043*	0.002**

POMS: Profile of Mood States; TMD: Total Mood Displacement; SD: Standard Deviation; ( $p < 0.05^*$ ); ( $p < 0.01^{**}$ )

p- value<sup>†</sup>= statistical significance level calculated for evaluating the difference in averaged difference scores of the evening and morning sessions in both control and experimental conditions.

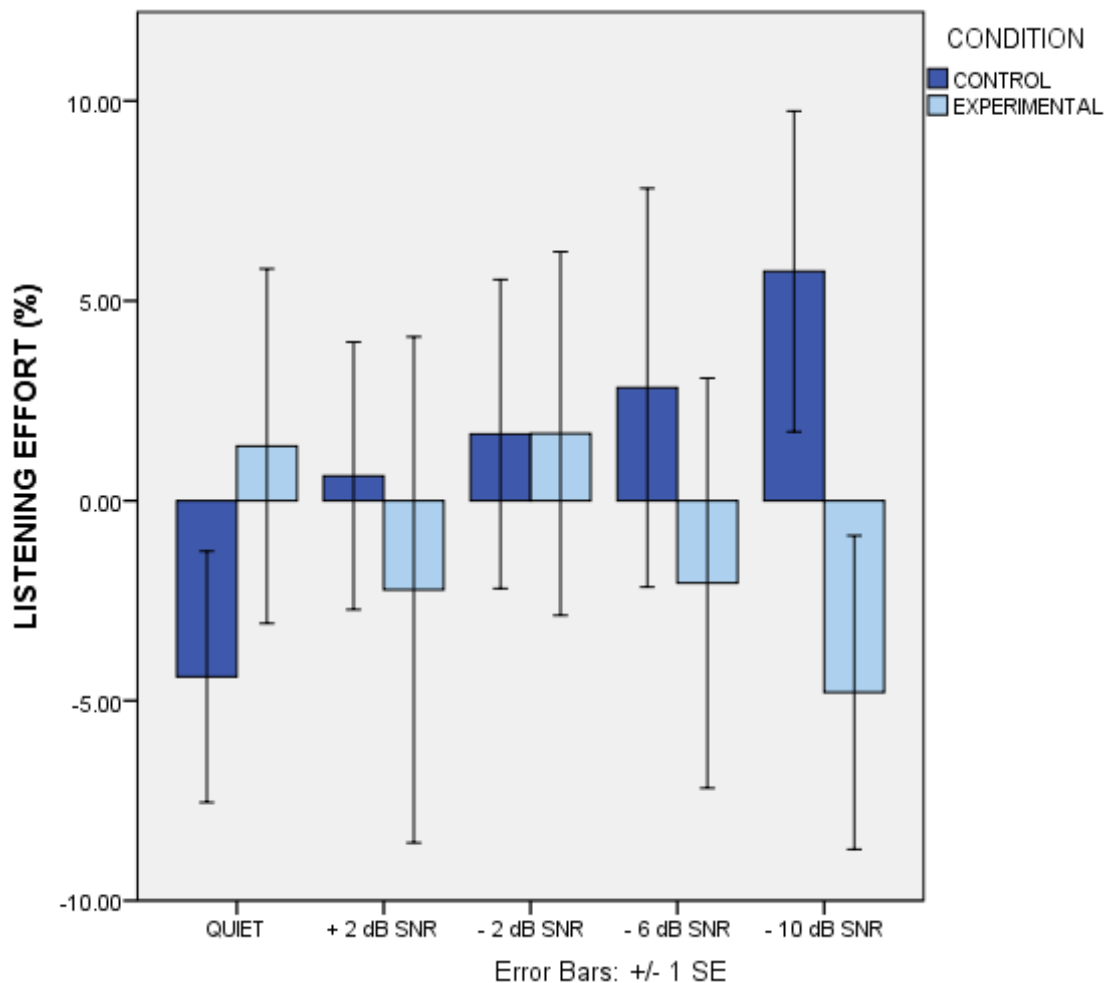
A significant increase in mood states scores was obtained at the end of sleep deprivation conditions, with the exception of the vigour mood state. Statistically significant differences were obtained for the anger ( $Z = 2.21$ ,  $p = .027$ ,  $r = .43$ ) and tension ( $t(26) = -2.13$ ,  $p = .043$ ,  $d = 0.41$ ) mood states. Highly significant differences were obtained for the majority of the mood states: TMD( $t(26) = -3.77$ ,  $p = .001$ ,  $d = 0.73$ ), confusion ( $Z = 3.41$ ,  $p = .001$ ,  $r = 0.66$ ), depression ( $t(25) = -2.80$ ,  $p = .01$ ,  $d = 0.55$ ), fatigue ( $t(26) = -6.74$ ,  $p < .01$ ,  $d = 1.30$ ) and vigour ( $t(26) = -3.37$ ,  $p = .002$ ,  $d = 0.65$ ).

### **3.3 Listening Effort (LE)**

The LE assessment tool was employed in both single and dual-task conditions. The LE assessment includes a visual memory task and a speech recognition task. The speech recognition task consisted of 5 different listening situations (quiet, +2 dB SNR, -2 dB SNR, -6 dB SNR, -10 dB SNR), during which digits were presented in the presence of background noise at different intensities.

Since LE test scores demonstrated a normal distribution ( $w = 0.93- 0.98$ ,  $p > 0.05$ ), a Paired T- Test was utilised to compare the percentage values on the LE test across listening situations for both the control and experimental conditions.

A comparison of the different LE percentage values between the evening and morning sessions for the various listening situations in both control and experimental conditions is presented in Figure 6.



**Figure 6: Mean difference percentages in listening effort (LE) between evening and morning sessions for both control and experimental conditions. (Error bars indicate +/- 1 standard error [SE]; SNR = signal- to-noise ratio) (n=27).**

A decrease in LE was observed for most of the listening situations in the experimental condition, with the exception of the quiet and - 2 dB SNR listening situations. On the contrary, an increase in LE for most of the listening situations was observed in the control condition, with the exception of the quiet listening situation. For the -10 dB SNR listening situation, the most effort experienced for any situation was observed in the control condition ( $M = 5.74\%$ ,  $SD = 20.84$ ), with the least effort experienced in the experimental condition ( $M = -4.80\%$ ,  $SD = 20.37$ ). A decrease in LE was also evidenced for the quiet situation in the control condition ( $M = -4.40\%$ ,  $SD = 16.33$ ), while an increase was seen in the experimental condition ( $M = 1.37\%$ ,  $SD = 23.05$ ).

The means and standard deviations of the LE scores for the control and experimental conditions of the evening and morning sessions across the different listening situations are presented in Table 6.

**Table 6: Mean, standard deviation and p-value for the listening effort (LE) required for listening situations in control and experimental conditions comparing evening and morning sessions (n=27).**

LE Situations		Conditions	Session	Quiet	SNR +2 dB	SNR -2 dB	SNR -6 dB	SNR -10 dB
Mean (SD) [%]	Control Condition		Evening	21.43 (19.76)	16.05 (20.65)	21.09 (21.00)	23.81 (20.89)	18.31 (23.11)
			Morning	17.03 (16.90)	16.67 (17.26)	22.75 (13.85)	26.64 (21.55)	24.05 (17.96)
			Difference Values	-4.40 (16.33)	0.622 (17.38)	1.67 (20.07)	2.83 (25.90)	5.74 (20.84)
	Experimental Condition		Evening	19.63 (18.32)	22.46 (21.50)	23.80 (20.05)	23.84 (24.00)	27.30 (19.13)
			Morning	21.00 (17.34)	20.23 (23.57)	25.48 (15.44)	21.80 (18.94)	22.51 (10.47)
			Difference Values	1.37 (23.05)	-2.23 (32.88)	1.68 (23.63)	-2.06 (26.65)	-4.79 (20.37)
<b>p- value<sup>†</sup></b>				0.313	0.698	0.998	0.559	0.870

LE: Listening Effort; SNR: Signal-to-noise ratio; dB: Decibels; SD: Standard Deviation

p- value<sup>†</sup>= statistical significance level calculated for evaluating the difference in averaged difference scores of the evening and morning sessions in both control and experimental conditions.

A higher percentage mean LE for the morning sessions in most of the listening situations was evident in the experimental condition in comparison to the control condition, with the exception of the – 6 dB SNR and – 10 dB SNR situations. No statistically significant differences were found between the difference values of the evening and morning LE scores when comparing the control condition to the experimental condition: quiet ( $t(26) = -1.03, p = 0.313, d = 0.20$ ), +2 dB SNR ( $t(26) = 0.39, p = 0.698, d = 0.08$ ), -2 dB SNR ( $t(26) = -0.00, p = 0.998, d = 0.00$ ), -6 dB SNR ( $t(26) = 0.59, p = 0.559, d = 0.11$ ), - 10 dB SNR ( $t(25) = 1.78, p = 0.870, d = 0.35$ ).

### 3.4 P300 Assessment

The P300 waveforms were elicited using an auditory odd-ball paradigm through the use of two different tone bursts, a target and a non-target stimulus.

All P300 latency and amplitude values showed normal distribution (Shapiro-Wilk test, latency  $w = 0.92- 0.98, p > 0.05$  and amplitude  $w = 0.84- 0.99, p > 0.05$ ). A comparison of the means of the control and experimental conditions for the P300 latency and

amplitude values was performed using a t-test statistical analysis. The one-way analysis of covariance (ANCOVA) test was used for the covariate and unstable pre-test (evening session) assessment of the latency values. The evening sessions were seen to play a role in affecting the results of the post-test (morning) sessions. This is because a significant difference was obtained when the comparisons for the evening and morning sessions in the control and experimental conditions were obtained separately. Therefore, a correction in the pre-test (evening session) assessment values was made and statistical analysis was then applied only on the difference between the post-test (morning) sessions for both control and experimental conditions (Durrheim & Tredoux, 2004).

Table 7 presents the P300 latency and amplitude values obtained from the evening and morning sessions, comparing these two measure for both the control and experimental conditions. The mean difference values were calculated between the evening and morning sessions for the control condition, and between the evening and morning sessions for the experimental condition. The difference scores were then compared and analysed using the ANCOVA for the P300 latency values. The Wilcoxon Signed Rank Test was used to compare the amplitude values.

**Table 7: Mean, standard deviation and p-value for P300 latency and amplitude in the control and experimental conditions comparing evening and morning sessions (n=27).**

P300 Responses	Condition	Session	P300 Latency [ms]	P300 Amplitude [ $\mu$ V]
Mean (SD)	Control Condition	Evening	315.80 (24.81)	5.33 (3.96)
		Morning	324.42 (22.95)	3.57 (5.01)
		Difference Values	7.29 (9.34)	-1.69 (4.48)
	Experimental Condition	Evening	327.15 (26.33)	5.00 (4.08)
		Morning	345.65 (28.02)	4.22 (4.71)
		Difference Values	18.47 (25.35)	9.21 (6.40)
p- value			0.016** ^	.000** †

*ms: milliseconds;  $\mu$ V: microvolts; SD: Standard Deviation; ( $p < 0.01$ \*\*)*

p- value<sup>†</sup>= statistical significance level calculated for evaluating the difference in averaged difference scores of the evening and morning sessions in both control and experimental conditions.

ANCOVA<sup>^</sup>= statistical significance level calculated for evaluating the difference in averaged difference scores of the morning sessions in both control and experimental conditions.

It is noteworthy that the mean latencies for the experimental condition were greater than those measured in the control condition. A highly significant difference ( $F(1, 51) = 6.17, p = 0.016, \eta_p^2 = 0.38$ ; Table 7) was obtained.

A decrease in mean amplitude values was obtained when comparing the evening sessions of the control and experimental conditions. A larger SD was observed in the morning session of the control condition in comparison to the morning sessions of the experimental condition. No statistically significant differences were evident when comparing the amplitude values of the evening and morning sessions for the control and experimental conditions. However, a statistically highly significant difference ( $t(26) = -8.22, p < 0.01, d = 1.58$ ) was obtained when comparing the difference values for the amplitudes measured during the control and experimental conditions.

### **3.5 Summary of chapter**

The chapter provided in depth information on the results obtained after data analysis was conducted. The following important points were observed in this section:

- Statistically significant differences were obtained for the POMS assessments and the P300 responses, specifically, the different mood states and the P300 latency and amplitude values, respectively. This implies that the POMS and the P300 responses were affected by sleep deprivation.
- No statistically significant differences were found for the different listening situations regarding the LE assessment. The insignificant changes observed in this study give an indication that the present form of LE assessment was not significantly affected by sleep deprivation.

The next chapter will present a discussion of possible causes and theories related to these results.

## **Chapter 4** **Discussion**

### **4.1 Introduction**

Although sleep deprivation is a recurring condition in the present young population, researchers are still speculating about its impact. It is known that several cognitive processes, such as attention and memory, are affected when a person experiences sleep deprivation. These cognitive processes of the prefrontal cortex are also seen to be involved in, and can therefore be assessed through listening effort (LE) tasks. An increase in LE is believed to be a result of, amongst other factors, a decrease in the cognitive processes of the prefrontal cortex (Gagné et al., 2017; Goel et al., 2009). P300 waveforms, which provide information on auditory processing and identification of change in auditory stimuli, are known to be affected by sleep deprivation. Some functions of the prefrontal cortex similarly assessed by LE tasks, have been shown to be affected by sleep deprivation (Lee et al., 2003). Therefore, the present study investigated the impact of sleep deprivation on LE and P300 responses. The participants' mood states were also taken into account using the Profile of Mood States (POMS) questionnaire to determine the subjective effort experienced as a result of sleep deprivation.

### **4.2 Profile of Mood States (POMS)**

The results obtained demonstrated that total mood displacement (TMD) was mostly affected after sleep deprivation, thus confirming that the participants' overall emotions were affected as a result of lack of sleep. Vigour decreased significantly after sleep deprivation. The vigour mood state determined the participant's physical strength and good health at the time of the assessment in comparison to negative mood states (Sandridge et al., 2015). The fatigue mood state, on the other hand, had increased after 24-hour sleep deprivation. The decreased vigour mood state and increased fatigue further confirmed the displaced emotions, demonstrating that negative emotions dominated the positive moods when the participants underwent sleep deprivation (Goel et al., 2009). Other mood states which increased as a result of sleep deprivation included confusion and tension. The confusion, fatigue and tension mood states are known to be some of the negative moods associated with lack of sleep (Goel et al., 2009). The significant shifts observed for all mood states substantiated

that a 24-hour period of sleep deprivation was emotionally strenuous for the participants.

Baum et al. (2014) studied the impact of restricted sleep patterns over five days on adolescents. Although they did not apply acute sleep deprivation, it was found that their study population struggled with constant mood state changes. The participants demonstrated increased confusion, attention deficits, and dissociation symptoms when sleep deprived as a result of an interruption in the transition from sleep to wakefulness. They also reported continuous decrease in energy and increase in fatigue and confusion (Baum et al., 2014; Lo et al., 2015), which was similarly reported by the participants in the present study. In the study by Lo et al., (2015), a decline in positive emotions was evidenced when participants were exposed to two nights of restricted sleep, which supports the present studies' findings. The POMS verified that the participants in the present study did experience increased fatigue, confusion, and anger with a decreased vigour state after sleep deprivation. Therefore, it is plausible to presume that the participants underwent increased emotional reactivity as a result of the sleep deprivation condition.

A study similar to the present study made use of the POMS to measure fatigue levels after acute sleep deprivation (Selvi, Kilic, Aydin, & Guzel Ozdemir, 2015). Insignificant differences in the TMD of the POMS scores before and after sleep deprivation were reported. However, the study reported an increase in fatigue, confusion, anxiety and irritability mood states. A simultaneous decrease in excitement, activity, and vigour mood states was evidenced (Baum et al., 2014; Goel et al., 2009; Selvi et al., 2015). These outcomes correlate with several other sleep deprivation studies (Baum et al., 2014; Goel et al., 2009; Lo et al., 2015; Selvi et al., 2015), including the present study. The present study demonstrated statistically significant differences in the TMD scores for the two conditions (with and without sleep deprivation), demonstrating considerable mood variations as a result of sleep deprivation. Similarly, large variations were also shown in the other mood states, demonstrating an increase in anger, confusion, depression, fatigue, and tension, and a decrease in vigour was present. This implies that mood displacement was experienced as a result of sleep deprivation. Therefore, it is important to understand and expect persistent mood displacement under conditions of acute sleep deprivation.

The POMS assisted in detecting the displaced moods experienced after sleep deprivation, and provided a subjective means of discerning the mental effort required as a result of lack of sleep. The results demonstrated that the participants experienced effortful circumstances when undergoing sleep deprivation.

### **4.3 P300 Assessment**

After the sleep deprivation condition, a statistically significant increase in mean latency values was evidenced in the present study. This increase in latency suggested that a decrease in concentration was experienced by the sleep deprived participants (Ray et al., 2012; Zukerman, Goldstein, & Babkoff, 2007). Furthermore, a reduction in amplitude was evident after sleep deprivation, which was also found to be statistically significant. This reduction in amplitude indicated that the participants presented with reduced selective attention after sleep deprivation (Ray et al., 2012). The measurements provided objective electrophysiological evidence that the active listening task required during P300 was cognitively more demanding after sleep deprivation.

Lee et al. (2003) established that changes in P300 waves as a result of sleep deprivation were related to cognitive decline and not the result of drowsiness. The change is believed to be related to a delay in information processing as a result of a reduction in alertness and an increase in reaction time. This is further supported by another study assessing the effect of behavioural changes on event related potentials (ERPs), where it was found that a shift in waves demonstrated a delay in cognitive processing speed (Kadambi et al., 2013). From the perspective of neurophysiological effects, an individual experiences reduced sensitivity to auditory stimuli. This leads to a reduction in signal sensitivity related to the auditory cortex and reduction in processing speed (Ray et al., 2012). According to Kadambi et al. (2013), an alteration in the P300 results is associated with fatigue in relation to reduced focus and processing speed. This was proposed due to the fact that sleep deprivation recreates a similar effect to the one experienced as a result of increased task difficulty (Ray et al., 2012). Sleep deprivation is known to affect overall attention. It is also seen to result in a difficulty when correctly categorising stimuli in discrimination tasks (Zukerman et al., 2007). These findings provide support to the results obtained in the present study, wherein a delayed P300 waveform was evidenced.

P300 also measures processes associated with the prefrontal cortex, such as working memory and attention (Tsolaki et al., 2015). The P300 assessment provides information on the time taken for cognitive processing of information to occur, including attention, perception, and concentration (Ray et al., 2012; Zukerman et al., 2007). This ERP is elicited based on selective attention necessary to identify the target stimuli or the infrequent tones and is believed to be influenced by the individual's level of alertness (Ray et al., 2012). The latency is linked to the ability to rapidly classify stimuli during memory stimulation, whereas amplitude is reportedly related to memory and the attention level of the individual (Ray et al., 2012). Numerous studies that determined the effect of sleep deprivation on P300 responses found that the latency tends to increase along with a reduction in the amplitude (Kadambi et al., 2013; Lee et al., 2003; Polich, 2011; Ray et al., 2012). The findings reported in the literature support the results obtained in the present study. The increase in latency and decrease in amplitude possibly demonstrated that the participants' attention may have deteriorated as a result of sleep deprivation. It is proposed that information processing speed was decreased, as a result of reduced attention due to sleep deprivation. This in turn demonstrated overall late P300 responses.

This ERP assessment is related to information processing, attention and processing speed (Alhola & Polo-Kantola, 2013; Patrick et al., 2017; Ray et al., 2012; Zukerman et al., 2007). On the POMS, the participants did report having experienced fatigue subjectively after sleep deprivation. This, along with a delay in the P300 latency and a reduction in amplitude, may have resulted in a decrease in concentration and inability to discriminate the target stimuli of the P300. The increase in latency was also possibly related to perceived increase in task difficulty when participants were sleep deprived. Based on the findings of the present study, it is suggested that a cognitive decline was experienced in relation to the higher executive functions associated with the P300 assessment. Specifically, concentration and information processing are believed to have been affected as a result of sleep deprivation.

#### **4.4 Listening Effort (LE)**

After sleep deprivation, the results depicted reduced effort expended for the + 2 dB SNR, - 6 dB SNR and - 10 dB SNR listening situations in comparison to LE measured under normal sleep conditions. These results are surprising as the latter two listening

situations (– 6 dB SNR and – 10 dB SNR) were expected to be the most difficult. Therefore, it was postulated that these were most likely to demonstrate increased LE (Degeest et al., 2015). On the contrary, the participants experienced increased effort with the quiet listening situation after sleep deprivation, demonstrating that the participants required extra effort in order to complete this task. The same amount of effort was used for the – 2 dB SNR listening situation during the normal sleep condition and sleep deprivation condition. The results obtained demonstrated no statistically significant differences in all listening situations after sleep deprivation. This implied that, although effort was applied for task completion during some listening situations while others did not require added effort, it was not significant enough to show a statistical difference. Therefore, this confirms that less LE was expended after sleep deprivation.

There are several possible reasons why LE decreased instead of increasing after sleep deprivation. Firstly, disagreement persists on the amount of sleep deprivation necessary to result in a cognitive deterioration (Lee et al., 2003). Some studies found cognitive degeneration after more than 46 hours of sleep deprivation, whereas others stated that a cognitive degeneration was present after less than 45 hours of sleep deprivation (Alhola & Polo-Kantola, 2013; Goel et al., 2009). Several others reported that one night of sleep deprivation, or acute sleep deprivation, was sufficient to obtain results demonstrating cognitive deterioration (Alhola & Polo-Kantola, 2013; Goel et al., 2009; Lee et al., 2003). Increased LE is presumed to be linked to cognitive degeneration as a result of cognitive overload and an increase in the cognitive functions involved when undergoing sleep deprivation (Gagné et al., 2017; Lemke & Besser, 2016; McGarrigle et al., 2014). Since 24-hour sleep deprivation was used in the present study, it is possible that this amount of sleep deprivation was inadequate to determine cognitive deterioration in the population group selected. This may be particularly relevant for the population that the participants were taken from, namely the student population.

Patrick et al. (2017) established that the young population of university students are more efficacious in dealing with the impact of sleep deprivation. It was suggested that the effect of sleep deprivation on a university student may not be as extensive because the memory components of the visual memory task were preserved (Patrick et al., 2017). These results correlate with the findings of the present study as an increase in

LE was not evident after sleep deprivation in the university population utilised, suggesting that a cognitive overload was not experienced when assessing LE when the participant was sleep deprived. Other cognitive variables, aside from working memory and executive functions, should be considered and assessed in future studies to investigate possible links between cognitive overload and a change in LE (Patrick et al., 2017). However, the amount of sleep deprivation and choice of participants are unlikely to be the reasons for the unexpected LE. Not only did the POMS confirm statistically increased subjective fatigue, but P300 latencies and amplitudes were significantly delayed. The latter indicates reduced auditory processing speed and attention to changes in auditory stimuli.

The third issue which may explain the unexpected LE results after deprivation relates to the manner in which LE is measured, a topic that is currently actively debated. There are also divergent opinions on the best way to measure LE through dual-task assessments. A review by Gagné et al. (2017) established that various combinations of the dual-task paradigm are being used, although, which combination is correctly assessing LE is yet to be determined. Gagné et al. (2017) suggested that the most sensitive primary task used to assess LE consisted of a word-category recognition task (Gagné et al., 2017). However, the word-category recognition task was also used as a secondary task in the reported case (Picou & Ricketts, 2014). This selection of tasks brings into question whether the linguistic tasks, as both primary and secondary tasks, were more cognitively demanding, or whether the linguistic processing task merely involved deeper processing functions (Gagné et al., 2017; Picou & Ricketts, 2014). Other studies found that the use of a visual-pattern recognition task as the secondary task brought about an increase in LE (Gosselin & Gagné, 2011b, 2011a; Wu et al., 2014). The type of secondary task used is believed to influence the sensitivity of the assessment when measuring LE (Gagné et al., 2017). According to literature, the ideal combination to assess LE is a visual memory and word-recognition task (Gagné et al., 2017), which was the combination used in the present study. Nevertheless, it is inappropriate to conclude that any form of secondary task will correctly assess LE, based on the afore-mentioned combination attempts. Questions have been raised regarding the assessment of specific functions by different tasks and whether the varying tasks are equally sensitive to measure LE (Gagné et al., 2017). It is possible that the combination of tasks used in the present study did not correctly

assess the LE expended by the participants. Therefore, further research may be necessary to obtain an accurate combination of tasks that assess LE for speech understanding and are sensitive to the changes in LE.

The fourth caveat, concerning the results obtained in the present study was raised by Gagné et al. (2017). The authors pointed out that the priority set by the participant on the different LE tasks during the dual task evaluation would possibly affect the measure of LE expended by the individual. Despite informing the participant that priority should be given to the primary task, it is not always possible to monitor whether the instruction was followed. It is possible that the participants understood the secondary task (visual memory task) to be more important than the primary task (speech recognition task) in the dual task evaluation and, therefore, placed priority on the “wrong” task when sleep deprived. The interchangeable placement of importance is crucial in calculating the LE expended, considering that LE is measured as a change in the visual memory task when comparing the single-task evaluation to the dual-task evaluation (Degeest et al., 2015). As a result, it is possible that this led to the participants experiencing less effort during the more difficult SNR listening situations, such as - 6 dB SNR and - 10 dB SNR, even when sleep deprived.

Finally, a practice effect may have been at play as the participants repeated the LE test four times over a period of three days. In addition to the interchangeable priority set by participants, studies confirmed that numerous other intra-subject confounding aspects also play a role on their performance as a result of sleep deprivation (Goel et al., 2009; Lee et al., 2003; Patrick et al., 2017). Patrick et al. (2017) made use of a cognitive test that assessed working memory and executive functions, to determine the effect of sleep deprivation on university students. The cognitive assessment evaluated functions similar to those involved in the LE tasks (Gagné et al., 2017). Reports on repeated cognitive tests showed a practice effect, which was also validated by other studies that made use of similar cognitive tasks assessing higher executive functions (Goel et al., 2009; Lee et al., 2003). Therefore, the participants' performance continued to improve after each assessment as it was believed to be a repetitive task (Goel et al., 2009; Lee et al., 2003; Patrick et al., 2017). Decreased performance as a result of sleep deprivation is believed to be more evident on a new unskilled, monotonous and unstimulating task (Goel et al., 2009; Lee et al., 2003). Alhola et al. (2007) agreed that despite high demands placed on cognitive capacity as a result of

divided attention, individuals eventually reduced the effort experienced by automating simple procedures of a multitask in order to complete the task. This resulted in ameliorated performance scores with increased exposure to the test (Alhola & Polo-Kantola, 2013). The repeated measurements may have influenced the results obtained if participants made use of simple, automated routines to complete the dual task evaluation, especially for the difficult listening situations, leading to reduced LE after sleep deprivation.

The combination of the interchangeable priority set by participants and intra-subject confounding aspects are believed to have contributed to the diverse amounts of effort expended in the LE tasks after sleep deprivation. It is necessary to acquire a means of accounting for the intra-subject confounding aspects involved and priorities set by the participants when making use of such cognitive assessments in future research studies.

The influence of the amount of sleep deprivation, population choice, LE evaluation combination, setting of priority during LE test and intra-subject variables aside, it is possible that LE is indeed insensitive to sleep deprivation. To our knowledge, prior to the current study no other studies have been conducted to evaluate LE after sleep deprivation, or studies did not make use of the dual-task paradigm to assess LE. Complex cognitive tasks comprising higher executive functions are often regarded as insensitive to sleep deprivation (Goel et al., 2009). This may be a function of the different complex cognitive assessing tools available, and, also the reality that these processing functions are usually not discernible or easy to measure (Goel et al., 2009). A similar point was made by Killgore (2010), who suggested that studies assessing working memory impairments as a result of sleep deprivation were perhaps reporting on the established deterioration of attention and vigilance as opposed to a specific deficit. Working memory impairments are believed to signal an altered cognitive process (Killgore, 2010). Novel-logic based tasks also showed minor cognitive deterioration after sleep deprivation, while complicated recognition tasks were not impacted by sleep deprivation (Goel et al., 2009; Lee et al., 2003). Similarly, it is believed that both the recognition and memory tasks of the LE assessment possibly did not target the intended higher executive functions (Goel et al., 2009). As a result, no discernible LE was expended due to the absence of cognitive overload in the

prefrontal cortex, despite subjective reports of fatigue from the POMS and objective evidence of reduced efficacy of detection of auditory changes during P300 testing.

Despite the inability to identify working memory and higher executive function deficits as a result of sleep deprivation, various reports state that sleep deprivation impacted the performance on some tasks related to working memory. It is theorised that not all components of higher executive functions were affected (Goel et al., 2009; Killgore, 2010). Although some functions remain unaffected or affected to some extent, other cognitive functions are likely to be impacted by sleep deprivation either completely or partially. Hence, results portray an unaffected global performance, while individual functions are affected to varying extent (Jackson et al., 2013a). These findings possibly validate the results obtained in the present study. Although no global deficit was evidenced in the present study, it is likely that some functions unrelated to the prefrontal cortex, or functions not assessed by or sensitive to the LE tasks, were affected.

Non-executive functions, such as response time, may demonstrate an impairment as a result of sleep deprivation rather than executive functions such as working memory and resistance to proactive interference (Killgore, 2010). Alhola et al. (2007) stated that in self-paced tasks, deterioration in speed is more evident, whereas accuracy remains unaffected. The opposite effect would be present with experimenter-paced tasks (Alhola & Polo-Kantola, 2013). The present study made use of self-paced tasks, but speed was not a variable assessed in the study. Therefore, a deterioration in LE was possibly not evident as reaction time was not assessed. It would be beneficial for future studies to incorporate response time when assessing LE in order to depict an increase in LE expended when sleep deprived.

The present study intended to assess the impact of sleep deprivation on the cognitive functions related to LE (Degeest et al., 2015). It is evident from the results obtained on the LE evaluation that less LE was measured after sleep deprivation in some listening situations. Listening effort scores measured after sleep deprivation may have decreased due to the interchangeable priority participant's place on the dual-task evaluation, intra-subject confounding aspects present in each individual, and the university student population used in the study. Although LE possibly increased, the results did not reflect this as a result of the short duration of sleep deprivation, the

combination of LE tasks used and insufficiently sensitive tasks utilised. In addition, the tasks used possibly assessed different functions than those intended, and sleep deprivation may not impact working memory and higher executive function. Lastly, the assessment of speed may reflect a change in LE more effectively than assessment of accuracy. It is, therefore, prudent to accept that, for the current study, less LE was expended after sleep deprivation.

#### **4.5 Summary**

An in depth discussion of the results was based on supporting literature. The following chapter will provide a conclusion to the study's findings.

## **Chapter 5** **Conclusion**

### **5.1 Introduction**

A conclusion will be provided in this chapter to bring the study to a close. The following aspects will also be discussed: study limitations, clinical implications, recommendations for further research and final comments.

### **5.2 Conclusion of findings**

Sleep deprivation poses a threat to the health of the general population, most importantly to the integrity of the cognitive abilities of a sleep-deprived individual. Cognitive processes believed to be affected by sleep deprivation may be assessed by a series of listening effort (LE) tasks and P300 responses. Listening effort is believed to increase when an individual is exposed to a demanding auditory situation as a result of processing overload. The P300 assessment incorporates an auditory-evoked event-related potential (ERP) to analyse higher executive functions, amongst others those associated with the prefrontal cortex. The aim of this study was to determine the impact of 24-hour sleep deprivation LE and P300 responses in a group of young university students.

Twenty-seven participants were assessed four times over three days. The assessments comprised the Profile of Mood States (POMS) questionnaire, the dual-task paradigm LE evaluation and P300 wave responses. Through the POMS, participants reported that fatigue was experienced after sleep deprivation. It was also considered feasible to presume that the active listening task required to measure P300 responses was cognitively more demanding after sleep deprivation, hence bringing about a cognitive decline associated with the higher executive functions of the assessment. More specifically, a delay in the P300 latency and a reduction in amplitude were evident, indicating a possible decrease in concentration and inability to discriminate the target stimuli of the P300. The LE measured demonstrated that the participants possibly expended less LE after 24-hour sleep deprivation. However, placing the influence of the amount of sleep deprivation, population choice, LE evaluation combination, prioritisation during LE test, and intra-subject variables aside, it is possible that LE is indeed insensitive to sleep deprivation.

### 5.3 Study limitations

As is the case with any experiment, this research study presented with some limitations. Firstly, the present study made use of a small sample size comprising of 27 participants. The small sample size limits the range of the results obtained and may not represent the larger population available.

The second limitation is that 24 hours of sleep deprivation was possibly not sufficient to bring about the substantial and global cognitive deterioration in order to obtain a change in LE. Researchers argue that although 24-hour sleep deprivation may bring about a change in cognitive abilities, 45-46 hours was evidenced to bring about measurable cognitive deterioration (Alhola & Polo-Kantola, 2013; Goel et al., 2009; Lee et al., 2003). Therefore, future research studies should attempt to make use of longer sleep deprivation times.

Thirdly, as observed by Patrick et al. (2017), university students are frequently exposed to limited amounts of sleep, therefore they were believed to be able to cope with the effects of sleep deprivation. It is possible that the choice of participants influenced the results and explains why a change in LE was not evident. The current study employed university students, who may be able to manage or cope with the consequences of sleep deprivation.

A fourth limitation would be that this research study did not incorporate a cognitive test specifically designed to assess overall cognitive abilities in order to detect a change in cognitive abilities after sleep deprivation. Future studies should consider including such assessments when assessing sleep deprivation. A standardized cognitive assessment will provide a more reliable means of determining cognitive functions before and after sleep deprivation.

An additional caveat would be that reaction time to complete LE tasks was not measured in the present study. Various studies incorporated reaction time to measure LE, in order to determine the presence or absence of a decline in processing speed and cognitive function. Studies have shown that in self-paced tasks, a deterioration in speed is evident, whereas accuracy remains unaffected (Alhola & Polo-Kantola, 2013). Since, the LE evaluation is a self-paced task a deterioration in LE was possibly not evidenced as speed was not evaluated. Future research should attempt to involve

reaction time as a variable in the assessment. This will help to determine the impact of sleep deprivation on the cognitive aspects associated with the LE tasks.

Finally, it is possible that after repeating the LE evaluation four times over three days, LE scores may have improved despite sleep deprivation, as a result of the practice effect. It is speculated that the participants made use of simple automated procedures during multitasking to complete the dual-task evaluation. As a result, less LE was expended after sleep deprivation.

#### **5.4 Clinical implications**

The P300 is consistently implemented in clinical practice. However, the LE evaluation is a fairly recent procedure in the clinical setting. Based on the findings of the current study, the following conclusions regarding the clinical implications of the tests have been made:

- Clinicians should be aware that the LE evaluation is insensitive to sleep deprivation, and it may be of little value for assessing sleep deprivation. This brings in to question the combination of tasks employed to measure LE. Therefore, clinicians should be cautious of the combination of tasks used in this study.
- Clinicians should also be cautioned that, although P300 responses are affected by sleep deprivation, other factors may also play a role in delaying P300 waves. These include hearing loss, stimulants and age.

#### **5.5 Recommendations for further research**

Based on the research conducted and the results obtained, the following recommendations can be made for future research studies in this field.

- A larger sample size would represent the larger dynamic population more accurately than a small sample size. Therefore, future research should make use of a larger sample size.
- Future research studies should consider longer sleep deprivation times. A measurable cognitive deficit is more likely to be present when participants undergo longer periods of sleep deprivation.

- Studies should incorporate reaction time as a variable in the LE task. Sleep deprivation is known to influence speed in completing assessments, which is related to processing speed.
- Future research should include a cognitive assessment to measure cognitive ability. Although the POMS played a role in assessing fatigue, it is not an assessment that identifies cognitive deterioration. Similarly, the LE tasks are believed to assess a specific cognitive function, but, this is not sufficiently accurate to determine overall decline. Therefore, a dedicated cognitive assessment would assist in identifying overall cognitive abilities.
- It would be ideal to conduct further research utilising a combination of LE tasks believed to assess LE effectively. Further research on other cognitive abilities involved in the LE tasks employed, separately from the higher executive functions of the prefrontal cortex, is recommended.
- Intra-subject variables, such as practice effect, automating simple procedures, and interchangeable priority, were theorised to affect the findings obtained by the LE evaluation. Therefore, it would be beneficial to explore how one could control or account for these variables to reduce their impact in future research.
- When assessing LE, future researchers should instruct participants to place equal importance on both LE tasks. This exercise will force the participant to make use of all of their available cognitive resources in the CAP system.

## **5.6 Final comments**

Sleep deprivation is known to have a detrimental impact on the health and cognitive functions of an individual. The current study supported this statement through subjective reporting of the participants by the POMS and analysis of listening and attention through P300 responses. However, the impact of sleep deprivation was not evident when assessing an individual's ability to multi-task in a demanding auditory situation through the LE tasks. Finally, it is safe to conclude that LE is insensitive to 24-hours of sleep deprivation, despite its impact on P300 responses.

*Research is what I'm doing when I don't know what I'm doing; which is all the time!*

- Wernher von Braun ft. Reetal Jani

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## **Appendices**

Appendix A: Ethical Clearance Form: Faculty of Humanities

Appendix B: Institution Permission: Department of Student Affairs

Appendix C: Informed Consent

Appendix D: Participant Questionnaire

Appendix E: Profile of Mood States Questionnaire

**Appendix A:  
Ethical Clearance Form: Faculty of Humanities**



27 September 2017

Dear Ms Jani

**Project:** The impact of short-term sleep deprivation on listening effort and P300 responses  
**Researcher:** R Jani  
**Supervisor:** Dr L Biagio  
**Department:** Speech-Language Pathology and Audiology  
**Reference Number:** 12077535 (GW20151109HS)

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** at an ad hoc meeting on 14 September 2017 and by the Dean of Humanities on 22 September 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 Research Ethics**  
**Faculty of Humanities**  
**UNIVERSITY OF PRETORIA**  
**e-mail: tracey.andrew@up.ac.za**

CC: Dr L Biagio (Supervisor)  
Prof BHME Vinck (HoD)

**Appendix B:**  
**Institution Permission: Department of Student Affairs**



UNIVERSITEIT VAN PRETORIA  
UNIVERSITY OF PRETORIA  
YUNIBESITHI YA PRETORIA

**Faculty of Humanities**

Department of Speech-Language Pathology and Audiology

**January 2017**

**Attention: Dr Matete Madiba**

**DIRECTOR: Department of Student Affairs**

Dear Dr Madiba

### **REQUEST TO RECRUIT PARTICIPANTS FROM THE UNIVERSITY OF PRETORIA**

I, Reetal Rajesh Jani, am conducting a research study for the completion of my Master's degree in MA(Audiology) at the University of Pretoria. For this study, I will be assessing the impact of sleep deprivation on the listening effort (situations where a listener is expected to rely on more cognitive resources to understand speech in the presence of competing noise, making the listening task more effortful and difficult) and P300 responses (an event related potential providing neurophysiological means of analysing higher cerebral function associated with cognition, attention, working memory and auditory processing of information) of young normal hearing adults.

**Title:** The impact of short-term sleep deprivation on listening effort and P300 responses.

**Design and Procedure:** A quantitative, prospective, descriptive design was selected. The aim is to randomly approach students from the University of Pretoria willing to participate in the study. Ethical clearance will be obtained from the ethics committee at the Faculty of Humanities.

**Participants:** Thirty participants between the ages of 18 and 30 years old will be selected. The participants will be requested to visit the Department of Speech-Language Pathology and Audiology; where, upon arrival, it will be solicited from them to fill in a questionnaire on their hearing status and medical history. After the completion of the questionnaire, a hearing test and auditory processing test will be conducted to confirm normal results. Following this process, a listening effort assessment will be administered; whereby a speech recognition task, as well as a memory task, will be included. An electrophysiological test, the P300, will also be conducted to assess cognition, attention and working memory. A baseline assessment (both assessments) will be conducted on Day 1, two days prior to the day of sleep deprivation. The participants will be requested to obtain proper sleep (6-8 hours) and will be tested (both tests) the day of normal sleep pattern (Day 2). Hereafter, another baseline assessment (both assessments) will be conducted the evening of sleep deprivation (Day 2). The listening effort test, as well as the P300, shall also subsequently be administered after 24 hours of sleep deprivation (Day 3).

**Ethical Considerations:** A student's participation will only take place after they have consented to, and fully understood the terms of the study. The participants will be free to withdraw from

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**Fakuleit Geesteswetenskappe**  
Departement Spraak-Taalpatologie en Oudiologie  
**Lefapha la Bomotho**  
Kgoro ya Phatholotši ya Polelo-Maleme le Go kwa

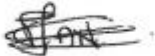
participating in the study at any given time after they have given consent through written consent (signing of informed consent). Should participants not be able to comply with the requirements for the sleep deprivation period or fall asleep, they will be excluded from the study with no repercussions. They will be informed that anonymity and confidentiality will be granted. The data collected will be stored for 15 years for research purposes.

**Risks and Benefits:** Discomfort due to sleep deprivation may be experienced, however, the participants will be informed to take precautionary measures to prevent any accidents from taking place.

Should you require further information, kindly contact our supervisor at 012 420 2375 or 012 420 6774. My contact details are as follows: 079 458 4609.

With sincere appreciation for your co-operation.

Yours sincerely



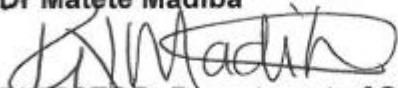
Reetal Rajesh Jani.

**PERMISSION TO RECRUIT STUDENTS FROM THE UNIVERSITY OF PRETORIA FOR  
RESEARCH STUDY**

Herewith, I \_\_\_\_\_ give permission for the students from the University of Pretoria to be used as voluntary participants in the research titled: *The impact of short-term sleep deprivation on listening effort and P300 responses.*

Pending the approval  
of the Ethics Committee

**Dr Matete Madiba**



**DIRECTOR: Department of Student Affairs**

Date: 20/07/2017

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**Faculty of Humanities**  
Department of Speech-Language Pathology and Audiology  
**Fakulteit Geesteswetenskappe**  
Departement Spraak-Taalpatologie en Oudiologie  
**Lefapha la Bomotho**  
Kgoro ya Phatholotši ya Polelo-Maleme le Go kwa

**Appendix C:  
Informed Consent**



Dear Participant

## REQUEST FOR PARTICIPATION IN A RESEARCH STUDY AND INFORMED CONSENT

I am presently conducting research to complete my Master's degree [MA (Audiology)] at the University of Pretoria. The aim of the study is to assess the impact of 24-hour sleep deprivation on the listening effort (situations where a listener is expected to rely on more cognitive resources to understand speech in the presence of competing noise, making the listening task more effortful and difficult) and P300 responses (an assessment providing neurophysiological means of analysing higher cerebral function associated with cognition, attention, working memory and auditory processing of information) of young normal hearing adults.

The outcomes collected from the study are to contribute to future research investigations, as this may demonstrate the need for updated normative data on Listening Effort.

When agreeing to participate in this study, you are requested to visit the Department of Speech-Language Pathology and Audiology at the University of Pretoria, for a time frame of 3 days. Testing sessions are likely to last an hour to an hour and a half per day and are very time specific.

- You are requested to fill in a brief case history with regards to your hearing and medical history. Assessments will be conducted to identify your hearing and auditory processing status. Hereafter, a listening effort assessment will be administered; whereby a speech recognition task, as well as a memory task, will be included. An electrophysiological test, the P300, will also be conducted to assess cognition, attention and working memory.
- A baseline assessment will be conducted on Day 1 (after the selection criteria have been conducted), the day prior of sleep deprivation. The assessment will include both listening effort as well as P300 testing.
- You will then be requested to obtain normal sleep (6-8 hours) and will be tested (both tests) the morning of Day 2.
- Another baseline assessment consisting of both assessments will again be obtained the evening of sleep deprivation (Day 2).
- Hereafter, you will then be requested to be sleep deprived for 24 hours (Day 2-3) where the researchers will control you at the sleep lab. Subsequently, the listening effort and P300 shall be conducted to obtain objective measurements (Day 3).

Should you not be able to comply with the requirements for 24-hour sleep deprivation or fall asleep, you will be excluded from the study with no negative consequences. You may withdraw from the study at any time with no repercussions.

The information obtained from data collection will be kept confidential. These results will be stored for at least 15 years in both, digital and hard copy at the Department of Speech-Language Pathology and Audiology, with the intentions of archiving and future research purposes within this field. The information obtained will be made readily available to my supervisors, Dr L. Pottas and Dr L. Biagio de Jager, as well as, the Head of Department of Speech-Language Pathology and

Audiology, Prof B. Vinck. All the necessary results will be used with the sole intention to compile a dissertation and publication of an article. You are granted access to these results. Should you want a copy of your results, an electronic copy will be made available to you.

Should you require further information, you may contact the supervisor at 012 420 2375 or 012 420 6774. My contact details are as follows: 079 458 4609.

Your participation in my study will be highly appreciated.

Yours sincerely



Reetal Rajesh Jani

\_\_\_\_\_  
Participant Initials

Supervisors:



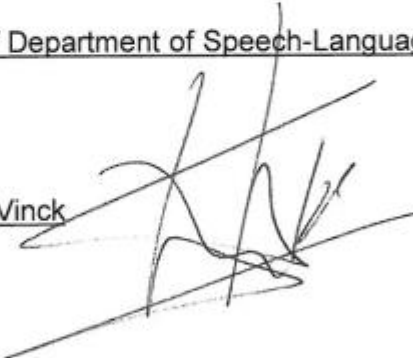
Dr L. Pottas



Dr L. Biagio de Jager

Head of Department of Speech-Language Pathology and Audiology

Prof B. Vinck



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**Faculty of Humanities**  
Department of Speech-Language Pathology and Audiology  
**Fakulteit Geesteswetenskappe**  
Departement Spraak-Taalpatologie en Oudiologie  
**Lefapha la Bomotheo**  
Kgoro ya Phatholotši ya Polelo-Maleme le Go kwa

## PERMISSION FOR PARTICIPATION

Participant Name: \_\_\_\_\_

Age: \_\_\_\_\_

Please tick one of the boxes regarding your consent option in participating for my study.

I, \_\_\_\_\_ have read the terms and condition and:

I, as a participant, fully understand what this study entails and am willing to fully co-operate

OR

I am not willing to participate in this study.

\_\_\_\_\_  
Participant Signature

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**Faculty of Humanities**  
Department of Speech-Language Pathology and Audiology  
**Fakulteit Geesteswetenskappe**  
Departement Spraak-Taalpatologie en Oudiologie  
**Lefapha la Bomotheo**  
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**Appendix D:  
Participant Questionnaire**

**Participant Questionnaire:**

Name: \_\_\_\_\_

Date of Birth: \_\_\_\_\_

**Case History:**

Age: \_\_\_\_\_

Gender:      Male      Female

Academic Status:

Undergraduate

Postgraduate

Dexterity:

Right handed

Left handed

**Medical History:**

1- Do you have a history of middle ear infection when you were young?

Yes      No

2- Have you had middle ear infection recently?

Yes      No

3- Do you have difficulty with hearing?

Yes      No

If yes, please specify (all the time, in background noise, etc.).

\_\_\_\_\_

4- Have you experienced any trauma/ injury to your head?

Yes      No

5- Have you ever experienced epileptic seizures?

Yes      No

6- Have you been diagnosed with a learning disability? E.g ADHD, Dyslexia, etc.

Yes      No

Please specify: \_\_\_\_\_

7- Have you been diagnosed with a neurological disability?

Yes      No

Please specify: \_\_\_\_\_

8- Are you currently taking any chronic medication?

Yes      No

Please specify: \_\_\_\_\_

9- Have you been diagnosed with a sleeping disorder? E.g. Insomnia, etc.

Yes      No

Please specify: \_\_\_\_\_

10- Do you have difficulties with your eye- sight?

Yes      No

If yes, is it corrected?:      Yes      No

**NB TO NOTE:**

ON DAY OF TESTING- PLEASE REFRAIN FROM THE FOLLOWING **24** HOURS PRIOR:

- COFFEE
- ALCOHOL
- NICOTINE
- NOISE EXPOSURE- CONCERTS, CLUBS, ETC.
- EXCESSIVE EXERCISING- PHYSICAL AND MENTAL
- AVOID FOODS AND BEVERAGES CONTAINING CAFFEINE
- NO MEDICATION WHICH CAN AFFECT COGNITION AS WELL AS SLEEP ARCHITECTURE

**Appendix E:  
Profile of Mood States Questionnaire**

## Profile of Mood States

Subject's

Initials

Birth date

Date

Subject Code No.

*Directions: Describe HOW YOU FEEL RIGHT NOW  
by circling the most appropriate number after each of the words listed  
below:*

<b>FEELING</b>	Not at all	A little	Moderate	Quite a bit	Extremely
1. Friendly	1	2	3	4	5
2. Tense	1	2	3	4	5
3. Angry	1	2	3	4	5
4. Worn Out	1	2	3	4	5
5. Unhappy	1	2	3	4	5
6. Clear-headed	1	2	3	4	5
7. Lively	1	2	3	4	5
8. Confused	1	2	3	4	5
9. Sorry for things done	1	2	3	4	5
10. Shaky	1	2	3	4	5
11. Listless	1	2	3	4	5
12. Peeved	1	2	3	4	5
13. Considerate	1	2	3	4	5
14. Sad	1	2	3	4	5
15. Active	1	2	3	4	5
16. On edge	1	2	3	4	5
17. Grouchy	1	2	3	4	5
18. Blue	1	2	3	4	5
19. Energetic	1	2	3	4	5
20. Panicky	1	2	3	4	5
21. Hopeless	1	2	3	4	5
22. Relaxed	1	2	3	4	5
23. Unworthy	1	2	3	4	5
24. Spiteful	1	2	3	4	5
25. Sympathetic	1	2	3	4	5
26. Uneasy	1	2	3	4	5
27. Restless	1	2	3	4	5
28. Unable to	1	2	3	4	5
29. Fatigued	1	2	3	4	5

30. Helpful	1	2	3	4	5
31. Annoyed	1	2	3	4	5
32. Discouraged	1	2	3	4	5
33. Resentful	1	2	3	4	5
34. Nervous	1	2	3	4	5
35. Lonely	1	2	3	4	5
36. Miserable	1	2	3	4	5
37. Muddled	1	2	3	4	5
38. Cheerful	1	2	3	4	5
39. Bitter	1	2	3	4	5
40. Exhausted	1	2	3	4	5
41. Anxious	1	2	3	4	5
42. Ready to fight	1	2	3	4	5
43. Good-natured	1	2	3	4	5
44. Gloomy	1	2	3	4	5
45. Desperate	1	2	3	4	5
46. Sluggish	1	2	3	4	5
47. Rebellious	1	2	3	4	5
48. Helpless	1	2	3	4	5
49. Weary	1	2	3	4	5
50. Bewildered	1	2	3	4	5
51. Alert	1	2	3	4	5
52. Deceived	1	2	3	4	5
53. Furious	1	2	3	4	5
54. Effacious	1	2	3	4	5
55. Trusting	1	2	3	4	5
56. Full of pep	1	2	3	4	5
57. Bad-tempered	1	2	3	4	5
58. Worthless	1	2	3	4	5
59. Forgetful	1	2	3	4	5
60. Carefree	1	2	3	4	5
61. Terrified	1	2	3	4	5
62. Guilty	1	2	3	4	5
63. Vigorous	1	2	3	4	5
64. Uncertain about things	1	2	3	4	5
65. Bushed	1	2	3	4	5