PERIPHERAL VISION FIELD FATIGUE DURING SIMULATED DRIVING: THE EFFECTS OF TIME ON TASK AND TIME OF DAY ON SELECTED PSYCHOPHYSIOLOGICAL, PERFORMANCE AND SUBJECTIVE RESPONSES

BY

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THESIS

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ABSTRACT

Worldwide, motor accidents are responsible for a large number of deaths and disabilities (Connor et al., 2001), and one of the major causes of motor accidents is driver fatigue. Although majority of drivers are aware of the dangers of fatigued driving, accidents related to this continues to contribute to a large percentage of all accidents, between 5 and 50% (Nilsson et al., 1997; Williamson et al., 2011). The purpose of the research was to establish the effect that fatigue renders on an individual's peripheral visual field and to determine whether a decrement in driving performance occurs at the same rate as a decrement in peripheral visual performance. Fatigue was induced through time of day as well as time on task. Sixteen students from Rhodes University were recruited, subject to no previous sleep disorders, among other criteria. Each participant was required to partake in two conditions, namely a day condition (09h00–11h00) and a night condition (23h00–01h00).

Each condition consisted of a 90 minute dual task; the primary task was a tracking task, in which participants were instructed to track a white line as accurately as possible. A secondary peripheral response task was introduced, in which participants were instructed to respond as quickly as possible to the peripheral stimuli, by pressing one of two clickers located on the steering wheel. The peripheral stimuli were located at 20°, 30° and 40° visual angle. Psyc hophysiological, performance and subjective measures were obtained before, during and after the main task. The pre- and post-tests included core body temperature, critical flicker fusion frequency threshold, a digit span memory test, Wits Sleepiness Scale and a NASA-TLX questionnaire. The psychophysiological and performance measures of heart rate, heart rate variability, blink frequency, blink duration, lane deviation, number of saccades towards peripheral stimuli, response time to peripheral stimuli and the percentage of missed peripheral responses were all recorded throughout the 90 minute main dual task.

The results revealed significant differences ($p<0.05$) for heart rate variability, number of saccades towards peripheral stimuli and the Wits Sleepiness Scale, with regard to time of day. For time on task, significant effects were established for lane deviation, response time to peripheral stimuli, percentage of missed peripheral responses, heart rate, heart rate variability, blink frequency, blink duration, critical flicker fusion frequency threshold, core body temperature and the Wits Sleepiness Scale.

Eccentricity was analysed and found to be significant for response time to peripheral stimuli, as well as for the percentage of missed peripheral responses; there was a significant increase in both measures with an increase in the stimuli eccentricity. No significances were established for time of day or between the pre- and post-tests conducted for the digit span memory performance; however, a significant interactional effect between the two was established. When assessing the percentage rate of decrement of driving performance compared to the percentage rate in the decrement of the missed peripheral responses, it was found that the percentage rate of decrement was equal for both measures.

Thus from this research it can be seen that, concurrent with a decrement in driving performance, there are adverse effects on an individuals' peripheral vision, which have great implications for the safety of workers in industry and transport, as well as motorists. It was also established that time on task is possibly a more appropriate variable to consider than time of day, when implementing work schedules and rest breaks in industry, transport and fields alike, as more significant findings were seen for time on task compared to time of day.

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CHAPTER I

1 INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Human fatigue is an imperative aspect to understand for the transportation industry, largely due to the safety critical nature of the job (O’Neill and Heitmann, 2004). Driving is classified as a complex, multitask activity (Regan et al., 2008); due to this, driving can be seen as innately more dangerous than other daily activities, and when coupled with fatigue, makes for a hazardous combination (O’Neill and Heitmann, 2004). The occurrence of vehicle accidents cannot be attributed to a single cause, but needs to be seen as a combination of factors (Hills, 1980). Some of the contributing factors include impaired driver vision, physical restrictions to visibility, limitations of peripheral vision (Hills, 1980), voluntary risk taking on the part of the driver (Clarke et al., 2005), sleepiness or fatigue (Åkerstedt et al., 2001), degradation of the driver’s visual field (Leibowitz and Owens, 1977), weather conditions (Konstantopoulos et al., 2010), and any interaction of these factors.

Time of day has also been shown to have an effect on the number and severity of accidents that occur (Clarke et al., 2006). Night time driving poses a problem across the globe, due to the fact that the risk of fatal crashes increases fourfold during night driving compared to day driving (Williams, 2003). Driving for a prolonged period of time can exacerbate fatigue as well, causing performance decrements and changes in an individual’s psychophysiological functions (Okogbaa et al., 1994). When an individual is fatigued, ability to perform is impaired, coupled with subjective states that reflect performance decrements, which increase driving risks (Lyznicki et al., 1998). Accidents related to fatigue are seen to be responsible for a significant percentage of road fatalities, up to 50% (Lal and Craig, 2001; Williamson et al., 2011). A survey conducted by McCartt et al. (1996) indicated that fatigue had a greater effect on an individual’s ability to drive safely compared to adverse weather and minimal alcohol intake. As stated by Nilsson et al. (1997), fatigue can be seen as one of the major reasons drivers are unable to avoid making errors.

Driving is inarguably a highly visual task in which the controlling of a vehicle occurs in a visually cluttered environment, and due to the complexity of the driving task it requires the simultaneous use of one’s central and peripheral vision, also referred to as the visual field (Owsley and McGwin Jr, 2010). The visual field can be defined as the area visible at a single glimpse without having to move the eyes or head (Rantanen and Goldberg, 1999) and is a major element in car driving (Rogé et al., 2003). It has been shown that an individual’s visual field is not fixed and varies with certain factors, one of them being fatigue (Rogé et al., 2002a). Other factors affecting the size of the visual field include high cognitive workloads, boredom, certain eye diseases, age, and the arousal state of an individual (Rogé et al., 2002a; Owsley and McGwin Jr, 2010). Although during everyday activities, such as driving, there are multiple information sources, the human visual system can only focus sharply on one point, known as the central focus; this results in a reduced peripheral visual performance and may lead to the occurrence of accidents (Rogé et al., 2003). It is in an individual’s peripheral visual field that the quality and quantity of visual information, dependent on the size and shape of the visual field, are critically important for safety (Rantanen and Goldberg, 1999; Rogé et al., 2004). While driving, it is imperative that key information is absorbed; this includes being able to detect road signs, other vehicles and obstacles in the surrounding environment as soon as possible (Rogé et al., 2003). A state of fatigue reduces a driver’s visual field, increasing the chance that key information will be missed, and thus will have an adverse effect on a driver’s peripheral visual field (Hills, 1980; Rogé et al., 2003). However, the degree to which it is affected is unknown as, according to Rogé et al. (2003), the visual field has not been well researched during driving.

1.2 STATEMENT OF THE PROBLEM

While it is well known that with an increase in fatigue the phenomenon of tunnel vision arises, little is understood about the effects that driver fatigue has on the peripheral visual system. The extent of the alteration that occurs to a driver’s peripheral visual field while fatigued, the effects of time of day and the effects of time on task, also need to be explored. A reduction in a driver’s peripheral visual field results in a reduced driver safety and increased safety costs; thus it is important to establish to what extent the peripheral visual field is affected during a state of fatigue

Seemingly, a common thought is that the peripheral visual field becomes compromised as a state of fatigue increases. The objective of the current study was to identify whether significant interaction effects exist between peripheral visual performance and a state of fatigue, induced through time of day and time on task.

1.3 PRACTICALITY

Knowledge associated with this study may enable companies, labour legislation and traffic laws to determine, and implement, the length of time a driver can drive safely before their visual field is compromised, which will have a positive effect on the number of fatigue related accidents that occur. The findings may also influence display placements within a vehicle, as well as whether the peripheral visual field can be used to provide information to a driver, for example, in-vehicle information systems, during an individual’s vigilant and fatigued states that occur within a 24 hour day.

CHAPTER II

2 REVIEW OF RELATED LITERATURE

Since the nineteenth century, fatigue, as a possible risk factor affecting health and performance, has driven psychologists, physiologists and engineers to minimise and eliminate its effects (Noy et al., 2011) and is still, to date, a common feature of modern life (Dawson et al., 2011). Fatigue is caused by various factors and manifests itself in different forms, namely behavioural, cognitive, somatic and affective symptoms, thereby establishing itself as a complex phenomenon (Lee et al., 2010; Saito, 1999). It is identified as occurring from long-term stress or disease (Lewis and Wessely, 1992), although the aspects of stress implicated in the causal chain are unknown (Åkerstedt et al., 2004). The consequences of fatigue can be categorised as short-term risk, usually associated with poor safety outcomes, and long-term risk, involving a reduction in an individual's physical and/or psychological health (Gregory, 2008). Fatigue is frequently eliminated through a good quality rest period or sleep (Philip et al., 2005b; Gander et al., 2011). This chapter will begin by defining fatigue (section 2.1), with the types of fatigue (section 2.2), theories on fatigue (section 2.3) and causes of fatigue (section 2.4) following. Fatigue in the context of driving (section 2.5) and the various indicators of fatigue (section 2.6) will then be discussed, concluding the chapter with a brief summary and the rationale behind the study (section 2.7).

2.1 DEFINING FATIGUE

Fatigue is a term that is used in numerous senses but has no single accepted definition to date (Dawson et al., 2011) as complications arise from its non-specific etiology, individual differences regarding responses, and lack of agreement with regard to its measurement (Noy et al., 2011). A universally accepted definition of fatigue may also be elusive because it is a multidimensional construct involving processes that are physical, psychosocial and behavioural in nature (Shen et al., 2006b; Maycock, 1997). Shen et al. (2006a) affirm that no 'gold standard' test exists for measuring fatigue, and although it would be advantageous, the establishment of a gold standard to distinguish and quantify fatigue would have limitations (Di Milia et al., 2011). Such a construct would ignore individual differences in response to fatigue, as well as neglect the possible effect of other factors on the indicator, such as illness (Di Milia et al., 2011; Smolensky et al., 2011).

However, among attempts to define fatigue, there are definitions that try to identify the specific source of the fatigue, such as muscle dysfunction, whereas other definitions adopt a more behavioural view thus focusing on fatigue in terms of performance decrements (Chalder et al., 1993). Brown (1994) states that when an individual becomes fatigued there is an unwillingness to continue with the task at hand, which leads to an increasing impairment in human efficiency once the individual is aware of their fatigued state, while Hockey (1997) defines fatigue as a mode of control of behaviour, as well as information processing in high workload situations, underpinning the diverse fatigue responses. In 1942, McFarland et al. explained fatigue as a group of phenomena which are associated with impairment or loss of efficiency and skill. Grandjean (1979) described fatigue as a state in which the outcome is a reduction in efficiency and a general unwillingness to continue working; however fatigue is resolved after a period of rest.

Bartley and Chute (1947) claim that fatigue should be seen as a purely psychological phenomenon, and that fatigue can occur without a performance decrement, as well as a performance decrement occurring without psychological fatigue. According to Chalder et al. (1993:147), fatigue can be characterised as “a single phenomenon or discrete variable, but it is probably more appropriate to view it as a continuous dimension, which is experienced as a subjective internal feeling”. Fatigue can also be described as an individual’s subjective desire to rest and/or an aversion to continue working, which is coupled with an objective performance decrement (Jones et al., 2005). From an arousal viewpoint, this illustrates fatigue as a graded condition in which the declining alertness will eventually cause the individual to fall asleep (Hartley, 1995), which is the natural end result of fatigue (Nilsson et al., 1997). This is supported by Lal and Craig (2001) who state that fatigue is the transitory phase between when an individual is awake and asleep and, if this phase continues uninterrupted, it can result in sleep. More contemporary literature illustrates fatigue as an inability to function at a desired level, arising from incomplete recovery from various demands and activities (Gander et al., 2011).

According to Philip et al. (2003), fatigue can be defined as a gradual and cumulative process, which is associated with reluctance toward effort, and eventually results in reduced performance efficiency. Williamson et al. (2011) depict fatigue as a construct that is not directly observable or objectively measurable, but produces measurable phenomena. Simply stated, fatigue can be seen as an outcome state, a feeling of tiredness or sleepiness (Di Milia et al., 2011). Although a consensus is still to be reached in literature regarding an adequate definition for the phenomenon, it must be noted that fatigue is regarded as a symptom of most acute and chronic infirmities as well as having an association to normal everyday healthy functioning (Shen et al., 2006b). In order to obtain a sound understanding of fatigue it is imperative to differentiate between sleepiness, drowsiness, boredom and fatigue.

2.1.1 Sleepiness versus Drowsiness versus Fatigue

There are three terms, namely fatigue, drowsiness and sleepiness, which are critical to understand, as the terms are frequently confused and used interchangeably (Philip et al., 2005a; Johns, 1998). Fatigue and drowsiness result from different causes and processes; however, the two terms are often considered interchangeable due to the same outcome or result being produced (Vanlaar et al., 2008). Drowsiness is defined as the intermediate state between when an individual is awake and asleep, and can be detected using the pattern of brain waves (EEG) and eye movements, as well as muscle activity (Johns, 2000). It is accompanied by psychophysiological changes that are a threat to safe driving, such as visual perception impairment, an inability to maintain visual focus and the impairment of higher cognitive functions (Lamond and Dawson, 1999). Sleepiness refers to the difficulty in staying awake, even while activities are being carried out (Dement and Carskadon, 1982). According to Johns (2000) it is neither a state nor a process, but rather depicts a position along a continuum of arousal states from alert wakefulness to asleep. It is related to circadian and homeostatic influences and is resolved after sleep (Philip et al., 2005a). Drowsiness and sleepiness usually define an individual’s desire to fall asleep, which is caused by a physiological state of the body and can only be altered with sleep (Vanlaar et al., 2008). Both terms are ruled by the circadian cycle and the sleep homeostatic process, within which people feel the need for sleep twice a day (Vanlaar et al., 2008).

Fatigue results in a decreased capacity to perform a task, coupled with subjective states that are associated with a performance decrement; it is related to both physiological and psychological processes (Thiffault and Bergeron, 2003a). Psychological fatigue involves cognitive changes that may be due to mental fatigue, causing a reduction in executive control processes (Williamson, 2009), while physiological fatigue occurs in the muscles and is marked by a decrease in the strength of muscle contractions with sustained use (Johns, 2000). The neurophysiological mechanisms that result in mental fatigue are not as well researched and known in comparison to physiological fatigue (Johns, 2000). However, the management of the afore mentioned factors in the operational environment still remains a challenge, as it is difficult to generalise the results of laboratory-based studies to the workplace (Fletcher and Dawson, 2001).

2.1.2 Boredom versus Fatigue

Understanding the association between boredom and fatigue is essential, as one can affect or produce the other (Lal and Craig, 2001). Boredom has been found to cause a diminished activation level of the brain, thus some researchers deem boredom to be a special form of fatigue (Grandjean, 1979). Decreased stimulation and repeated stimuli, as well as low mental and physical demands result in physiological characteristics associated with boredom (Grandjean, 1979). Along with diminished cerebral activation levels, an increased subjective sleepiness, reduced vigilance, aversion to the task and a decrease in vigilance are other effects of boredom. These characteristics are comparable to those experienced when fatigued (Lal and Craig, 2001). Therefore boredom, tiredness and driver inattention also need to be considered as symptoms of fatigue (Nelson, 1997). It is essential to gain an understanding of passive and active fatigue; active fatigue occurs during tasks requiring continuous and prolonged perceptual-motor adjustment, while passive fatigue manifests during tasks which require minimal perceptual-motor adjustments (Desmond and Hancock, 2001). Thus, active fatigue arises from an over-load phenomenon, while passive fatigue develops from an underload phenomenon, in which minimal interaction is required from the individual (refer to section 2.4.1 a) (Desmond and Hancock, 2001).

The definition of fatigue is largely dependent on the particular paper in which it is found (Åkerstedt et al., 2004; Williamson et al., 2011); therefore, for the purpose of this research, the use of the term fatigue will be adapted from Dinges (1995), as sleepiness resulting from the neurobiological processes which regulate sleep and circadian rhythms, or in lay terms, as the biological drive for recuperative rest (Williamson et al. (2011). This definition will be used as it incorporates the effects of circadian rhythm, which is a key aspect in this research.

2.2 TYPES OF FATIGUE

Fatigue is generally categorised as acute or chronic fatigue (Mohren et al., 2007), and can be further differentiated into muscular fatigue, mental fatigue, central fatigue and psychomotor fatigue (Dawson et al., 2011). The following study incorporates mental and physical fatigue, and thus only these two types of fatigue will be highlighted below. Central fatigue and psychomotor fatigue will not be considered as both are more applicable to exercise induced fatigue.

2.2.1 Mental Fatigue

Mental fatigue is a common everyday phenomenon; however, the psychophysiological mechanisms underlying it are mostly unknown (Boksem et al., 2005). According to Grandjean (1979), Lal and Craig (2001) and Boksem et al. (2005), mental fatigue can be seen as a process that is both gradual and cumulative, and can be associated with a feeling of tiredness, frequent lapses in attention, reluctance to exert mental or physical effort, decreased alertness and competence, as well as reduced mental performance. Normally, mental fatigue occurs during or after extensive periods of cognitive activity (Boksem et al., 2005) and can be reversed through rest (Lal and Craig, 2001). Attention during every day activities is an imperative human behaviour as it allows for the processing of relevant information regarding a task at hand, and the discarding of information that is irrelevant and has the ability to distract the individual from the main task (Dosher and Lu, 2000). There are many factors that could affect the level of an individual’s mental fatigue, such as nutrition, physical health, physical activity, motivation, the environment and recovery time (Okogbaa et al., 1994; Nilsson et al., 1997).

2.2.2 Physical Fatigue

Physical fatigue transpires when a muscle is stressed and results in reduced performance, muscular power and movement (Lal and Craig, 2001). It reduces an individual’s co-ordination, and thereby increases the risk of errors and accidents (Grandjean, 1979). Physiological characteristics of physical fatigue include reduced alertness, decreased work output and elevated core temperature, as well as reduced speed and strength of muscular contraction (Astrand and Rodahl, 1986). If hard physical labour has taken place before driving, it could amplify the risk of driver fatigue (Lal and Craig, 2001).

2.3 THEORIES ON FATIGUE

The available theories on the causes of fatigue mostly focus on the requirements for sustained attention and the monotony of certain tasks (Williamson, 2009). Many of these theories, such as the arousal theory, the resource theory and the effort-compensation theory, have been advanced in order to include changes that occur in performance during sustained attention (Williamson, 2009).

2.3.1 The Arousal Theory

The arousal theory postulates that the performance decrement occurs as a result of a decrease in arousal, due to the high monotony of the stimulus being presented (Mackworth, 1969). According to Mackworth (1969), a monotonous stimulus presentation results in habituation, which leads to a decreased arousal and thus performance decrements. However, by decreasing the monotony of the stimulus presentation, there will be an increase in an individual’s performance (Smit et al., 2004). This theory proposes that extraverts are more aroused than introverts by stimulus presentation, and thus extraverts have a superior performance under stress or stimulation (Eysenck and Eysenck, 1985). There are numerous ways to measure an individual’s level of arousal, such as heart rate variability (Bonnet and Arand, 1997), pupil diameter (Wickens, 2002) and through self-reports (Matthews and Amelang, 1993).

2.3.2 The Resources Theory

The resources theory states that information processing resources are limited, and that a performance decrement occurs with sustained attention, as well as with time on task, which causes a depletion of attentional resources (Wickens and Kessel, 1980). Wickens (2008) stated that dual task performance will result in decreased time-sharing ability and therefore result in performance decrements. If one resource is required by both components comprising the dual-task, there will be interference, and a performance decrement will occur in one or both tasks (Wickens, 2002; 2008). However, when the dual-task requires two different resources there is less interference in time-sharing (Wickens, 2002). Task interference is less prevalent in underload situations, while in overload situations individuals are usually required to perform two or more tasks simultaneously (Young and Stanton, 1997), in which case performance breakdown will occur (Wickens, 2002).

2.3.3 The Effort Regulation Theory

The effort regulation theory considers that performance decrements occur over time because the extended effort that is needed to maintain attention is both taxing and stressful (Hockey, 1997). When an individual strives for a higher achievement level, there will be an increase in the invested effort in order to obtain the goal at hand; however, with the abandonment or down-regulation of a goal, there will be a reduction in the invested effort (Venables and Fairclough, 2009). When an individual’s performance is threatened, by factors such as increased task complexity and sleep deprivation, the individual will invest more effort, as a compensatory mechanism, in order to maintain the goal standard (Hockey, 1997). The increase in the effort invested will only occur if the individual perceives the success of the goal to be attainable and worthwhile (Hockey, 1997). When more effort is invested, there may be a decrement in the lower priority aspects of performance, or it may result in increased levels of anxiety or tension (Hockey, 1997), which can be used as indicators of effort investment (Venables and Fairclough, 2009).

2.4 CAUSES OF FATIGUE

The research on the causes of fatigue shows an extensive range of factors; these factors have been conceptualised as relating primarily to endogenous factors, which have a profound effect on an individual's alertness levels (Williamson, 2009). Thiffault and Bergeron (2003a) categorise the factors of fatigue into endogenous, resulting from within the individual, and exogenous, resulting from the interaction between the individual, the task and the environment. Endogenous factors, as illustrated in the circle in Figure 1, include the influence of the circadian rhythm (time of day) and the amount of sleep obtained by the individual (sleep need and sleep debt) (Williamson, 2009). These endogenous factors lead to an elevated fatigue state (Williamson et al., 2011). Exogenous factors include time on task, task-related factors and education, among others which can be seen surrounding the circle in Figure 1 (Di Milia et al., 2011). Many other factors can lead to a fatigued state, such as monotony, extra demands during driving, hard work preceding driving (Nilsson et al., 1997), cognitive workload, sleep deprivation/loss and shift work (Wahlberg, 2008), sleep experience the night before driving, temperature and mood states (Ji et al., 2004).

Figure 1: Potential endogenous and exogenous variables affecting fatigue (adapted from Di Milia et al., 2011, pg 517).

There are three main influences, noted by Williamson et al. (2011), that lead to an increased level of fatigue, namely circadian influences (time of day), sleep homeostasis (time awake) and factors related to task characteristics, as depicted in Figure 2.

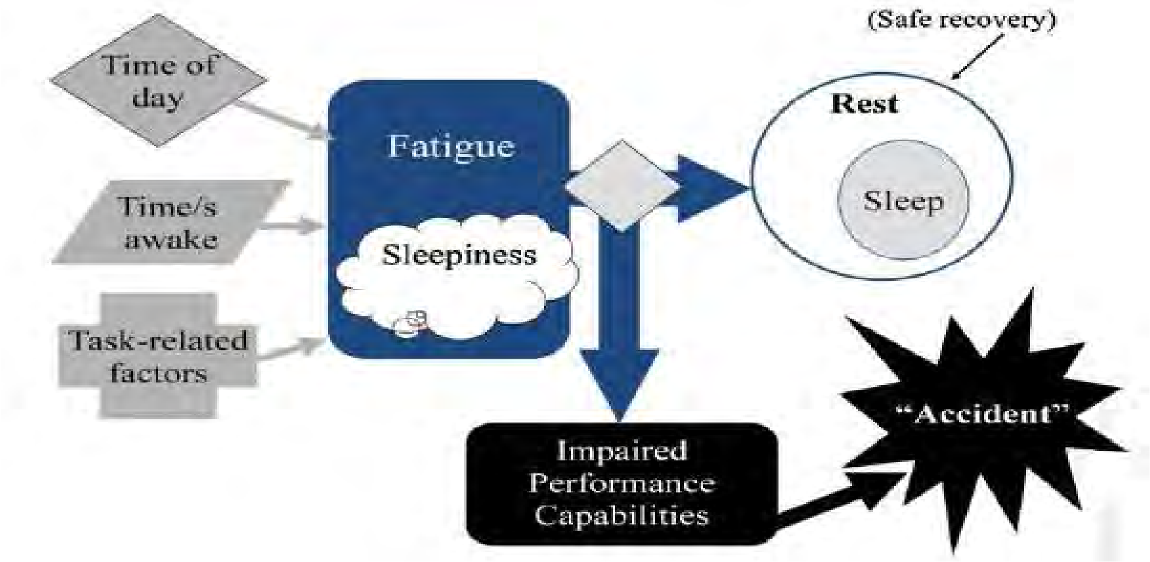


Figure 2: Framework of factors affecting fatigue (adapted from Williamson et al., 2011, pg 499).

According to May and Baldwin (2009), fatigue can be divided into sleep-related (SR) and task-related (TR) fatigue according to the causal factors that contribute to the state of fatigue. Task demands can produce fatigue, even though no sleep-related causes may be apparent: the level of task demand, time on task, environmental characteristics and a secondary task can result in task-related fatigue (May and Baldwin, 2009; Gimeno et al., 2006). Task-related fatigue can result from both active and passive fatigue (Desmond and Hancock, 2001). Active fatigue is usually the most common fatigue that occurs in drivers and is due to high task demands, which result in mental overload (Gimeno et al., 2006). This is reiterated by Desmond and Hancock (2001) who state that active fatigue arises due to continuous and prolonged, task-related perceptual-motor regulations. Passive fatigue on the other hand is most likely to occur due to underloaded conditions (Gimeno et al., 2006), usually when the driving task is predictable or monotonous (May and Baldwin, 2009; Porter, 2011). Drivers start to rely on mental schemas of the task at hand, which results in a reduction in the effort exerted (Gimeno et al., 2006). This type of fatigue develops when an individual has little to do, or be occupied by, over a number of hours (Desmond and Hancock, 2001). Sleep influences performance in a number of ways (Porter, 2011). Factors affecting sleep-related fatigue include the extent of sleep deprivation, the individual's duration of wakefulness, and the time of day during which an activity occurs (May and Baldwin, 2009).

2.4.1 Task-Related Fatigue

a. Task Demand

It is well accepted that behavioural performance is impaired under monotonous conditions (Thiffault and Bergeron, 2003b), as well as for tasks requiring sustained attention (Horrey et al., 2011). Fatigue has been associated with low and unchanging levels of stimulation, also referred to as the underload principle; however, fatigue can also be brought about through high levels of stimulation or overload (Hancock and Verwey, 1997).

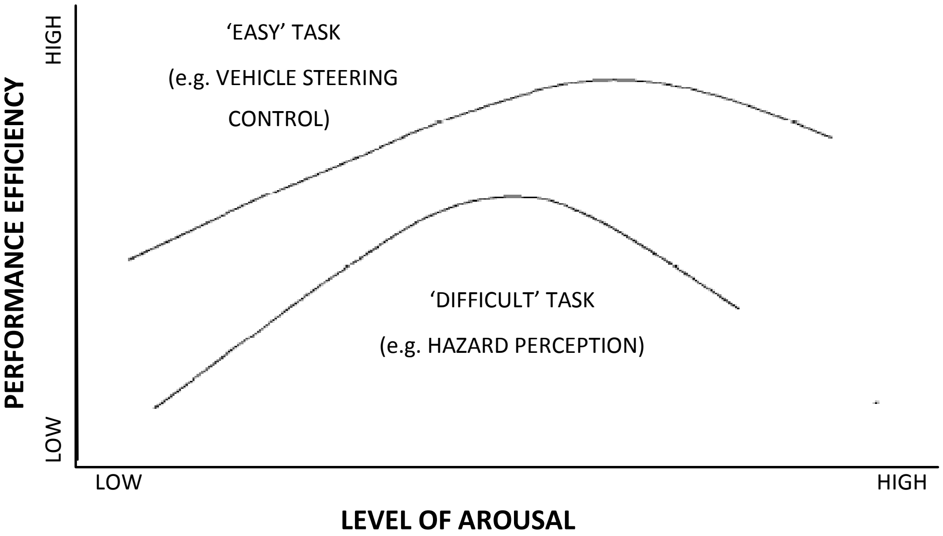


Figure 3: The 'inverted-U' relationship between level of arousal and performance (adapted from Brown, 1982, pg 86).

Stimulation comes from either the task or the surrounding environment, and if the level is too low or too high, it leads to relevant demands being disregarded (Hancock and Verwey, 1997). Figure 3 represents the 'inverted-U' relationship between performance and arousal, which illustrates that, when arousal levels are at a minimum, there is low performance efficiency; however, the efficiency increases and reaches a peak with an increasing level of arousal (Brown, 1982). As the level of arousal continues to increase there is a decrease in the efficiency of performance, this occurs for both simple and complex tasks (Brown, 1982). According to Matthews and Desmond (2002), the most important effect on performance is not resource ability, but rather the ability of the individual, to match the effort level required by the task demands. Tasks that are monotonous, or occur under monotonous conditions, cause a loss of task directed effort (Williamson et al., 2011), and a decrease in alertness, which negatively impacts performance (Smiley, 1990; Gander et al., 2011). This indicates that the individual either has to increase the amount of effort needed to perform the task (Williamson et al., 2011), or to lower the effort required by lowering performance (Matthews and Desmond, 2002). A decrease in alertness leads to the brain being less sensitive to incoming or relevant stimuli, resulting in important information being overlooked or missed; a reduction in alertness can also result in an individual falling asleep (Smiley, 1990). Regarding driving and task demands, Brown (1982) stated that continuous driving under monotonous conditions leads to the impairment of driving skills. This occurs as a result of monotony impacting an individual’s alertness or wakefulness, due to a decrease in arousal levels, which impairs performance and information processing (Thiffault and Bergeron, 2003a).

b. Time on Task

Fatigue can be seen as a simple variable, which has a strong positive correlation with time on task (Paley and Tepas, 1994). Time on task is often defined as time on duty, time into work shift, or driving duration (Williamson et al., 2011). It can be modified or confounded by factors such as time of day, sleep homeostasis and time spent on task (Williamson et al., 2011). Fatigue has been associated with, inter alia, long hours on duty (time on task) and reflects a causal relationship with accident occurrence, where the frequency of accidents is seen to increase after approximately eight hours of driving when a regular schedule was followed, and significantly earlier with an irregular schedule (Mackie and Miller, 1978). This was supported by McCartt et al. (2000) who illustrated that drivers are more prone to feelings of fatigue and drowsiness when driving for long hours. Other studies have indicated that drivers can drive for up to five hours before starting to feel drowsy (McCartt et al., 1996).

Madsen (1982) established that driving errors started occurring after four hours, whereas Hamelin (1987) conducted a study in which he found that accidents progressively increased when driving exceeded eight hours. Dalziel and Job (1997) established that accidents occurred more towards the end of shifts, due to the increased effect of fatigue resulting from the prolonged time on task. The effects of time on task can also lead to an increase in the percentage of missed signals, as well as an increase in the number of false alarms incurred (Boksem et al., 2005). Long travelling times, exceeding 35 minutes, coupled with reduced sleep durations, less than 6 hours, have been associated with impaired performance as well as increased sleep propensity (Di Milia, 2006; Gander et al., 2011). Due to this, driver fatigue needs to be considered when implementing working hours for drivers (Evans and Courtney, 1985). When assessing simulated driving studies, Thiffault and Bergeron (2003a) found performance decrements occurring after only 20–25 minutes, while Ting et al. (2008) noted increased sleepiness scores coupled with decreased performance after 80 minutes. Under controlled conditions Galinsky et al. (1993) observed that marked indications of fatigue occurred in participants after only 60 minutes of driving or partaking in vigilance tasks. The progressive withdrawal of attention from the road and surrounding environment is, according to Brown (1994), the main time on task effect during driving, and results in a task performance decrement. During long distance driving, an individual’s reaction time gets slower with each hour of driving, which negatively affects safety while driving (Philip et al., 2003), and performance decrements occur with time on task (Porter, 2011).

2.4.2 Sleep-Related Fatigue

a. Sleep Deprivation/Loss

The extent of fatigue experienced is caused, and compounded by, sleep deprivation/loss, which results in further decreases in alertness and performance (Williamson and Friswell, 2011; Porter, 2011). This takes place when sleep loss occurs over several nights, resulting in ‘sleep debt’ (Dalziel and Job, 1997). Sleep debt is the cumulative build up of sleep pressure, resulting from lack of sleep over several nights (Van Dongen et al., 2003). Sleep deprivation results in slower reaction times, decreased concentration and poor decision making, as well as worsened mood (Dalziel and Job, 1997). Sleep loss contributes to fatigue and occurs for a number of reasons, including working overtime, night shift work, social events, social responsibilities, such as family and moonlighting, and driving long distances (Fell and Black, 1997; Åkerstedt et al., 2004). This can result in fatigue incidences occurring at any time of the day; however, having a day that extends beyond normal working hours makes it more probable that incidences will occur towards the end of the day (Fell and Black, 1997). When looking at the interaction between sleep loss and driving it can be seen that sleep loss exacerbates the effects that fatigue renders on driving, as well as interacting with the time on task effect and circadian rhythmicity (Brown, 1994). With extended wakefulness during driving, there is an increase in lane drift, speed deviation and tracking variability (Philip et al., 2005a; Ingre et al., 2006).

According to McCartt et al. (1996) the frequency of drowsy driving that was reported was found to be inversely related to the number of hours of sleep reported each night. Sleep durations of less than six hours have the same adverse effects as sleep loss, and resulted in driving performance impairments (Di Milia, 2006). Philip et al. (2005a) suggest that work schedules should allow for sleep schedules before, as well as during, work periods to ensure driver safety and safe driving.

b. Circadian Rhythm and Sleep Homeostatic Pressure

The two-process model of sleep regulation can be used to understand the regulation of sleep (van Dongen and Dinges, 2003). It addresses the circadian and homeostatic aspects of sleep (Achermann, 2004), which interact neurobiologically with each other, and the interaction of these two processes is seen to predict the timing and duration of sleep (Achermann et al., 1993). Circadian rhythm is distinguishable from time of day based on the quantitative amount of exposure, such that if measures are obtained infrequently or limited to certain times of the 24 hour day, the term ‘time of day’ should be used, whereas if measures are taken more frequently and during the majority of the 24 hour day, the term ‘circadian’ is applicable (Williamson et al., 2011). For the purpose of this research, the term time of day will be used as infrequent measures were obtained during the 24 hour day.

Circadian Rhythm

All individuals possess an endogenous biological clock that generates and maintains chronobiological rhythms, which in turn control the sleep and wakefulness of the individual (Philip et al., 2005a). It is known as the circadian rhythm/master pacemaker and is located in the suprachiasmatic nuclei (SCN) (Dijk and Lockley, 2002). The circadian rhythm is independent of prior sleep and waking (Achermann, 2004); however, light is the main zeitgeber for the SCN (Wirz-Justice, 2006). The circadian wakefulness signal becomes progressively stronger during the day and dissipates after melatonin is secreted during the night (Edgar et al., 1993), therefore indicating that the body is ready for work during the day and rest during the night (Smiley, 1990). The circadian rhythm determines the alteration of periods with high and low sleep predisposition (Borbély and Achermann, 1999). As the day progresses human rhythms generate a drop in vigilance, however a very alert period occurs towards the end of the afternoon (Lavie, 1986). It has been shown that performance is best during the morning and late afternoon, whereas it is poor during the early afternoon and during the night.

This could be attributed to the two nadirs that occur within the 24 hour circadian cycle (Smiley, 1990), which affect alertness and cause individuals to feel sleepy (Rom and Markowitz, 2007). The stronger nadir occurs during the night between 10pm and 8am, peaking around 4am, and the second nadir occurs between 2pm and 4pm, which is also referred to as the ‘post lunch dip’ (Rom and Markowitz, 2007). Circadian changes in physiological functions are paralleled by similar changes in mental alertness and performance (Smiley, 1990) and therefore the disruption of an individual’s circadian rhythm can result in fatigue (Dalziel and Job, 1997). The consequences of such changes are often apparent in mood, alertness and performance (Reilly and Edwards, 2007), and can include high subjective sleepiness and fatigue, increasing the possibility of falling asleep on the job and increasing the risk of accidents occurring in the workplace and on the road (Åkerstedt, 1988). The extent to which performance is affected by the circadian rhythm depends on several interacting factors, such as, individual characteristics, domestic circumstances and the environmental conditions (Brown, 1994). The human sleep-wake cycle is, however, not driven only through the circadian rhythmicity, but through the interaction of the circadian rhythm and a sleep-wake oscillatory process, called sleep homeostasis (Dijk and Lockley, 2002).

Sleep Homeostatic Pressure

If an individual remains awake for extended periods of time, or sleep restriction increases, there is an increase in sleep pressure; this results in the generation of cumulative sleepiness, which causes impaired neurobehavioral functioning (Froberg, 1977). In lay terms, the longer an individual is awake, the more pressure is felt to sleep (Porter, 2011). Sleep homeostatic pressure depends on the extent of prior sleep or wakefulness, and indicates the need for sleep or sleep pressure (Taillard et al., 2003). It occurs with increasing sleep propensity during waking as well as sleep deprivation, and is resolved through sleep (Borbély and Achermann, 1999; Dijk and Lockley, 2002; Taillard et al., 2003). Sleep homeostasis attempts to balance the time an individual spends awake with the time an individual spends sleeping (van Dongen and Dinges, 2005). As the day progresses, there is an increase in the homeostatic sleep pressure, which continues to accumulate even during the night, until a sleep state is initiated (van Dongen and Dinges, 2005), as illustrated in Figure 4. The sleep drive peaks between 10pm and 12am (Porter, 2011). During the evening, maintenance of optimal performance levels may prove challenging, as the increasing sleep propensity gradually overrides the wake-promoting circadian signal (Schmidt et al., 2009); thus performance decreases as time awake increases (Porter, 2011).

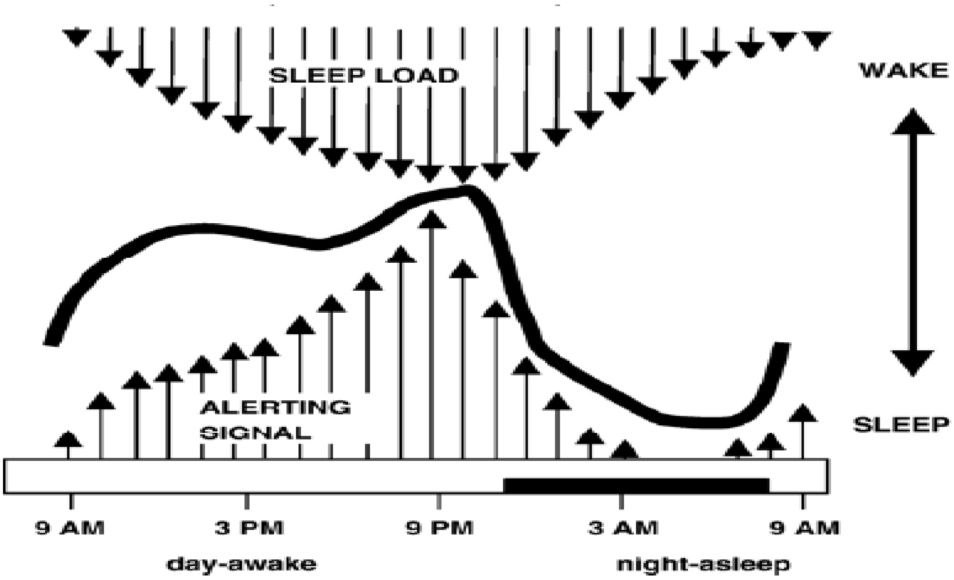


Figure 4: The build up of sleep pressure over the course of 24 hours (adapted from Blatter and Cajochen, 2007, pg 202).

As can be seen, there are many factors contributing to an individual’s state of fatigue; however, regardless of the causes of fatigue, the outcome is usually the same, such as an increase in response time, missing critical signals and a reduction of effort input (Williamson, 2009).

2.5 FATIGUE IN THE CONTEXT OF DRIVING

The effects of fatigue have major implications for a large number of industries and it commonly affects areas such as shift work, healthcare, mining, transport and manufacturing (Fletcher and Dawson, 2001). Van Orden et al. (2000) state that the loss of alertness associated with fatigue and sleep pressure is a concern for any system that requires sustained monitoring by a human operator to ensure efficient and safe operation. Fatigue can result from physical labour and/or monotonous tasks, in which driving long distances is categorised (Vanlaar et al., 2008). Land transport forms a vital part of a country’s economy, as it is used for transporting both goods and persons (Oggero et al., 2006). This includes various modes of transport such as road and rail, where driving can be seen as a complex task requiring the simultaneous execution of cognitive, sensory, physical and psychomotor skills (Young and Regan, 2007). According to Sung et al. (2005) driving is a continuance of complex behaviours that involve diverse abilities such as perceptions, decision-making and motor skills. Motor accidents are responsible for a large number of deaths and disabilities (Connor et al., 2001), and one of the major causes of motor accidents is driver fatigue, resulting in implications for road safety (Lal and Craig, 2001).

According to Williamson et al. (1996) fatigue is a state in which an individual experiences decreased mental alertness, which results in performance decrements across cognitive and psychomotor tasks, such as driving. It has been acknowledged for some time that fatigued drivers pose a potential traffic safety hazard, which increases the risk of crashing (Dinges, 1995). This is reiterated by Åkerstedt and Kecklund (2001) who state that driver fatigue has been identified worldwide as a leading cause in road accidents. There is a high frequency of conflicts that occur between physiologic needs and social/ professional activities and therefore understanding the effects of fatigue is fundamental in accident prevention (Philip et al., 2003). According to Nilsson et al. (1997) fatigue is one of the critical reasons why most drivers are unable to avoid making errors. A momentary reduction of a driver's attention can have dire consequences (Weissman et al., 2009), such as slowed reaction time when braking or reacting to unexpected events (Beede and Kass, 2006). When drivers' vigilance levels diminish, they are easily distracted and less focused on the road as well as their surroundings (Bunn et al., 2005); there is a marked reduction in perception, recognition and vehicle-control abilities and this results in drivers placing their life, as well as the lives of others, in danger (Ji et al., 2004). The scientific, as well as general, communities are becoming more aware of the increased risks associated with sleepiness and fatigue in operational environments and on the road (Summala and Mikkola, 1994). However, most drivers overlook the decrease in driving performance caused by everyday phenomena, such as mental and physical fatigue as well as sleep deprivation, and this can lead to motor accidents (Corfitsen, 1994). Driver fatigue usually occurs as a result of extensive and irregular working hours (Brown, 1994), and numerous drivers combine sleep deprivation and prolonged driving for economic and/or socio-cultural reasons (Philip et al., 2003).

Factors contributing to driver fatigue include time on task, time of day, number and length of rest breaks and the amount of sleep had by the driver (Brown, 1994). Driver fatigue can be reversed through time away from the task or through sleep (Bunn et al., 2005). Hartley (1995) stated that fatigue is as serious a safety threat and problem on the road as that of driving under the influence of alcohol. Åkerstedt (2000) found that fatigue surpasses alcohol, as well as other drugs, as the largest identifiable and avoidable cause of accidents across all modes of transportation. However, Williamson (2009) stated that driving fatigue is more dangerous than drunk driving and other driver behaviour-related problems, such as speeding, due to the fact that less is understood about driver fatigue, its causes or the countermeasures for mitigating the effects it renders. Despite most drivers being aware of the dangers of fatigued driving, there continues to be a large percentage of accidents (between 5 and 50%) attributed to fatigue (Nilsson et al., 1997; Williamson et al., 2011). Drivers still maintain that they are able to control the risks associated with fatigue even though there is extensive research disproving this (Vanlaar et al., 2008). Many of these accidents are due to the failure of attention and information processing rather than a driver's lack of skill in performing certain responses (Shinar, 1978). These accidents cause injury, damage, emergency service costs, disruption and administrative costs (Evans, 1994). According to Ji et al. (2004), 57% of fatal truck accidents are caused by driver fatigue. As many as 70% of American drivers have reported driving fatigued; 100 000 accidents are estimated to be caused by drowsy driving and this has resulted in over 1500 deaths in America over a period of one year (Ji et al., 2004). Research conducted in South Africa in 1997 revealed that driver fatigue is responsible for 5–10% of accidents and 25–35% of all fatal accidents (Ministry of Transport, 2000). During peak seasons in South Africa the main causes of accidents are driver fatigue, speeding, reckless driving, and poor roadworthy vehicles (Ministry of Transport, 2002). South Africa's road mortality rate, due to factors such as fatigue, alcohol and negligent driving, is 26% higher than any other African country and double that of the global rate (Seedat et al., 2009). Based on crash statistics for 2009, obtained from the National Highway Traffic Safety Administration (NHTSA), 2.7% of all fatal accidents are attributed to factors such as fatigue and sleepiness (National Traffic Safety Administration, 2011).

However, there is consensus among most researchers that accidents related to fatigued or drowsy driving are under-reported due to there being limited evidence to support the fact that fatigue or drowsiness was a factor in a crash (McCartt et al., 1996). In such cases, police reports are often incomplete with regards to these aspects (Corfitsen, 1994). Surveys conducted in England, Finland and New South Wales indicated that crashes related to fatigued or drowsy driving could be more prevalent than specified by crash data (Horne and Reyner, 1995). The proportion of fatigue-related crashes could also be underestimated due to the fact that there is no universally accepted definition for what contributes to driver fatigue (Dobbie, 2002).

2.5.1 Driver Fatigue and the Visual Field

Driving is known to be a complex task and involves all sensory modes, such as auditive, proprioceptive and visual modalities (Rogé et al., 2002a). Of all the sensory modes, visual perception is attributed to be the main source of information during driving because 90% of information that is processed is of visual origin (Hills, 1980). However, for visual perception to be effective, attention is essential (Recarte and Nunes, 2000). A consequence of driving while fatigued is that a driver's useful visual field can be compromised, which will have a resultant effect on the safety of the driver, as well as the safety of others (Williamson, 2009). A driver’s useful visual field starts to deteriorate when (s)he has been deprived of sleep (Rogé et al., 2003), and studies conducted during driving have indicated that a driver’s useful visual field is modulated by the driver’s state of alertness (Rogé et al., 2008). It can thus be said that the dysfunction of an individual’s visual system leads to impaired driving performance, and a consequent increased accident risk (Rogé et al., 2002a). In a study conducted by Rogé et al. (2004), it was found that with high speeds drivers detected fewer peripheral stimuli, but when driving at lower speeds drivers detected fewer stimuli in the central visual field, which may be explained as a trade-off in attention based on different speeds.

A decrease in the activation level of an individual during driving, due to monotony and time on task, can have an impact on their visual perception (Rogé et al., 2008). When driving under monotonous and prolonged conditions a deterioration of a driver’s peripheral perception occurs; however, it is not homogenous throughout the visual field, but rather depends on the speed of the peripheral stimuli (Rogé et al., 2002a). During prolonged driving it has been found that an individual’s level of alertness decreases, and with this decreased alertness, less stimuli are detected centrally as well as in the periphery (Rogé et al., 2009), regardless of the stimuli eccentricity (Rogé et al., 2004). An increase in arousal levels can lead to sensory environmental cues being restricted, thus an increase in the number of missed peripheral stimuli will occur; this phenomenon results from stress and severe fatigue (Easterbrook, 1959). This attentional capacity deterioration results in delayed information processing, incorrect analysis of relevant information and severe accidents during driving (Rogé et al., 2009). The risk of fatal accidents during driving increases fourfold during the night (Williams, 2003), but it is interesting to note that according to Leibowitz and Owens (1977) night driving conditions have little effect on an individual’s peripheral vision; an individual’s central/focal vision is impaired.

2.5.2 Useful Field of Vision (UFOV)

An individual’s useful field of vision (UFOV) is defined as the area where more information regarding the stimulus needs to be extracted, such that the stimulus can be recognised, categorised and identified before a reaction is elicited (Rantanen and Goldberg, 1999). The time between when the eye leaves a target and when the manual response occurs is known as the decision time (Recarte and Nunes, 2003). According to Williams (1982), the UFOV has a radius of 2° to 4° around the point of fixation; this is significantly smaller than the radius of the visual field which extends approximately 60° upwards and inwards, 70° to 75° downwards and 100° to 110° outwards from the point of fixation (Harrington, 1981). The visual field is limited, as it is restricted by the anatomy of an individual's facial bones and the anatomy of the eye, namely the curvature of the cornea, the distance between an individual's cornea and iris, and the anatomy and physiology of the retina (Rantanen and Goldberg, 1999). It is important to note that the size of the UFOV does not remain constant but rather varies based on the nature of the perceptive task, the situation in which the task takes place (Sanders, 1970), and the state of arousal of the individual (Rogé et al., 2002a). It also varies according to individual characteristics, such as age (Rogé et al., 2008). External factors, such as the size of the stimulus, colour of the stimulus, contrast, movement, luminance and background luminance, all have a profound effect on the size of an individual's visual field (Engel, 1971; Engel, 1974).

It has been indicated that, with an increase in mental workload, there is a narrowing of the visual field although it is uncertain whether this occurs for the full extent of the visual field (Rantanen and Goldberg, 1999), as well as longer dwelling times and a reduction in saccade amplitude when observing an individual's eye movements (May et al., 1990). Rogé et al. (2003) state that with regard to time on task and driver drowsiness, the visual field decreases, especially in the peripheral area near the vertical axis in the field of vision, and according to Konstantopoulos et al. (2010), both central and peripheral attention alter with task experience. When an individual's visual field is reduced during driving, the driver is slower to detect critical signals or information and may not perceive them at all, which may ultimately result in an accident (Rogé et al., 2003). This is supported by Olsson and Burns (2000) and Martens and van Winsum (2000) who found response time to stimuli increases with a decrease in the driver's functional visual field size.

2.5.3 Peripheral Vision

The peripheral field of view occurs within an individual's visual field; the visual field is defined as the visible area in which targets/stimuli can be perceived without eye or head movement in the targets/stimuli's direction (Rantanen and Goldberg, 1999).

Mackworth (1965) refers to the visual field as the area around the point of fixation wherein information can be obtained and extracted rapidly during a visual task. It is an important aspect in human visual behaviour; it plays a major role during driving with regard to analysing the surrounding environment (Rogé et al., 2004). Peripheral vision can be affected by the size and shape of an individual's visual field (Rantanen and Goldberg, 1999), and is often used as an indicator of fatigue. A reduction of the peripheral field needs to be considered a sign of fatigue onset (Recarte and Nunes, 2003); this is emphasised by Ji et al. (2004), who explained that when an individual is fatigued, there tends to be a narrowing of the gaze pattern. The detection of simple peripheral stimuli is sensitive to the perceptual load in the central field as well as to the task load (Harms and Patten, 2003). A reduction in peripheral visual performance is independent from the angle of eccentricity, and some studies have even found that with a performance decrement there is an increase in retinal eccentricities (Voss, 1981).

Peripheral vision can be measured using a dual task method: an individual is given a central detection task (primary-task) and while performing the central task, a peripheral detection task (secondary-task) is introduced, in which stimuli are presented at varying eccentricities (Rogé et al., 2003; Harms and Patten, 2003). Jahn et al. (2005) explained that the performance of the secondary-task is a reflection of the change in resource demand of the primary-task and that, if the dual tasks are well matched, the secondary-task performance is found to be inversely proportional to that of the primary-task. The limitation to applying the dual task method is that the introduction of a secondary-task leads to interference with the primary-task, and thus can be considered obtrusive, causing a deterioration of the useful visual field (Chan and Courtney, 1994; Jahn et al., 2005). An individual's peripheral visual performance, which is obtained through the response time to the stimuli, increases, and the eccentricity of the stimuli that the individual is able to decipher decreases with an increase in situational demands (Rantanen and Goldberg, 1999). According to Rogé et al. (2002c) if the stimuli used to measure peripheral field performance are static then deterioration, with the duration of the task, occurs at the inner most eccentricities; whereas with dynamic stimuli the deterioration occurs at the outer most eccentricities of the visual field (Rogé et al., 2002b).

Many studies confirm that with an increase in environmental demands there is a decrease in the detection of peripheral stimuli, in which the left side of the visual field is affected to a larger extent than the right side (Harms and Patten, 2003). There are different forms of deterioration that can occur during peripheral performance; sometimes it is general interference, where the deterioration at all eccentricities is homogenous (Williams, 1988), in other cases the outer most eccentricity point is affected (Bartz, 1976). The latter is referred to as the tunnel vision phenomenon, whereas in instances where the inner most eccentricity point is affected, the phenomenon is referred to as inverted tunnel vision (Bartz, 1976). According to Ball et al. (1988), most researchers have found that the deterioration that occurs in peripheral visual performance with fatigue or increased workload correlates to that of tunnel vision; this may be due to reduced and minimally guided visual scanning (Miura, 1986). There are various methods by which to capture a driver's attention and present stimuli, one being stimulus-driven attentional capturing which can be achieved through the sudden onset of a stimulus; however, it must be noted that if an individual's attention is focused elsewhere, this may not occur and can result in impaired processing (Yantis and Jonides, 1984). With spatial gaze concentration, in which an individual's gaze is concentrated in the central field of vision, it may result in an impairment of stimuli detection, which in turn will affect the peripheral visual field to a greater extent; this is again the tunnel vision effect (Recarte and Nunes, 2003). Tunnel vision and a decrease in peripheral vision performance can also be brought about through an increase in mental workload (Rantanen and Goldberg, 1999) as well as prolonged monotonous simulated driving tasks (Rogé et al., 2002a).

2.5.4 Tunnel Vision

Tunnel vision, also known as tunnelling, is a restriction in the functional field of view and perceptual narrowing (Mills et al., 2001; Williams, 1995), and can be defined as a reduced aperture angle of the visual cone (Voss, 1981). Rogé et al. (2008), on the other hand, state that the phenomenon of tunnel vision occurs when the impaired performance of the peripheral task increases with the eccentricity of the peripheral stimuli. In this concept, the perceived cues or stimuli are progressively limited to the central visual field (Mills et al., 2001). Easterbrook (1959) illustrates tunnelling as a relationship between arousal and cognitive efficiency, using the classic inverted U-shape; where a restricted focus accompanies moderate emotional arousal levels and this benefits as irrelevant information is excluded and only relevant information is taken in. However, when high levels of emotional arousal are present this results in attentional mechanisms being overloaded and an individual’s ability to gather and process information is impaired (Easterbrook, 1959). Dirkin and Hancock (1985) disagreed, stating that tunnel vision or the term visual tunnelling should be replaced with the term cognitive tunnelling, as the impairment of the visual field is brought about by an increased cognitive workload and selective attention, and if stimuli located in the peripheral field were relevant to the performance of the centrally located task, there would be no adverse effects on performance. According to Rantanen and Goldberg (1999), the tunnel vision hypothesis states that a higher degree of impairment occurs for higher eccentricities; therefore, the degree of impairment that occurs is analysed as a function of the visual target’s eccentricity (Recarte and Nunes, 2003). Eccentricity is defined as “the visual angle between the target location and the actual gaze direction at the moment the target was activated” (Recarte and Nunes, 2003:127).

2.6 INDICATORS OF FATIGUE

Fatigue is portrayed to be a construct, with no universally accepted definition and thus cannot be measured directly; therefore, measurements of fatigue have to rely on the indirect measures of its effects (Williamson, 2009). Indirect measures comprise subjective indicators, such as self-reports and expert judgements (Brookhuis and de Waard, 2001), and objective indicators, including driving performance, response time, missed responses and changes in an individual’s physiological state, such as heart rate and heart rate variability (Williamson, 2009). According to Williamson and Friswell (2011) the circadian rhythm has an impact on objective measures of performance as well as on subjective performance and sleepiness ratings. Attempts have been made in respect to measuring fatigue objectively, as well as subjectively (Chalder et al., 1993). There have been several studies conducted, such as Gillberg et al. (1994) and Åkerstedt et al. (2005), which highlight a degree of association between subjective and objective fatigue manifestations (Jones et al., 2005). Morris and Miller (1996) affirm that fatigue can be categorised as subjective or objective/performance-related, where subjective fatigue includes feelings of discomfort or dissatisfaction, which accompanies activities of prolonged periods, while performance fatigue involves task performance decrements. It is known that one aspect may occur without the other, such that an individual may not feel fatigued but a performance decrement is reflected; alternatively, an individual may experience feelings of fatigue or discomfort that are not reflected in the individual's performance, which remains consistent (Brown, 1994). This is emphasised by May and Kline (1988) who state that fatigue is an objective inability to maintain a specific power output; however, it is not necessarily accompanied by a subjective feeling of fatigue.

2.6.1 Subjective Indicators of Fatigue

From a subjective perspective, fatigue can be seen as an output of a feedback system or mechanism which causes the body to avoid over-exerting itself and thus protects it from harm (Brown, 1982). Alternatively, it refers to a subjective nature of drowsiness (Brown, 1994). If subjective estimates of sleepiness and performance are accurate, the individual is the best placed to make decisions to avert accidents (Tremaine et al., 2010). It is imperative to obtain the subjective component of fatigue, and as such numerous questionnaires and rating-scales are applied to obtain information about fatigue, such as the time of appearance and other contributing factors (Lal and Craig, 2001). Subjective indicators are reasonable predictors of sleep onset and have been known to precede performance decrements (Dinges et al., 1997). Scott et al. (2006) found there to be significant correlations between an individual's self-reported mood and performance, indicating the possibility of mood-state as a useful predictor of performance. There are many self-rating scales, checklists and fatigue questionnaires available, such as the Karolinska Sleepiness Scale (KSS) (Åkerstedt and Gillberg, 1990), the Samn–Perelli Fatigue Scale (Samn and Perelli, 1982), the Wits Sleepiness Scale (WSS) (Maldonado et al., 2004) and the National Aeronautics and Space Administration-Task Load Index (NASA-TLX) (Hart and Stavenland, 1988). All questionnaire and rating-scale answers should be obtained at the end of a study at which stage symptoms of time on task fatigue are found to be most prominent (Lal and Craig, 2001).

a. Wits Sleepiness Scale (WSS)

The Wits Sleepiness Scale is a South African validated pictorial scale comprising five cartoon faces (Figure 5); an individual points to one of the five cartoon faces that best describes how they are feeling at that moment (Maldonado et al., 2004). In their study, Bieri et al. (1990) found that pictorial scales are well established as tools for depicting pain, especially with children. Based on these findings, Maldonado et al. (2004) designed a pictorial scale for the vastly diverse South African adult and child population, in which many individuals' home language is not English. This scale is useful as it allows for comparisons across languages, cultures and races as there is no word association on the scale, only cartoon faces (Maldonado et al., 2004). The scale has been validated against other established scales, namely the Karolinska Sleepiness Scale (KSS) and the Stanford Sleepiness Scale (SSS), and its utility assessed in practical situations (Maldonado et al., 2004). When the scale was developed, attention was paid to the eyes and facial features in order to eliminate any gender and ethnical features, thus ensuring its widespread application (Maldonado et al., 2004). An advantage of the Wits Sleepiness Scale is that no explanation or translation is required when applying it (Maldonado et al., 2004).

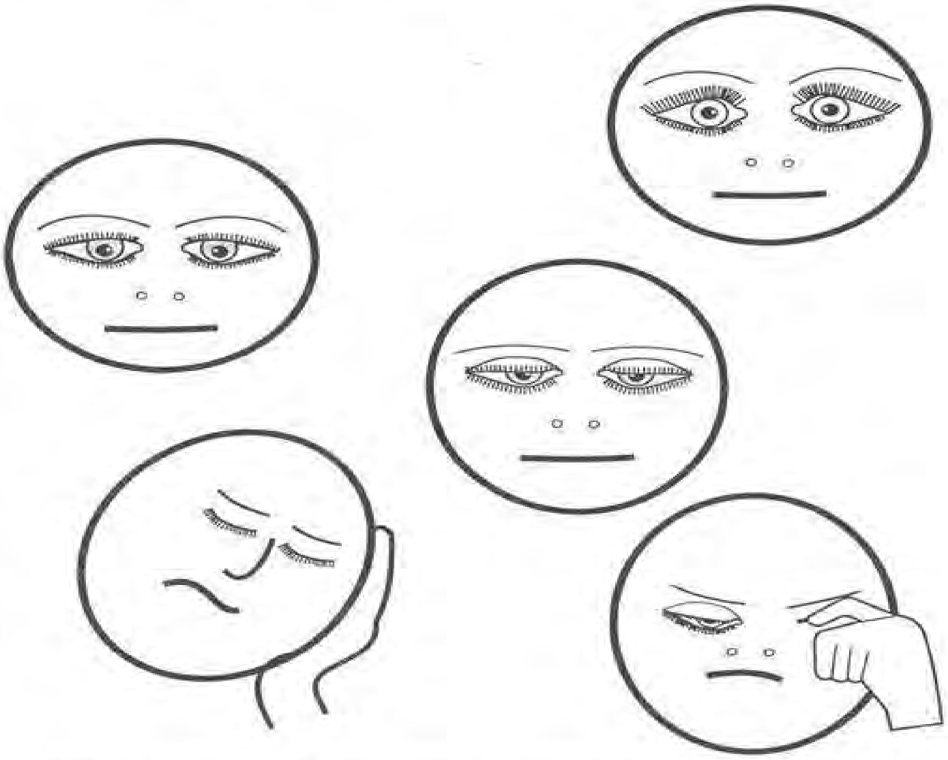
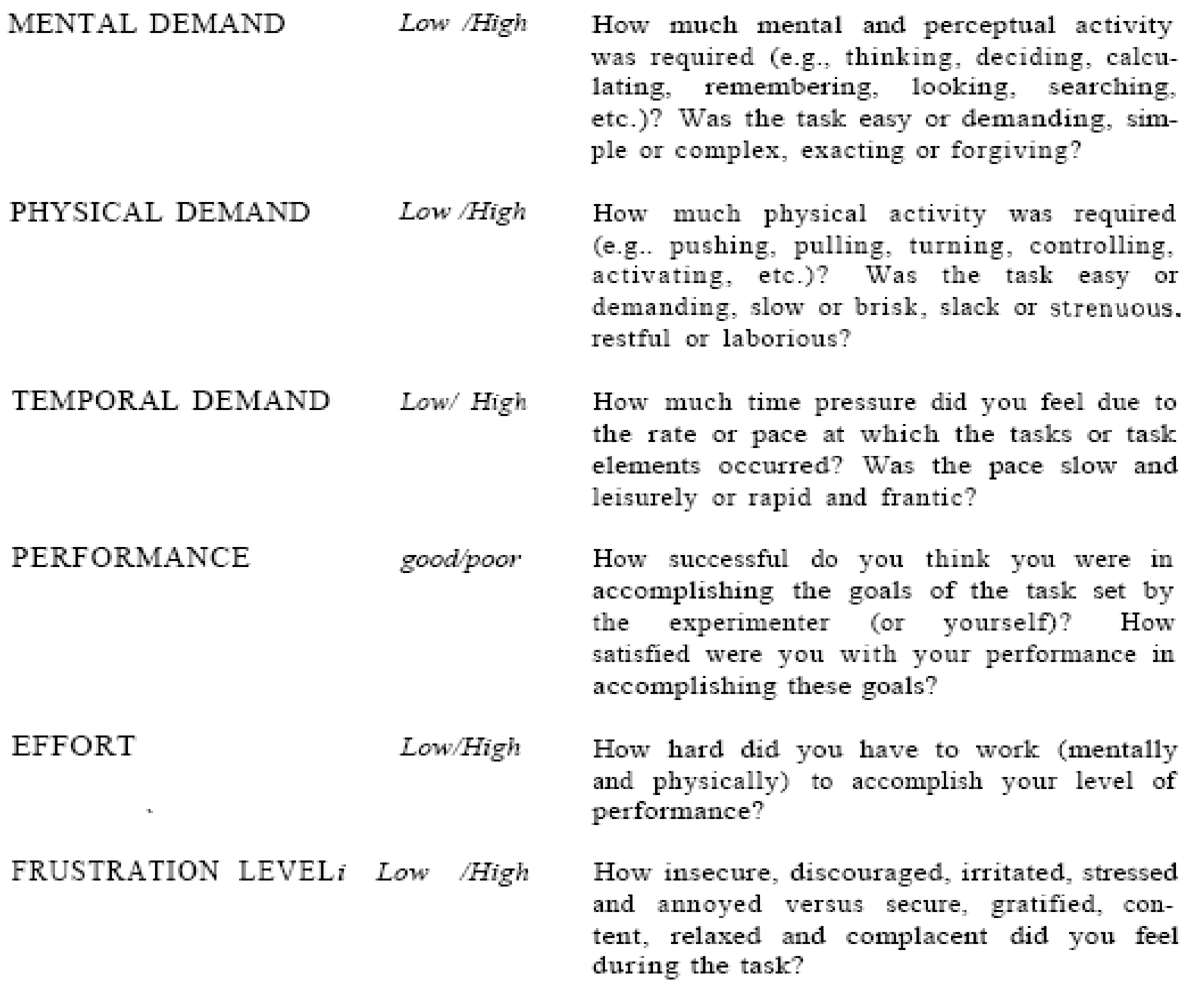


Figure 5: The five pictorial cartoon faces comprising the Wits Sleepiness Scale (adapted from Maldonado et al., 2004, pg 543).

b. National Aeronautics and Space Administration-Task Load Index (NASA-TLX)

The National Aeronautics and Space Administration- Task Load Index is a multidimensional, self-reported assessment technique which gives an overall estimation of the task performance and mental effort associated with the given workload (Hart and Staveland, 1988; Cao et al., 2009). It is one of the most valid subjective measures of workload, with a high user acceptance and small between-participants variability (Lan et al., 2010). Rubio et al. (2004) established that the NASA-TLX questionnaire possessed properties such as, sensitivity, diagnostic capabilities, selectivity, low intrusiveness and reliability, as well as ease of implementation. Studies such as Dillon et al. (2004) and Baulk et al. (2007) have used the NASA-TLX questionnaire as a fatigue indicator. It is sensitive and found to be more reliable than other subjective rating scales (Hill et al., 1992).

The questionnaire is filled out upon completion of a task, and consists of two parts, a rating section and a weights section (Cao et al., 2009). The overall score is calculated and weighted on the average ratings of six subscales, namely physical demand, mental demand, temporal demand, own performance, effort level and frustration level, to produce a global score (Rubio et al., 2004; Lan et al., 2010). Three of the subscales are associated with the demands placed on the individuals, namely mental, physical and temporal demand, while the others are more concerned with the interaction between the individual and the task, specifically performance, effort and frustration level (Cao et al., 2009). Each subscale is divided into twenty equal intervals, with labels reading from ‘Low’ to ‘High’ or ‘Good’ to ‘Bad’, individuals had to evaluate the task by indicating the contribution of each subscale (Dorrian et al., 2011), see Figure 6. This contribution is then converted into a rating score between 0 and 100 is attained for each of the six subscales (Rubio et al., 2004).



MENTAL DEMAND	*Low /High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low /High*	How much physical activity was required (e.g.. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous. restful or laborious?
TEMPORAL DEMAND	*Low/ High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	*good/poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL*i*	*Low /High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Figure 6: The definitions of the six subscales encompassing the NASA-TLX questionnaire (adapted from Hart and Staveland, 1988, pg 30).

When using subjective indicators, the advantages and disadvantages need to be carefully considered. Advantages of subjective indicators include allowance being made for those concerned to convey their experience feelings; they are easily obtained, non-invasive and require no complex knowledge, making them a popular choice when researching (Brookhuis and de Waard, 2001). Limitations of subjective indicators are that questionnaires cannot provide fluctuations in sleepiness from minute to minute and that self-rating scales cannot be considered to measure sleepiness per se (Lal and Craig, 2001). Individuals are sometimes unaware of internal changes and thus may not accurately reflect changes (Brookhuis and de Waard, 2001) Due to their limitations, subjective indicators should be coupled with more objective measures in order to maintain scientific validity and to identify fatigue (Lal and Craig, 2001).

2.6.2 Objective Indicators of Fatigue

Nilsson et al. (1997) identified objective indicators of fatigue, which include performance, electrophysiological and biochemical measures, while Wijesuriya et al. (2007) classify indicators of objective fatigue into performance decrement and physiological measures. These indicators can be seen through increasing lapses in performance, cognitive slowing, which causes a lowering of optimum performance, problems with memory, slowed response times and decrements related to the time on task as well as an inability to maintain the required vigilance in order to perform given tasks (Dinges and Kribbs, 1991).

2.6.2.1 Psychophysiological Indicators

Psychophysiological measures are those that attempt to measure an individual's physical tiredness, using factors such as time of day, or the cumulative effect of lack of sleep, also known as sleep debt (Johns, 2000), drowsiness and sleepiness (Wijesuriya et al., 2007). Even when an individual is experiencing low levels of fatigue, a reduction in physiological arousal, sensorimotor function decrements and impaired information processing, can all have a negative effect on one's ability to react to certain situations (Mascord and Heath, 1992).

a. Heart Rate (HR) and Heart Rate Variability (HRV)

Heart Rate

Heart rate is derived by the inherent rhythmicity of the sino-atrial (S-A) node; however the sympathetic and parasympathetic processes have an effect on the inter-beat-interval (IBI) of the heart (Mascord and Heath, 1992). According to Lacey and Lacey (1974), an increase in heart rate reflects internal attentional processes, while a decrease in heart rate is indicative of external attentional demands placed on an individual. Heart rate has been used as a fatigue indicator (Hartley et al., 1994; Lal and Craig, 2001), where it increases with task difficulty and under conditions of distraction, and decreases with decreased task difficulty and tasks involving elevated fatigue levels (Mascord and Heath, 1992). Factors affecting heart rate include age, body position and respiration (Jorna, 1992). It has also been found to be sensitive to changes in mental workload, emotional strain and physical activity (Jahn et al., 2005). Exercise and emotional excitement causes a release of noradrenalin near the S-A node, resulting in a sympathetic acceleration in an individual’s heart rate (Mascord and Heath, 1992).

Heart Rate Variability

Heart rate variability can be defined as the amount of heart rate fluctuations surrounding the mean heart rate of an individual (van Ravenswaaij-Arts et al., 1993). It is measured by analyzing the variations of the intervals that occur between consecutive normal heart beats and time series of beat to beat intervals (R-R intervals) (Patel et al., 2011). It is therefore the totality of changes over time (Pumprla et al., 2002; Jahn et al., 2005). Heart rate variability has been used as a measure of mental workload, especially for the effort used in tasks that require controlled processing, with a decrease in heart rate variability occurring under conditions of increasing effort levels and task complexity (Jorna, 1992; Mascord and Heath, 1992). Heart rate variability can be assessed in two ways, through time domain analysis or by spectral analysis (van Ravenswaaij-Arts et al., 1993). According to Malik et al. (1996), the time domain analysis is the simplest measure, which determines either the heart rate at any point in time or the intervals between consecutive normal complexes.

Time domain analysis consists of two types of heart rate variability indices, namely short term variability (STV), which indicates fast changes in heart rate, and long term variability (LTV), representing slower fluctuations in heart rate (van Ravenswaaij-Arts et al., 1993). On the other hand, spectral analysis, which indicates the distribution of variance as a function of frequency, entails the decomposition of the sequential R-R intervals into a sum of sinusoidal functions of various amplitudes and frequencies through appropriate mathematical algorithms (van Ravenswaaij-Arts et al., 1993; Malik et al., 1996). Short term recordings, of 2–5 minutes, reflect three main spectral analysis components, very low frequency (VLF), low frequency (LF) and high frequency (HF) (Malik et al., 1996). By analysing the LF and HF bands, as well as through the LF/HF ratio, the fatigue state, mental load, stress, strain and arousal levels of an individual can be determined (Sammer, 1998; Patel et al., 2011). However, there have been studies where heart rate variability has failed to reflect anything (Mulder, 1992).

Body position, physical fitness, age and respiration all have an effect on an individual's heart rate and heart rate variability (Jorna, 1992).With regard to driving it has been established that with a decrease in driving performance there is an increase in heart rate variability, coupled with feelings of fatigue; and this change in heart rate variability can be seen as a decrease in an individual's alertness and an increase in fatigue levels (Mascord and Heath, 1992; Lal and Craig, 2001; Oran-Gilad and Ronen, 2007). For the purpose of this study, heart rate variability coefficient will be used, as it reflects an individual's level of arousal (Bonnet and Arand, 1997).

b. Critical Flicker Fusion Frequency (CFFF)

The physiological basis for which perception of flicker/fusion lights can be perceived by a human is located in the cerebral cortex of the brain, and thus the perception of the flashes depends on the arousal level of the retina (Łuczak and Sobolewski, 2005). The critical flicker fusion frequency (CFFF) examines the central nervous system's ability to process information; some studies, such as the one conducted by Kishida (1973), have indicated success in relating it to fatigue, while others, such as Nilsson et al. (1997), have not. The critical flicker fusion frequency (CFFF) threshold is observed when an individual subjectively identifies a flickering light as a steady, non-flickering light (Smith and Misiak, 1976; Wells et al., 2001; Łuczak and Sobolewski, 2005). Seitz et al. (2006) define CFFF as the lowest rate of continuous flicker that an individual subjectively perceives as a steady source of light. A CFFF threshold test can be conducted in an ascending or descending fashion (Łuczak and Sobolewski, 2005). The ascending method is conducted such that the lowest frequency reading (Hz) is recorded when the individual perceives the flickering light to be a solid light, in lay terms from flickering to fusion; whereas for the descending method, the threshold is obtained at the highest frequency (Hz), when the individual indicates that the solid light is a flickering one, more simply from fusion to flickering (Smith and Misiak, 1976; Łuczak and Sobolewski, 2005).

According to Baschera and Grandjean (1979) and Weber et al. (1980), a decrease in the CFFF threshold value is indicative of a decrease in the arousal and consciousness levels of the brain. It has been stated that the critical flicker fusion frequency (CFFF) might be a useful indicator of fatigue for the central visual system or mental fatigue (Maas et al., 1974; Łuczak and Sobolewski, 2005), but not as an indicator of fatigue for the peripheral visual system (Curran et al., 1990). CFFF is known to be affected by factors such as target luminance, target colour, target shape, target size, place on the individuals retina where the light is perceived (retinal eccentricity) and light intensity (Landis, 1951). An individual's psychological response bias, which is difficult to control during testing, can also have a resultant effect on the CFFF threshold (MacNab et al., 1985).

c. Core Body Temperature

Body temperature has been used as an indication of fatigue, as core body temperature follows the circadian rhythm, where the minimum body temperature rhythm occurs between 3am and 5am daily (Rosekind et al., 1994), and peaks in the late afternoon/early evening (Johns, 2000). Childs et al. (1990) and Klein et al. (1993) found tympanic temperature to be an accurate reflection of core body temperature, whereas Fulbrook (1997) found no correlation between core temperature and tympanic temperature. Tympanic temperature calculates an individual's body temperature by measuring the infrared radiation expelled by the tympanic membrane and auditory canal (Chamberlain et al., 1995). A drop in core body temperature during the evening is associated with sleep, low motor activity, decreased alertness, performance decrements and worsened mood states (Rosekind et al., 1994; Bentley, 2007). The inhibition of melatonin secretion during the night is responsible for a decrease in core temperature, the same as for the circadian cycle (Bentley, 2007). Using tympanic temperature is advantageous as it is easy to use, quick, non-invasive and hygienic when compared to other means of measuring temperature (Chamberlain et al., 1995; Moran et al,. 2007). Care should be taken when using body temperature measures, other than the pulmonary artery (PA), to indicate the circadian rhythm and core temperature, as other factors can influence and alter an individual's core body temperature, such as food intake, photic stimulation and physical activity (Myers and Badia, 1995; Moran et al., 2007).

d. Oculomotoric Indicators

The analysis of an individual’s eye movements allows insight into how the individual processes the visual scene while driving; this information is important as it is not consciously available to the driver to report on (Chapman et al., 2002). The use of oculomotoric parameters as indicators of fatigue have been shown to be sensitive to time on task, which is linked indirectly to the onset of drowsiness in task environments that are monotonous (Van Orden et al., 2000).

Blink Frequency and Blink Duration

Eyelid movement (blink frequency and duration), pupil movement and gaze patterns are other oculomotoric parameters that reflect an individual’s level of fatigue (Caffier et al., 2003; Ji et al., 2004). When looking at eyelid movement there are two ocular measures that can indicate fatigue, namely percentage of eye closure over time (PERCLOS), blink duration, and the average eye closure speed (ACES), blink frequency (Ji et al., 2004).

Blink Frequency

Blinking is required for the lubricating and cleansing of the corneal surface; many blinks are controlled by the central nervous system, however some can be affected by the environmental surroundings, such as humidity (Stern et al., 1994a). When the frequency of eye blinks increases, it is indicative of fatigue, because with an increase in fatigue the ability to inhibit blinks is compromised (Stern et al., 1994a). An increase in blink frequency is also associated with increased time on task; however, not all studies have found this to be accurate (Stern et al., 1994a). Fatigue is only one of many variables that have an effect on an individual’s blink rate (Stern et al., 1994a). Other factors include the level of task demand, as well as stimuli timing and presentation, in which predictable intervals of stimuli presentation result in blink frequency being externally paced, while unpredictable stimuli presentation causes a decrease in blink frequency (Sirevaag and Stern, 2000). A detection task, where the target activation is uncertain, can cause response times of several seconds because, when the target appears, an individual’s gaze may be directed elsewhere, the individual may be blinking, or more information may be required before a response is elicited (Recarte and Nunes, 2003). According to Stern et al. (1994b) an individual’s blink frequency is related to the visual demand required by the task. Tasks which place a greater visual demand on the individual result in a greater blink inhibition when compared to less visually demanding tasks (Sirevaag and Stern, 2000).

Blink Duration

It has been stated that PERCLOS is a more reliable technique to use, as it has been validated as the most valid ocular parameter for assessing fatigue levels in an individual (Dinges et al., 1998). It has been found that the assessment of blink duration shows significant effects for time on task under numerous conditions (Sirevaag and Stern, 2000). Blink duration is seen as the period of time in which the pupil is obscured by the eyelid during a blink (Sirevaag and Stern, 2000). During this time, it can be stated that no information can be acquired due to the eye being closed. Different studies set different criteria for eye closures in order to distinguish between eye blinks and eye closures; this can vary between 300 milliseconds and 1000 milliseconds (Sirevaag and Stern, 2000; Stern et al., 1994b). The shape of the pupil can indicate the degree of eye opening, as when an individual's eyes start to close the pupils change shape and become more elliptical (Ji et al., 2004). Higher levels of sleepiness and an increased time on task have been linked to longer eye blink durations (Caffier et al., 2003; Åkerstedt et al., 2005).

Unfortunately, few studies have been conducted on the evaluation of visual fatigue or on the load of the visual task (Ohtani, 1971). This is reinforced by Porcu et al. (1998) who acknowledge that there is a lack of studies conducted on the effects of circadian factors, sleep deprivation, sleepiness, and altered sleep-wake schedules, using oculomotoric parameters.

2.6.2.2 Performance Indicators

Performance indicators focus on an individual's diminished alertness, which leads to impaired competence and willingness to perform a task (Kroemer and Grandjean, 1997). It also results in reduced cognitive and psychomotor skills (Williamson et al., 1996). Performance for sustained periods of time is required during driving, and this usually requires more effort cognitively than physically (Brown, 1994). Cognitive effort requires prolonged vigilance, selective attention, complex decision making and intermittently perceptual-motor control skills (Lal and Craig, 2001). Cognitive slowing or distraction during driving can be seen when a driver's thoughts absorb the driver's attention such that the driver is unable to navigate through the road network in a safe manner (Williamson, 2009). This is accompanied by a slowed reaction time (Williamson, 2009). However, it must be affirmed that performance is significantly dependant on the task given, as well as the motivational context in which the experiment occurs (Nilsson et al., 1997).

a. Driving Performance

The level of vigilance of a driver can be associated with the behaviour of the vehicle that the driver is operating, such as speed, lateral position (lane deviation), turning angle and if the driver changes course (Ji et al., 2004). There are limitations to implementing these techniques as they can be affected by vehicle type, driver experience and driving conditions (Ji et al., 2004). Driving performance is affected by overload and underload conditions, where driving under monotonous and prolonged conditions leads to a deterioration in an individual's ability to guide the vehicle (Verwey and Zaidel, 1999; Thiffault and Bergeron, 2003a; Richter et al., 2005). An increase in corrective steering wheel movements may be indicative of an increase in effort spend on the driving task (Johansson et al., 2008). Lane deviation increases with an increased time awake and time on task (Åkerstedt et al., 2005; Porter, 2011), therefore it can be used to indicate an individual's level of fatigue, as lane deviation is greater in a state of sleepiness compared to in an alert state (Arnedt et al., 2001; He et al., 2011).

b. Memory Performance

With memory tests, a performance decrement is associated with fatigue (Lal and Craig, 2001), as fatigue affects an individual's working memory, resulting in performance decrements (Tyagi et al., 2009). This is reiterated by Babkoff et al. (1988), who state that fatigue impairs performance in various components, such as memory. When establishing the effects that circadian rhythm has on memory performance, Reilly and Waterhouse (2009) found that a minimum is reached during the temperature nadir. Hockey et al. (1972) established that long term memory performance was better during the night than during the morning; however, research conducted on short term memory effects have indicated mixed results with the circadian rhythm (Williamson et al., 2011). In a study by Wyatt et al. (1999), a circadian effect was not found, but it was seen that short term memory decreased with time since waking. A problem with implementing these types of tests is that the heavy demand placed on the individual causes an increase in the level of cerebral activity and in turn temporarily masks signs of fatigue (Grandjean, 1979).

c. Response Time (RT)

Response time is the time that elapses between the presentation of a stimulus and the appearance of a response to the stimulus (Drowatzky, 1981), and reflects the speed with which an individual can perceive and respond to the environment (Drowatzky, 1981). Response time can be induced by either the presentation of light, sound or touch stimuli (Singer, 1968). There are several components encompassing response time, such as the time taken for mental processing, movement time and the device's response time (Green, 2000). A latent period occurs from the presentation of a stimulus to the time the impulse reaches the correct destination; therefore, the further the impulse has to travel through the body, the longer the period of latency (Drowatzky, 1981). There are two types of response time, namely choice and simple response time. Choice response time occurs when there is a choice of responses to be made as a stimulus appears (Wickens, 1984). Simple response time involves providing an individual with one response that (s)he needs to make as soon as a stimulus appears or occurs (Wickens, 1984). Welford (1980), Williamson et al. (2001) and Horowitz et al. (2003) found that simple response times get slower with fatigue, sleep deprivation and time of day. An increasing time awake also results in deterioration in response time (Baulk et al., 2008). Choice response time is usually longer than simple response time (Wickens, 1984), and the deterioration in response time is greater for more complex tasks than for simple tasks (Singleton, 1953). There are four major variables that influence response time speed, namely stimulus modality, stimulus intensity, temporal uncertainty and expectancy (Wickens, 1984). With regard to stimulus modality, simple response time to visual stimuli is approximately 170 msec with this response time decreasing with an increase in intensity of the stimulus (Wickens, 1984). Temporal uncertainty involves the degree of predictability of when the stimulus will occur; if the occurrence can be predicted there will be an increase in response speed (Wickens, 1984).

Response time can be influenced by factors such as age, sex, learning, fatigue, distractions and motivation as well as physical and mental abilities. It can, however, also be influenced by the task variables, such as the nature and complexity of the stimulus and the complexity of the task at hand (Drowatszy, 1981). Studies that have investigated gender as a variable influencing response time have discovered that males have lower response time values than females (Drowatzky, 1981). It was found that mental fatigue, namely sleepiness, had the greatest effects on response time (Welford, 1980). Distractions, such as background noise lengthen an individual's response time by inhibiting parts of the cerebral cortex (Trimmel and Poelzl, 2006). Brebner and Welford (1980) showed that visual stimuli perceived by different parts of the eye result in different response times. The fastest response times are elicited when the individual is looking straight at the stimulus, thus the stimulus is seen by the cones; however, if a stimulus is picked up by the rods the individual's response time will be slower (Ando et al., 2002).

Response speed will increase with the number of times the same response is repeated; this is referred to as a learning effect or learn-by-doing (Teplitz, 1991). It has been noted that a spontaneous or induced change in an individual's body temperature is conversely proportional to a change in the individual's reaction time (Monk et al., 1996). The use of response tests as indicators of fatigue have been appraised in different ways. On the one hand, response tests are stated to show changes in performance levels, with increased response times as a defining criterion of sleep onset; this was supported by Kribbs and Dinges (1994) who stated that functional sleep onset is, by definition, performance based. On the other hand, it has been found that response time tasks are insensitive to fatigue (Gillberg et al., 1996).

d. Missed Stimuli

When there is an increase in the number of missed responses it could be attributed to tunnel vision (Bartz, 1976) as well as fatigue (Jorna, 1992). According to Martens and van Winsum (2000), an increased workload results in an increased number of missed signals. The effects of time on task can lead to an increase in the percentage of missed signals, as well as an increase in the number of false alarms incurred (Chinn and Alluisi, 1964; Ahsberg et al., 2000; Boksem et al., 2005). During prolonged tasks, it has been found that there is an increase in the number of missed stimuli, both centrally and peripherally, due to a decrease in an individual’s alertness levels (Rogé et al., 2009), regardless of the stimuli eccentricity (Rogé et al., 2004).

e. Number of Saccades

Saccades can be defined as fast eye movements which are elicited to catch an image of interest on the fovea at a rapid speed (Crevits et al., 2003). There are different parts of the brain involved in the generation of saccades, for example, the colliculus superior is crucial for the generation of reflective or reactive saccades, although this structure is inhibited by the dorsolateral prefrontal cortex if a reflexive saccade needs to be prohibited (Crevits et al., 2003). The evaluation of saccades has become an interesting tool in sports as well as in a number of neurological and psychiatric diseases (Crevits et al., 2003). It can also be used in industry to analyze or prevent fatigue, as when the numbers of saccadic eye movements, per unit time, are counted, it indicates the requirements of visual tasks for workers (Ohtani, 1971). Saccades occur too fast to be corrected based on sensory feedback received during the movement and thus it is easy to establish if the worker is fatigued, which is indicated by slower saccadic eye movements (Becker, 1989).

It was found by Bahill and Stark (1975) that fatigue produces glissades, double saccades and low- velocity, non-main sequence saccades, which may account for the apparent decrease in the saccade peak velocity. Different types of saccades can be distinguished; reflexive or exogenous saccades are externally triggered by a target that appears suddenly within an environment (Crevits et al., 2003). Cotti et al. (2007) refer to reflexive saccades as reactive and these are said to be elicited in reaction to the sudden appearance of a salient visual element. In contrast, voluntary or intentional saccades are internally triggered and are made with a goal to redirect the individual’s gaze between permanently visible objects (Crevits et al., 2003; Cotti et al., 2007). There are two types of voluntary or intentional saccades, namely voluntary pro-saccades, which are made in the direction of the target anti-saccades, which are made in the opposite direction to a suddenly appearing visual stimulus (Crevits et al., 2003). Based on studies previously conducted on saccades and cognitive tasks, it has been stated that voluntary saccades, due to being frontally mediated, should be more affected than reflective or reactive saccades after sleep deprivation (Crevits et al., 2003).

With regard to driving, it has been established that the number of eye movements increases with increased complexity and demands of the visual field, which corresponds with a decrease in mean fixation duration (Erikson and Hörberg, 1980). This increase in eye movements, which is required to detect stimuli, reflects a narrowing of the visual field (Rantanen and Goldberg, 1999); however, Owsley and McGwin Jr (2010) state that, even though visual field impairment occurs, not all aspects of driving performance are compromised. This is supported by Chapman and Underwood (1998) who found that mean fixation duration increased on rural roads and decreased when driving through urban streets; this can be attributed to the fact that there is a greater visual complexity associated with urban streets as opposed to rural roads.

2.7 SUMMARY AND RATIONALE BEHIND CURRENT STUDY

In summary, fatigue is a construct which has no universal definition (Dawson et al., 2011) and the meaning of fatigue is therefore dependant on the study in which it appears (Williamson et al., 2011). It needs to be reiterated that, for the purpose of this paper, use of the term fatigue will refer to the biological drive for recuperative rest (Williamson et al. (2011). Fatigue is a by product of factors such as task demands, time on task, sleep deprivation, the circadian rhythm and homeostatic sleep pressure. These factors affect the transport industry to a large extent, as one of the main causes of motor accidents is driver fatigue (Lal and Craig, 2001; Oggero et al., 2006). Fatigue affects performance, as well as the useful field of vision, which could have implications when observing critical signals during driving (Williamson et al., 2009). Based on this it is imperative to establish the degree to which the peripheral visual field is affected when fatigued, as well as whether performance decrements occur at the same rate as the peripheral visual field decrements. Therefore, this study set out to determine the effects that fatigue, induced through time of day and time on task, has on a driver’s peripheral visual field. For the purpose of this research, the term time of day will be used, as infrequent measures were obtained during the 24 hour day and thus the term ‘circadian’ does not apply (Williamson et al., 2011).

CHAPTER III

3 METHODOLOGY

3.1 BACKGROUND

Visual cues provide 90% of the information a driver requires during driving (Hills, 1980), so it is imperative that drivers have a fully functional and clear visual field at all times, as any defect in an individual’s visual field can lead to accidents (Lövsund et al., 1991). If a driver’s visual field is reduced, it results in slower detection rates or even missed signals, which can result in accidents (Rogé et al., 2003). An individual’s normal field of vision allows for the early detection of objects situated in the peripheral visual field (Lövsund et al., 1991). According to McKee and Nakayama (1984), most measures of the visual field reflect a decline with increasing retinal eccentricities. It must be noted that the size of an individual’s visual field does not remain constant but rather varies depending on the situational demands and the task at hand (Rogé et al., 2003). With prolonged monotonous tasks, when a driver feels drowsy and during tasks involving increased mental workload, the visual field deteriorates into what is known as “tunnel vision” (Rantanen and Goldberg, 1999; Rogé et al., 2003). Numerous studies, such as those by Martens and van Winsum (2000), Mills et al. (2001) and Rogé et al. (2003), have been conducted that indicate tunnel vision occurs in the central visual field when a driver is fatigued; however, there is limited research on how the peripheral visual field is affected with the onset of fatigue and whether the peripheral visual field follows the same decrease as driving performance with the onset of fatigue. Therefore, the focus of this study is to determine the extent of the effects fatigue has on a driver’s peripheral visual field and whether driving performance and the peripheral visual field, measured through peripheral visual performance, decrease at the same rate when a driver is fatigued.

3.2 EXPERIMENTAL DESIGN

The design of this research was based on fatigue induced through time of day and time on task and the only difference between the two conditions was the time at which the testing session commenced, as the task duration was held constant. All participants attended two testing sessions, one during the day and one during the night (repeated measure design). During the testing session, they performed a continuous driving task together with a stimulus response task, using the peripheral visual modality.

The Day Condition occurred from 09h00 to 11h00, while the Night Condition occurred from 23h00 to 01h00. The times of the testing session were established based on the circadian phases. It has been shown that performance is best during the morning and late afternoon, indicative of a circadian upswing, while being poor during the early afternoon and the night, depicting a circadian downswing (Smiley, 1990). Within a 24 hour cycle two major nadirs occur, which result in decreased alertness and performance; the stronger of the two nadirs occurs during the night between 10pm and 8am, with the peak occurring around 4am (Rom and Markowitz, 2007). For each participant, a minimum of one day was afforded between the conditions in order for the subject to rest and recover completely. According to Brown (1994), under sleep restricted regimes, individuals can perform reasonably well as long as 4 to 5 hours of sleep are attained per day. A study conducted on 1–3.5 days total sleep deprivation indicates that the negative effects of sleep loss on alertness and performance can be reversed through one to two days in which 8–12 hours sleep is obtained (Wesensten et al., 2005). This is reiterated by Lamond et al. (2007), who state that one night of sleep deprivation is recoverable through 9 hours nocturnal sleep. Participants were only exposed to an accumulation of sleep pressure over the day of Night Condition and no sleep deprivation per se; therefore it can be argued that if one full night sleep is sufficient for recovery in sleep deprivation studies, then one full night sleep between test sessions was more than adequate to ensure the alleviation of the accumulated sleep pressure so that participants were rested and able to perform the task at hand. Participants had to wake up at 07h00 at the latest on the morning of the Day Condition test session to ensure the elimination of any effect that sleep inertia, which occurs after awakening from slow wave sleep

(Purnell et al., 2002), may have had on the results. According to Rosekind et al. (1995) the effect of sleep inertia can vary from a few minutes to half an hour after awakening, therefore awakening 90 minutes prior to test session was seen as sufficient time for any sleep inertia effects to elapse. Participants were not permitted to take any naps at any time during the day of their Night Condition test session; this was to ensure that any differences found during the Night Condition might be attributed to time of day effects coupled with homeostatic sleep pressure. If, however, participants had been permitted to nap, accurate effects would have been unattainable as sleep pressure is resolved through sleep (Borbély and Achermann, 1999).

Each condition was based on a dual task concept, where the primary task was a driving task and the secondary task involved responding to peripheral stimuli. The primary driving task was performed for 90 minutes continuously; therefore no breaks were permitted during this time. The primary driving task duration was ascertained through pilot tests (see Appendix C1, section 8.3.1). The participants were instructed to track the white middle line of a curvy road as accurately as possible without removing their eyes from the road. The curvature of the road was selected based on pilot tests (see Appendix C2, section 8.3.2) and literature, which states that drivers are more likely to deviate from their lane position on a straight road rather than a curvy road (Oran-Gilad and Ronen, 2007). According to Hancock et al. (1990), a curvy road imposes a higher demand on the subject, which would cause an earlier onset of fatigue, as it requires more attention resources (Baldauf et al., 2009).

3.3 HYPOTHESES

3.3.1 Research Hypotheses

The purpose of this research project was two-fold.

Firstly, to investigate the effect of time of day and homeostatic sleep pressure on a driver’s peripheral visual field, driving performance, psychophysiological and subjective parameters. In this regard, it was hypothesised that there would be differences established in all measures, with regard to the Day and Night Conditions.

Secondly, to establish the effect time on task has on a driver's peripheral visual field, driving performance, psychophysiological and subjective parameters. It was hypothesised that there would be no change for all measures between the beginning and the end of the testing session.

3.3.2 Statistical Hypotheses

Hypothesis 1: The null hypothesis states that there is no difference between the Day and Night Conditions, with regard to performance, psychophysiological and subjective responses. The alternate hypothesis states that there will be a difference between the Day and Night Conditions, regarding performance, psychophysiological and subjective responses.

Hypothesis 2: The null hypothesis states that all performance, psychophysiological and subjective parameters obtained would remain unchanged between the beginning and the end of the test session. The alternate hypothesis states that all performance, psychophysiological and subjective parameters obtained will differ between the beginning and the end of the test session.

3.4 DEPENDENT VARIABLES

Various measures were obtained during the test sessions and divided into objective and subjective indicators. Objective indicators included all performance and psychophysiological measures, while subjective indicators included self-rating scales and questionnaires. Performance measures recorded throughout the main task included driving performance (lane deviation), the number of saccades, response time to peripheral stimuli and the number of missed responses to peripheral stimuli, while memory performance and ascending critical flicker fusion frequency (CFFF) threshold were recorded before and after the main dual task. Psychophysiological measures obtained for the duration of the main task included heart rate, heart rate variability, eye measures, specifically blink frequency and blink duration, with tympanic temperature obtained before and after the main task. Subjective measures were used, namely the Wits Sleepiness Scale, recorded before and after main task and the NASA-TLX questionnaire, which was completed at the end of each test session.

3.4.1 Psychophysiological Analyses

a. Heart Rate (HR) and Heart Rate Variability (HRV)

Heart rate and heart rate variability are non-invasive methods that can be used to assess an individual’s state of fatigue (Patel et al., 2011). Heart rate was used as a fatigue indicator in the study based on its ease of measurement and because it has been found to decrease with tasks involving elevated fatigue levels (Jorna, 1992; Mascord and Heath, 1992). According to Patel et al. (2011), heart rate variability provides useful data indicating when fatigue becomes a problem. An increase in heart rate variability is reflected by a decrease in performance; this change in heart rate variability can be seen as an increase in fatigue levels (Oran-Gilad and Ronen, 2007). Therefore, heart rate and heart rate variability would reflect whether a difference in the level of fatigue exists between the different conditions. Suunto T6 heart rate memory belts were used to record the participants’ cardiac responses throughout both test sessions. Located in the electrode of the heart rate belt was a microchip that was responsible for recording and storing all the heart rate data.

b. Eye Measures

During the research, two eye measures, namely blink frequency and blink duration, were of interest. All were measured using a 25 hertz head mounted eye tracker (Dikablis) incorporating two cameras. One camera was aimed in the direction of the individual’s eye (eye camera). This detected the cornea reflex and identified the pupil, then recorded the pupil movements and produced x and y axis coordinates of the eye movements. The second camera was directed in the direction of the participant’s gaze (field camera) and recorded the field of view. The eye tracker is comprised of three subunits, 1) head unit, 2) receiver and 3) recorder, as illustrated in Figure 7.

Figure 7: Dikablis eye tracking system

The head unit (Figure 7) is comprised of two cameras, which captured the image of the left eye and the field of view respectively. The eye detection camera was situated just above the left cheek bone, while the field view camera was situated just above the nose support; this latter camera provided a coloured wide angle picture depicting the participant’s field of view.

The head unit transfers the video information to the receiving unit, which then transfers the information to the recording unit. The recording unit contains a special frame grabber card which digitises the analogue PAL signals in real time and saves the information to hard disc. The head unit consists of three parts, the forehead device, the camera mount with a nose support and two cameras. The forehead device consists of all the electronics, such as the radio transmitter and the power control. The weight of the head unit is supported using the nose support. The head unit is kept secure on the subject’s head with an elastic retaining band. The head unit has a power cable that attaches to the power supply (Figure 8).

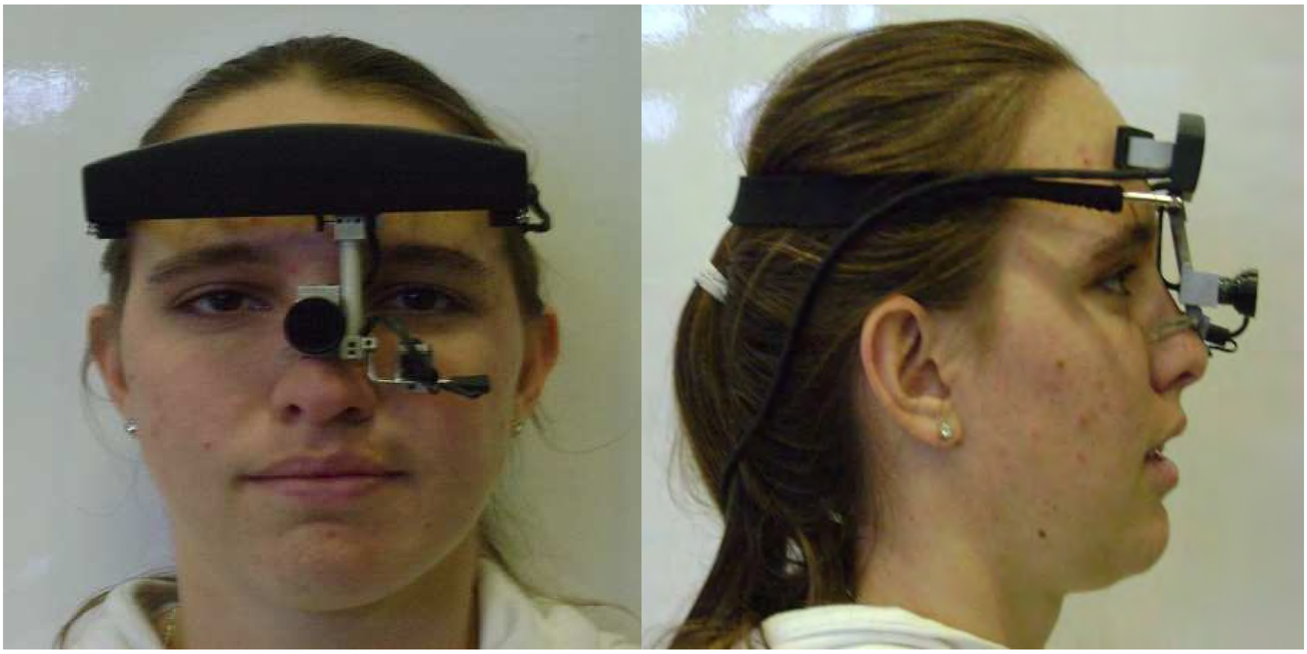


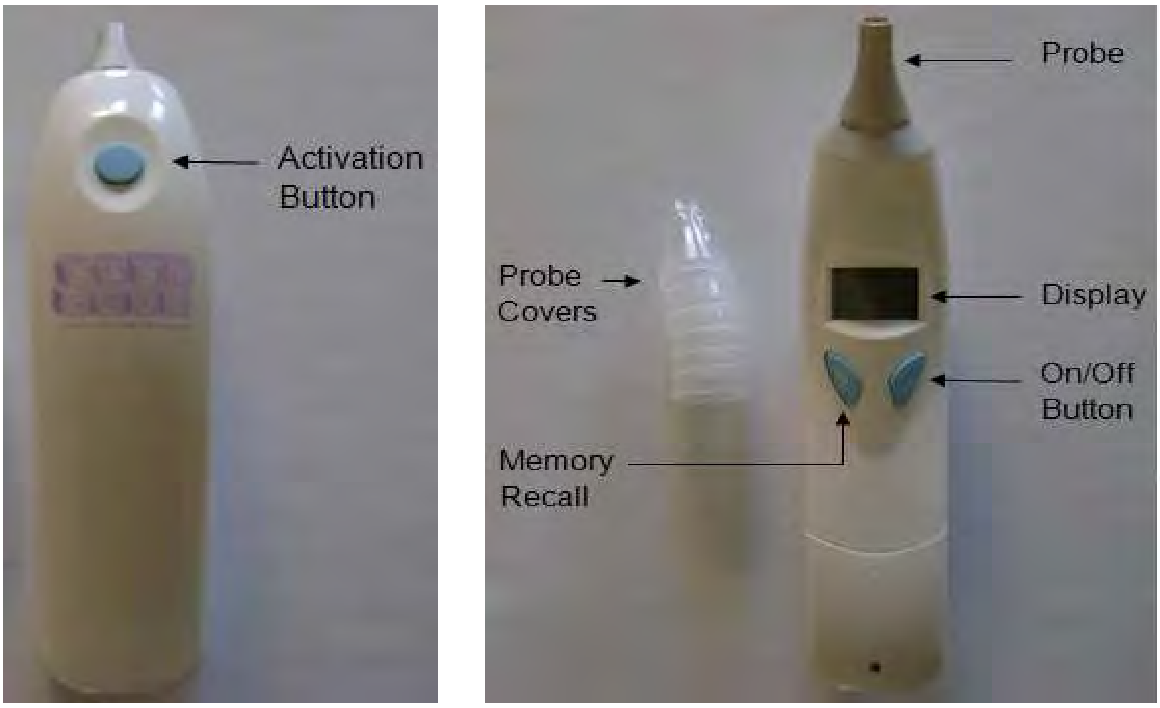
Figure 8: An anterior and profile image illustrating how the head unit is fitted to a subject.

The two eye measures were chosen as fatigue indicators based on literature, which stated that an increase in the frequency of eye blinks is indicative of fatigue (Stern et al., 1994a) and longer eye blink durations are linked to higher levels of sleepiness and an increased time on task (Caffier et al., 2003; Åkerstedt et al., 2005).

c. Core Body Temperature

Core body temperature can provide vital information regarding an individual’s circadian rhythm, following that, body temperature has been used as an indication of fluctuations in the 24 hour circadian cycle. Although core body temperature can be influenced by other factors, such as food intake and physical activity (Myers and Badia, 1995), a drop in core body temperature results in a decrease in alertness, which subsequently brings about feelings of fatigue, low motor activity and performance decrements (Rosekind et al., 1994). This study made use of tympanic temperature, a non-invasive method, which is obtained by measuring infrared radiation from the tympanic membrane and surrounding tissue of an individual’s ear (Chamberlain et al., 1995). Tympanic temperature reflects core temperature and is an easy, quick, safe, hygienic and affordable method to use (Childs et al., 1990; Chamberlain et al., 1995). A Baby Club Digital Ear Thermometer (Figure 9), with a fitted disposable ear probe cover, was used to acquire a tympanic temperature reading at the beginning and end of each test session. Tympanic temperature was taken three times consecutively, from the subject's right ear. According to Childs et al. (1990), at least two measurements should be obtained and the readings were restricted to the right ear as this limited the temperature variation between the two ears (Childs et al., 1990). A normal temperature range when using the Baby Club Digital Ear Thermometer is between 35.8 and 38℃, however this range decreases as age increases (manual for the Baby Club Digital Ear Thermometer). Participants taking part in the research were between the ages of 19–33 years and therefore, according to the manual for the Baby Club Digital Ear Thermometer, a normal temperature range for individuals aged between 11 and 65 years is 35.9–37.6℃.

Figure 9: The infrared Baby Club Digital Ear Thermometer used to measure tympanic temperature.



Care must be taken when using tympanic temperature as a representative of core temperature because other factors, such as ear infections and whether a subject has recently been lying on the ear from which the readings are obtained, may alter the temperature readings (Fulbrook, 1997).

d. Critical Flicker Fusion Frequency (CFFF) Threshold

Visual and mental fatigue of the participants was measured using the CFFF threshold, in which a pair of modified binoculars was used. Critical flicker fusion frequency (CFFF) can be used to determine whether an individual is visually fatigued or not (Maas et al., 1974) and according to Weber et al. (1980) a decrease in the CFFF threshold value is indicative of a decrease in the arousal and consciousness levels of the brain. It has been stated that the CFFF can be used as a measure of fatigue for the central visual system or mental fatigue (Maas et al., 1974), but it is not a reliable indicator of fatigue for the peripheral visual system (Curran et al., 1990). The far end of the pair of binoculars was darkened using covers, thus ensuring that no ambient light could enter and affect the CFFF threshold results. The subject had a monocular observation of one white light-emitting diode (LED) in their right visual filed, whereas the left visual field observed darkness. For the purpose of this research, the CFFF threshold was used as confirmation that the participants state of fatigue differed between the two conditions as well as between the pre- and post-critical flicker fusion frequency threshold tests and not as an indicator of peripheral visual fatigue.

3.4.2 Performance Analyses

a. Response Time and Error Rate of Peripheral Stimuli

A simple response time test was used in which the participant’s response time to the peripheral stimuli, presented throughout the 90 minute driving task, was used as a psychomotor performance indicator. Mascord and Heath (1992) stated that early signs of fatigue include longer response times to external stimuli. Similarly, Welford (1980), Williamson et al. (2001), Horowitz et al. (2003) and Baulk et al. (2008) stated that with an increase in an individual’s fatigue levels there will be a slowed response time. A longer response time is indicative of the slowing of an individual’s mental processing and sensory mechanisms due to a fatigued state (Mascord and Heath, 1992). This slowed response time can result in a reduced capacity to respond timely to emergency situations during driving (Mascord and Heath, 1992). The percentage of missed stimuli was used to determine time on task effects during the different conditions, as well as differences between conditions, if any, because fatigue (Jorna, 1992), decreased levels of alertness and prolonged tasks (Rogé et al., 2009) all result in an increase in the number of missed responses, regardless of the stimuli eccentricity (Rogé et al., 2004).

b. Lane Deviation

When drivers are in a state of fatigue their ability to guide the vehicle starts deteriorating (Verwey and Zaidel, 1999) and thus results in increased lane deviation. An increase in lane deviation indicates degraded control and thus an increased probability of accidents occurring (Johansson et al., 2008). According to Jorna (1992), boring, monotonous tasks are more difficult to perform and maintain at a certain level of performance when fatigued than interesting tasks. Through the creation of negative discrepancies, fatigue causes a decrease in mental efficiency, which results in performance decrements (Kahneman, 1973), such as an increase in lane deviation during driving. The version of the driving simulator used for the main driving task was DriveSim_v7.02 (for the driving simulator settings refer to Appendix B4).

c. Digit Span Memory Test

There have been numerous studies conducted, such as the one by Babkoff et al. (1999) which have indicated that with an increase in fatigue there is an increase in memory performance decrement. This is supported by Tyagi et al. (2009), who state that changes in an individual’s working memory occur due to fatigue and result in impaired performance. A PEBL Battery-0.6 digit-span audio memory test (No author, 2010) was conducted before and after the main driving task. The digit-span memory test is a progressive memory test, in which the computer began with articulating a span of 4 random digits; the subject was then required, upon hearing a beep signal, which had a 5 second delay, to verbally repeat the span of digits back to the researcher who recorded the subject’s answers in the space provided on the computer. If the subject gave the correct sequence of digits the computer would then generate a new sequence of 5 random digits and the same procedure was repeated. For every correct span of digits given by the subject, the sequence of digits would increase by 1 digit. However, if the subject gave an incorrect sequence of digits, the span of digits would decrease by 1. A span of 3 digits was the lowest possible sequence and a span of 10 digits was the highest possible sequence.

Each sequence produced by the computer was a batch of randomly selected digits ranging from 1 to 9. The PEBL Battery-0.6 digit-span audio memory test was modified in order that participants remained unaware of how many sequences they correctly and incorrectly answered. If the subject knew they were continuously getting sequences incorrect, it may result in a change in motivation to get more sequences correct, which would alter their fatigued state and consequently the research findings. This was found by Mascord and Heath (1992) where, following the onset of fatigue, performance levels were maintained through increased motivation.

d. Number of Saccades

The number of saccades was selected as a performance measure based on literature, which states that there is an increase in eye movements with an increased fatigue state, indicating a narrowing of the visual field (Rantanen and Goldberg, 1999).

3.4.3 Subjective Analyses

a. Wits Sleepiness Scale (WSS)

The Wits Sleepiness Scale is a subjective measure of fatigue involving a South African validated pictorial scale (Maldonado et al., 2004). This scale is useful as it allows for comparisons across languages, cultures and races as there is no word association on the scale, only cartoon faces (Maldonado et al., 2004). It was used as a subjective measure of the participants' state of fatigue primarily because it is a multi-cultural scale and therefore the possibility of cross-cultural misinterpretations could be eliminated.

b. National Aeronautics and Space Administration-Task Load Index (NASA-TLX)

The National Aeronautics and Space Administration-Task Load Index is a subjective questionnaire that gives an estimation of the subject's task performance as well as the mental effort associated with the given workload (Hart and Staveland, 1988). There are six subscales, namely physical demand, mental demand, temporal demand, own performance, effort level and frustration level, in which the participants give a rating for each (see Appendix B2: section 8.2.2). An overall score is then calculated and weighted on the average ratings of six subscales (Lan et al., 2010). The use of the NASA-TLX questionnaire as a fatigue indicator was based on studies, such as Dillon et al. (2004) and Baulk et al. (2007), which successfully used the NASA-TLX questionnaire to indicate an individual's state of fatigue. It is a sensitive measure and has been found to be more reliable than other subjective rating scales (Hill et al., 1992).

3.5 EXPERIMENTAL PROCEDURE

3.5.1 Screening of Participants

Potential participants, who fulfilled the criteria outlined (see Appendix A1: section 8.1.1), were asked to partake in a basic visual screening exercise, which was conducted by a local optometrist in Grahamstown, this was to ensure that potential participants did not have any major visual defects. If the results of the visual screening were satisfactory, participants were then asked to fill in a sleep disorder questionnaire (see Appendix A4: section 8.1.4). If participants were found to have no major visual defects and no history of sleep disorders, they were then allocated a habituation session.

3.5.2 Habituation

A 30 minute habituation session was conducted at the Human Kinetic and Ergonomics department. It was during this session that the participants were allocated two testing session times and dates. Participants were given a letter of information (see Appendix A5: section 8.1.5) explaining the general procedure of each condition and what was expected of the participant; this was also done verbally. The letter of information listed the risks and benefits of participating in the study as well as highlighted the “do’s” and “don’ts” applicable before and during the testing sessions. All equipment that was to be used during the testing sessions was demonstrated to the participants. All questions and concerns were dealt with throughout the habituation session. Participants were asked to be seated in the driving simulator where they were made to drive, with the head mounted eye tracker on, until they indicated that they were comfortable with the task and understood all aspects involved. The peripheral stimuli were then displayed for the subject to familiarise themselves with; however, during the habituation session the peripheral stimuli were shown in successive order from -40° eccentricity through to +40° eccentricity. It was emphasised that during the actual test sessions the peripheral stimuli would appear in a randomised fashion and not in a successive order as demonstrated. Once the subject was comfortable with the procedure and all questions had been answered, they were asked to fill in a general demographic questionnaire (see Appendix A2: section 8.1.2) as well as the Horne and Östberg (1979) Morningness-eveningness questionnaire (see Appendix A3: section 8.1.3); this was to ensure that the different effects found, if any between the two conditions, were not attributable to an unequal chronotype distribution. Upon completion of these forms, participants were again reminded verbally about the “do’s” and “don’ts” related to each testing session as well as their allocated times and dates for each session.

3.5.3 Experimentation

The research project was conducted over 5 weeks, during which each of the 16 participants partook in 2 conditions. Each subject participated in one condition’s test session, followed by at least one days rest and then returned for the second condition’s test session. The Day Condition began at 09h00 and ended at 11h00, with participants required to report to the Human Kinetics and Ergonomics Department at 08h30 in order for familiarisation of the driving task and the equipment used. Alternatively, the Night Condition required participants to arrive at the Human Kinetics and Ergonomics Department at 22h30 for familiarisation of the task and equipment, with the test session commencing at 23h00 and ending at 01h00.

At the beginning of the testing session the subject was welcomed and asked to sign a consent form (see Appendix A6: section 8.1.6), indicating that they understood the procedure of the test as well as the risks and benefits. The procedure was then verbally explained to the subject again to ensure that they knew what was expected of them during the test session. The heart rate belt was then given to the subject to put on and a change room was provided for privacy. The electrode/chest strap was secured around the mid-chest of the subject, at the inferior border of the pectoralis major muscle and in line with the apex of the left ventricle. Conductive gel was placed on the electrodes of the heart rate belt to ensure a stronger conduction and reading of the subject’s heart rate. Once the heart rate monitor was activated, the subject was instructed to sit comfortably in the driving simulator, upon which the subject’s reference heart rate was obtained over a 5 minute period. Over this period the subject was instructed to remain as still as possible with no talking being permitted.

Once the subject’s reference heart rate was obtained four pre-tests were conducted. The first involved obtaining the subject’s degree of sleepiness using the Wits Sleepiness Scale. Participants were asked to point out which of the five cartoon faces depicted on the WSS most accurately represented how they were feeling at that point in time. Each cartoon face was represented by a numeric value (see Appendix B1: section 8.2.1) and this number was then recorded by the researcher. For tympanic temperature, the participants placed the thermometer in the external auditory canal and held the activation button, at the back of the thermometer, down for a period of approximately one second. The temperature was electronically calculated and three readings were successively taken, with the average of the three being calculated and recorded. This was followed by the critical flicker fusion frequency (CFFF) threshold test, the subject was required to place the binoculars firmly over both eyes and ensure that no light could enter through the sides of the binoculars. Once the binoculars were correctly placed, the researcher began to increase the flickering of the LED in an ascending staircase method, starting at 30 Hz, until the subject indicated that the light they perceived was no longer flickering but a steady light. This frequency (Hz) value was then recorded by the researcher; this process was conducted three times successively (the average of the three readings was recorded). The final pre-test was the PEBL memory test. At the end of the 5 minute memory test, an average of the subject’s memory span was produced by the computer, which was then recorded and viewed only by the researcher.

Once all four pre-tests were completed, the head mounted eye tracker was placed on the subject and calibrated. This was done by instructing the subject to direct their gaze at the four corners of the main task display without moving their head and adjusting the settings until all four corners were calibrated. Using the Dikablis hardware and software, all participants’ eye data were recorded throughout the 90 minute main task.

The driving simulator program was started first, followed by the eye tracker recording and lastly the peripheral presentation software. For the primary task participants performed a simulated tracking task for 90 minutes continuously, in which they were instructed to track the white line, located in the middle of the road, as accurately as possible with the yellow triangle, which represented the bonnet of the vehicle (see Figure 10).

Figure 10: Participants wearing the head mounted eye tracker and performing the primary driving task.

While the 90 minute main driving task was in progress a secondary task was introduced, using peripheral stimuli software. A white dot, with a 15mm diameter and a luminance of 46 cd/m², was randomly permutated to appear continuously in the subject's peripheral vision, on average every 5 seconds, at three different eccentricities, namely 20°, 30° and 40° visual angl e. The stimulus size and luminance, as well as the different degrees of eccentricity used, were established through the results of a previously conducted study (Zschernack et al., in preparation) which only used two eccentricities, ±20° and ±40°. Since this study wanted to establish the effects of fatigue on a driver's peripheral vision, a third eccentricity (±30°) was introduced.

A data projector was used to project the stimuli onto a 2800mm x 1400mm black screen, which had a luminance of 5.6 cd/m², using the stimulus presentation software. The stimuli appeared for 250 ms in the peripheral visual field in line with the middle of the primary tracking task at three different eccentricities, namely 20°, 30° and 40° visual angles, as depicted in Figure 11 and had an object refresh rate of 30 hertz (Hz).

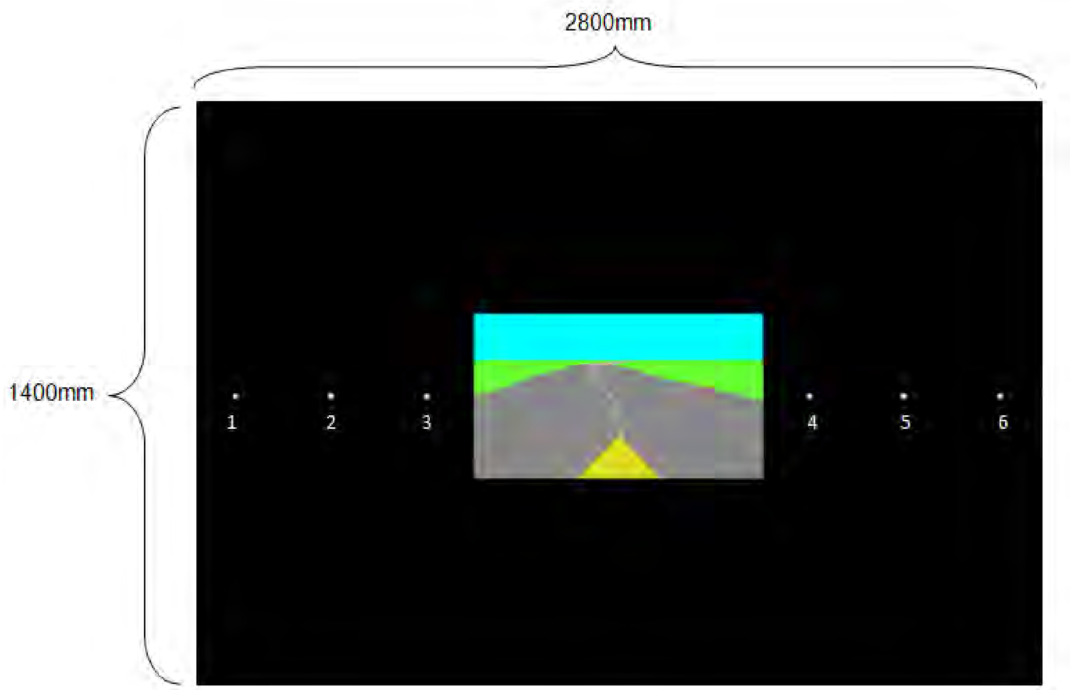


Figure 11: The location of the six peripheral stimuli and the size of the screen used.

Participants were instructed to keep their eyes on the primary driving task and their head still. When a peripheral stimulus was perceived by the subject they had to respond as quickly as possible by clicking either of the two clickers located on the steering wheel. One clicker was located on the right hand side of the steering wheel and the other on the left hand side, as depicted in Figure 12, to ensure that response time was not affected by participants using only their non-dominant hand to respond to the stimuli.

Figure 12: The two clickers located on the steering wheel for stimuli response.

Once 90 minutes had elapsed, the peripheral stimuli software automatically stopped, upon which the driving task was terminated. The eye tracker recording was also stopped at this point. The eye tracker was then removed from the subject's head and the four tests conducted prior to the main task were conducted post-test. Once all four post tests were complete, the subject was asked to fill in a computerised version of the NASA-TLX questionnaire (Hart and Staveland, 1988), in which they were asked to rate each of the six categories based only on the 90 minute main task, including the peripheral stimuli and not the pre- and post-tests that were conducted. A definition sheet was provided for each subject, clarifying what each category meant (see Appendix B3: section 8.2.3). The subject was then instructed to remove the heart rate belt, upon which they were free to leave. Table I illustrates a breakdown of the time requirements for each condition; measures obtained throughout the 90 minute main task fall into the 90 minute dual task time frame.

Table I: Time requirement for each condition.

CONDITION	DESIGN	TOTAL TIME REQUIRMENT
1	Day Condition (9am -11am)	1 test session - 1 x 90 minute dual task - 6 x 30 seconds temperature - 6 x 30 seconds CFFF - 2 x 5 minute memory test - 2 x 1 minute self-rating scale - 1 x 5 minute questionnaire
2	Night Condition (11pm-1am)	1 test session - 1 x 90 minute dual task - 6 x 30 seconds temperature - 6 x 30 seconds CFFF - 2 x 5 minute memory test - 2 x 1 minute self-rating scale - 1 x 5 minute questionnaire

3.5.4 Ethical Approval

Ethical approval for the research was obtained from the Human Kinetics and Ergonomics ethical committee. All procedures and participant requirements for the study were fully disclosed to the ethical committee, such as methodological considerations, risks and benefits of the study, letter of information to the subject and informed consent that participants were required to sign (see Appendix A6: section 8.1.6), upon which ethical approval was granted. For the Night Condition, participants were offered something to drink at the end of the test session, allowing time for any fatigue effects the task may have incurred to be reversed, this was a very important aspect if participants were driving themselves home. If a subject was driving themselves home and had not made prior arrangements to be collected after the Night Condition, the subject was asked to sign a disclaimer form indicating that they had been informed and were aware of the risks involved in driving themselves home after the test session (see Appendix A7: section 8.1.7).

3.6 CONTROLLED PARAMETERS

Certain factors needed to be controlled throughout testing to ensure that the validity of the data remained high and that extraneous variables did not have an adverse effect on the data obtained. This was done to ensure that any observed changes were in fact due to the effects of the conditions and not external factors. The room used for testing at the Human Kinetics and Ergonomics department allowed for the constant controlled exposure of lighting during the Day and Night Conditions. The room's windows were boarded up and artificial lighting was used, enabling the Day and Night Conditions to be exposed to the same type and amount of lighting during test sessions. Fluorescent lighting was used and held constant at 109.6 lux, measured at the participants' eye level, throughout all test sessions. The time of day at which the test sessions commenced was kept constant across all participants. All participants were tested at 08h30 for the Day Condition and at 22h30 for the Night Condition. The duration of each test session was held constant at 2 hours 30 minutes. All participants were exposed to the main driving task and peripheral stimuli software for 90 minutes. All pre- and post-tests were conducted an equal number of times on each subject, with the duration of the PEBL memory test being consistent across all participants and conditions. The distance of the driving simulator from the main driving task display was held constant at 1400mm and the location of the peripheral stimuli were displayed at 20°, 30° and 4 0° eccentricity horizontally on either side of the main driving display for all participants. This was measured from the centre (horizontally and vertically) of the main task display. The main driving display was held constant at 1000 mm in width and 810 mm in height. The luminance, as well as the size, of all peripheral stimuli was kept constant at 46 cd/m² and 0.61° visual angle respectively.

3.7 DATA REDUCTION AND STATISTICAL ANALYSIS

a. Heart Rate and Heart Rate Variability

At the end of each test session, once the subject had left, the heart rate data was downloaded from the subject’s heart rate belt using a Suunto docking station and the Suunto training manager 2.2.0 software. Once the heart rate file was downloaded from the heart rate belt it was converted into an sdf. file, using the Suunto training manager software. The sdf. file was then processed through a data reduction tool, developed by the Human Kinetics and Ergonomics Department at Rhodes University, which allowed for the basic analysis of the data. The heart rate data reduction software provided the researcher with a complete beat to beat analysis and ratios necessary for determining the subject’s heart rate and heart rate variability.

b. Eye Measures

The stored eye data, in the form of a txt. file, was processed through a data reduction tool, developed by the Human Kinetics and Ergonomics department at Rhodes University, which allowed for the analyses of the blink frequency and blink duration for each subject.

c. Peripheral Stimuli Data

The peripheral stimuli response times and the number of missed peripheral stimuli were recorded throughout the 90 minute driving task and processed using the peripheral stimuli software. Exclusion criteria were set for the peripheral response test such that the first 2 trials of the response test, as well as response times of less than 0.1 second or greater than 1.5 seconds, were eliminated.

d. Lane Deviation

The driving simulator record file was processed and analysed using the DriveSim_v7.02 software. Once the record file had been processed, the researcher transformed the record file into an ASCII file using the DriveSim_v7.02 software, allowing for further analyses of the data using the excel spread sheet, which produced the lane deviation of each subject for the duration of the main task.

Statistical analyses were performed using STATISTICA (version 10) statistical software programme. One-factorial, two-factorial and three-factorial repeated measures analyses of variances (ANOVAs) were conducted in order to assess the general differences between the two conditions, the time on task and the eccentricities. A one-factorial ANOVA was conducted for the number of saccades, in which time of day was the factor, whereas three-way ANOVAs were used to analyse response time and the percentage of missed stimuli, in which time of day, time on task and the different eccentricities were the factors. For all other measures two-factorial ANOVAs were conducted, using time of day and time on task as the factors. A confidence level of 95% with a corresponding alpha level of 0.05 ($p<0.05$) was used across all statistical analyses to indicate significant effects in the data. This confidence interval was used in order to reduce the chances of a type I error occurring. The heart rate, eye tracker, stimuli and driving data were all analysed using a data reduction tool developed by the Human Kinetics and Ergonomics department at Rhodes University. The data reduction tool produced the heart rate, heart rate variability, blink frequency and duration, percentage of missed stimuli, response times to stimuli and the driving deviation results. The conclusive statistics were obtained following the application of two- and three-factorial ANOVAs. When analysing whether the percentage decrement in driving performance was equal to the percentage decrement in missed responses, all relevant data was normalised against the first 10 minute interval for the various measures. Two- and three-factorial ANOVAs were then performed on the data and a Tukey post hoc test performed in order to allow for comparisons to be made between the different measures. Tukey Post Hoc Analyses were conducted on the data for all measures in order to establish where the significance differences lay within the data.

3.8 PARTICIPANTS

16 participants, eight male and eight female, were recruited from the Rhodes University student population to participate in the research; the participants’ ages ranged from 19–33 years. Preceding the study, basic demographical data was

collected from all the participants; this included age, sex, race and education level as well as information pertaining to the participants' level of morningness-eveningness, which was calculated using a questionnaire adapted from Horne and Östberg (1976) (see Appendix A3: section 8.1.3). The participants' education level, which was measured as the number of academic years the subject had been at university, and the level of morningness-eveningness were recorded to ensure that all participants selected allowed for homogeneity across the two conditions, thus negating a possible data skewing effect. All participants indicated no history of sleeping disorders, had a normal visual field range, were non-smokers, and attained an average of 7–8 hours sleep a night. Participants who did not meet the criteria stated in the advertisement (see Appendix A1: section 8.1.1) were not included in the study.

Table II: A summary of characteristics for the male and female participants

Sex	**n**	**Age (years)**	**Race**	**Education Level** (Score based on number of academic years at university)	**Morning-Evening Score** (Scored based on Horne and Östberg's scale)
Male	8	22 (±2.26)	7 White 1 Black	3.38 (±1.40)	53.25 (±11.85)
Female	8	25 (±3.85)	8 White	5.62 (±1.59)	50.37 (±14.43)

CHAPTER IV

4 RESULTS

4.1 INTERPRETATION

The two test conditions each entailed a 90 minute simulated drive in which participants had to respond to peripheral stimuli at three different eccentricities, specifically 20°, 30° and 40° visual angles. In a repeated measures design, one condition exposed participants to performing during a circadian upswing, and the second condition required participants to perform the task during a circadian downswing, thereby using time of day as a fatigue inducer. Response time to stimuli, percentage of missed stimuli, driving performance, eye measures, heart rate and heart rate variability were measured throughout the primary task, with critical flicker fusion frequency threshold, tympanic temperature, Wits Sleepiness Scale and a digit span memory test used as pre- and post-test measures. The NASA-TLX questionnaire was completed by the participants at the end of each test session. For statistical analysis of the results, the confidence level was set at 95% ($p<0.05$) for all the results obtained, which is indicated by the error bars in all the figures.

For the interpretation of the results, the following terms are used to refer to the different effects:

- *Time of day* refers to the difference between conditions, namely between the Day Condition and the Night Condition.

- *Time on task or task duration* refers to the effects seen over the 90 minute duration of the main driving and peripheral response task.

The following intervals were used when analysing the various measures:

- *5 minute intervals:* Heart Rate, Heart Rate Variability, Blink Frequency and Blink Duration.

- *10 minute intervals:* Response Time, Missed Stimuli and Lane Deviation.

4.2 PSYCHOPHYSIOLOGICAL MEASURES

4.2.1 Heart Rate

Table III: Two-factorial ANOVA for heart rate (bt.min^{-1}) for time of day as well as time on task (* = significant differences, p<0.05).

HR Effect	**p**
time of day	0.58
time on task	p<0.05 *
time of day *time on task	p<0.05 *

a. Time of Day

No significant difference was established for heart rate with regard to time of day.

b. Time on Task

Table III illustrates that a significant difference (p<0.05) was established for time on task. The average heart rate of all participants remained relatively stable over the duration of the testing session, although a slight increase can be seen from 5 minute interval to 40 minute interval; thereafter, a slight decrease is observed. It was established, through a Tukey post hoc analysis, that the 85th minute interval was significantly different to minutes 20, 25 and 30 minute intervals, as depicted in Figure 13.

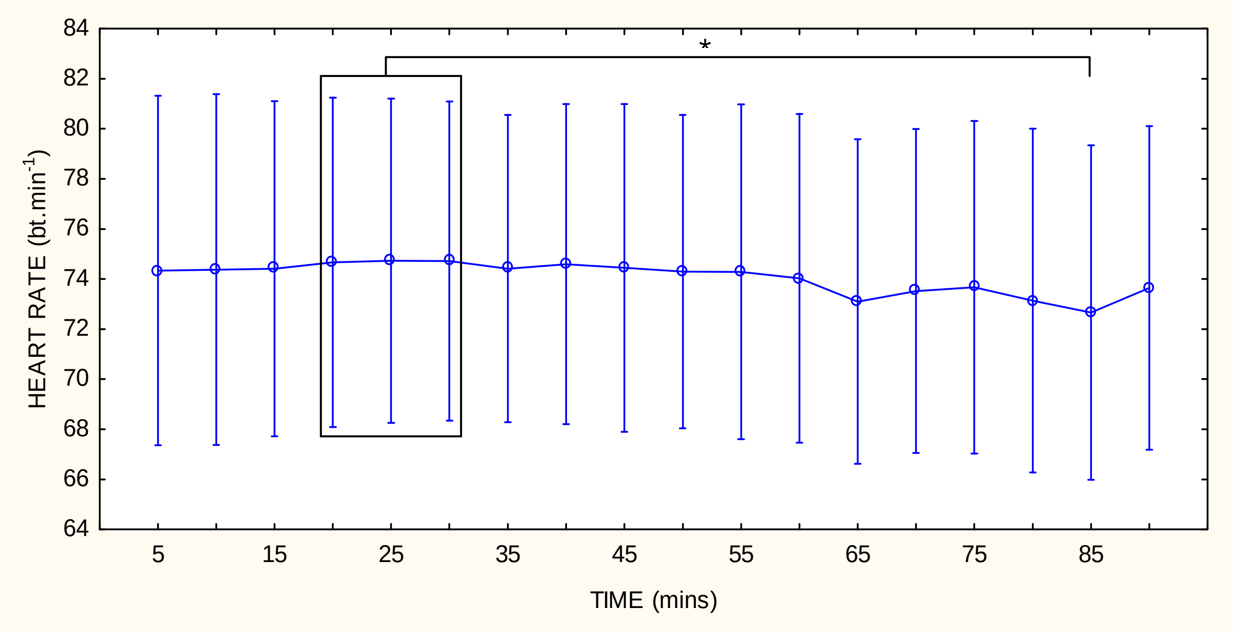


Figure 13: Average heart rate (bt.min^{-1}) measured over the duration of the main task (* represents a significant difference, $p<0.05$; I-denote 0.95 confidence intervals).

c. Interactional Effects

A significant difference was found for the interactional effect between the time of day and time on task (Table III and Figure 14). For the Day Condition the participants' average heart rate, at the beginning of the task, was approximately 76 bt.min $^{-1}$, while for the Night Condition the participants' average heart rate was approximately 73 bt.min $^{-1}$ at the start of the task. During the Day Condition, heart rate is seen to fluctuate in a decreasing manner over the duration of the task, with an increase between the 85th and 90th minute. The Night Condition shows a slight increase in heart rate between the 5th and 55th minute, thereafter slight fluctuations are observed until the end of the task. From Figure 14 it can be seen that although there is a decrease in heart rate over the duration of the task for the Day Condition and an increase in heart rate for the Night Condition, both conditions end the task with approximately the same average heart rate of 74 bt.min $^{-1}$.

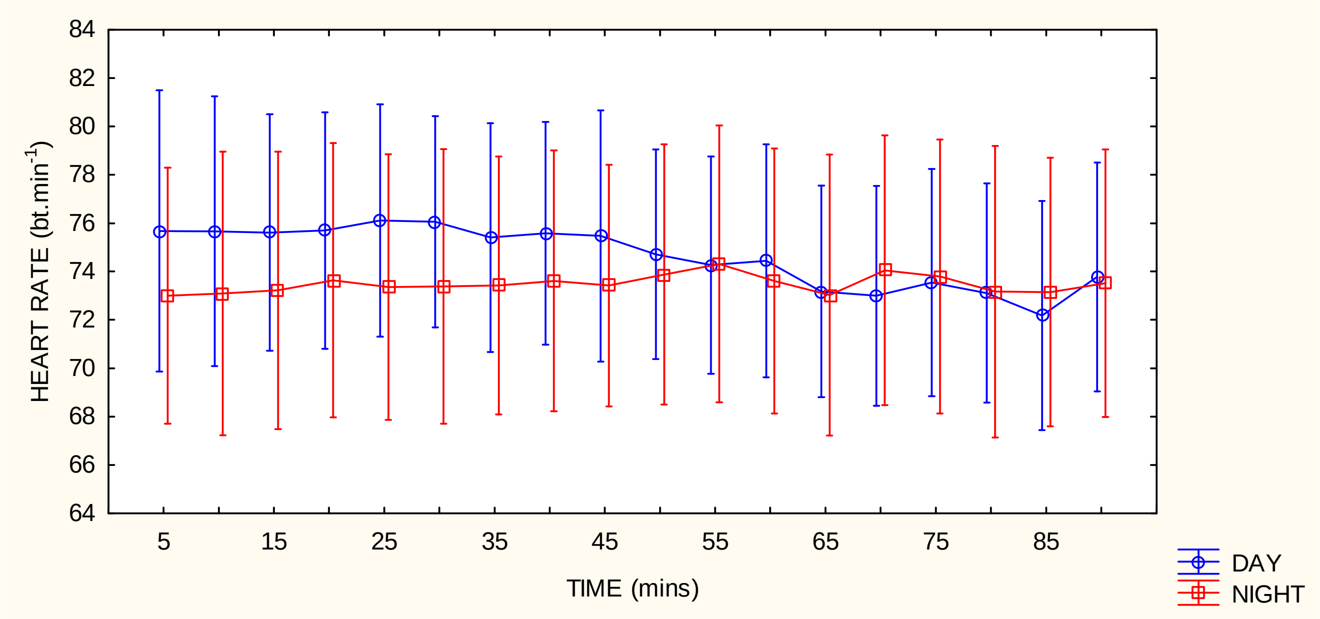


Figure 14: Average heart rate (bt.min^{-1}) obtained across the different conditions for task duration (I-denote 0.95 confidence intervals).

4.2.2 Heart Rate Variability

Table IV: Analysis of variance of heart rate variability (bt.min^{-1}) for time of day and time on task (* = significant differences, p<0.05).

HRV Effect	**p**
time of day	p<0.05 *****
time on task	p<0.05 *****
time of day *time on task	0.14

a. Time of Day

Referring to Table IV, a significant difference was found for time of day. The graphical representation of the heart rate variability data indicates that during the Day Condition participants display a higher heart rate variability, of approximately 5.5 bt.min^{-1}, when compared to the Night Condition, which has an average heart rate variability of 5 bt.min^{-1}, illustrated in Figure 15.

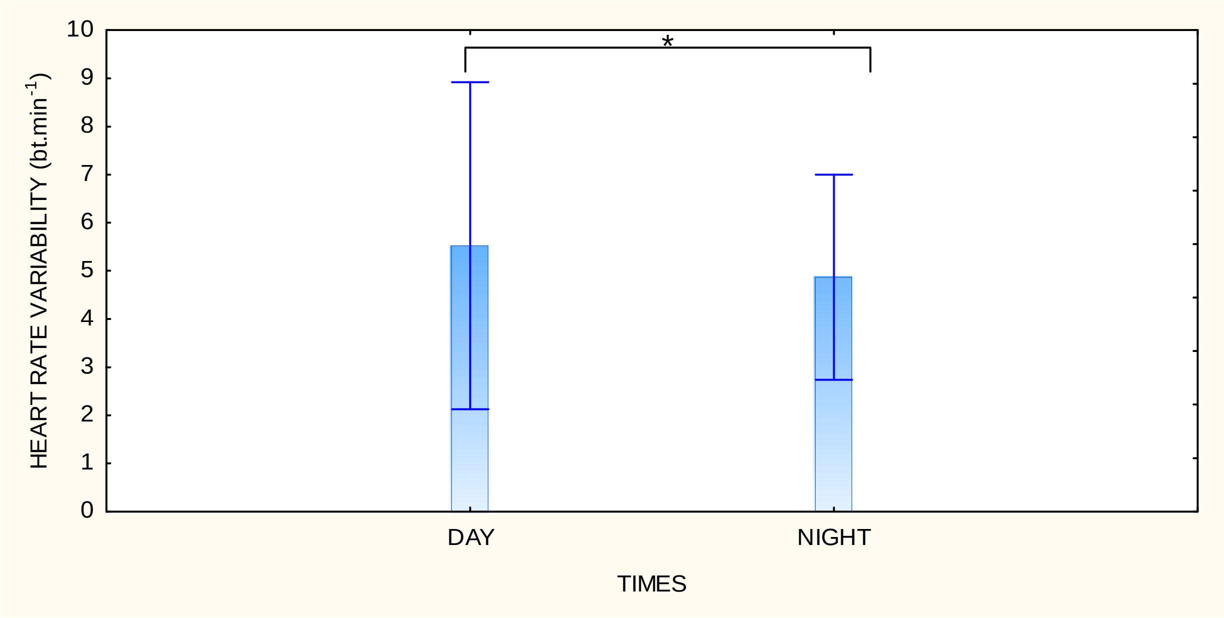


Figure 15: Average heart rate variability (bt.min^{-1}) attained for the different times of day (* represents a significant difference, $p<0.05$; I-denote 0.95 confidence intervals).

b. Time on Task

A significant effect was established for time on task, where Figure 16 highlights a significant increase in the average heart rate variability over the 90 minute task duration. Between the 5th and 10th minute intervals of the main task there was a decrease in the average heart rate variability, followed by a steady increase between the 10th and 55th minute intervals. For a period of 10 minutes, between the 55th and 65th minute, there is a slight decrease, thereafter heart rate variability increases again. At the beginning of the main task heart rate variability was approximately 4.75 bt.min^{-1}, while at the end of the main task heart rate variability had a recording of approximately 5.75 bt.min^{-1}.

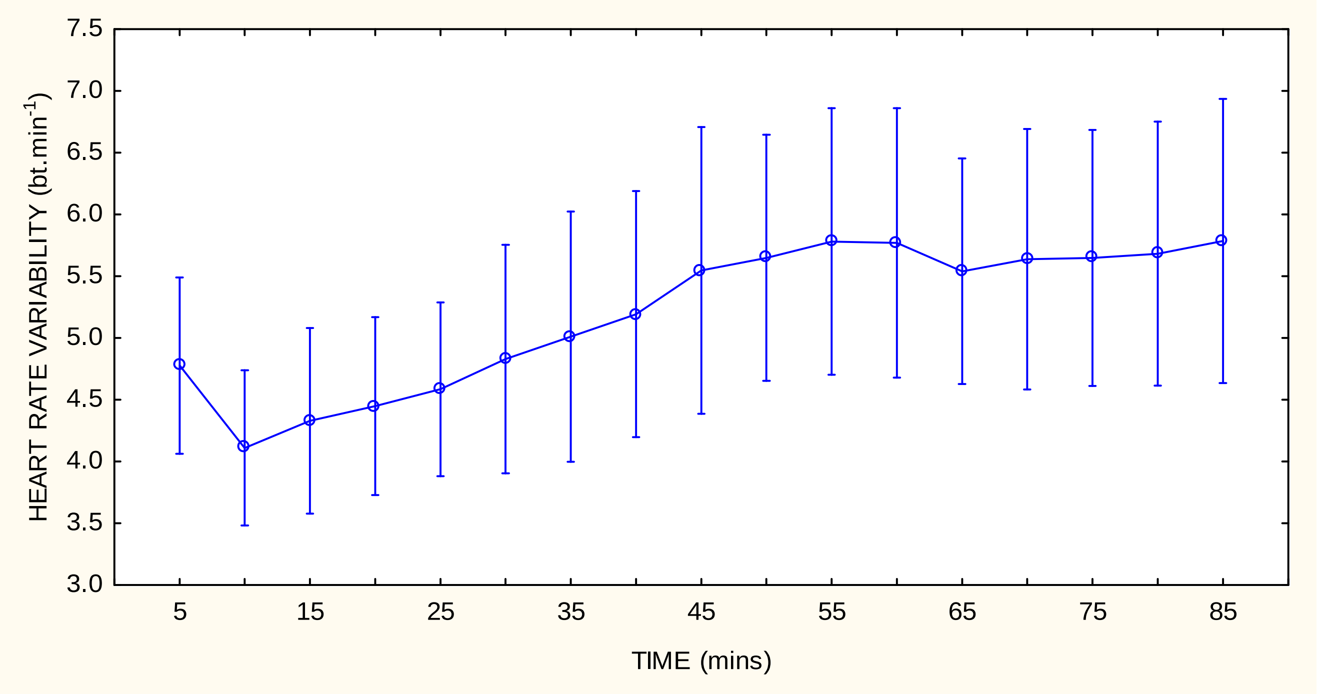


Figure 16: Average heart rate variability (bt.min^{-1}) measured for time on task (I- denote 0.95 confidence intervals).

Through the conduction of a Tukey post hoc test, significant differences in the heart rate variability data were found from the 30th minute interval to the 85th minute interval, and are emphasised in Table V. Refer to Appendix D2 for complete post hoc analysis table.

Table V: Tukey post hoc analysis conducted for heart rate variability indicating significances within the data.

			INTERVAL											
			30mins	**35mins**	**40mins**	**45mins**	**50mins**	**55mins**	**60mins**	**65mins**	**70mins**	**75mins**	**80mins**	**85mins**
INTERVAL	**5mins**	…				p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05
	10mins	…	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05
	15mins	…			p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05

	20mins	...			p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05
	25mins	...				p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05	p<.05
	30mins	...				p<.05	p<.05	p<.05	p<.05		p<.05	p<.05	p<.05	p<.05
	35mins	...						p<.05	p<.05					p<.05
	...													

c. Interactional Effects

No significant difference was obtained for the interactional effect between the time of day and the time on task.

4.2.3 Tympanic Temperature

It should be noted that any conclusions derived from, as well as any discussion involving, tympanic temperature are considered to be representative of the core temperatures of the participants.

Table VI: Two-factorial ANOVA conducted for tympanic temperature, using time of day and pre–post tests as factors (* = significant differences, p<0.05).

Temperature Effect	**p**
time of day	0.64
pre–post	p<0.05 *
time of day *pre–post	0.34

a. Time of Day

No significant results were found for tympanic temperature with regard to time of day.

b. Pre–Post Tests

Table VI shows the significant difference that was ascertained between the pre- and post-tests conducted for tympanic temperature. Figure 17 gives a depiction of the average tympanic temperature measures obtained before the main task (pre-test) and once the main task was terminated (post-test). A significant ($p<0.05$) decline in tympanic temperature was calculated between the pre- and post-test, with a pre-test average tympanic temperature reading of 35.3℃, whereas the post-test average recording had a value of 34.9℃.

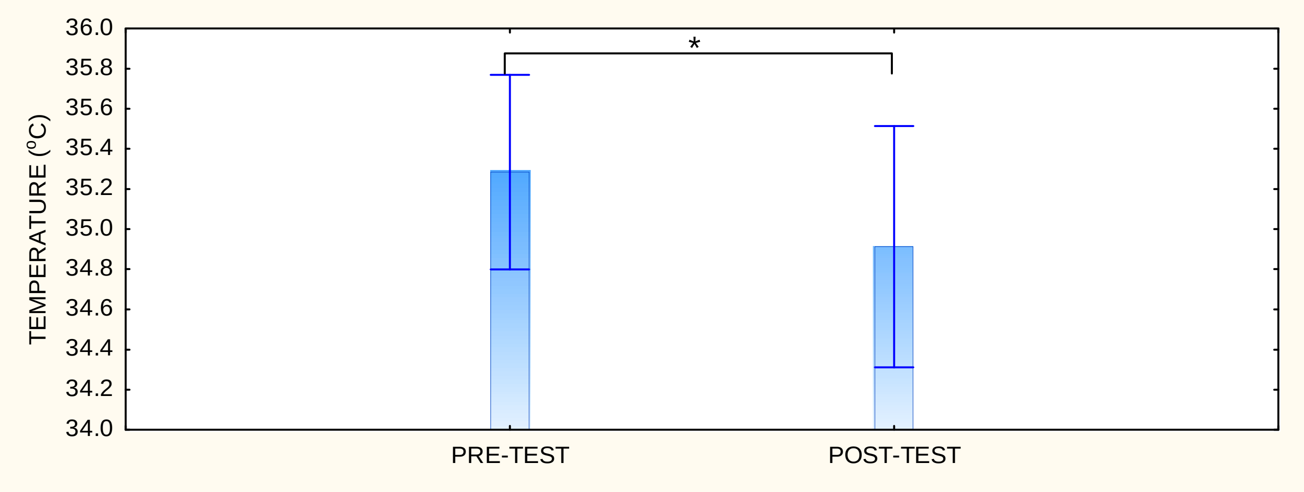


Figure 17: Average tympanic temperature obtained prior to and after the main task (* represents a significant difference, $p<0.05$; I-denote 0.95 confidence intervals).

c. Interactional Effects

For the interactional effect between time of day and the pre- and post-tests conducted no significances were established.

4.2.4 Critical Flicker Fusion Frequency (CFFF) Threshold

Table VII: Two-factorial ANOVA conducted for critical flicker fusion frequency, with time of day and pre–post tests as the two factors (* = significant differences, $p<0.05$).

CFFF Effect	**p**
time of day	0.73
pre–post	p<0.05 *
time of day *pre–post	0.13

a. Time of Day

No significant differences were found for time of day.

b. Pre–Post Tests

From Table VII it can be seen that a significant effect was established between the pre- and post-tests conducted for the critical flicker fusion frequency (CFFF) threshold; this is depicted in Figure 18. There is a significant decrease in the average critical flicker fusion frequency threshold values between the pre- and post-tests performed. The average critical flicker fusion frequency threshold pre-test reading is 55 Hz, while the post-test average critical flicker fusion frequency threshold value is 52Hz, indicating that the 90 minute task duration resulted in a 3 Hz reduction in the average critical flicker fusion frequency threshold.

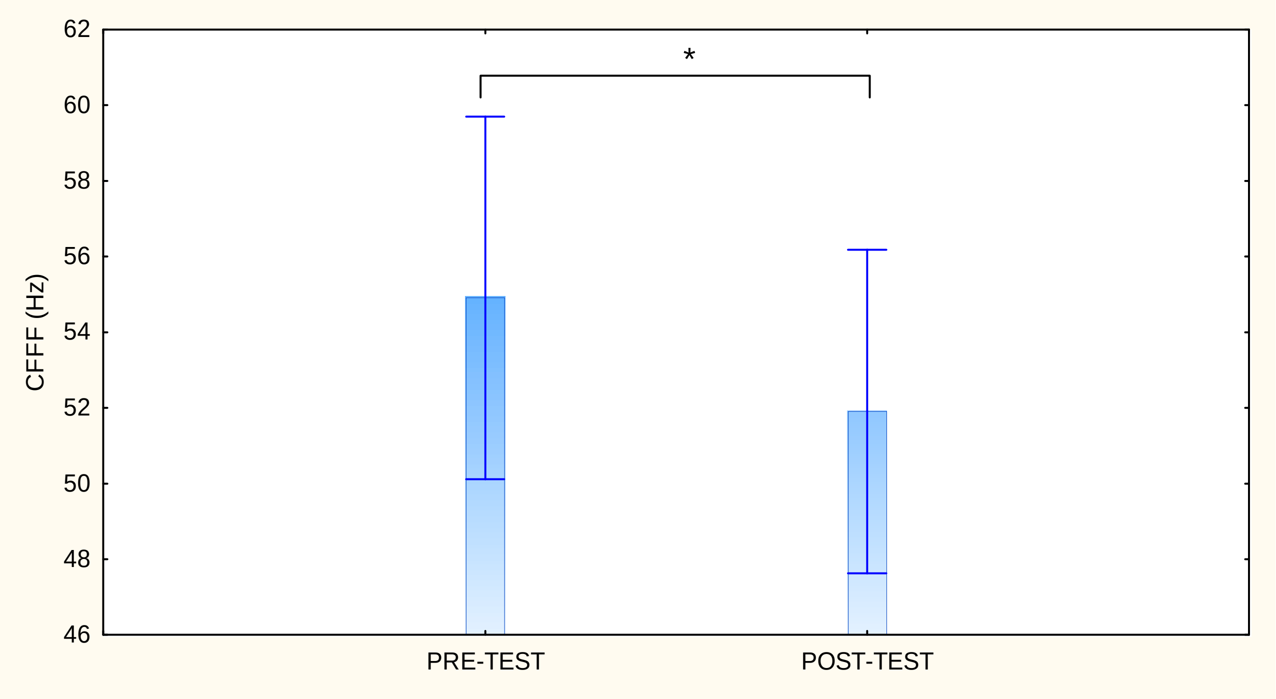


Figure 18: Critical flicker fusion frequency threshold measures for the pre- and post-tests (* represents a significant difference, $p<0.05$; I-denote 0.95 confidence intervals).

c. Interactional Effects

No significant effects were seen for the interactional effect between time of day and the pre- and post-tests conducted.

4.2.5 Eye Measures

4.2.5.1 Blink Frequency

When analysing the eye blink data, parameters were put in place such that eyelid closures less than 300 ms were categorised as normal blinks.

Table VIII: Analysis of variance conducted for blink frequency, with time of day and time on task as factors (* = significant differences, $p<0.05$).

Blink Frequency Effect	**p**
time of day	0.24
time on task	p<0.05 *
time of day *time on task	0.73

a. Time of Day

For time of day, no significant differences were established.

b. Time on Task

As portrayed in Table VIII, a significant effect ($p<0.05$) was obtained for average blink frequency over the 90 minute main task duration.

The average blink frequency at the start of the main task was measured at 14 blinks/min and increased to an average of 17blinks/min at the end of the main task (Figure 19).

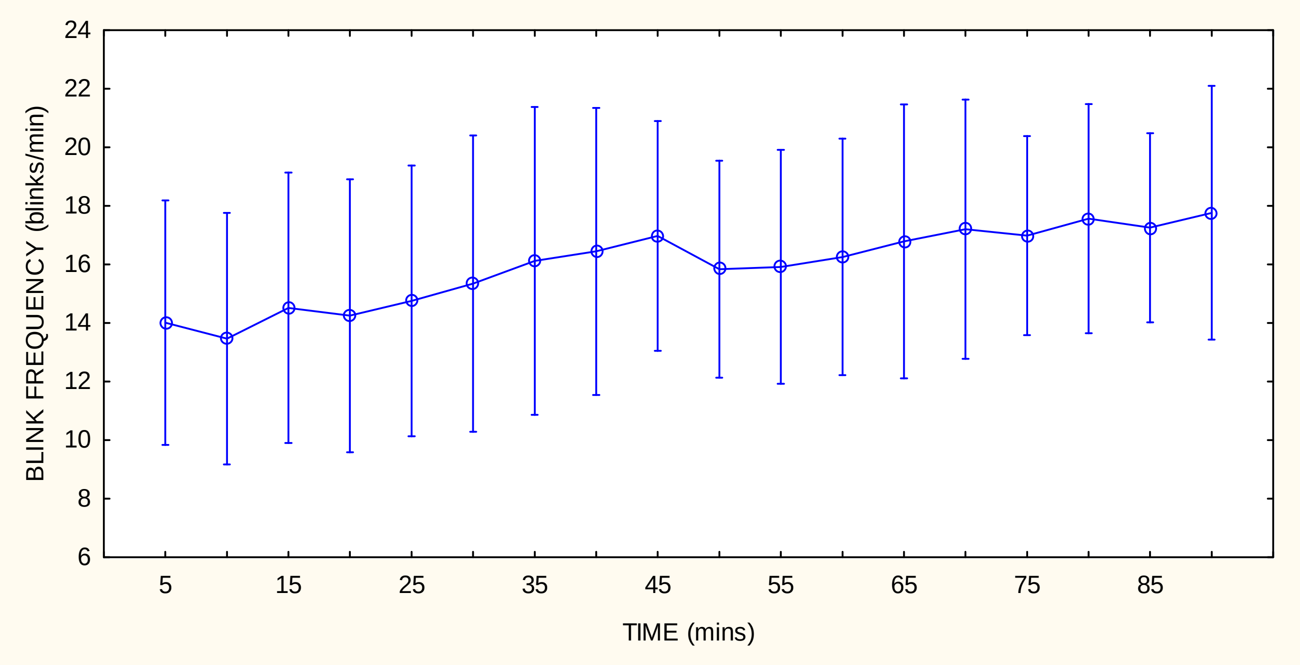


Figure 19: Average blink frequency (blinks/min) measured during the 90 minute main task (I-denote 0.95 confidence intervals).

A Tukey post hoc test was conducted on the average blink frequency in order to ascertain where the significant differences lay within the data, upon which it was established that the significant differences were found at the 45 minute interval, as well as from the 65 minute interval through to the 90 minute interval (Table IX).

Table IX: Tukey post hoc analysis conducted for blink frequency, indicating significances within the data.

INTERVAL												
			45mins	**50mins**	**55mins**	**60mins**	**65mins**	**70mins**	**75mins**	**80mins**	**85mins**	**90mins**
INTERVAL	**5mins**	…						p<.05		p<.05	p<.05	p<.05
	10mins	…	p<.05				p<.05	p<.05	p<.05	p<.05	p<.05	p<.05
	15mins	…										p<.05
	20mins	…								p<.05		p<.05
	…											

c. Interactional Effects

No significant effects were obtained for the interactional effect between time of day and time on task.

4.2.5.2 Blink Duration

Table X: Two-factorial ANOVA for blink duration, measured during the main task, with time of day and time on task as the factors (* = significant difference, $p<0.05$).

Blink Duration Effect	**p**
time of day	0.18
time on task	$p<0.05$ *
time of day *time on task	0.63

a. Time of Day

For blink duration no significant effect was ascertained between the different times of day.

b. Time on Task

Two-factorial ANOVA (see Table X) indicated that a significant difference was established for time on task. It can be seen in Figure 20 that the average blink duration remains relatively stable for the first 15 minutes of the main task, thereafter increasing marginally until the 70th minute interval. Between the 70 and 85 minute intervals, there is a considerable increase in the average blink frequency results. At the beginning of the task the average blink frequency measure was estimated at 150 ms , while at the end of the main task the average blink frequency measure was approximately 185 ms, indicating that there was a 35 ms increase in the blink duration from the start to the termination of the main task.

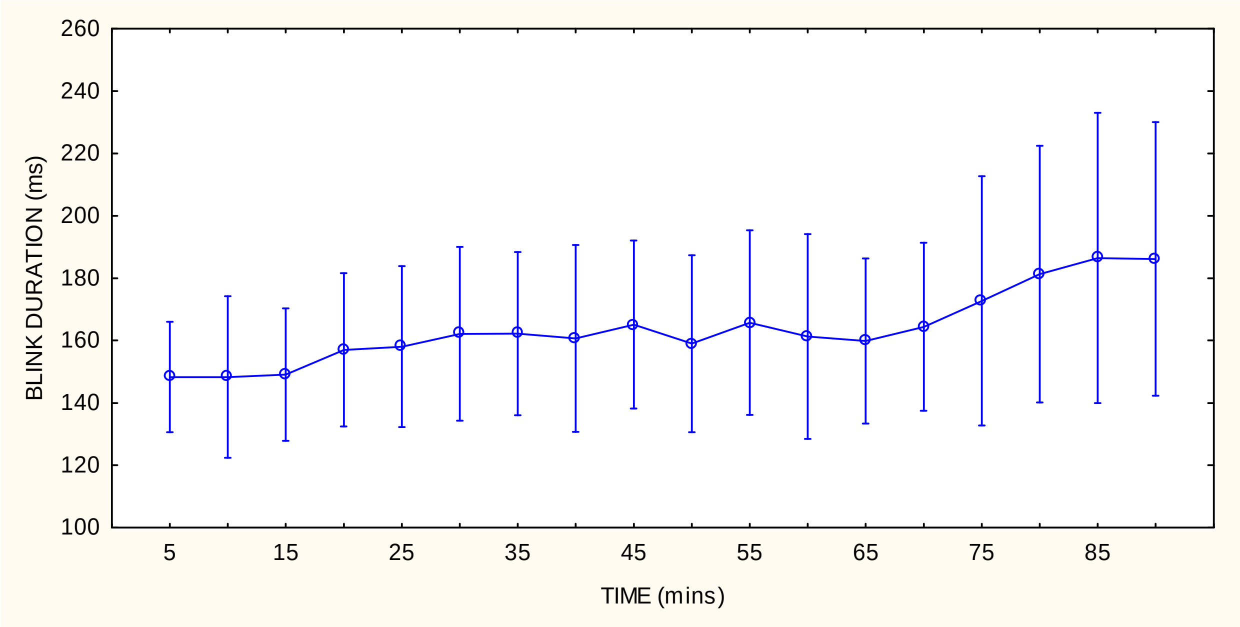


Figure 20: The average blink duration (ms) measured over the duration of the main task (I-denote 0.95 confidence intervals).

The 5, 10 and 15 minute intervals were found to be significantly different to the 80, 85 and 90 minute intervals, while the 20 and 25 minute intervals are both significantly different to the 85 and 90 minute intervals. These findings were established through a Tukey post hoc test (refer to Table XI).

Table XI: Significant differences for blink duration, established through a Tukey post hoc test.

	INTERVAL				
INTERVAL			**80mins**	**85mins**	**90mins**
	5mins	…	p<.05	p<.05	p<.05
	10mins	…	p<.05	p<.05	p<.05
	15mins	…	p<.05	p<.05	p<.05
	20mins	…		p<.05	p<.05
	25mins	…		p<.05	p<.05
	…				

c. Interactional Effects

No significant results were found for the interactional effect between time of day and time on task.

4.3 PERFORMANCE MEASURES

4.3.1 Peripheral Response Time

Table XII: Three-factorial ANOVA conducted for response time, with time of day, time on task and eccentricity as factors (* = significant difference, p<0.05).

Response Time Effect	**p**
time of day	0.35
eccentricity	p<0.05 *
time on task	p<0.05 *
time of day *eccentricity	0.76
time of day *time on task	0.55
eccentricity*time on task	0.22
time of day *eccentricity*time on task	0.54

a. Time of Day

No significant differences were found for time of day concerning response time.

b. Eccentricity

Through a three-factorial analysis of variance it was found that eccentricity had a significant effect on response time (see Table XII). It can be seen from Figure 21 that -40° eccentricity obtained an average response time of ±0.4 s, -30° eccentricity a response time of ±0.33 s, -20° eccentricity a response time of ±0.32 s. +20° and +30° eccentricity both attained a response time of ±0.30 s, while +40° eccentricity a slower response time of ±0.36 s. The fastest response time was attained for +20° and +30° eccentricity, while the two outer most eccentricities, namely -40° and +40° eccentricity, have the slowest response times.

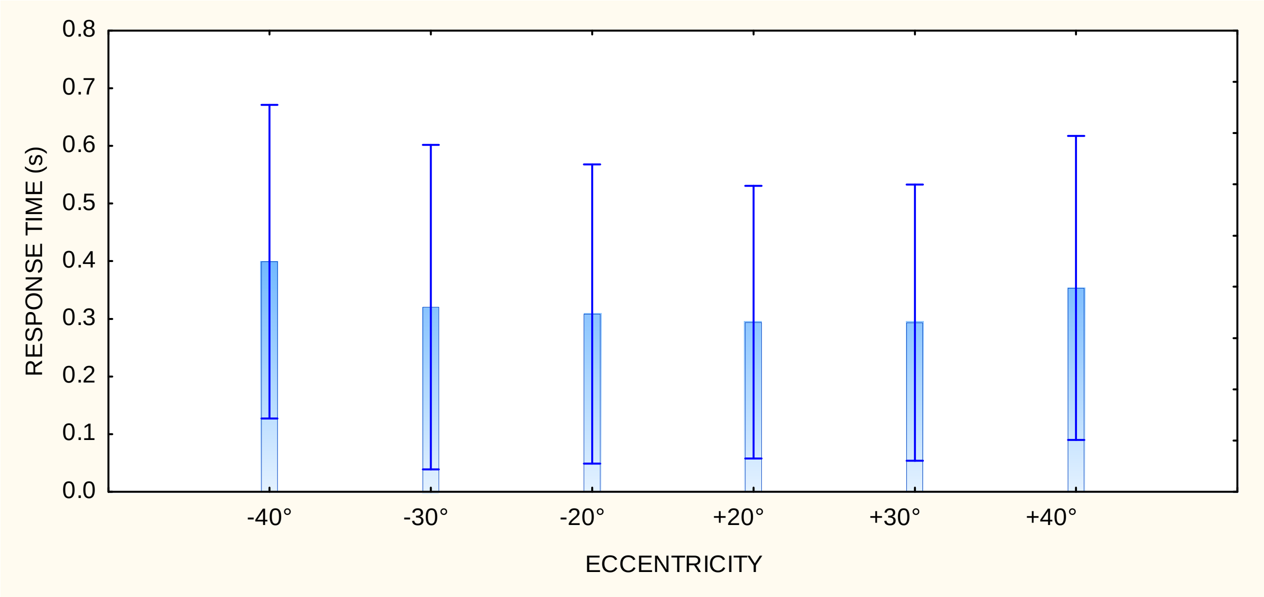


Figure 21: Average peripheral response times (s) for the six eccentricities assessed during the main task (p<0.05; I-denote 0.95 confidence intervals).

From the results of a Tukey post hoc test, conducted on the different eccentricities for response time (see Appendix D2 for detailed table), it was established that -40° and +40° eccentricity are significantly different to all other eccentricities, including each other, while -30° is significantly different to all other eccentricities except -20° eccentricity, -20° eccentricity was found to be significantly different from -40° and +40° eccentricity and lastly +20° and +30° eccentricity were both found to be significantly different from -40°, -30° and +40° eccentricity. These significant effects are highlighted in Table XIII.

Table XIII: Significant differences found between the six different eccentricities, using a Tukey post hoc test

		ECCENTRICITY				
		-30°	**-20°**	**+20°**	**+30°**	**+40°**
ECCENTRICITY	**-40°**	p<0.05	p<0.05	p<0.05	p<0.05	p<0.05
	-30°			p<0.05	p<0.05	p<0.05
	-20°					p<0.05
	+20°					p<0.05
	+30°					p<0.05

c. Time on Task

Figure 22 depicts a significant increase in the response time to the peripheral stimuli over the duration of the 90 minute main task. The first 10 minute interval obtained an average response time of ±0.28 s, the 20 minute interval an average response time of ±0.31 s, the 30 minute interval an average response time of ±0.32 s, the 40 minute interval an average response time of ±0.34 s, the 50, 70 and 80 minute intervals all a response time of ±0.36 s, the 60 minute interval an average response time of ±0.365 s and lastly the 90 minute interval an average response time of ±0.37 s.

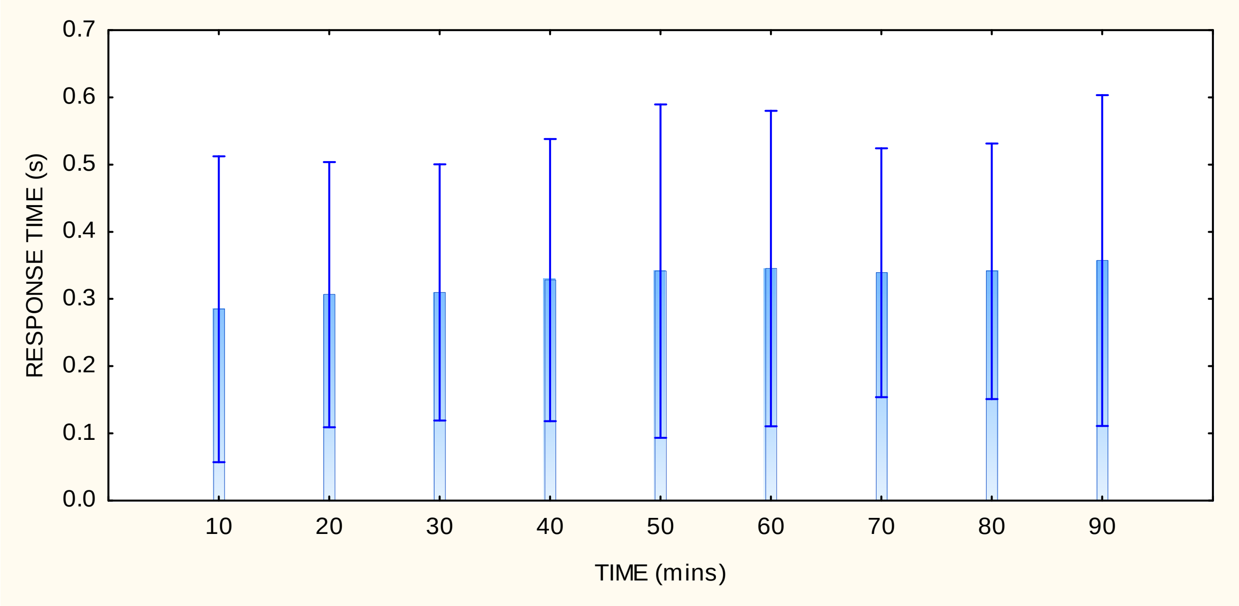


Figure 22: The average response time for the peripheral stimuli taken over the 90 minute main task (I-denote 0.95 confidence intervals).

Upon further analysis, in the form of a Tukey post hoc test (see Appendix D2 for complete table), it was found that the first 10 minute interval was significantly different from the 40 minute interval until the 90 minute interval, the 20 minute interval significantly different from the 60 minute and the 90 minute intervals, and the 30 minute interval was found to be significantly different to the 90 minute interval. These significances are depicted in Table XIV.

Table XIV: Tukey post hoc test conducted for response time to stimuli over the 90 minute main task

		INTERVAL								
INTERVAL		10mins	20mins	30mins	40mins	50mins	60mins	70mins	80mins	90mins
	10mins				p<0.05	p<0.05	p<0.05	p<0.05	p<0.05	p<0.05
	20mins						p<0.05			p<0.05
	30mins									p<0.05
	...									

d. Interactional Effect

The interactional effect between time of day and the eccentricities, the interactional effect between time of day and time on task, the interactional effect between eccentricities and time on task, and the interactional effect between time of day, eccentricities and time on task were all found to be non-significant.

Percentage of Missed Peripheral Stimuli

Table XV: Three-factorial ANOVA for the percentage of missed responses during the main task, using time of day, time on task and eccentricity as factors (* = significant difference, p<0.05).

Percentage of Missed Stimuli Effect	**P**
time of day	0.17
eccentricity	p<0.05 *
time on task	p<0.05 *
time of day *eccentricity	0.91
time of day *time on task	0.66
eccentricity*time on task	0.11
time of day *eccentricity*time on task	0.60

a. Time of Day

Time of day yielded no significant difference concerning the percentage of missed stimuli.

b. Eccentricity

Significant results can be seen for the eccentricities, as shown in Table XV. From Figure 23 it can be observed that the two extreme eccentricities, -40° and +40°, realised the greatest percentage of missed responses compared to the other four eccentricities, which remained relatively stable in relation to each other. The percentage of missed responses, in relation to each eccentricity, is as follows: -40° eccentricity has a missed response rate of ±30%, -30° and +20° eccentricities both have a missed response rate of ±10%, whereas -20° and +30° eccentricity have a missed response rate of 8%, and +40° eccentricity has a 20% missed response rate. The +40° eccentricity has double the percentage of missed responses in relation to the four inner eccentricities, while -40° eccentricity has more than double the missed response percentage when compared to the inner four eccentricities, namely +30°, +20°, -20° and -30°.

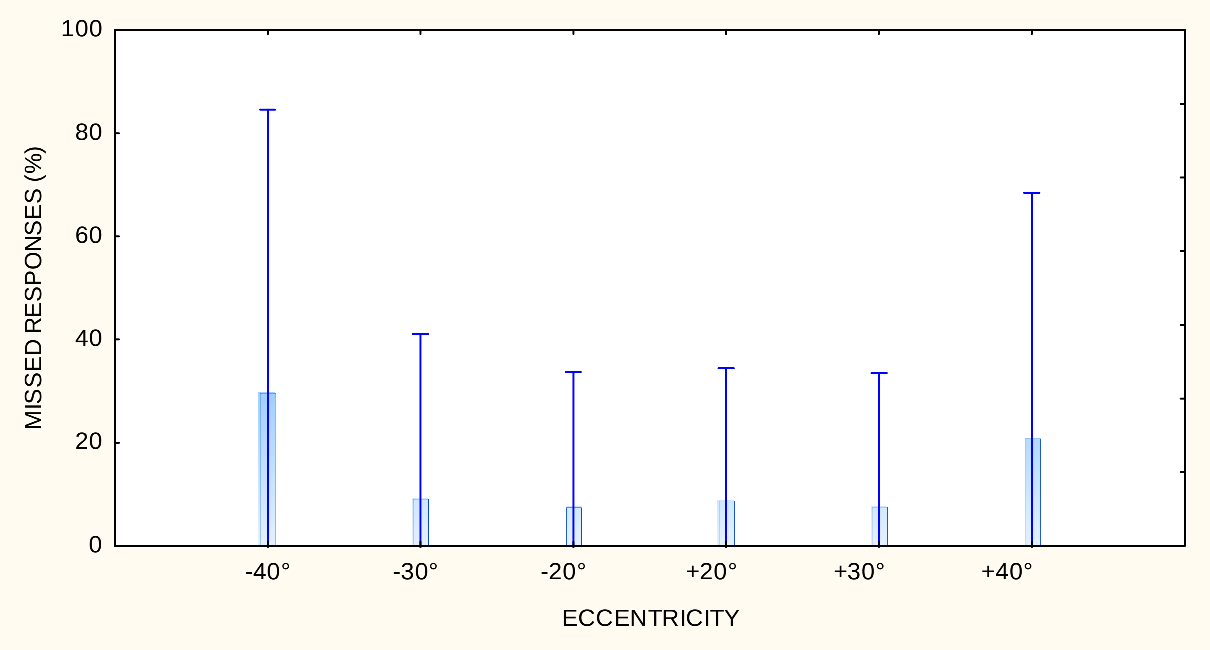


Figure 23: The percentage of missed peripheral stimuli obtained at the different eccentricities (I-denote 0.95 confidence intervals).

A post hoc test (Tukey) was conducted on the eccentricities of the missed responses (see Appendix D2 for detailed post hoc test findings), as when looking at Figure 23, it was observed that the -40° eccentricity had a higher percentage of missed responses when compared to the other five eccentricities. It was assumed that the eye camera, of the head mounted eye tracker, which is situated under the left eye (refer to Methodology for pictures), might have interfered with participants being able to perceive the -40° eccentricity stimulus in their periphery. However, the post hoc test confirmed that the -40° eccentricity stimulus was not different to the +40° eccentricity stimulus, which had no interference from the eye camera, but was different to all other eccentricity stimuli, (see Table XVI).

Table XVI: Significant differences established through a post hoc test for percentage of missed stimuli, regarding eccentricity.

		ECCENTRICITY				
		-30°	**-20°**	**+20°**	**+30°**	**+40°**
ECCENTRICITY	**-40°**	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$	
	-30°					$p<0.05$
	-20°					$p<0.05$
	+20°					$p<0.05$
	+30°					$p<0.05$

c. Time on Task

Figure 24 illustrates a significant increase in the percentage of missed peripheral stimuli rate with an increase in time on task. For the 10 minute interval there is a missed stimuli rate of ±8%, for the 20 minute interval a missed stimuli rate of ±10%, for the 30 and 40 minute intervals there is a missed stimuli rate of ±12%, at 50 minutes there is a missed stimuli rate of ±16%, with a slight decrease in percentage of missed stimuli during the 60 minute interval with a reading of ±14%, at the 70 minute interval a ±18% missed stimuli rate, the 80 minute interval has a ±19% missed stimuli rate and the 90 minute interval has a missed stimuli rate of ±20%. From these results it can be seen that there is an increase in the percentage of missed responses over the duration of the task, with the exception of the 60 minute interval, which depicts a slight decrease.

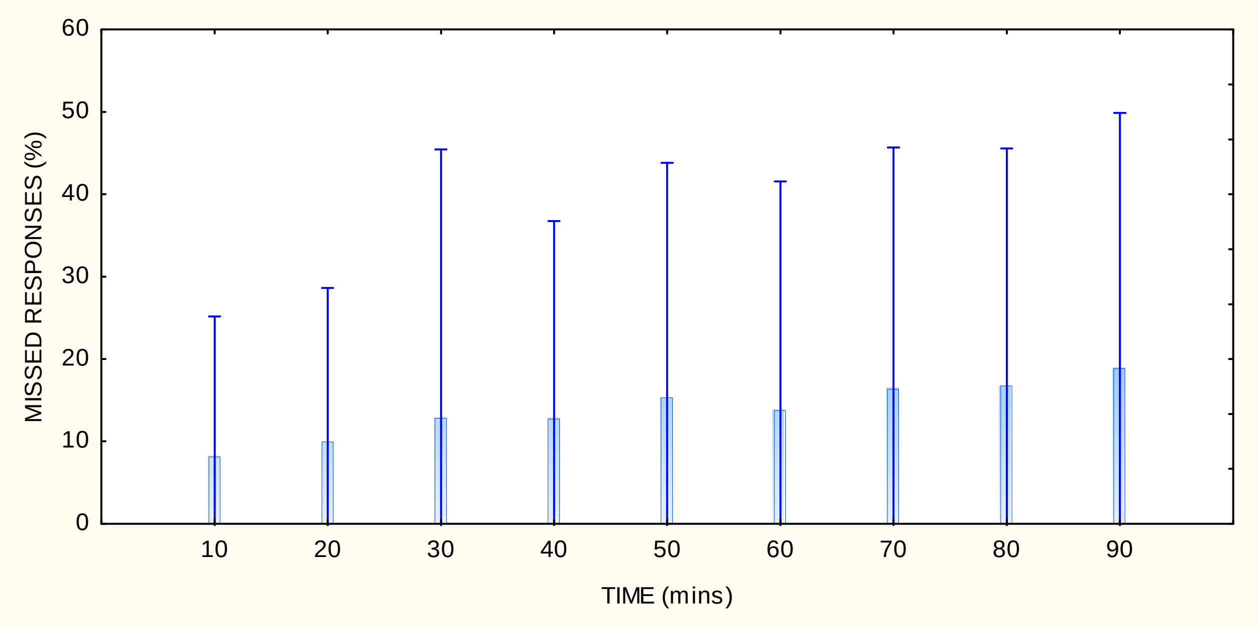


Figure 24: Missed peripheral response rate (%) over the 90 minute task duration (I-denote 0.95 confidence intervals).

Significant differences were found for various intervals based on the findings of a Tukey post hoc test (see Appendix D2 for a detailed analysis). These findings are presented: the 10 minute interval was found to be significantly different to the 50 minute interval through to the 90 minute interval, the 20 minute interval to the 50, 70, 80 and 90 minute intervals, and the 30 and 40 minute intervals to the 90 minute interval (Table XVII).

Table XVII: Tukey post hoc test results indicating significant differences for the percentage of missed stimuli during the main task.

		INTERVAL								
INTERVAL		**10mins**	**20mins**	**30mins**	**40mins**	**50mins**	**60mins**	**70mins**	**80mins**	**90mins**
	10mins					$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$
	20mins					$p<0.05$		$p<0.05$	$p<0.05$	$p<0.05$
	30mins									$p<0.05$
	40mins									$p<0.05$

d. Interactional Effect

No significant differences were seen for the interactional effect between time of day and time on task, between time of day and eccentricities, between time on task and eccentricities, as well as between time of day, time on task and the eccentricities.

4.3.2 Digit Span Memory Test

Table XVIII: Two-factorial analysis of variance conducted on the results of the memory test, with time of day and pre–post tests as factors (* = significant difference, $p<0.05$).

Digit Span Memory Effect	**P**
time of day	0.11
pre–post	0.42
time of day *pre–post	$p<0.05$ *

a. Time of Day

The time of day was found not to have a significant effect on memory.

b. Pre–Post Tests

The difference between the pre- and post-memory tests conducted yielded a non-significant effect.

c. Interactional Effect

A significant effect was ascertained for the interactional effect between time of day and the pre- and post-tests, as shown in Table XVIII and Figure 25. The average digit span for the Day Condition pre-test was recorded as 6.9, while the reading for the post-test digit span memory test was a lower 6.6. It was found that during the Night Condition the pre-test digit span had an average of 6.3, whereas the average for the post-test was 6.7. An increase in the digit span memory test was found for the Night Condition, while a decrease was observed for the Day Condition.

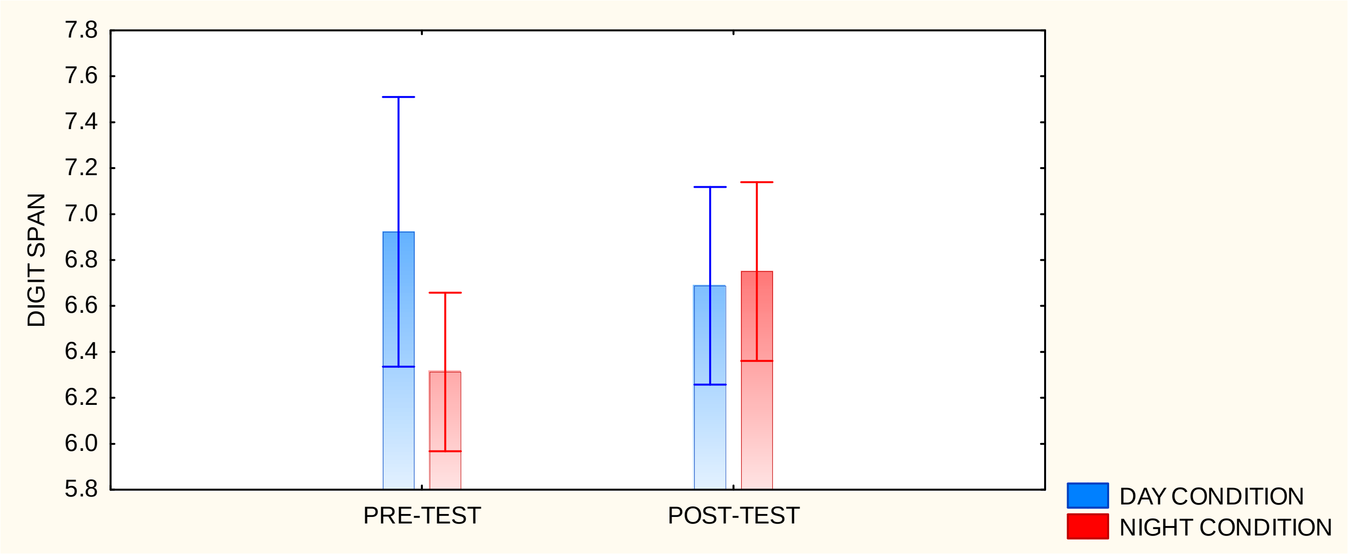


Figure 25: Significant effect between time of day and the pre–post tests administered (I-denote 0.95 confidence intervals).

4.3.3 Lane Deviation

A two-factorial analysis of variance (ANOVA) was performed on the driving data in order to establish the average lane deviation achieved over the 90 minute task duration, results are displayed in Table XIX.

Table XIX: Analysis of variance for lane deviation established during the main task, with time of day and time on task as the two factors (* = significant difference, $p<0.05$).

Lane Deviation Effect	**p**
time of day	0.33
time on task	$p<0.05$ *
time of day *time on task	0.92

a. Time of Day

There was no significant effect found for time of day.

b. Time on Task

A significant effect was found for time on task and is characterised by Figure 26.

There is a fluctuating increase in the lane deviation, measured in meters, over the duration of the 90 minute task. The first 10 minute interval has a recorded lane deviation of ±0.0120m, 20 minute interval of ±0.0110m, 30 minute interval of ±0.0130m, 40 minute interval ±0.0140m, 50 minute interval of ±0.0155m, 60 minute interval ±0.0145m, 70 minute interval of ±0.0150m, 80 minute interval ±0.0155m, and the final 90 minute interval a recording of ±0.0165m average lane deviation.

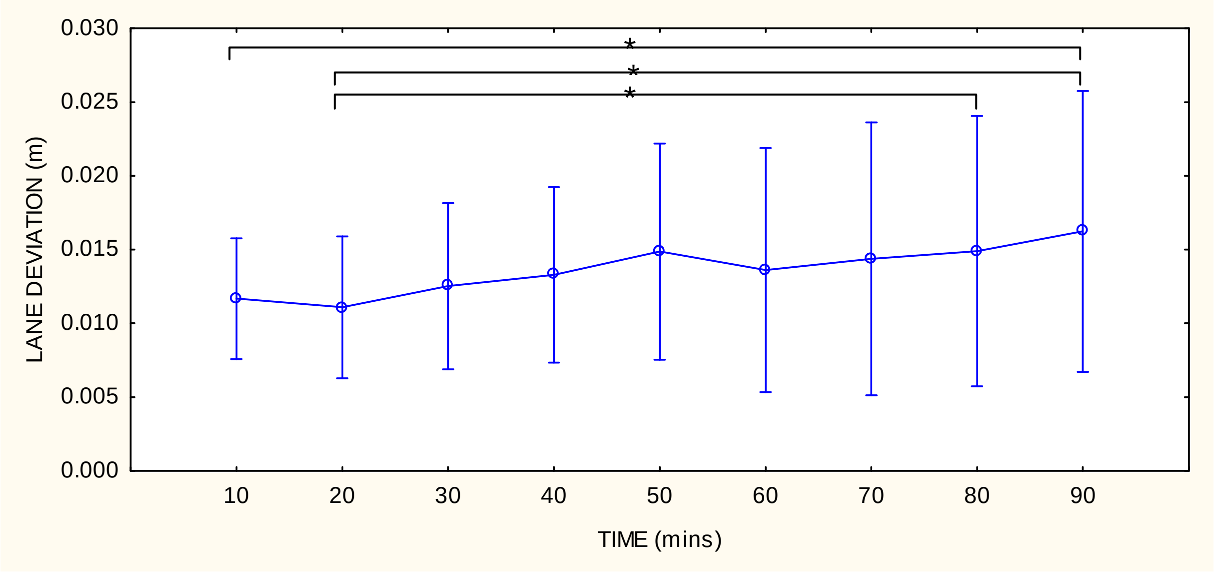


Figure 26: Significant effect for time on task, regarding lane deviation (* represents a significant difference, $p<0.05$; I-denote 0.95 confidence intervals).

A Tukey post hoc analysis was conducted on the average lane deviation data in order to determine where the significances lay within the data. It was established that the 10 minute interval was significantly different to the 90 minute interval and the 20 minute interval was significantly different to the 80 and 90 minute intervals, as denoted in Figure 26.

c. Interactional Effects

No significant difference was found for the interactional effect between time of day and time on task.

4.3.4 Number of Saccades

It must be noted that the number of saccades presented in the results does not comprise all the saccades that occurred over the 90 minute duration, but rather saccades that were elicited and aimed outside the primary driving screen into the periphery.

Table XX: One-factorial analysis of variance conducted for the number of saccades, with time of day as the factor (* = significant differences, p<0.05).

Number of Saccades Effect	**p**
time of day	p<0.05 *

a. Time of Day

Table XX provides the significant effect found for the number of saccades for time of day. This significant difference is illustrated by Figure 27, where for the Day Condition the average number of saccades was 5, while the average number of saccades for the Night Condition was 10. This indicates that the average number of saccades increased by 100% during the Night Condition, when compared to the average number of saccades that were elicited during the Day Condition.

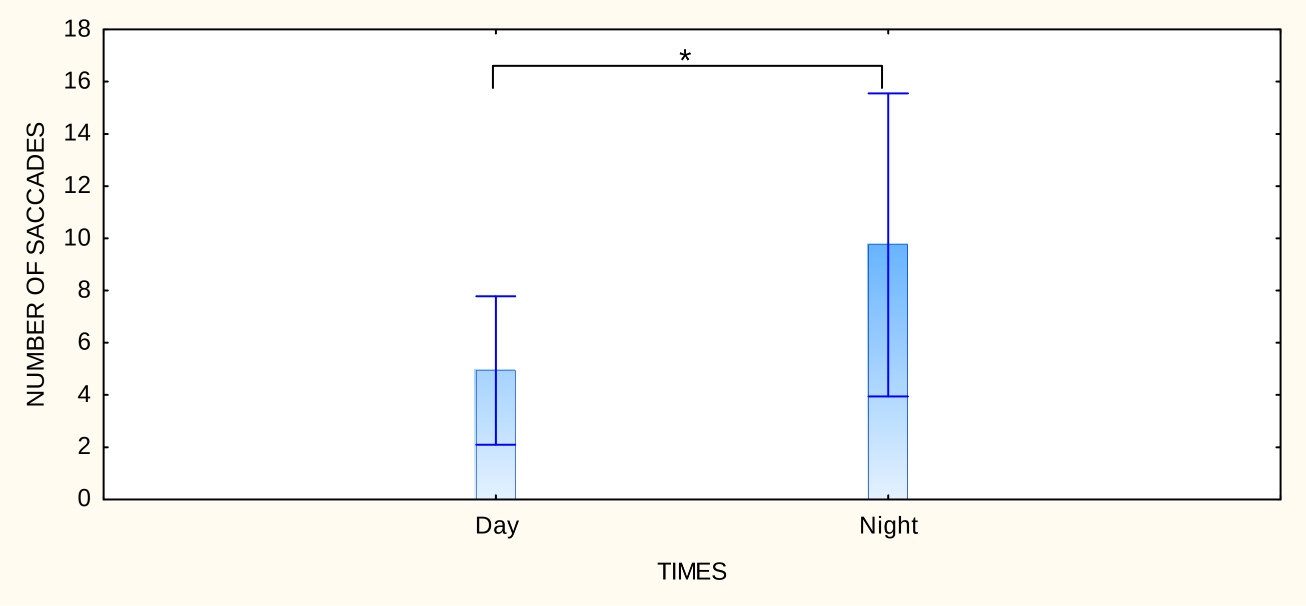


Figure 27: The number of saccades recorded during the different times of day (* represents a significant difference, p<0.05; I-denote 0.95 confidence intervals).

4.4 SUBJECTIVE MEASURES

4.4.1 Wits Sleepiness Scale

For data processing, the five cartoon faces were numbered from 1 to 5, with 1 being extremely alert and 5 representing an individual who is unable to keep their eyes open (refer to Methodology).

Table XXI: Two-factorial ANOVA performed for the Wits Sleepiness Scale scores, using time of day and pre–post tests as the two factors(* = significant difference, $p<0.05$).

Wits Sleepiness Scale Effect	**P**
time of day	p<0.05 *
pre–post	p<0.05 *
time of day *pre–post	0.41

a. Time of Day

Referring to Table XXI, time of day was found to be significantly different for the Wits Sleepiness Scale analysis. The average degree of sleepiness, assessed using the Wits Sleepiness Scale, was higher during the Night Condition compared to the Day Condition (Figure 28). During the Day Condition, the average degree of sleepiness was 2.34, which, when referred back to the scale used (see Appendix B1), indicates a moderately alert state, as it is the next state after extremely alert and the closest picture to the reading obtained. However, during the Night Condition the average degree of sleepiness was 2.81, and would correspond most closely to the third cartoon face, which illustrates a sleepy individual.

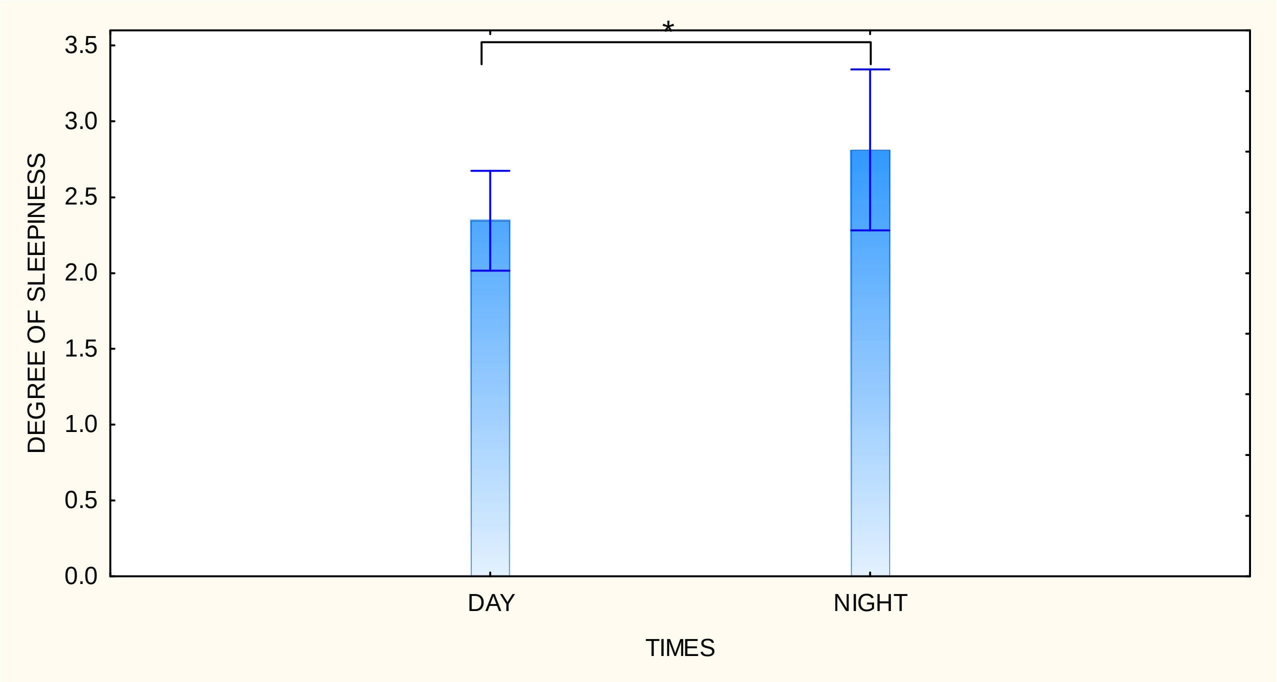


Figure 28: Significant effect for time of day with regard to the Wits Sleepiness Scale (* represents a significant difference, p<0.05; I-denote 0.95 confidence intervals).

b. Pre–Post Tests

The difference between the pre- and post-test conducted for the Wits Sleepiness Scale yielded a significant difference (see Table XXI).

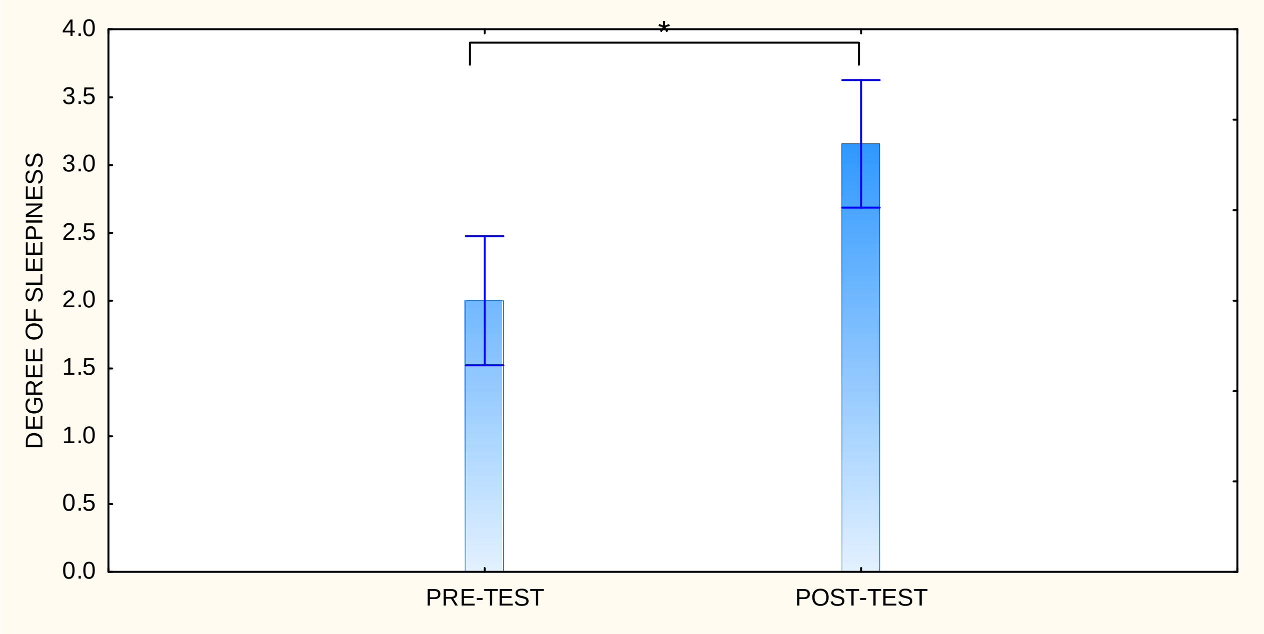


Figure 29: Significant difference found for the Wits Sleepiness Scale scores between the pre- and post-test (* represents a significant difference, p<0.05; I-denote 0.95 confidence intervals).

When comparing the pre- and post-test Wits Sleepiness Scale results, it was established that during the pre-test measure the average degree of sleepiness was 2, depicting a moderately alert individual, whereas the post-test measure's average degree of sleepiness was 3.15, as displayed in Figure 29, representing a relatively fatigued cartoon face, which is the closest representation to the score attained.

c. Interactional Effect

The interactional effect between time of day and the pre–post tests had no significant effect.

4.4.2 National Aeronautics and Space Administration-Task Load Index (NASA-TLX)

Table XXII: Two-factorial ANOVA conducted on NASA-TLX questionnaire data (* = significant difference, p<0.05).

NASA-TLX Effect	**P**
time of day	0.10
categories	p<0.05 *****
time of day *categories	0.22

a. Time of Day

Overall ANOVA (see Table XXII) indicated that no significant difference was established for time of day.

b. Categories

Significant differences were found between the different categories for the NASA-TLX questionnaire. It can be established from Figure 30 that the rating scores for effort and mental demand are greatest, while physical demand and temporal demand attained the lowest rating scores. For mental demand an average score of ±66% was recorded, for physical demand an average score of ±42%, for temporal demand an average score of ±43%, for performance an average score of ±60%, for effort an average rating score of ±68%, and for frustration an average score of ±64%. Lastly all the scores of the six sub-scales were weighted and an average total workload rating was calculated, which was ±63%.

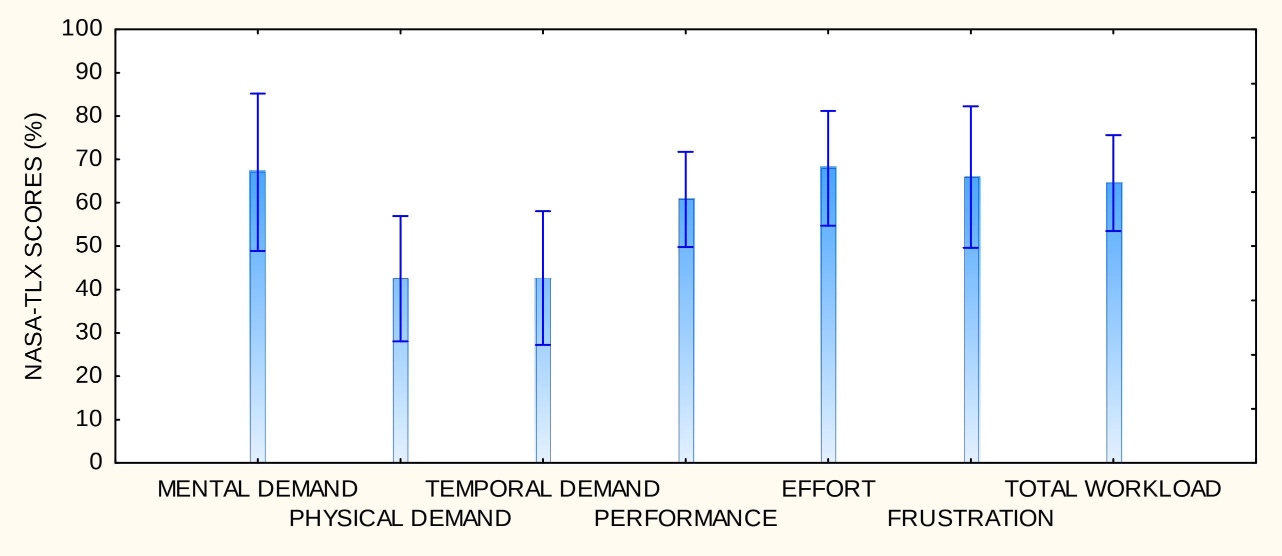


Figure 30: Significant effect between the different categories comprising the NASA-TLX questionnaire (I-denote 0.95 confidence intervals).

c. Interactional Effect

For the interactional effect between time of day and the different categories, which comprise the NASA-TLX questionnaire, no significant differences were seen.

4.5 PERCENTAGE RATE OF DECREMENT

Tukey post hoc analyses were conducted on the driving and percentage of missed peripheral stimuli data, in order to assess whether the percentage decrement occurs at the same rate for both measures. In order to be able to compare the two measures, the driving data were relativised against the first 10 minute interval, and the percentage of missed stimuli was first converted to a percentage of correctly identified stimuli, and then relativised against the first 10 minute interval. Table XXIII and Table XXIV depict the significances found within the driving and missed stimuli data respectively. For detailed post hoc test tables refer to Appendix D2.

Table XXIII: Tukey post hoc test conducted on the driving data, which were relativised against the first 10 minute interval.

		20mins	**30mins**	**40mins**	**50mins**	**60mins**	**70mins**	**80mins**	**90mins**
INTERVAL	**20mins**				$p<0.05$		$p<0.05$	$p<0.05$	$p<0.05$
	30mins								$p<0.05$
	40mins								$p<0.05$
	50mins								
	60mins								$p<0.05$

Table XXIV: Results of a Tukey post hoc analysis established for the percentage of missed stimuli, relativised against the first 10 minute interval.

		20mins	**30mins**	**40mins**	**50mins**	**60mins**	**70mins**	**80mins**	**90mins**
INTERVAL	**20mins**				$p<0.05$		$p<0.05$	$p<0.05$	$p<0.05$
	30mins								$p<0.05$
	40mins								$p<0.05$
	50mins								
	60mins								$p<0.05$

From the post hoc analysis results displayed in Table XXIII and Table XXIV, it can be seen that the significances within the driving and missed stimuli data start occurring at 50 minutes for both measures. For both the driving and missed stimuli, the 20 minute interval was found to be significantly different to the 50 minute, 70 minute, 80 minute and 90 minute intervals. The 30 minute interval, 40 minute interval and 60 minute interval are all significantly different to the 90 minute interval.

4.6 SEX DIFFERENCES

ANOVAs were conducted using sex as a covariate, in order to establish the effects of sex on the numerous indicators employed in this research. Sex was found to be significant for the parameters of tympanic temperature and response time to the peripheral stimuli; however, no interactional effects between sex and fatigue related decrements (time of day or time on task) were found.

4.7 SUMMARY OF RESULTS

Table XXV, Table XXVI and Table XXVII provide an overview of the non-significant and significant (p<0.05) results observed for all the performance, psychophysiological and subjective measures obtained during the testing sessions.

4.7.1 Measures Taken During Main Task

Table XXV: Significant and non-significant effects found between the various indicators during the primary driving task (where: N.S = Non- significant difference; S = Significant difference; / = Not measured).

		TIME OF DAY	**TIME ON TASK**	**ECCENTRICITY**	**TIME OF DAY *TIME ON TASK**
Performance	Lane Deviation	N.S	S	/	N.S
	Response Time	N.S	S	S	N.S
	Missed Responses	N.S	S	S	N.S
	Number Saccades	S	/	/	/
Psycho-physiological	HR	N.S	S	/	S
	HRV	S	S	/	N.S
	Blink Frequency	N.S	S	/	N.S
	Blink Duration	N.S	S	/	N.S

a. Impact of Time of Day

Significant Effects

Heart rate variability and the number of saccades were found to be significant, see Table XXV.

Non-Significant Effects

As indicated in Table XXV, no significant differences were established for all performance indicators, namely lane deviation, response time to stimuli and the percentage of missed stimuli, obtained during the main task. With regard to psychophysiological indicators heart rate, blink frequency and blink duration all yielded non-significant effects for time of day.

b. Impact of Time on Task

Significant Effects

All performance and psychophysiological indicators obtained during the main task indicated significant differences regarding time on task (see Table XXV).

c. Interactional Effects

Significant Effects

Significances were established for the interactional effect between time of day and time on task with regard to the psychophysiological measure of heart rate (Table XXV).

Non-Significant Effects

The interactional effect between time of day and time on task reflected no significant differences for all performance measures (lane deviation, response time, percentage missed stimuli), as well as for the psychophysiological measures of heart rate variability, blink frequency and blink duration (Table XXV). No significances were established for response time and the percentage of missed stimuli with regard to the interactional effect between time of day and eccentricity, the interactional effect between eccentricity and time on task, and lastly the interactional effect between time of day, eccentricity and time on task (see Appendix D1 for tables).

4.7.2 Measures Taken Pre- and Post-Main Task

Table XXVI represents the non-significant and significant results obtained during the pre- and post-tests conducted for the various indicators. A brief summary is given below.

Table XXVI: Significant and non-significant results found for the different indicators for the pre- and post-tests conducted (where: N.S = No Significant difference; S = Significant difference).

		TIME OF DAY	**PRE–POST**	**TIME OF DAY *PRE–POST**
Performance	Memory	N.S	N.S	S
Psychophysiological	CFFF	N.S	S	N.S
	Tympanic Temperature	N.S	S	N.S
Subjective	Wits Sleepiness Scale	S	S	N.S

a. Time of Day

Significant Effects

A significant effect was found for the Wits Sleepiness Scale, regarding time of day (see Table XXVI).

Non-Significant Effects

All performance and psychophysiological measures, taken before and after the main task, yielded non-significant results for time of day, as illustrated in Table XXVI.

b. Pre- versus Post-Test

Significant Effects

Significant differences were established for all psychophysiological measures (CFFF and tympanic temperature) as well as for the subjective measure (Wits Sleepiness Scale) obtained.

Non-Significant Effects

The performance indicator (memory) showed no significant difference with respect to the difference between the pre- and post-tests conducted (refer to Table XXVI).

c. Interactional Effects

Significant Effects

The interactional effect between time of day and the pre–post tests was significant for the performance measure of memory (Table XXVI).

Non-Significant Effects

For CFFF, tympanic temperature and the Wits Sleepiness Scale, the interactional effect between time of day and the pre–post tests conducted yielded no significant differences.

4.7.3 Measures Taken at the End of Test Session

A summary of the NASA-TLX questionnaire results, which was obtained at the end of each test session, can be seen below, with reference to Table XXVII.

Table XXVII: Significant and non-significant results obtained for the NASA-TLX questionnaire (where: N.S = No Significant difference; S = Significant difference).

		TIME OF DAY	**CATEGORIES**	**TIME OF DAY *CATEGORIES**
Subjective	NASA-TLX	N.S	S	N.S

a. Impact of Time of Day

Non-Significant Effects

Results obtained for the NASA-TLX questionnaire, a subjective measure, indicate no significant difference for time of day.

b. Impact of Categories

Significant Effects

A significant effect was found between the seven different categories, including total workload, encompassing the NASA-TLX questionnaire.

c. Interactional Effects

Non-Significant Effects

No significant differences were found for the interactional effect between time of day and the categories that comprise the NASA-TLX questionnaire

4.8 RESPONSES TO HYPOTHESES

Hypothesis 1: The null hypothesis states that there will be no difference between the Day and Night Conditions for all performance, psychophysiological and subjective responses. The alternate hypothesis states that there will be a difference between the Day and Night Conditions for all performance, psychophysiological and subjective responses.

Therefore, as there were significant differences found between the Day and Night Conditions for heart rate variability, number of saccades towards the peripheral stimuli, and the Wits Sleepiness Scale, the null hypothesis was tentatively rejected and the alternate hypothesis accepted. Alternatively, due to lack of significant differences for the other responses, the null hypothesis is tentatively accepted for these variables.

Hypothesis 2: The null hypothesis states that all performance, psychophysiological and subjective parameters obtained would remain unchanged between the beginning and the end of the test session. The alternate hypothesis states that all performance, psychophysiological and subjective parameters obtained will differ between the beginning and the end of the test session.

Significant differences were established between the beginning and the end of the test session for lane deviation, response time, percentage of missed responses, heart rate, heart rate variability, blink frequency, blink duration, critical flicker fusion frequency threshold, core body temperature and the Wits Sleepiness Scale, therefore the null hypothesis is rejected for these measures. Alternatively the null hypothesis is tentatively accepted for all the other measured variables.

CHAPTER V

5 DISCUSSION

5.1 PRELUDE

The aim of the research was to determine the effect that fatigue renders on an individual's peripheral visual field and to establish whether a decrement in driving performance occurs at the same rate as a decrement in peripheral visual performance. Objective and subjective parameters were measured in order to analyze fatigue occurrence. The results presented in the previous chapter allude to the possibility that task duration is key when assessing the effects that fatigue has on a driver's peripheral vision. The following chapter will discuss the effects of time of day for all psychophysiological, performance and subjective measures, followed by the effects of time on task for all measures obtained during the test sessions. Afterwards the procedure will be reflected upon.

5.2 PSYCHOPHYSIOLOGICAL MEASURES

5.2.1 Heart Rate

a. Time of Day Effect

No significant difference was established for heart rate, regarding time of day. This was an unexpected result, as during the Night Condition fatigue levels would have been more elevated than during the Day Condition. This is based on the body being ready for work during the day and rest during the night (Smiley, 1990), as well as on the considerations that during the Night Condition participants would have been awake for a longer period of time and thus would have felt more pressure to sleep (Porter, 2011), and that, according to Mascord and Heath (1992), heart rate decreases under conditions involving elevated levels of fatigue. Heart rate is however affected by many factors, such as physical activity, respiration, and health state (Jorna, 1992; Jahn et al., 2005), and since the participants' actions before and after the test sessions could not be controlled, partaking in physical activity, although forbidden, may have contributed to no significances being established for time of day.

b. Time on Task Effect

A significant effect was found for heart rate over the duration of the main task (Figure 13). This was an expected finding, as according to Mascord and Heath (1992) heart rate decreases with decreased task difficulty, as well as during long distance driving. A decrease in heart rate is associated with an increased level of fatigue; therefore a decrease in the average heart rate over the task duration coincides with task related fatigue. The main tracking task was a monotonous one and thus was associated with a low task difficulty (Hancock and Verwey, 1997), and the 90 minute duration of the main task can be considered a long distance drive, under controlled conditions (Di Milia, 2006; Gander et al., 2011). The decrease in the average heart rate of the subjects over the 90 minute main task depicts that the attentional demands were external to the subjects during this particular task (Lacey and Lacey, 1974), and that with time on task there was an elevation in the subjects’ fatigue levels (Mascord and Heath, 1992). However, it needs to be considered that this result may reflect that the participants were active before the test session and once they were seated and began the main task their heart rate slowed down as they became more inactive.

c. Interactional Effects

When assessing the significant difference found for the interactional effect between the two conditions and the task duration (Figure 14), it was seen that during the day there was a decrease in heart rate, while during the night there was a slight increase in the average heart rate obtained by the subjects. Heart rate reflects task demands, with a decrease in heart rate reflecting a low level of task demand, such as reflected during the Day Condition (Jorna, 1992; Mascord and Heath, 1992), and an increase in heart rate reflecting a high level of task demand, which is depicted by the Night Condition (Mascord and Heath, 1992). This was an unexpected result as according to Hartley et al. (1994) heart rate should decrease during prolonged night time driving. During the Night Condition subjects may have placed more effort into the task than during the Day Condition, as during the night subjects were faced with the compound effect of time of day fatigue, caused by the circadian cycle and a build up of sleep pressure (Achermann et al., 1993), time on task fatigue as well as task related fatigue (Smiley, 1990; Williamson et al., 2011), and thus in order to maintain performance throughout the task more effort had to be put into the task (Lacey and

Lacey, 1974; Hockey, 1997). This may be reflected in the increase in the average heart rate of the subjects during the Night Condition, when compared to the Day Condition.

5.2.2 Heart Rate Variability

a. Time of Day Effect

Heart rate variability was observed to have a significant effect for time of day (Figure 15). During the Day Condition heart rate variability was higher than during the Night Condition, this unexpected finding may possibly be attributed to the fact that heart rate variability reflects workload and effort, and a decrease in heart rate variability, depicted by the Night Condition, indicates an increase in workload or effort (Mascord and Heath, 1992), while the Day Condition reflects a low workload, effort and level of alertness (Lal and Craig, 2001). It was assumed that during the night there would be an increase in heart rate variability because according to Mascord and Heath (1992) with increased fatigue levels, there is a increase in heart rate variability, however during the Night Condition there was a decrease in heart rate variability indicating that subjects may have had to place more effort into the task at hand, in order to counteract performance decrements brought about through time of day fatigue (Hockey, 1997). This is supported by Jorna (1992) who stated that heart rate variability decreases under conditions of increasing effort levels, and this increase in effort is reflected in the decrease in the average heart rate variability during the Night Condition.

b. Time on Task Effect

Figure 16 represents the significant difference found for time on task. It can be seen that overall there is an increasing trend reflected in the average heart rate variability; this increase in heart rate variability over the duration of the main task may be associated with the fact that during long distance driving there is an increase in fatigue levels, which is reflected by an increase in heart rate variability (Oran-Gilad and Ronen, 2007). The increase in heart rate variability over the task duration may signify a task related fatigue brought about by the monotonous tracking task, as monotony leads to decreased arousal levels (Smiley, 1990; Thiffault & Bergeron, 2003a).

5.2.3 Core Body Temperature

Tympanic temperature was used as a representative of core temperature during this research (Childs et al., 1990; Klein et al., 1993).

a. Time of Day Effect

When assessing the results attained for tympanic temperature, it was found that there was no significant effect for time of day. This was unexpected due to the fact that core body temperature follows the circadian rhythm (Johns, 2000), and although time of day was more of an interest than the circadian effect, it was expected that during the mid morning, when the Day Condition test session was conducted, core body temperature would be significantly higher when compared to the Night Condition, which was conducted during a circadian downswing. This is in accordance with Bentley (2007) who stated that during the evening there is a decrease in core body temperature, which is associated with sleep. However, the average tympanic temperature remained consistent over the two conditions, with the average day and night tympanic temperature both being recorded at 35.1℃ (±0.04). Myers and Badia (1995) and Sund-Levander et al. (2002) provide a possible explanation for this, whereby they state that core body temperature is influenced by many factors, other than the 24 hour circadian cycle, such as food intake, illness, individual characteristics and physical activity. Although subjects were instructed not to exercise for 24 hours prior to each test session, this and the time at which subjects consumed food could not be controlled, as subjects were not under the supervision of the researcher leading up to each test session. The subjects' state of health as well as their individual characteristics could not be controlled by the researcher either.

b. Pre–Post Tests Effect

The significant effect found for tympanic temperature between the pre- and post-test measurements may indicate a decrease in tympanic temperature over the task duration. The pre-test tympanic temperature reading was 35.3℃ (±0.14) whereas the post-test tympanic temperature had a recording of 34.9℃ (±0.05). This finding was expected as time on task has a strong correlation to fatigue (Paley and Tepas, 1994), and fatigue is associated with a drop in core body temperature (Rosekind et al., 1994). Thus, this decrease in core body temperature may be a reflection of time on task fatigue experienced by the subjects over the duration of the 90 minute main task. It needs to be noted that that fatigue is not the only factor to affect core body temperature; it is also affected by, among others, physical activity (Myers and Badia, 1995), which will lead to an increase in core body temperature, however once inactive, core body temperature will decrease, such as that reflected in the results. As the participants were not monitored before and after test sessions, it is not possible to conclude that the decrease in core body temperature was caused only due to time on task.

5.2.4 Critical Flicker Fusion Frequency (CFFF) Threshold

a. Time of Day Effect

According to Maas et al. (1974) critical flicker fusion frequency (CFFF) can be used to determine whether an individual is visually or mentally fatigued, therefore it was adopted as a measure during this research. It was assumed that during the Day Condition individuals would obtain a higher CFFF threshold value than during the Night Condition, based on the fact that during a circadian downswing, when the Night Condition was conducted, individuals are naturally more fatigued both mentally and physically, but no significant effect was established for time of day. During the Day Condition the CFFF threshold was 53 Hz (±1.59), while during the Night Condition it was 54 Hz (±2.65), indicating relative stability across the two conditions. This is in accordance with Nilsson et al. (1997) and Stern et al. (1994) whose research was also unable to relate CFFF threshold to fatigue, while others such as Kishida (1973) have been successful.

b. Pre–Post Tests Effect

Statistical analyses revealed that a significant effect was displayed between the pre- and post-tests conducted for CFFF (Figure 18). For the pre-test an average CFFF threshold value of 55 Hz (±0.84) was obtained, whereas an average reading of 52 Hz (±0.22) was recorded for the CFFF threshold post-test. This finding could be explained by Baschera and Grandjean (1979) and Weber et al. (1980) who stated that a decreased CFFF threshold value reflects a decrease in brain arousal and consciousness levels, which indicate fatigue onset. Thus, it may possibly be stated that the decrease in the CFFF threshold between the pre- and post-tests may reflect mental and visual fatigue incurred over the 90 minute main task duration (Łuczak and Sobolewski, 2005).

5.2.5 Blink Frequency

a. Time of Day Effect

No significant effect was found for blink frequency with regard to time of day. This result is unexpected as according to literature, with fatigue there is an inability to inhibit blinks and as a result there is an increase in blink frequency (Stern et al., 1994a). Therefore, it was expected that during the Night Condition, when participants are more fatigued and have a greater accumulation of sleep pressure, there would be a significantly higher number of blinks occurring than during the Day Condition, when sleep pressure is low and participants are more alert. However, another possible explanation could be that fatigue is only one of many factors that affect blink frequency; factors include stimulus timing, stimulus presentation and the level of task demand (Sirevaag and Stern, 2000). During the Night Condition participants may have perceived a higher demand placed on them by the task, as they would have needed to place more effort into the task in order to counteract the effects of time of day fatigue, and the higher the task demand experienced, the greater the inhibition of blinks (Sirevaag and Stern, 2000).

b. Time on Task Effect

As expected, there was a significant effect found for blink frequency over the duration of the main task (Figure 20). The average blink frequency for the participants at the beginning of the main task was recorded at 14 blinks/min, which increased to 17 blinks/min at the termination of the main task. This increase is indicative of fatigue associated with time on task, as an increase in blink frequency reflects an increase in the fatigue state of an individual (Stern et al., 1994a), however it must be noted that there are many factors that can affect an individual’s blink frequency, thus it cannot be conclusively said that the increase in blink frequency attained in this research is as a result of fatigue. Other factors include the visual demand level of the task, in which blink frequency increases with a decrease in the demand level (Stern et al., 1994b). The main tracking task used in the study was not visually demanding and thus may have contributed to an increase in the blink frequency seen over the duration of the 90 minute task (Sirevaag & Stern, 2000).

5.2.6 Blink Duration

Blink duration is defined as the amount of time that the pupil is covered by the eyelid during a blink (Sirevaag and Stern, 2000), and for the purpose of this research any blink longer than 300 ms was considered an eye closure and thus not considered for analysis.

a. Time of Day Effect

Although no significant effect was found for time of day for blink duration, it was expected that the Night Condition would obtain a significantly higher blink duration when compared with the Day Condition, as it is known that an increase in the level of sleepiness, such as that experienced during the night due to circadian effects and an increased sleep pressure (Smiley, 1990; Rom and Markowitz, 2007), is linked with an increase in blink duration (Caffier et al., 2003; Åkerstedt et al., 2005). Due to the fact that participants were not monitored before the day and night shifts, activities undertaken during this time may have influenced this variable and thus yielded insignificant results.

b. Time on Task Effect

Blink duration was shown to increase significantly from 150 ms to 185 ms over the duration of the main task (Figure 21). This increase of 35 ms in the average blink frequency may be attributed to time on task fatigue. This was expected as blink duration has been found to show significant effects for time on task, with fatigue resulting in increased blink duration (Sirevaag and Stern, 2000). An increase in blink duration, as experienced over the duration of the task, may lead to an increase in the probability of accidents occurring, as the eyes are closed for longer durations and critical information may be missed (Stern et al., 1994a; Sirevaag and Stern, 2000).

5.3 PERFORMANCE MEASURES

5.3.1 Peripheral Response Time

The response time was measured as the time between a stimulus presentation and a response to that stimulus (Drowatsky, 1981).

a. Time of Day Effect

No significant differences were established for time of day; this finding disagrees with literature, which states that simple response times get slower with fatigue, time awake as well as time of day (Welford, 1980; Williamson et al., 2001; Horowitz et al., 2003; Baulk et al., 2008). Therefore, based on this literature it would be expected that during the Night Condition, response time to the peripheral stimuli would have been significantly slower in comparison to the Day Condition. Kribbs and Dinges (1994) found response time to be sensitive to fatigue, while Gillberg et al. (1996) did not. A possible reason for no significances being found for time of day could be due to the fact that fatigue is not the only factor that has an effect on response time. Sex, age, learning, distractions and motivation all have an impact on response time (Drowatzky, 1981).

b. Eccentricity Effects

The different eccentricities, namely ±40°, ±30° and ±20°, were found to have a significant effect with regards to the response time of the peripheral stimuli (Figure 22), with the two outer eccentricities, -40° and +40°, attaining the slowest response times of 0.4 s and 0.36 s respectively. -30° attained a response time of 0.33 s, -20° a response time of 0.32 s, and +20° and +30° both a response time of 0.30 s. The general trend that can be seen from these findings is that, with an increase in eccentricity, there is an increase in the time taken to respond to the peripheral stimuli. One explanation for this increase in response time, with regard to the different eccentricities, may be due to the different parts of the eye with which the different stimuli eccentricities are perceived. When a stimulus is perceived by the rods response time is found to be slower than when a stimulus is picked up by the cones in the eye (Ando et al., 2002). The inner eccentricities, namely -20° and +20°, were situated just outside the main driving screen and thus were perceived by the cones in the eye, whereas the outer eccentricities, namely -40°, -30°, +30°, +40°, would have been perceived by the rods, thus obtaining a slower response time. Through post hoc analysis, it was established that -30° eccentricity was significantly different to +30°, as well as -40° and +40° eccentricity being significantly different to each other. -40° eccentricity obtained a slower response time to +40° eccentricity, and -30° eccentricity obtained a slower response time to +30° eccentricity, for which a possible explanation could be due to the left side of the visual field being weaker than right side of the visual field (Harms and Pattern, 2003), and thus longer detection times are inevitable. According to Bub and Lewine (1988), faster and more accurate responses occur in the right visual field, which supports the findings in this study.

c. Time on Task Effect

Figure 23 depicts the significant effect for response time with regard to time on task. This significant increase over the duration of the 90 minute task is in accordance with Philip et al. (2003) who found response time to lengthen with an increase in fatigue levels, which may have adverse effects on driving safety. The main driving task was monotonous and therefore may have resulted in fatigue levels increasing (Hancock and Verwey, 1997), and had a negative impact on alertness and information processing (Thiffault and Bergeron, 2003a; Gander et al., 2011), which would have led to an increase in response time over the task duration. From these results, it would appear that after 40 minutes, on this particular task, there is a significant effect on the peripheral response time, indicating a performance decrement due to time on task fatigue.

5.3.2 Percentage of Missed Peripheral Stimuli

a. Time of Day Effect

The non-significant effect for the percentage of missed peripheral stimuli, with regard to time of day, was an unanticipated finding. It is well known that with tunnel vision, brought about through fatigue onset, there is an impairment of stimuli detection (Recarte and Nunes, 2003). During the Night Condition individuals would have been more fatigued, due to the circadian cycle as well as an accumulation of sleep pressure over the course of the day, and thus it was expected that during the night there would be a greater occurrence of tunnel vision, which would result in perceptual narrowing and an increase in the number of missed stimuli (Mills et al., 2001). Participants would have experienced an increase in workload during the night, as they would have had to place more effort into the task at hand in order to maintain a level of performance (Hockey, 1997), and according to Rantanen and Goldberg (1999) and Martens and van Winsum (2000), an increased workload leads to an increase in missed stimuli. However, it must be noted that other factors, excluding fatigue, affect the size of the visual field, such as boredom, age, and the arousal state of the participant (Rogé et al., 2002a; Owsley and McGwin Jr, 2010); due to the main task being monotonous, boredom and a decreased state of arousal would have been present during the Day and Night Condition and thus may have masked the effects of time of day.

b. Eccentricity Effect

Figure 24 depicts the significant effect established for the percentage of missed peripheral stimuli regarding eccentricity. The two outer eccentricities, namely -40° and +40°, obtained the highest percentages of missed responses, 30% and 20% respectively. This coincides with Hills (1980) and Rogé et al. (2003) who stated that with a state of fatigue, there will be a reduction in the visual field and thus an increase in the number of missed stimuli will occur. Based on the results from Tukey post hoc analysis, it was established that -40° eccentricity was not significantly different to +40° eccentricity, but was significantly different to all other eccentricities; this is in accordance with Rogé et al. (2002b) who stated that, when dynamic stimuli are used to measure peripheral performance, deterioration occurs at the outer most eccentricities of the visual field, a phenomenon which is referred to as tunnel vision (Bartz, 1976).

c. Time on Task Effect

The significant effect seen for time on task (Figure 24), when assessing the percentage of missed peripheral stimuli, is in agreement with Chinn and Alluisi (1964), Ahsberg et al. (2000) and Boksem et al. (2005), who all concur that the effects of time on task result in an increased percentage of missed stimuli. This finding is also supported by Rogé et al. (2009) who stated that with prolonged tasks there is a decrease in an individual’s alertness levels, which has a negative impact on the number of missed responses. Based on post hoc analysis results, it can be stated that there is a significant increase in the percentage of missed responses after the 50 minute interval, and thus, coupled with a decrease in response time, which occurs beyond the 40 minute interval, it is indicative of a progressive degradation over time possibly due to the effects of time on task.

5.3.3 Digit Span Memory Test

a. Time of Day Effect

No significant results were found for the digit span memory test, with regards to time of day. This finding was unforeseen as a decrement in memory performance is associated with fatigue (Lal and Craig, 2001; Tyagi et al., 2009). During the Night Condition, participants would have been more fatigued, due to time of day and sleep pressure accumulated over the hours awake, which should have been portrayed in a lower memory test score, in comparison to the Day Condition. Wyatt et al. (1999) concur by stating that short term memory tends to decrease with prolonged time awake, and since Night Condition participants had been awake for a longer period than for the Day Condition, memory performance should have decreased. A possible explanation for this could be due to the participants activities not being monitored before the tests, and thus if participants ignored the research guidelines pertaining to sleep, this may have resulted in undesirable effects.

b. Pre–Post Test Effect

For the analysis of the pre–post tests conducted for memory, no significant difference was established. A probable cause for this may have been that implementing this type of test, which places a great demand on the individual, results in an increased level of cerebral activity, which in turn temporarily masks signs of fatigue (Grandjean, 1979). Therefore, there would have been no significance seen between the pre-test memory scores and the post-test memory scores, as any fatigue effects incurred as a result of time on task would have been masked when the test was implemented.

c. Interactional Effect

For the interactional effect between time of day and pre–post tests conducted, a significant effect was found (Figure 26). The Day Condition memory result decreased from 6.9 (±1.10) during the pre-test to 6.6 (±0.81) during the post-test. This result is in accordance with Babkoff et al. (1988), Lal and Craig (2001) and Tyagi et al. (2009), who all state that with fatigue, in this instance task related fatigue, there will be a decrement in memory performance. However, for the Night Condition there was an increase in memory performance from 6.3 (±0.65) during the pre-test to 6.7 (±0.73) during the post-test, which contradicts the aforementioned literature. One explanation for this may be that participants may have experienced a feeling of relief when the Night Condition was terminated, and thus this feeling of relief may have been greater than the feeling of fatigue, such as experienced by night shift workers in research by Lobb et al. (2009), who found performance enhanced during post-tests conducted when compared to the pre-test.

5.3.4 Lane Deviation

a. Time of Day Effect

Arnedt et al. (2001) and He et al. (2011) found that lane deviation could be used to indicate an individual’s state of fatigue, with lane deviation increasing with an increased state of fatigue. The results for time of day go against the literature, as no significances were established between the Day and Night conditions. Lane deviation is found to increase with an increased time awake (Åkerstedt et al., 2005; Porter, 2011), thus indicating that the Night Condition should have rendered a significantly higher lane deviation, compared to the Day Condition, as participants would have been awake for a greater period of time before the Night Condition test session commenced. Due to participants activities not being monitored or recorded before the test sessions, it was unknown if all research guidelines had been adhered to and thus may have influenced the time of day effect.

b. Time on Task Effect

Figure 27 depicts the significant effect established for time on task, with regard to lane deviation. This finding is supported by literature which states that driving under monotonous and prolonged conditions, such as that of the main task, leads to deterioration in an individual’s ability to guide a vehicle, thus resulting in an increased lane deviation (Verwey and Zaidel, 1999; Thiffault and Bergeron, 2003a; Richter et al., 2005). This is reiterated by Åkerstedt et al. (2005) and Porter (2011) who found lane deviation to increase with an increased time on task. The monotonous conditions of the main task may have resulted in the impairment of the participants’ driving skills, which would have caused lane deviation to increase over time on task (Brown, 1982).

5.3.5 Number of Saccades towards the Peripheral Stimuli

a. Time of Day Effect

For the analysis of the number of saccades towards the peripheral stimuli, the significant effect established for time of day was expected, as it was presupposed that during the Night, due to the effect of sleep pressure build up and time of day fatigue (Porter, 2011), that the number of involuntary saccades would increase, due to the inability when fatigued to maintain inhibitory control over saccades, which are externally triggered by stimuli appearing suddenly within the environment (Cotti et al., 2007). During the Night Condition the average number of saccades elicited was 10 (±10), whereas for the Day Condition the average number of saccades was 5 (±5); these findings are in disagreement with Sirevaag and Stern (2000) who found that saccades become less regular with fatigue. Rantanen and Goldberg (1999), however, established that more eye movements are required to detect stimuli when situational demands are high. These high situational demands may have been self imposed by the participants, who would need to place more effort into the task at hand during the night in order to compensate for time of day fatigue (Hockey, 1997). It should be noted that these results are not based on all the saccades that occurred during the 90 minute main task, but rather those saccades that were elicited and aimed outside of the primary driving task screen and into the peripheral area, as subjects were told to keep their eyes on the driving task and only use their peripheral vision to detect the stimuli (see Methodology). It is difficult to establish extensive literature that supports the findings obtained in this research as most literature on saccades and fatigue are based on visual search tasks, which account for all saccades, such as Bahill & Stark (1975), Stern et al. (1994b), Sirevaag and Stern (2000) and Schleicher et al. (2008).

5.4 SUBJECTIVE MEASURES

5.4.1 Wits Sleepiness Scale

a. Time of Day

The significant effect found for time of day, shown in Figure 28, is to be expected due to the fact that the Day Condition occurred during a circadian upswing, in which individuals are generally more alert, whereas during a circadian downswing, such as when the Night Condition test session was conducted, individuals are naturally down regulating and are thus more fatigued. According to Porter (2011), the sleep drive peaks between 10 pm and 12 am, which is highlighted in the higher degree of sleepiness on the Wits scale experienced by the participants during the Night Condition.

b. Pre–Post Test Effect

The difference expressed between the pre- and post-tests in Figure 29 can be ascribed to the effect of time on task fatigue, as the pre-test degree of sleepiness is measured before the main task and the post-test degree of sleepiness is established after the main task has been completed. Thus the increase in the degree of sleepiness between the two tests reflects an increase in task related fatigue. Due to the monotony of the main task, participants would have experienced a decrease in alertness (Gander et al., 2011), which could result in an individual experiencing greater levels of sleepiness with time (Smiley, 1990). Based on this it can be established that participants had greater feelings of sleepiness at the end of the task, compared to the beginning, which is reflected in the significant increase found between the pre- and post-tests conducted for the Wits Sleepiness Scale.

5.4.2 NASA-TLX Questionnaire

The NASA-TLX questionnaire was completed at the end of each test session as it gives an overall estimation of the task performance and mental effort associated with the given workload.

a. Time of Day

No significances were established for time of day, which is unusual due to the fact that a higher subjective workload rating score would correlate with a higher level of fatigue, such as that experienced during the Night Condition, as the participant would perceive that the amount of effort put into a task to be greater when a fatigued state is greater (Hockey, 1997; Williamson et al., 2011). However, the NASA-TLX questionnaire was completed at the end of each test session and during the night, participants may have experienced a feeling of relief when the Night Condition was terminated, which may have masked the participants feelings of fatigue (Lobb et al., 2009), thus rendering the questionnaire invalid for the effect of time of day.

b. Categories Effect

Figure 30 illustrates the significant effect between the different categories comprising the NASA-TLX questionnaire. Effort and mental demand attained the highest percentage scores, 66% and 68% respectively. An explanation for mental demand being so high, could be attributed to the fact that the curvy road used in the task was used in order to induce a high workload level, one in which the participant had to concentrate throughout the task (Baldauf et al., 2009). This could also account for the high rating of frustration (64%) experienced by the participants as full concentration was required at all times, and with fatigue over time comes performance decrements, such as increased lane deviation (Verwey and Zaidel, 1999), which the participants may have found frustrating. When assessing the differences between the subscales which place demands on the individual (mental, physical and temporal demand), and the subscales which account for the interaction between the individual and the task (performance, effort and frustration level) (Cao et al., 2009), it can be seen that the interaction between the task and the individual obtained higher percentage scores than those subscales that place demands on the individual. This indicates that the interaction between the task and the individual was more taxing than the demands placed on the individual.

5.5 PERCENTAGE RATE OF DECREMENT

When assessing the results for the percentage rate of decrement in driving (Table XXIII) against the percentage rate of decrement in missed peripheral responses

(Table XXIV), it was found that significances start occurring at the 50 minute interval for both measures. This indicates that the percentage rate of decrement begins at the same time, thus illustrating a general decrement in performance, and not one measure decreasing first. This information can be useful as when an individual’s driving performance begins to decrease, it may possibly indicate that there is a performance breakdown with regard to their peripheral visual field, based on these findings.

5.6 SEX DIFFERENCES

5.6.1 Tympanic Temp

The recordings for the male and females are both lower than the normal tympanic temperature readings for individuals within the age range of the subjects; a normal temperature range for an individual aged between 11–65 years is 35.9–37.6℃. However, there are many reasons for this such as the accuracy of the thermometer used and the user experience of the subjects. Females had an average core body temperature of 35.5℃ (±0.53), while the males had a lower core body temperature of 34.7℃ (±0.95). A possible reason for this may be due to the fact that it is well known that generally females have a higher percentage of adipose tissue compared to males, and with a greater amount of adipose tissue there is a greater amount of heat production, thus core body temperature will be higher (Savastano et al., 2009). Another possible explanation is that when females ovulate there is an increase in body temperature (Baker and Driver, 2007), and as this was too invasive to account for, it cannot be ruled out as a possible contributor.

5.6.2 Peripheral Response Time

Females attained a faster response time compared to males; this contradicts literature which states that faster response times are attained by males (Drowatzky, 1981).

5.7 REFLECTION ON THE PROCEDURE

From the results it can be seen that there is a greater effect with regard to time on task, than there is for time of day. With time on task, significant driving performance decrements occur at the 40 minute interval; this is followed by a decrement in the peripheral visual field, indicated through an increase in the percentage of missed peripheral stimuli, at the 50 minute interval. This progressive decrease in performance over the duration of the task indicates time on task fatigue effects are more prominent than time of day effects, in which minimal significances were found, in this particular study.

While every effort was made to control and eliminate extraneous variables, it is not possible to control every impinging influence. Therefore, when examining the implications and subsequent conclusions from this research study, cognisance must be taken of the following limitations. The sample selected was one of convenience and was limited to 16 participants, which is a relatively small sample size. Although participants were informed verbally and in written form regarding the DO’s and DON’T’s at the habituation session, such as obtaining seven to eight hours sleep five days prior to the test sessions, not to consume caffeine, drugs or alcohol, or not to partake in vigorous physical activity, it was out of the control of the researcher, as the participants were not confined to the Human Kinetics and Ergonomics department for the duration of the study. The time of day at which the Night Condition was conducted, while providing valuable psychophysiological information, may not occur at enough of a circadian downswing, and thus could potentially affect the time of day and sleep pressure effects. Participants were habituated during the afternoon, thus a novelty effect may have compromised the findings as participants would have experienced feelings of excitement, especially concerning the Night Condition. Although participants were confined to the Human Kinetics and Ergonomics department for the duration of the testing sessions, the differences between the Day and Night conditions could not be fully controlled. The ambient temperature difference may have influenced tympanic temperature measures. Core body temperature tablets would have alleviated this problem; however the use of these tablets was not feasible, and thus the use of an ear thermometer was more affordable. Participants were screened for sleep disorders, using a sleep disorder questionnaire, but there were no means for the researcher to test for the presence of sleep disorders. Thus, the information provided by the participant had to be taken at face value, and should any participant suffer from any sleep disorder, their results will have an effect on the validity of the Night Condition responses. The times at which participants ate was not controlled by the researcher, and thus if participants consumed food shortly before the test sessions, this would potentially impact certain measures, which are influenced by food intake. The type of food consumed may also affect some measures, as foods with a high glycemic index, would have resulted in an early onset of fatigue, which would have in turn affected performance and arousal to a greater extent than fatigue, caused by time of day or time on task only. When assessing the results of the different eccentricities used, it may have been more suitable to exclude ±40°, as these two eccentricities had significantly greater response times and missed responses, indicating that they were potentially too extreme for participants to detect. With regard to the measures chosen for this study, it can been seen from the results that the digit span memory test had no significant effects for time of day and time on task, thus it can be said that it is a weak measure for this type of research. The NASA-TLX questionnaire, although used as a fatigue indicator, is more applicable for workload studies and thus the Samn–Perelli Fatigue Scale (Samn and Perelli, 1982) may be a more appropriate measure and give more sound findings. The Dikablis eye tracking system does not have a built in head tracker and therefore if participants moved their head, any time after the completion of calibration, the blink duration, blink frequency and number of saccades may have been compromised. This could be rectified through the use of an eye and head tracking system; however, due to affordability and availability the Dikablis system was used. The critical flicker fusion frequency was controlled by the researcher; this may have had an impact on the results as there may have been a delay between when the participant indicated that the light was a solid one and when the researcher stopped increasing the hertz. By allowing the participants to increase the hertz, this discrepancy could be minimised.

CHAPTER VI

6 CONCLUSIONS AND RECOMMENDATIONS

The results of the presented study indicate that there were more significant differences established for time on task, than for time of day. This illustrates that time on task could be the more important aspect to focus on when implementing work schedules and rest breaks, as when assessing the results of the current study it was found that the effects of time on task were greater than the effects of time of day. These significances were established through psychophysiological, performance and subjective parameters. The importance of performance for time of day is paramount, as there is a natural decline in responses and performance associated with circadian downswings (Van Dongen et al., 2003), in which the Night Condition occurred; however, no significant effects were found for any of the performance measures regarding time of day. Conversely, for the performance measures of eccentricity, it was found that both response time to peripheral stimuli and the percentage of missed peripheral responses increased significantly over the duration of the task; response time significantly increased (reactions became slower) after the 40 minute interval, while the percentage of missed peripheral stimuli significantly increased after the 50 minute interval. This could possibly reflect a cumulative decrement in peripheral performance, with regard to time on task, as there is first a significant slowing in the response time to the peripheral stimuli followed by a significant increase in the percentage of missed peripheral responses. The current research signifies the importance of taking an holistic approach when researching the effects of fatigue on a driver's peripheral vision. The assessment of all measured variables, individually and in conjunction with each other, provided valuable insight into time of day and time on task effects, as well as how the various components interacted and corresponded. This allows for interventions and implementations to occur in transport safety as well as industry settings.

Future research looking into the effect of time on task on a driver's psychological, performance and subjective responses during a secondary peripheral detection task in a simulated day and night drive should consider the following recommendations:

1) The sample size used in the current study was limited by feasibility and administrative purposes: it is recommended that a larger sample size be used at times that more accurately depict a circadian upswing and downswing, so that more accurate results could be obtained. The reason for the recommendation is attributed to the 24hour circadian cycle, as it was established that testing from 11h00 to 01h00 produced mainly non-significant effects, with regard to time of day. Thus if the same participants are observed during one of the circadian nadirs, more significant findings could possibly be established for the various measures, regarding time of day.

2) The confinement of the participants to the testing area for the total duration of the test schedule would allow for day time and night time activities to be continuously monitored, thereby ensuring that all participants adhere to the guidelines provided. This would eliminate many possible masking factors which may have attributed to the significant and non-significant findings in the current study.

3) The stage of the female participants' menstruation cycle should be considered and matched for, as this has been found to have an effect on certain measures, such as core body temperature.

4) The testing procedure should follow a design in which the various psychophysiological and performance measures, such as critical flicker fusion frequency, core body temperature and memory, are obtained on a more frequent basis, as this could possibly eliminate the effects that the feeling of relief, experienced by participants when the Night Condition was terminated, may have had on the results.

5) Conducting the presented research in situ may prove beneficial, as the fatigue induced through time on task may not adequately represent fatigue felt by drivers in the transportation sector, nor may it accurately represent the dangers associated with real driving. The task employed during the research was simple and monotonous, thus the resultant fatigue and the effects on the peripheral visual field may not have been attributed to time on task but rather boredom or down regulation related to the monotony of the tracking task. Therefore, more research needs to be conducted in order to gain an in depth understanding of the effects and related consequences that fatigue has on driving and the peripheral visual field.

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APPENDICES

7.1 APPENDIX A: GENERAL INFORMATION

1 Advertisement to Participants

2 Demographics Form

3 Morningness-Eveningness Questionnaire

4 Sleep Disorder Questionnaire

5 Letter of Information to the Participant

6 Participant Consent Form

7 Driving Disclaimer

8 Ethical Clearance

7.1.1 ADVERTISEMENT TO PARTICIPANTS

ATTENTION ALL RHODES STUDENTS

Are you a non-smoker?

Do you get 7–8 hours of sleep every night?

Do you have good eye sight/vision without the use of glasses?

Do you have a valid driver's licence?

Then we are looking for you to be a participant in an HKE MSc study.

The Human Kinetic and Ergonomics Department is running a Masters study relating to ***THE EFFECTS OF FATIGUE ON A DRIVER'S PERIPHERAL VISION*** which requires between 16 and 20 student participants.

Dates: Two testing sessions between **10th July** and **31st August**

Where: The Human Kinetics and Ergonomics Department (situated next to the Rhodes Health Suite).

Who: participants must fulfil all of the following criteria –

- **No history of sleep related disorders (insomnia, sleep apnea etc)**
- **No consumption of alertness enhancing medication**
- **Aged between 18–35 years**
- **Good physical health**

Time period: 2 testing sessions, one during the day and one during the night, of 2 hours each.

What you will be required to do: You will need to partake in a 90 minute simulated driving task while responding to peripheral stimuli.

What will be tested: A simple memory test, a reaction time task, driving performance over the test session as well as heart rate and various eye measures will be recorded over the testing session. A simple questionnaire will need to be filled in at the end of the both test sessions.

Benefits: You will be contributing to the body of knowledge regarding driver fatigue and thus help reduce accidents and injury related to this phenomenon.

IF YOU ARE INTERESTED IN PARTICIPATING OR WOULD LIKE TO FIND OUT MORE ABOUT THE STUDY, PLEASE CONTACT JADE ON 0826995963 OR g06r5889@campus.ru.ac.za.

*This study has been approved by the Human Kinetic and Ergonomic Ethics Committee.

7.1.2 DEMOGRAPHICS FORM

Subject-Number ___________

Gender: ○ female ○ male

Race: ○ black ○ white ○ other

Age: ________ years

Academic year: _________________

Social year: ____________________

Degree (BSc, BA, BCom): _______________

Do you have a valid driver's license ○ yes ○ no

If yes, in what year was it obtained? __________________

FOR RESEARCHER ONLY

Morningness-Eveningness Score: ____________________

Sleep Disorder Assessment Score: ____________________

7.1.3 MORNINGNESS-EVENINGNESS QUESTIONNAIRE

MORNINGNESS-EVENINGNESS QUESTIONNAIRE
(Self Assessment Version)
Adapted from Horne and Ostberg, 1976

Name: ____________________________ Date: ____________________________

For each question, please select the answer that best describes you by circling the point that best indicates how you have felt in recent weeks.

19. *Approximately* what time would you get up if you were entirely free to plan your day?
    5. 5:00 AM – 6:30 AM
    4. 6:30 AM – 7:45 AM
    3. 7:45 AM – 9:45 AM
    2. 9:45 AM – 11:00 AM
    1. 11:00 AM – 12 noon

2. *Approximately* what time you go to bed if you were entirely free to plan your evening?
    5. 8:00 PM – 9:00 PM
    4. 9:00 PM – 10:15 PM
    3. 10:15 PM – 12:30 AM
    2. 12:30 AM – 1:45 AM
    1. 1:45 AM – 3:00 AM

19. If you usually have to get up at a specific time in the morning, how much do you depend on an alarm clock?
    4. Not all at
    3. Slightly
    2. Somewhat
    1. Very much

19. How easy do you find it to get up in the morning (when you are not awakened unexpectedly)?
    1. Very difficult
    2. Somewhat difficult
    3. Fairly easy
    4. Very easy

19. How alert do you feel during the first half hour after you wake up in the morning?

    1. Not at all alert
    2. Slightly alert
    3. Fairly alert
    4. Very alert

19. How hungry do you feel during the first half hour after you wake?

    1. Not at all hungry
    2. Slight hungry
    3. Fairly hungry
    4. Very hungry

19. During the first half hour after you wake up in the morning, how do you feel?

    1. Very tired
    2. Fairly tired
    3. Fairly refreshed
    4. Very refreshed

8. If you had no commitments the next day, what time would you go to bed compared to your usual bedtime?

    1. Seldom or never later
    2. Less than 1 hour later
    3. 1–2 hours later
    4. More than 2 hours later

9. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week, and the best time for him is between 7–8 AM. Bearing in mind nothing but your own internal ‘clock’, how do you think you would perform?

    4. Would be in good form
    3. Would be in reasonable form
    2. Would find it difficult
    1. Would find it very difficult

10. At *approximately* what time in the evening do you feel tired, and, as a result, in need of sleep?

    5. 8:00 PM – 9:00 PM
    4. 9:00PM – 10:15 PM
    3. 10:15 PM – 12:45 PM
    2. 12:45 PM – 2:00AM
    1. 2:00 AM – 3:00 AM

11. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last two hours. You are entirety free to plan your day. Considering only your ‘internal clock’, which one of the four testing times would you choose?

    6. 8 AM – 10 AM
    4. 11 AM – 1 PM
    2. 3 PM – 5 PM
    0. 7 PM – 9 PM

12. If you got into bed at 11 PM, how tired would you be?

    0. Not at all tired
    1. A little tired
    3. Fairly tired
    5. Very tired

13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which one of the following are you most likely to do?

    4. Will wake up at usual time, but will not fall back asleep
    3. Will wake up at usual time and will doze thereafter
    2. Will wake up at usual time, but will fall asleep again
    1. Will not wake up until later than usual

14. One night you have to remain awake between 4–6 AM in order to carry out a night watch. You have no time commitments the next day. Which one of the alternatives would suit you best?

    1. Would not go to bed until the watch is over
    2. Would take a nap before and sleep after
    3. Would take a good sleep before and nap after
    4. Would sleep only before the watch

15. You have two hours of hard physical work. You are entirely free to plan your day. Considering only your internal ‘clock’, which of the following times would you choose?

    4. 8 AM – 10AM
    3. 11 AM – 1 PM
    2. 3 PM – 5 PM
    1. 7 PM – 9 PM

16. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week. The best time for her is between 10–11 PM. Bearing in mind only your internal ‘clock’, how well do you think you would perform?

    1. Would be in good form
    2. Would be in reasonable form
    3. Would find it difficult
    4. Would find it very difficult

17. Suppose you can choose your own work hours. Assume that you work a five-hour day (including breaks), your job is interesting, and you are paid based on your performance. At *approximately* what time would you choose to begin?

    5. 5 hours starting between 4 – 8AM
    4. 5 hours starting between 8 –9 AM
    3. 5 hours starting between 9AM – 2 PM
    2. 5 hours starting between 2 – 5 PM
    1. 5 hours starting between 5 PM – 4 AM

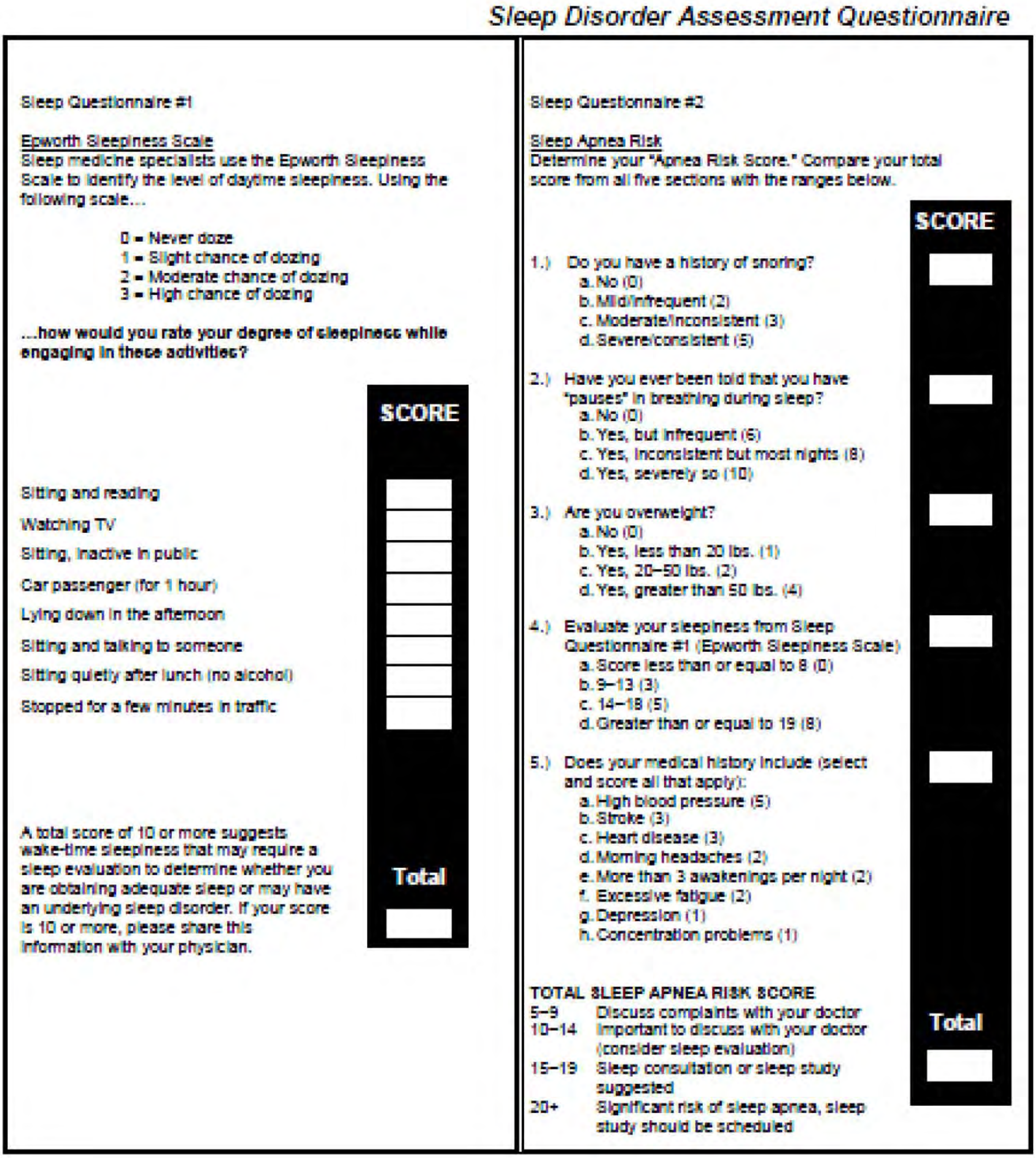
18. At *approximately* what time of the day do you usually feel your best?

5. 5 – 8 AM
4. 8 – 10 AM
3. 10 AM – 5 PM
2. 5 – 10 PM
1. 10 PM – 5 AM

19. One hears about “morning types” and “evening types”. Which one of these types do you consider yourself to be?

6. Definitely a morning type
4. Rather more a morning type than an evening type
2. Rather more an evening type that a morning type
1. Definitely an evening type

7.1.4 SLEEP DISORDER QUESTIONNAIRE



Sleep Disorder Assessment Questionnaire

Sleep Questionnaire #1

Epworth Sleepiness Scale
Sleep medicine specialists use the Epworth Sleepiness Scale to identify the level of daytime sleepiness. Using the following scale…

0 = Never doze
1 = Slight chance of dozing
2 = Moderate chance of dozing
3 = High chance of dozing

…how would you rate your degree of sleepiness while engaging in these activities?

	SCORE
Sitting and reading	
Watching TV	
Sitting, inactive in public	
Car passenger (for 1 hour)	
Lying down in the afternoon	
Sitting and talking to someone	
Sitting quietly after lunch (no alcohol)	
Stopped for a few minutes in traffic	
Total	

A total score of 10 or more suggests wake-time sleepiness that may require a sleep evaluation to determine whether you are obtaining adequate sleep or may have an underlying sleep disorder. If your score is 10 or more, please share this information with your physician.

Sleep Questionnaire #2

Sleep Apnea Risk
Determine your "Apnea Risk Score." Compare your total score from all five sections with the ranges below.

SCORE

1.) Do you have a history of snoring?
a. No (0)
b. Mild/infrequent (2)
c. Moderate/inconsistent (3)
d. Severe/consistent (5)

2.) Have you ever been told that you have "pauses" in breathing during sleep?
a. No (0)
b. Yes, but infrequent (6)
c. Yes, inconsistent but most nights (8)
d. Yes, severely so (10)

3.) Are you overweight?
a. No (0)
b. Yes, less than 20 lbs. (1)
c. Yes, 20–50 lbs. (2)
d. Yes, greater than 50 lbs. (4)

4.) Evaluate your sleepiness from Sleep Questionnaire #1 (Epworth Sleepiness Scale)
a. Score less than or equal to 8 (0)
b. 9–13 (3)
c. 14–18 (5)
d. Greater than or equal to 19 (8)

5.) Does your medical history include (select and score all that apply):
a. High blood pressure (5)
b. Stroke (3)
c. Heart disease (3)
d. Morning headaches (2)
e. More than 3 awakenings per night (2)
f. Excessive fatigue (2)
g. Depression (1)
h. Concentration problems (1)

Total

TOTAL SLEEP APNEA RISK SCORE

5–9	Discuss complaints with your doctor
10–14	Important to discuss with your doctor (consider sleep evaluation)
15–19	Sleep consultation or sleep study suggested
20+	Significant risk of sleep apnea, sleep study should be scheduled

7.1.5 LETTER OF INFORMATION TO PARTICIPANT

Dear ………………………………….

Thank you for participating in this project entitled:

“PERIPHERAL VISION FIELD FATIGUE DURING SIMULATED DRIVING: THE EFFECTS OF TIME ON TASK AND TIME OF DAY ON SELECTED PSYCHOPHYSIOLOGICAL, PERFORMANCE AND SUBJECTIVE RESPONSES”

The Department of Human Kinetics and Ergonomics at Rhodes University is interested in researching the effects of fatigue on the peripheral visual field during simulated driving. You will be required to participate in two 2 hour test sessions, namely a Day Condition and a Night Condition. The Day Condition will run from 9am–11am and the Night condition from 11pm–1am. You will be **assigned** your first session; you will then have a day in between and will return for the second session at the allocated time, depending which Condition it is.

Day Condition (9am–11am): This will require you to perform a Tracking Task using the driving simulator. The Tracking Task involves using the steering wheel of the driving simulator to track the white line, located in the centre of the road, as accurately as possible. While participating in the Tracking Task peripheral stimuli will be displayed, at the level of the steering wheel, to the right and left of you. You are instructed to keep your head facing forward and your eyes on the road with the Tracking Task as your main focus, however when you detect a peripheral stimuli you must respond as **quickly** as possible using either of the clickers, which are located on the steering wheel.

Night Condition (11pm–1am): The Night Condition will follow the same protocol as the Day Condition, where you will be required to perform a Tracking Task while responding to peripheral stimuli. The only difference between the two conditions will be the time of day when the testing occurs.

Procedure

You will be required to partake in a pre-test habituation session of 60 minutes during which the procedure and the experimental set up will be explained to you in detail. During this session you will also be made aware of the risks and benefits associated with the research you are participating in, both verbally and in written form. Both test sessions will be carried out in the Human Kinetics and Ergonomics Department, situated next to the Health Suite on Rhodes University campus. You will be required to take part in two test sessions; each session will last approximately 2 hours 30 minutes, this includes time taken to become accustomed to the task and equipment. Therefore, if your test session starts at 9am or 11pm you will be required to arrive at the Human Kinetics and Ergonomics department no later than 8:40am or 10.40pm respectively. At the end of each test session you will be asked to fill in a simple questionnaire called the NASA-TLX questionnaire, this should take approximately 10 minutes.

Each test session will include physiological and psychological measures that will be recorded over the 2 hours. These measures include a peripheral stimuli test, a NASA-TLX questionnaire, eye measures, which will require you to wear a head mounted eye tracker for the duration of the test and heart rate, measured using a heart rate belt worn by you during testing. None of these measures are invasive or impose any risks. After your first test session you will have one full day to rest before returning at your allocated time for your final test session. It is imperative that you get a **minimum** of 7 hours sleep for 5 consecutive nights **prior** to the first test session as well as the night before the second test session.

Requirements

Prior to testing, I ask that you refrain from the following (**DON'TS)**:

- Consumption of alcohol and drugs 48 hours prior
- Caffeine ingestion 24 hours prior
- Vigorous physical activity 24 hours prior
- Sleeping anytime during the day, evening and night of your Night Condition test session

Prior to and during testing, I ask that you (**DOS)**:

- It is imperative to get a minimum of 7 hours sleep for at least 5 consecutive nights PRIOR to your first test session, as well as the night before your second test session. This is due to the fact that accumulative sleep restrictions will increase your recovery time after the test session as well as have a negative effect on the results of the study
- Keep your head and eyes facing forward during driving
- You will be required to wake up at least 90 minutes before the Day Condition test session, this will ensure that you are completely awake by the time testing occurs. The Day Condition test session commences at 08h30 thus you will be required to wake up by 07h00 at the latest.
- Make transport arrangements for after the Night Condition, as you will not be fit to drive due to fatigue.
- Ask any questions you may have at any time regarding the study
- Report ANY feelings of drowsiness or nausea to the researcher and testing will be stopped with immediate effect
- Report any discomfort you may be feeling during the test, for example: if the eye tracker is too loose or too tight please DO NOT adjust it yourself, inform the researcher and it will be attended to

Risks and Benefits

Risks:

- **Fatigue, drowsiness and sleepiness** during the Night Condition, as you will be working against your natural circadian rhythm; however this is easily reversed through rest and sleep
- **Simulator sickness**, which results in a headache and feelings of nausea, can occur due to the prolonged duration of the driving task, however due to the type of simulator used the occurrence of simulator sickness is unlikely. In the event that simulator sickness does occur testing will stop with immediate effect
- **Visual fatigue** may occur during the prolonged drive, resulting in a headache, eye strain, eye fatigue, tired, burning, watering, itching, dry, sore, bloodshot or irritated eyes, as well as blurred or double vision. It is unlikely that this will occur as the task duration equates to watching a movie or sitting on a computer for 90 minutes. If visual fatigue does occur all these effects are temporary and are easily reversed through rest and sleep
- **Postural discomfort** may be experienced due to the fact that you are seated in one position for 90% of the test session, which equates to sitting in a car for 90 minutes. This is temporarily reversed through the slight shifting of your

body position as well as the stretching of your legs. All effects will be completely reversed at the end of the test session where you will be able to walk around and stretch

Benefits:

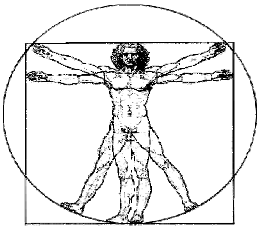
- You will be adding to the body of existing knowledge regarding driver fatigue and thus will contribute to making a difference in combating this worldwide problem

At the pre-test habituation session age and driving experience will be recorded, and you will be assigned your session dates and times. You will also be required to fill out Morningness – Eveningness Questionnaire (Horne and Östberg, 1976). The results of this assessment will be used as the criteria to classify and evenly distribute subjects across the conditions, according to chronotype.

If, at any period of time during the testing procedure, you feel the need to withdraw from testing **for whatever reason**, you are free to inform the researcher that you do not wish to continue to take part in the research any more. You are under no obligation to stay against your will, or to complete the testing. All information obtained will be **stored confidentially** and all data recorded during both test sessions will be coded to ensure your **anonymity**. Thank you for the interest you have shown this research, please feel free to ask any questions you may have about the research at any time.

Yours sincerely,
Jade Robertson
MSc student
Department of Human Kinetics and Ergonomics
Rhodes University
Cell: 0826995963
Email: g06r5889@campus.ru.ac.za

7.1.6 PARTICIPANT CONSENT FORM



I,……………………………………., having been fully informed of the research project entitled:

“PERIPHERAL VISION FIELD FATIGUE DURING SIMULATED DRIVING: THE EFFECTS OF TIME ON TASK AND TIME OF DAY ON SELECTED PSYCHOPHYSIOLOGICAL, PERFORMANCE AND SUBJECTIVE RESPONSES”

Do hereby give my consent to act as a subject in the above named research.

I am fully aware of the procedures involved as well as the potential risks and benefits associated with my participation as explained to me verbally and in writing. In agreeing to participate in this research I waive any legal recourse against the researcher of Rhodes University, from any and all claims resulting from personal injuries sustained whilst partaking in the investigation. This waiver shall be binding upon my heirs and personal representatives. I realise that it is necessary for me to promptly report to the researcher any signs or symptoms indicating any abnormality or distress. I am aware that I may withdraw my consent and may withdraw from participation in the research at any time. I am aware that my anonymity will be protected at all times, and agree that all the information collected may be used and published for statistical or scientific purposes.

I have read the information sheet accompanying this form and understand it. Any questions which may have occurred to me have been answered to my satisfaction.

SUBJECT (OR LEGAL REPRESENTATIVE):

……………………….	……………………..	…………………
(Print name)	(Signed)	(Date)

PERSON ADMINISTERING INFORMED CONSENT:

………………………	……………………...	…………………..
(Print name)	(Signed)	(Date)

WITNESS:

……………………….   ……………………….   …………………...

(Print name)   (Signed)   (Date)

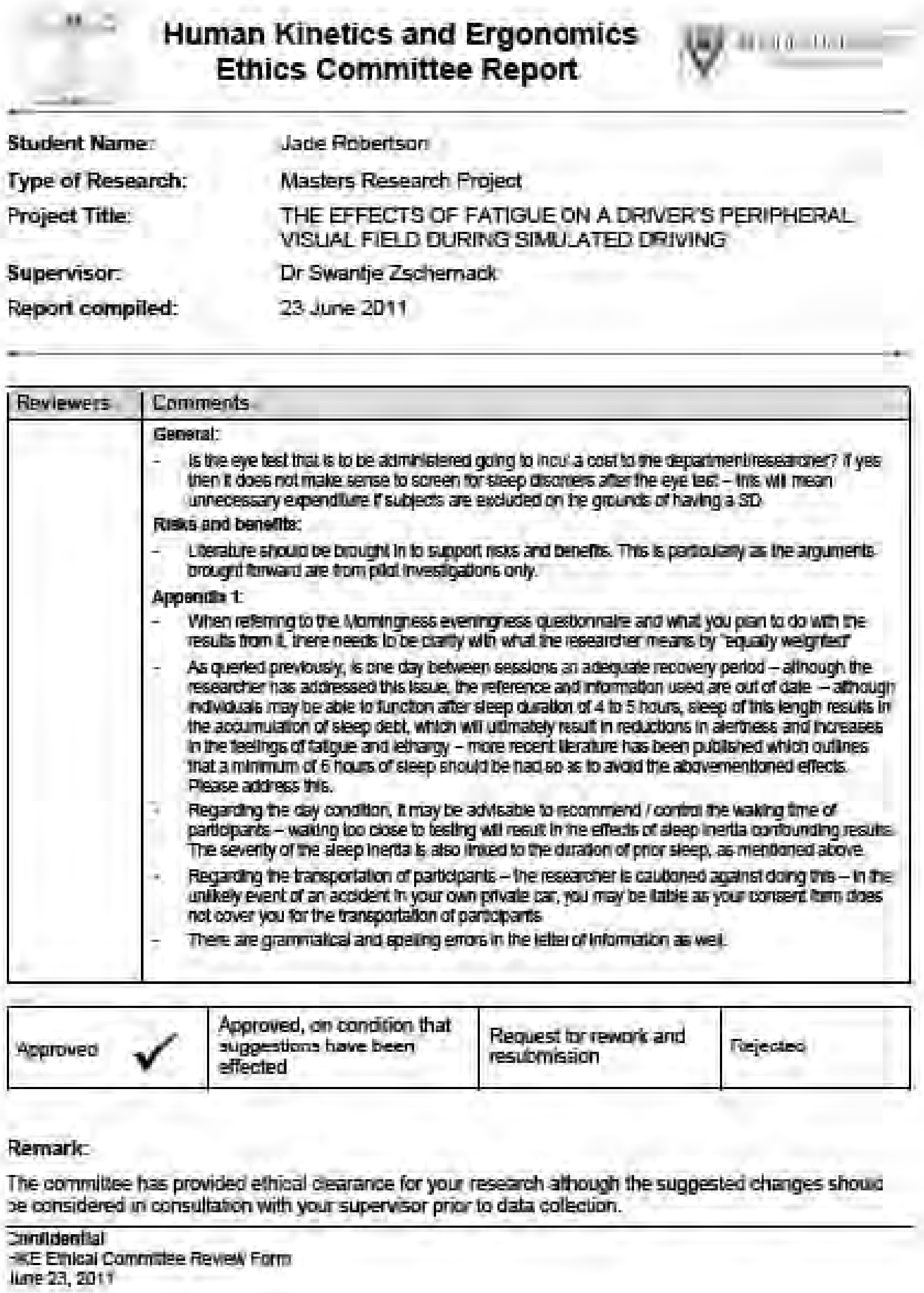
7.1.7 DRIVING DISCLAIMER

Disclaimer:

I, ___________________________, have read and understand the risks involved in driving myself home after a testing session. I understand that the researcher is not liable for any harm or damage that may occur to myself, my vehicle or any other persons or property due to my decision to drive myself home.

Signed: _____________________ Date: _________________

7.1.8 ETHICAL CLEARANCE



Human Kinetics and Ergonomics
Ethics Committee Report

Student Name: Jade Robertson

Type of Research: Masters Research Project

Project Title: THE EFFECTS OF FATIGUE ON A DRIVER'S PERIPHERAL VISUAL FIELD DURING SIMULATED DRIVING

Supervisor: Dr Swantje Zschernack

Report compiled: 23 June 2011

Reviewers	Comments
	General: - Is the eye test that is to be administered going to incur a cost to the department/researcher? If yes then it does not make sense to screen for sleep disorders after the eye test – this will mean unnecessary expenditure if subjects are excluded on the grounds of having a SD. **Risks and benefits:** - Literature should be brought in to support risks and benefits. This is particularly as the arguments brought forward are from pilot investigations only. **Appendix 1:** - When referring to the Morningness eveningness questionnaire and what you plan to do with the results from it, there needs to be clarity with what the researcher means by "equally weighted" - As queried previously, is one day between sessions an adequate recovery period – although the researcher has addressed this issue, the reference and information used are out of date. – although individuals may be able to function after sleep duration of 4 to 5 hours, sleep of this length results in the accumulation of sleep debt, which will ultimately result in reductions in alertness and increases in the feelings of fatigue and lethargy – more recent literature has been published which outlines that a minimum of 6 hours of sleep should be had so as to avoid the abovementioned effects. Please address this. - Regarding the day condition, it may be advisable to recommend / control the waking time of participants – waking too close to testing will result in the effects of sleep inertia confounding results. The severity of the sleep inertia is also linked to the duration of prior sleep, as mentioned above. - Regarding the transportation of participants – the researcher is cautioned against doing this – in the unlikely event of an accident in your own private car, you may be liable as your consent form does not cover you for the transportation of participants. - There are grammatical and spelling errors in the letter of information as well.

Approved ✓	Approved, on condition that suggestions have been effected	Request for rework and resubmission	Rejected

Remark:

The committee has provided ethical clearance for your research although the suggested changes should be considered in consultation with your supervisor prior to data collection.

Confidential
KE Ethical Committee Review Form
June 23, 2011

7.2 APPENDIX B: SCALE AND SETTINGS

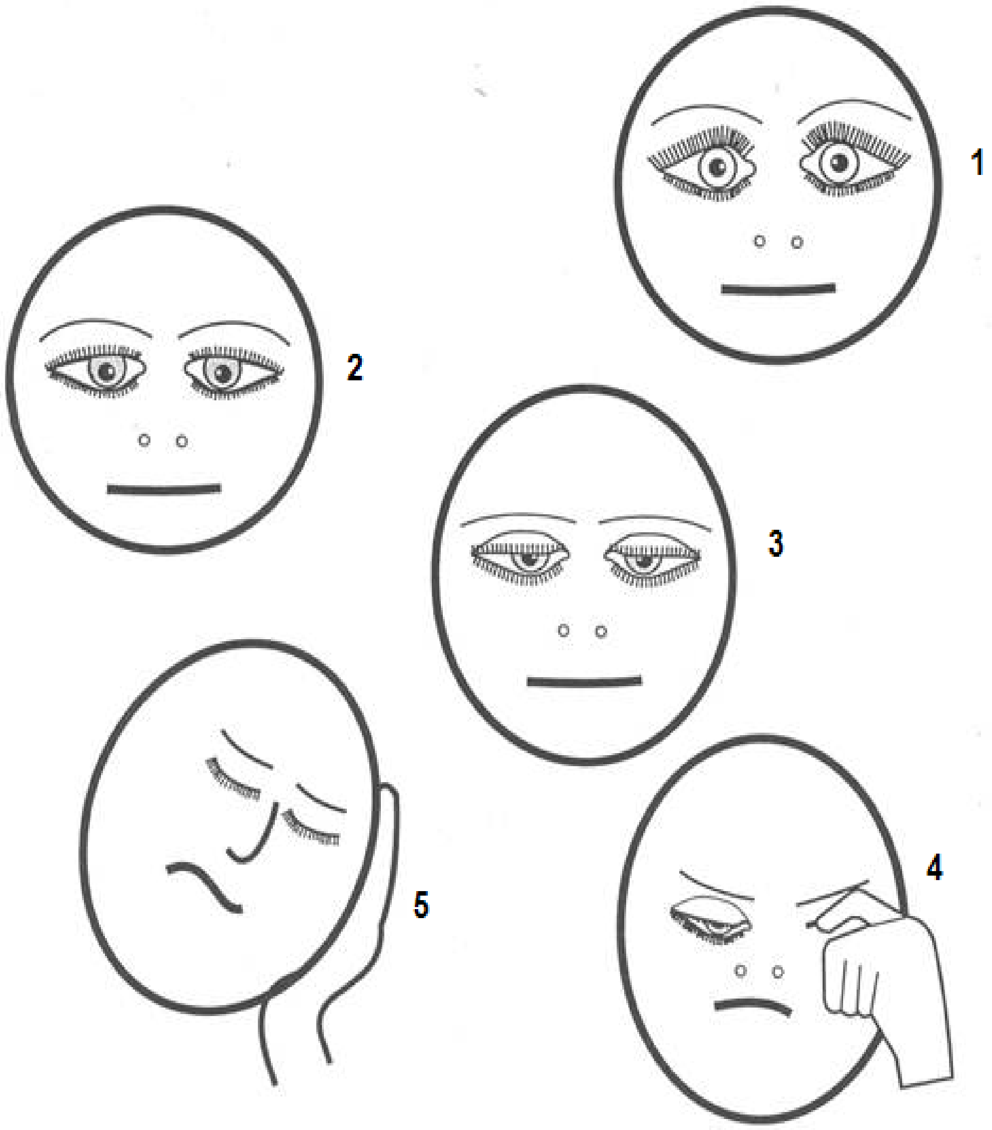
1 Wits Sleepiness Scale

2 NASA-TLX Questionnaire

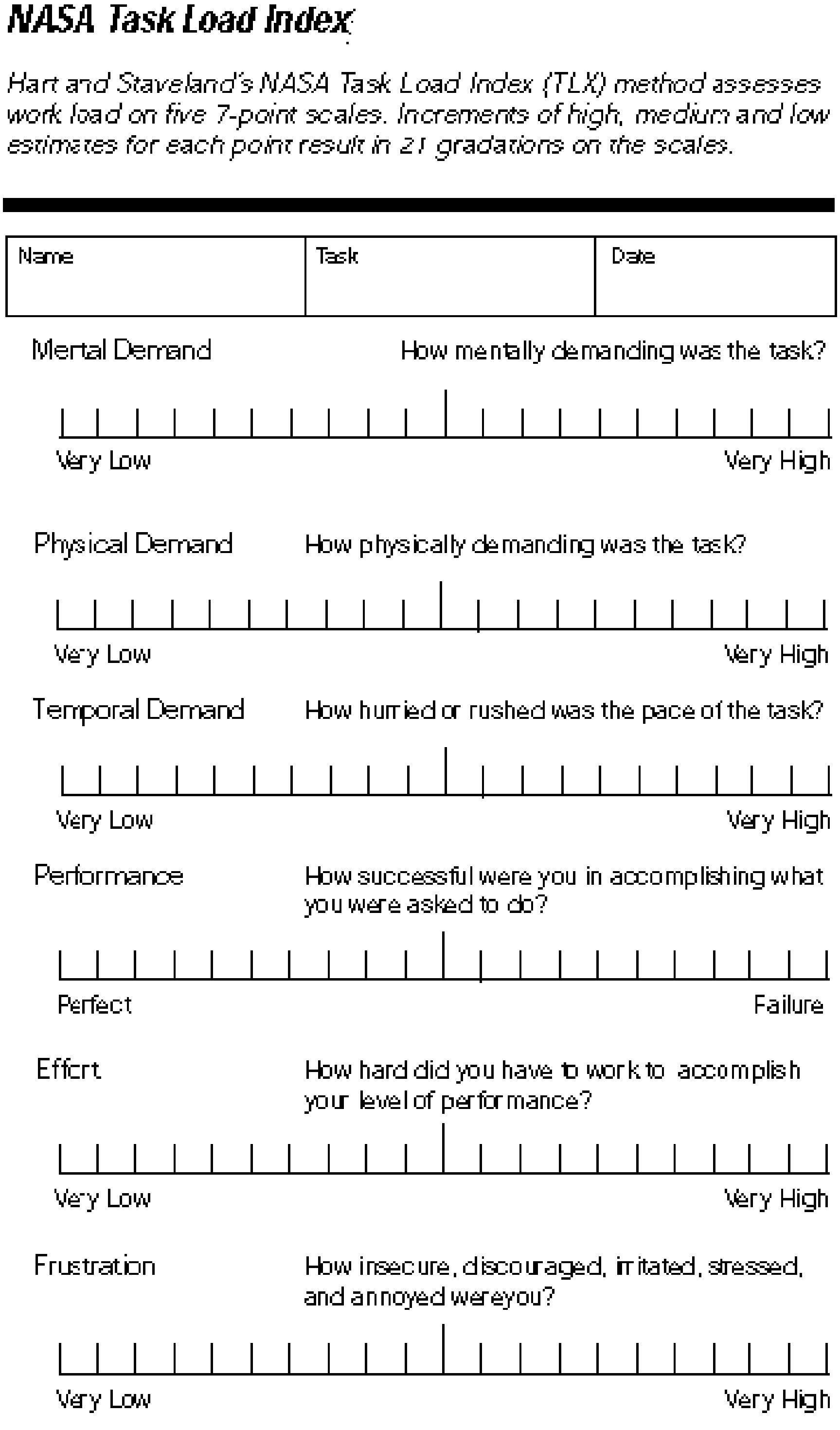
3 NASA-TLX Definition Sheet

4 Driving Simulator Settings

7.2.1 WITS SLEEPINESS SCALE



7.2.2 NASA-TLX QUESTIONNIARE



NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low — Very High

7.2.3 NASA-TLX DEFINITION SHEET

MENTAL DEMAND

How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

PHYSICAL DEMAND

How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

TEMPORAL DEMAND

How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

EFFORT

How hard did you have to work (mentally and physically) to accomplish your level of performance?

PERFORMANCE

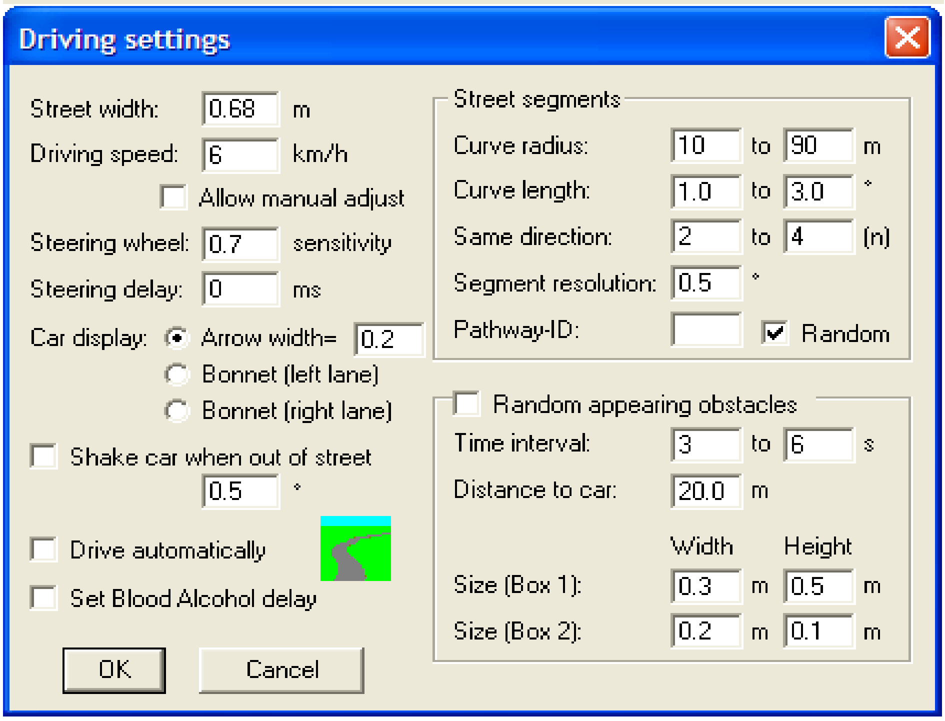
How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

FRUSTRATION LEVEL

How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

7.2.4 DRIVING SIMULATOR SETTINGS

Driving Parameter Settings



Street width: 0.68 m

Driving speed: 6 km/h

☐ Allow manual adjust

Steering wheel: 0.7 sensitivity

Steering delay: 0 ms

Car display: ● Arrow width= 0.2
○ Bonnet (left lane)
○ Bonnet (right lane)

☐ Shake car when out of street
0.5 °

☐ Drive automatically

☐ Set Blood Alcohol delay

Street segments

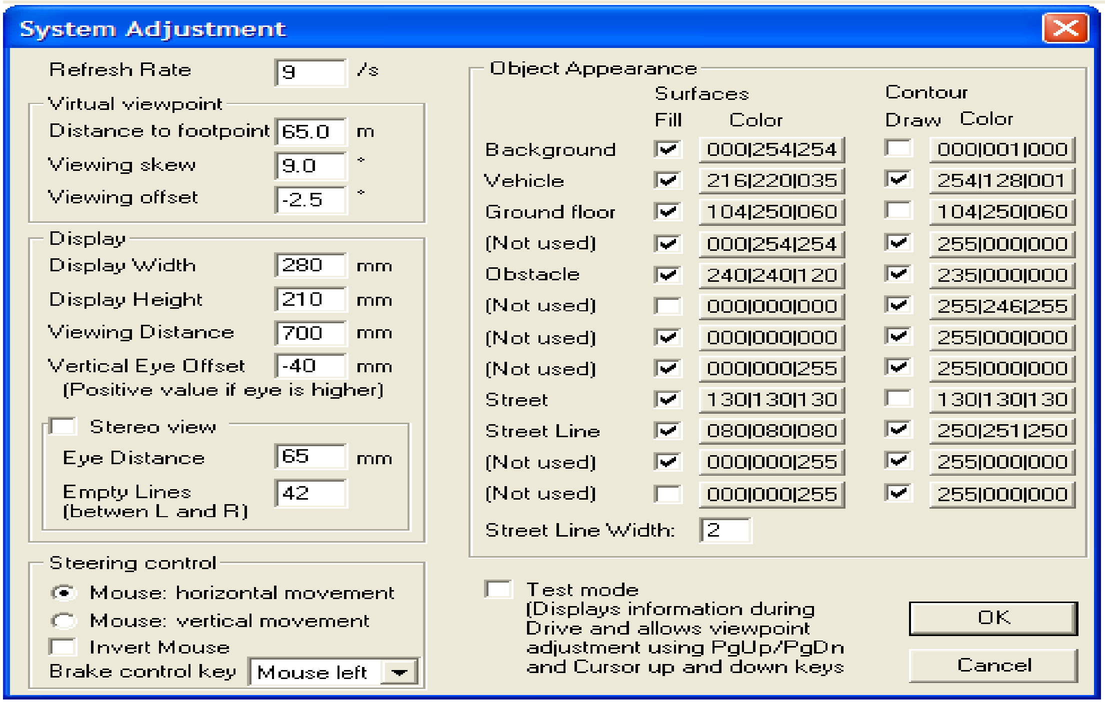
Curve radius: 10 to 90 m
Curve length: 1.0 to 3.0 °
Same direction: 2 to 4 (n)
Segment resolution: 0.5 °
Pathway-ID: ☑ Random

☐ Random appearing obstacles

Time interval: 3 to 6 s
Distance to car: 20.0 m

	Width		Height	
Size (Box 1):	0.3	m	0.5	m
Size (Box 2):	0.2	m	0.1	m

System Parameter Settings



Refresh Rate 9 /s

Virtual viewpoint
Distance to footpoint 65.0 m
Viewing skew 9.0 °
Viewing offset -2.5 °

Display
Display Width 280 mm
Display Height 210 mm
Viewing Distance 700 mm
Vertical Eye Offset -40 mm
(Positive value if eye is higher)

☐ Stereo view
Eye Distance 65 mm
Empty Lines (betwen L and R) 42

Steering control
● Mouse: horizontal movement
○ Mouse: vertical movement
☐ Invert Mouse
Brake control key Mouse left

Object Appearance

	Surfaces		Contour	
	Fill	Color	Draw	Color
Background	☑	000|254|254	☐	000|001|000
Vehicle	☑	216|220|035	☑	254|128|001
Ground floor	☑	104|250|060	☐	104|250|060
(Not used)	☑	000|254|254	☑	255|000|000
Obstacle	☑	240|240|120	☑	235|000|000
(Not used)	☐	000|000|000	☑	255|246|255
(Not used)	☑	000|000|000	☑	255|000|000
(Not used)	☑	000|000|255	☑	255|000|000
Street	☑	130|130|130	☐	130|130|130
Street Line	☑	080|080|080	☑	250|251|250
(Not used)	☑	000|000|255	☑	255|000|000
(Not used)	☐	000|000|255	☑	255|000|000

Street Line Width: 2

☐ Test mode
(Displays information during Drive and allows viewpoint adjustment using PgUp/PgDn and Cursor up and down keys

The luminance of the various colour objects used for the tracking task

Object	**Colour Sequence (RGB values)**	**Luminance (cd/m²)**
Background – Sky	000/254/254	96
Vehicle – Bonnet Fill	216/220/035	69
Ground Floor – Grass	104/250/060	84
Street	130/130/130	26
Street Line	250/251/250	46

7.3 APPENDIX C: PILOT STUDIES

1 Duration of Primary Driving Task

2 Type of Road Curvature

7.3.1 DURATION OF PRIMARY DRIVING TASK

AIM: The objective of this pilot test was to ascertain after what length of time fatigue occurred while performing a tracking task in a driving simulator. The results from this pilot study would determine the main task duration for the research.

METHOD: Subjects were recruited from the Rhodes University student population. Each subject was asked to complete one 2 hour day drive and one 2 hour night drive. The day drive commenced at 9am and the night drive commenced at 11pm. Each drive involved tracking a white line, with an arrow head, as accurately as possible while responding to peripheral stimuli. Subjects were instructed to keep their head as still as possible and face forward for the duration of the 2 hour drive. The subjects were instructed to, upon detection of peripheral stimuli, respond as quickly as possible by pressing either of the two clickers provided on the steering wheel. One whole day was given for complete recovery between testing sessions.

RESULTS:

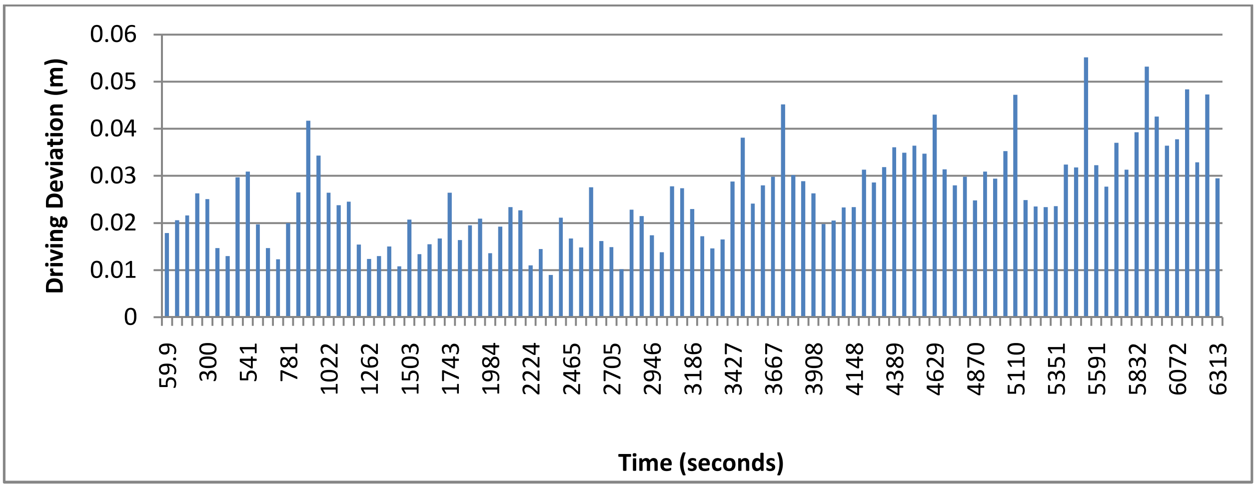


Figure A1: Driving deviation for subject one’s day drive

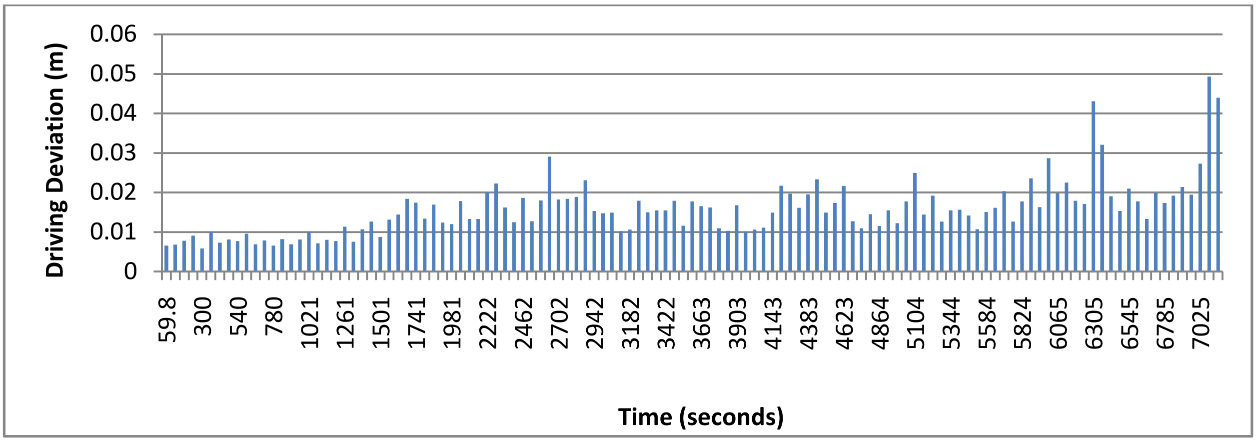


Figure A2: Driving deviation for subject two’s night drive

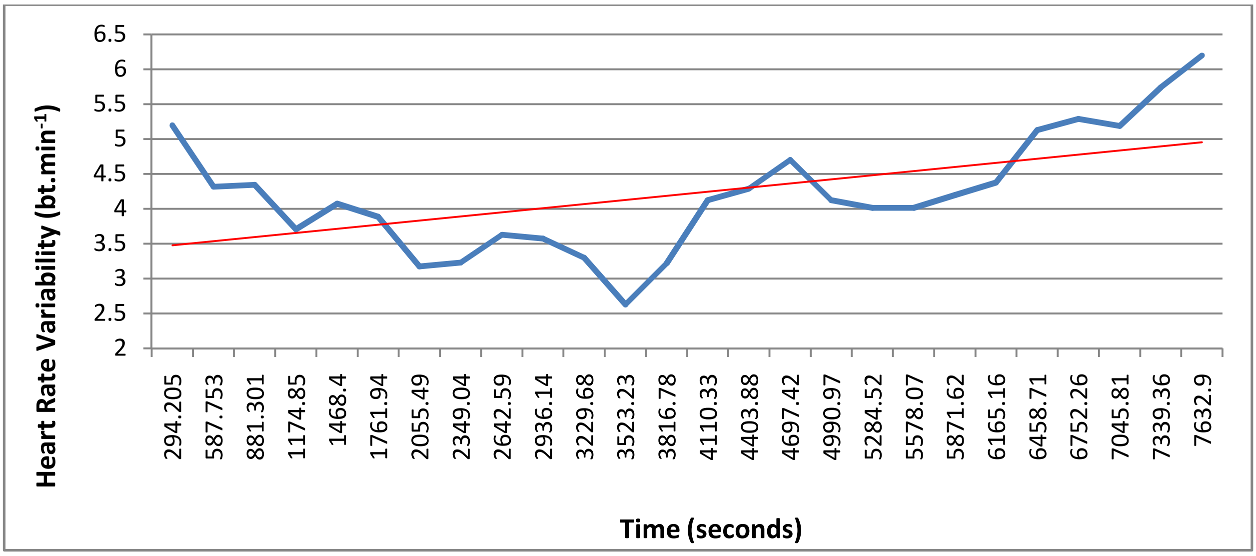


Figure A3: Subject one’s heart rate variability during the 2 hour day drive

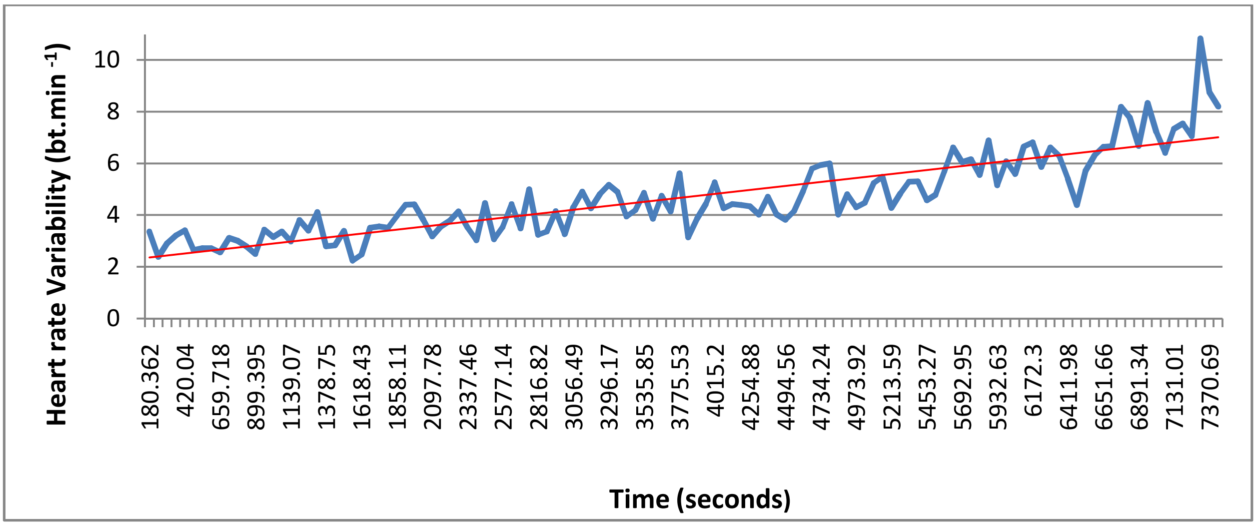


Figure A4: Heart rate variability of subject two during the night drive

From the above results it can be seen that for both the day and night drives the greatest increase in both driving deviation and heart rate variability occurs during the first 5400 seconds (90 minutes), thereafter there is still an increase in both however this increase is slight. Driving deviation and heart rate variability were used as driving deviation is a performance indicator thus an increase in fatigue will result in an increase in driving deviation. Heart rate variability is said to increase with an increase in fatigue (Mascord and Heath, 1992; Oran-Gilad and Ronen, 2007), and thus was used as a psychophysiological measure, to corroborate the driving deviation results obtained.

CONCLUSION: It was concluded from the pilot study that a driving duration of 90 minutes was sufficient enough to invoke fatigue responses required for the main research as under controlled conditions it has been observed by Galinsky et al. (1993) that marked indications of fatigue occurred in subjects after only 60 minutes of driving.

7.3.2 TYPE OF ROAD CURVATURE

AIM: The aim of the pilot test was to distinguish what type of road curvature required the most concentration and thus would result in a faster onset of fatigue. From the results the main primary task road curvature would be decided.

METHOD: Subjects were recruited from the Rhodes University student population. Each subject was asked to complete one 30 minute drive with a road curve radius of 40 to 70m and another 30 minute drive with a road curve radius of 10 to 90m. Each drive involved tracking a white line, with an arrow head, as accurately as possible. Each drive was conducted at the same time during the day, 11am, with a one day break between the test sessions. Heart rate variability was assessed in order to see which road curvature was more taxing.

RESULTS:

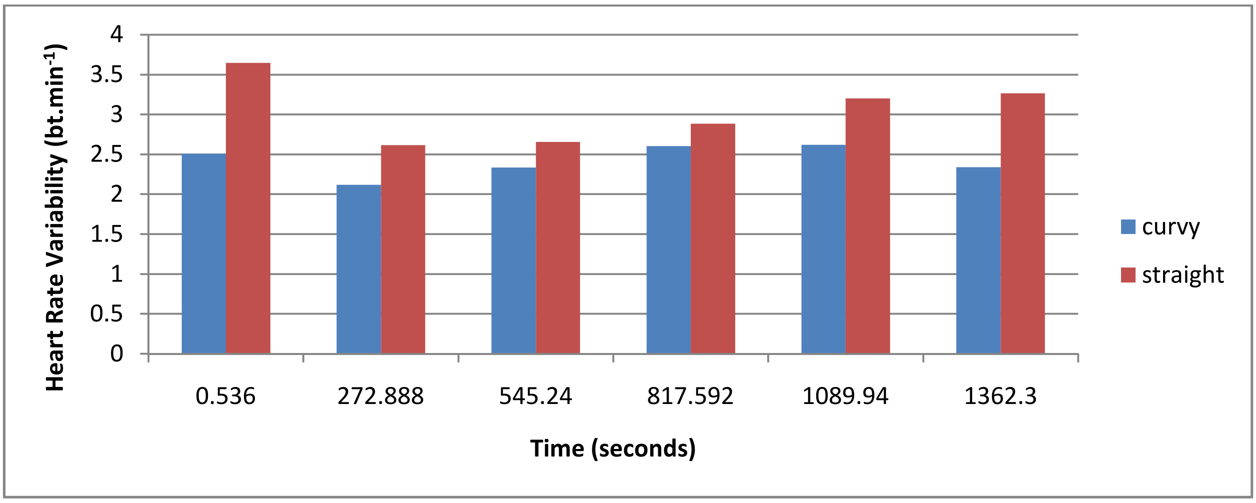


Figure B1: Differences in heart rate variability for the two road curvatures

From Figure B1 it can be seen that the curvy road has a greater mental demand than that of the straight road, as this is reflected by the lower heart rate variability values over the 30 minute drive. Heart rate variability is found to decrease under conditions of increasing effort levels and task complexity (Jorna, 1992; Mascord & Heath, 1992).

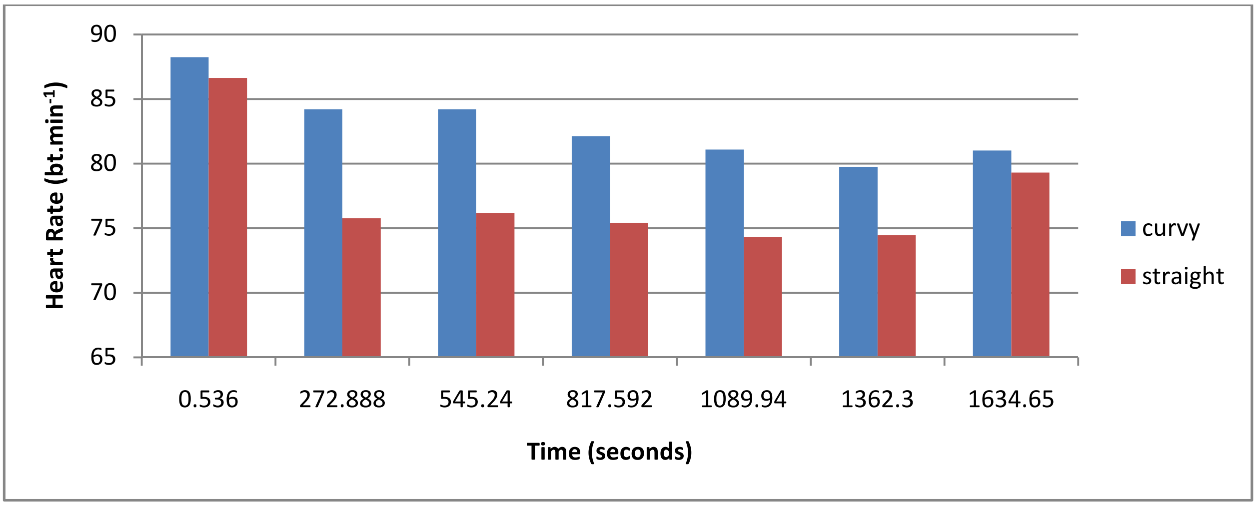


Figure B2: Heart rate values obtained for the different road curvatures

According to Mascord & Heath (1992), heart rate increases with task difficulty, whereas it will show a decrease with decreased task difficulty. It can be seen from Figure B2 that both types of road curvature result in a decrease in heart rate; however the curvy road produces a more steady decrease. The higher heart rate obtained for the curvy road can also be said to indicate a higher level of task difficulty.

CONCLUSION: From the results obtained it can be seen that a road curve radius of 10 to 90m placed more mental demand on subjects and thus subjects have to concentrate more in order to track the white line as accurately as possible. Due to this it was decided that a curvy road environment would be applied to the main study.

7.4 APPENDIX D: SUMMARY REPORTS

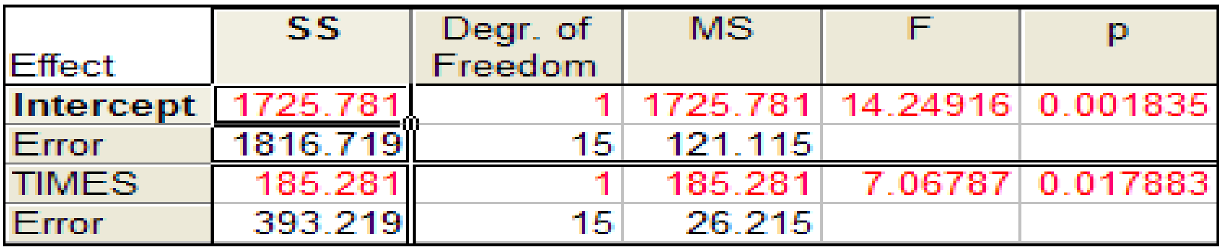
1 One, Two and Three-Factorial ANOVA Tables

2 Post-Hoc Analyses

7.4.1 ONE, TWO AND THREE-FACTORIAL ANOVA TABLES

One-Factorial ANOVA Table

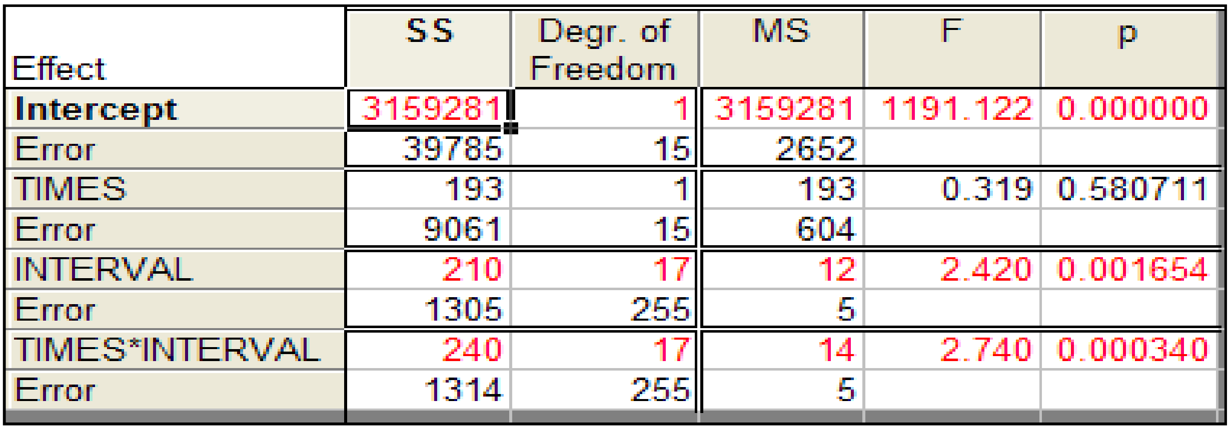
Number of saccades data for the two different conditions



Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1725.781	1	1725.781	14.24916	0.001835
Error	1816.719	15	121.115		
TIMES	185.281	1	185.281	7.06787	0.017883
Error	393.219	15	26.215		

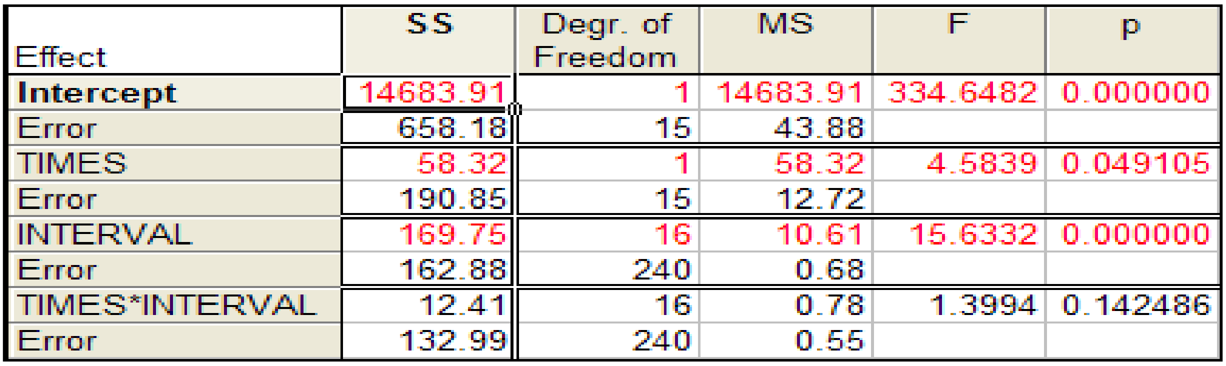
Two-Factorial ANOVA Table

Heart rate frequency responses for the two conditions and time on task



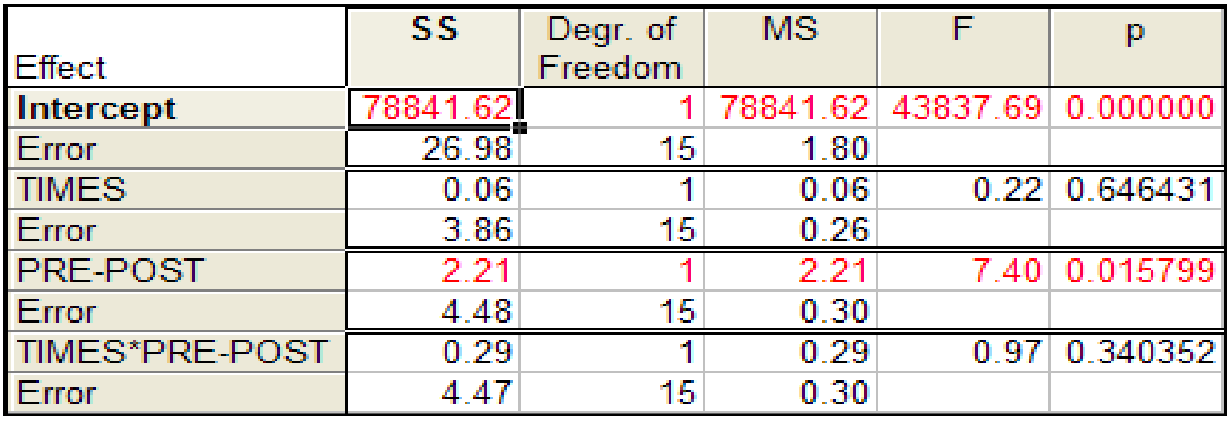
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	3159281	1	3159281	1191.122	0.000000
Error	39785	15	2652		
TIMES	193	1	193	0.319	0.580711
Error	9061	15	604		
INTERVAL	210	17	12	2.420	0.001654
Error	1305	255	5		
TIMES*INTERVAL	240	17	14	2.740	0.000340
Error	1314	255	5		

Heart rate variability coefficient for the two conditions as well as time on task



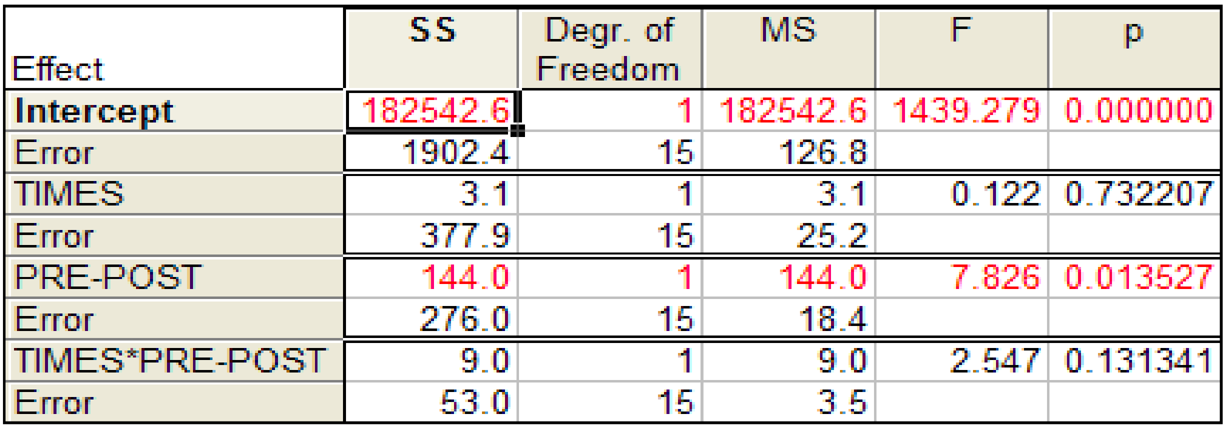
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	14683.91	1	14683.91	334.6482	0.000000
Error	658.18	15	43.88		
TIMES	58.32	1	58.32	4.5839	0.049105
Error	190.85	15	12.72		
INTERVAL	169.75	16	10.61	15.6332	0.000000
Error	162.88	240	0.68		
TIMES*INTERVAL	12.41	16	0.78	1.3994	0.142486
Error	132.99	240	0.55		

Tympanic temperature data for the two conditions and pre- and post-tests



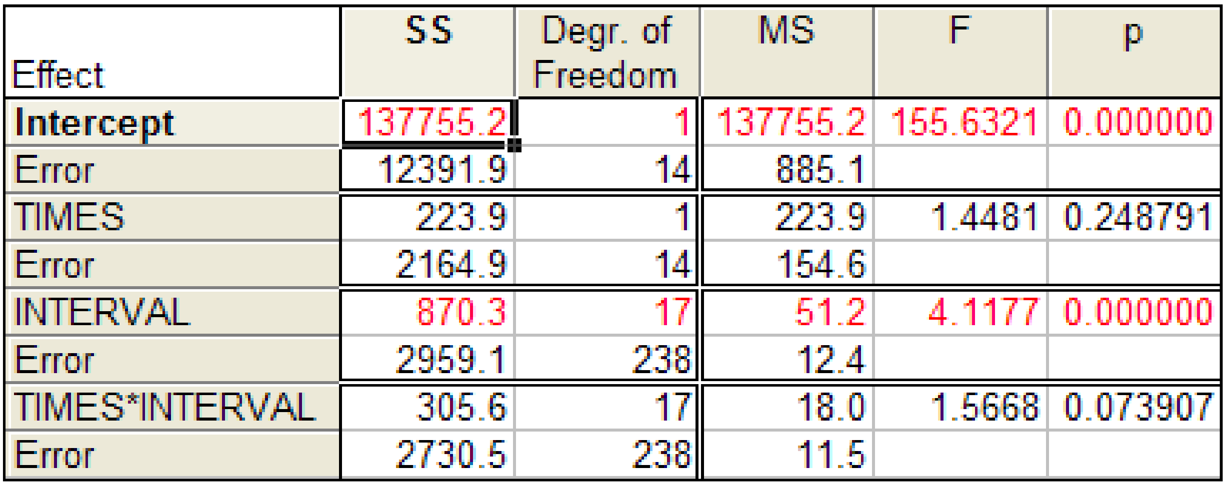
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	78841.62	1	78841.62	43837.69	0.000000
Error	26.98	15	1.80		
TIMES	0.06	1	0.06	0.22	0.646431
Error	3.86	15	0.26		
PRE-POST	2.21	1	2.21	7.40	0.015799
Error	4.48	15	0.30		
TIMES*PRE-POST	0.29	1	0.29	0.97	0.340352
Error	4.47	15	0.30		

Critical flicker fusion frequency threshold recordings for the two conditions and time on task



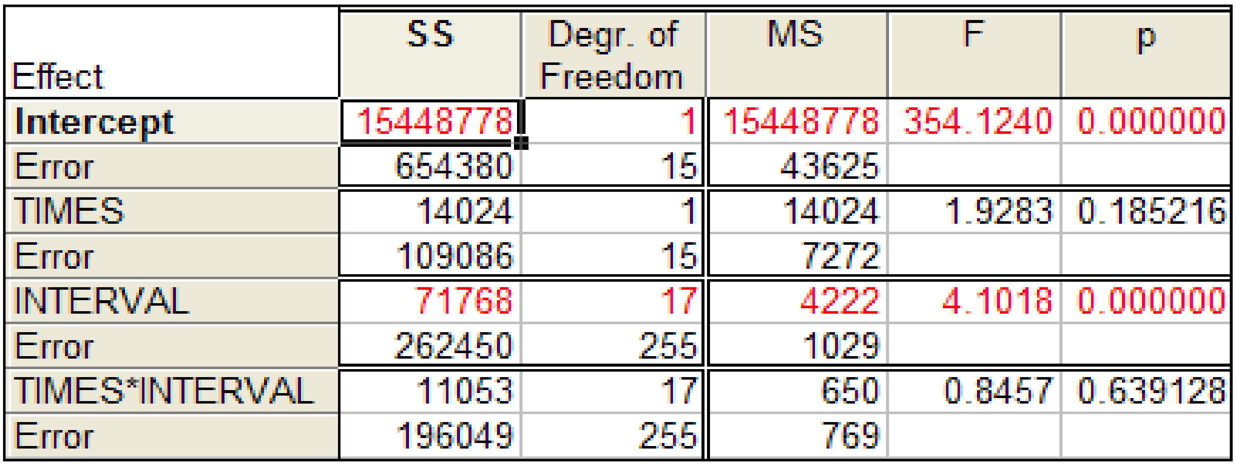
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	182542.6	1	182542.6	1439.279	0.000000
Error	1902.4	15	126.8		
TIMES	3.1	1	3.1	0.122	0.732207
Error	377.9	15	25.2		
PRE-POST	144.0	1	144.0	7.826	0.013527
Error	276.0	15	18.4		
TIMES*PRE-POST	9.0	1	9.0	2.547	0.131341
Error	53.0	15	3.5		

Blink frequency data recorded for the two conditions and time on task



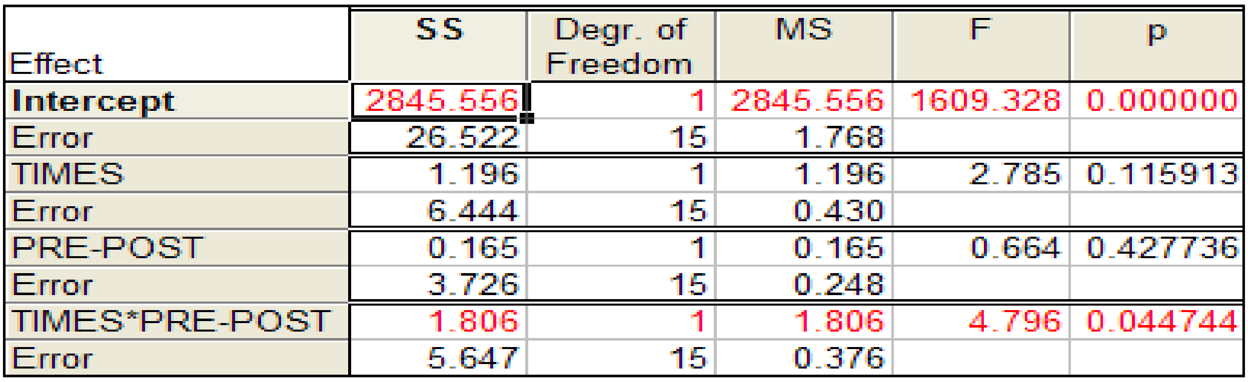
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	137755.2	1	137755.2	155.6321	0.000000
Error	12391.9	14	885.1		
TIMES	223.9	1	223.9	1.4481	0.248791
Error	2164.9	14	154.6		
INTERVAL	870.3	17	51.2	4.1177	0.000000
Error	2959.1	238	12.4		
TIMES*INTERVAL	305.6	17	18.0	1.5668	0.073907
Error	2730.5	238	11.5		

Blink duration data recorded over the two conditions and main task duration



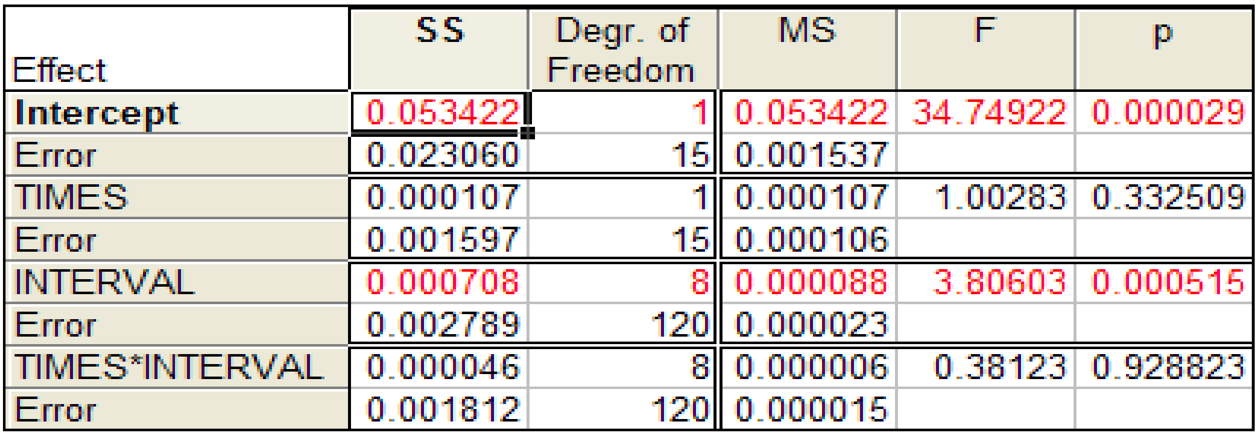
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	15448778	1	15448778	354.1240	0.000000
Error	654380	15	43625		
TIMES	14024	1	14024	1.9283	0.185216
Error	109086	15	7272		
INTERVAL	71768	17	4222	4.1018	0.000000
Error	262450	255	1029		
TIMES*INTERVAL	11053	17	650	0.8457	0.639128
Error	196049	255	769		

Memory test data obtained for the two conditions and the pre- and post-tests.



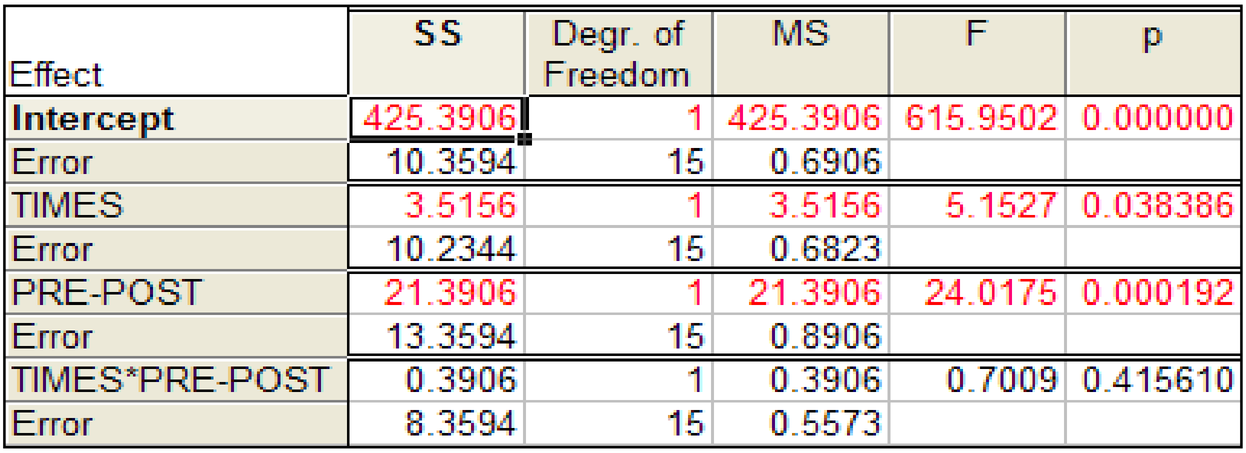
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2845.556	1	2845.556	1609.328	0.000000
Error	26.522	15	1.768		
TIMES	1.196	1	1.196	2.785	0.115913
Error	6.444	15	0.430		
PRE-POST	0.165	1	0.165	0.664	0.427736
Error	3.726	15	0.248		
TIMES*PRE-POST	1.806	1	1.806	4.796	0.044744
Error	5.647	15	0.376		

Lane deviation recorded for the duration of the main task, across the two conditions



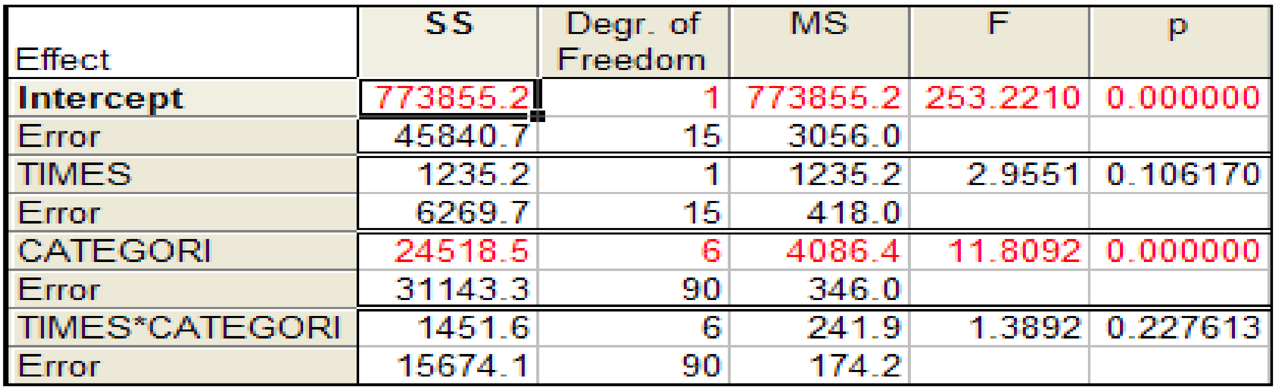
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	0.053422	1	0.053422	34.74922	0.000029
Error	0.023060	15	0.001537		
TIMES	0.000107	1	0.000107	1.00283	0.332509
Error	0.001597	15	0.000106		
INTERVAL	0.000708	8	0.000088	3.80603	0.000515
Error	0.002789	120	0.000023		
TIMES*INTERVAL	0.000046	8	0.000006	0.38123	0.928823
Error	0.001812	120	0.000015		

Wits Sleepiness Scale measures obtained pre- and post-test across the two conditions



Effect	SS	Degr. of Freedom	MS	F	p
Intercept	425.3906	1	425.3906	615.9502	0.000000
Error	10.3594	15	0.6906		
TIMES	3.5156	1	3.5156	5.1527	0.038386
Error	10.2344	15	0.6823		
PRE-POST	21.3906	1	21.3906	24.0175	0.000192
Error	13.3594	15	0.8906		
TIMES*PRE-POST	0.3906	1	0.3906	0.7009	0.415610
Error	8.3594	15	0.5573		

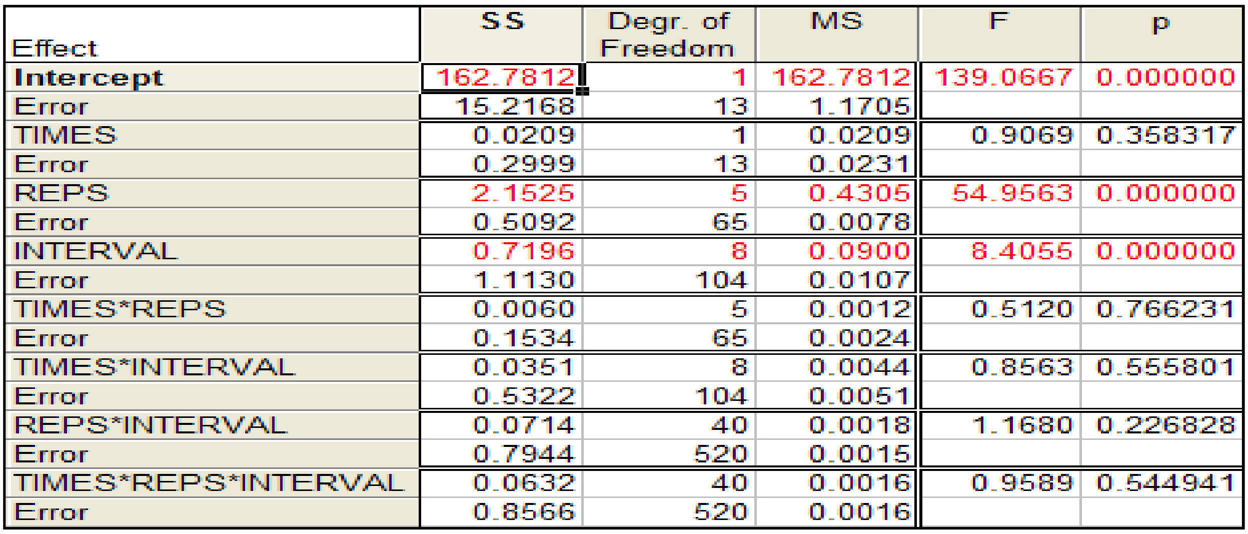
NASA-TLX data obtained for the different categories and the different conditions



Effect	SS	Degr. of Freedom	MS	F	p
Intercept	773855.2	1	773855.2	253.2210	0.000000
Error	45840.7	15	3056.0		
TIMES	1235.2	1	1235.2	2.9551	0.106170
Error	6269.7	15	418.0		
CATEGORI	24518.5	6	4086.4	11.8092	0.000000
Error	31143.3	90	346.0		
TIMES*CATEGORI	1451.6	6	241.9	1.3892	0.227613
Error	15674.1	90	174.2		

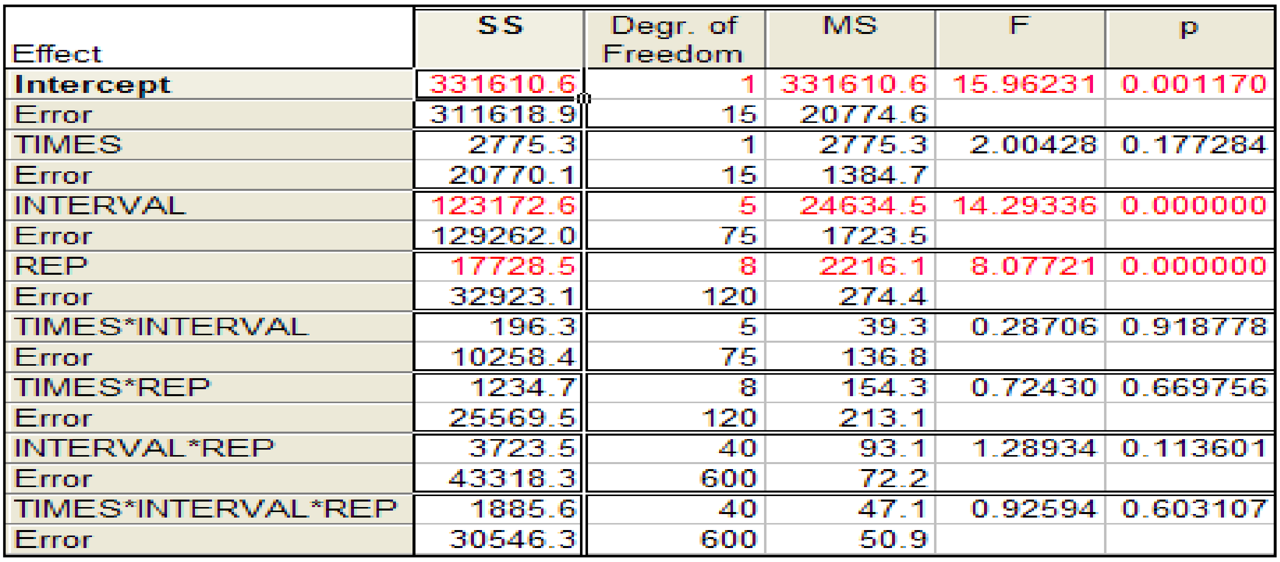
Three-Factorial ANOVA Table

Response time data recorded for the duration of the dual task, across the two conditions and six eccentricities



Effect	SS	Degr. of Freedom	MS	F	p
Intercept	162.7812	1	162.7812	139.0667	0.000000
Error	15.2168	13	1.1705		
TIMES	0.0209	1	0.0209	0.9069	0.358317
Error	0.2999	13	0.0231		
REPS	2.1525	5	0.4305	54.9563	0.000000
Error	0.5092	65	0.0078		
INTERVAL	0.7196	8	0.0900	8.4055	0.000000
Error	1.1130	104	0.0107		
TIMES*REPS	0.0060	5	0.0012	0.5120	0.766231
Error	0.1534	65	0.0024		
TIMES*INTERVAL	0.0351	8	0.0044	0.8563	0.555801
Error	0.5322	104	0.0051		
REPS*INTERVAL	0.0714	40	0.0018	1.1680	0.226828
Error	0.7944	520	0.0015		
TIMES*REPS*INTERVAL	0.0632	40	0.0016	0.9589	0.544941
Error	0.8566	520	0.0016		

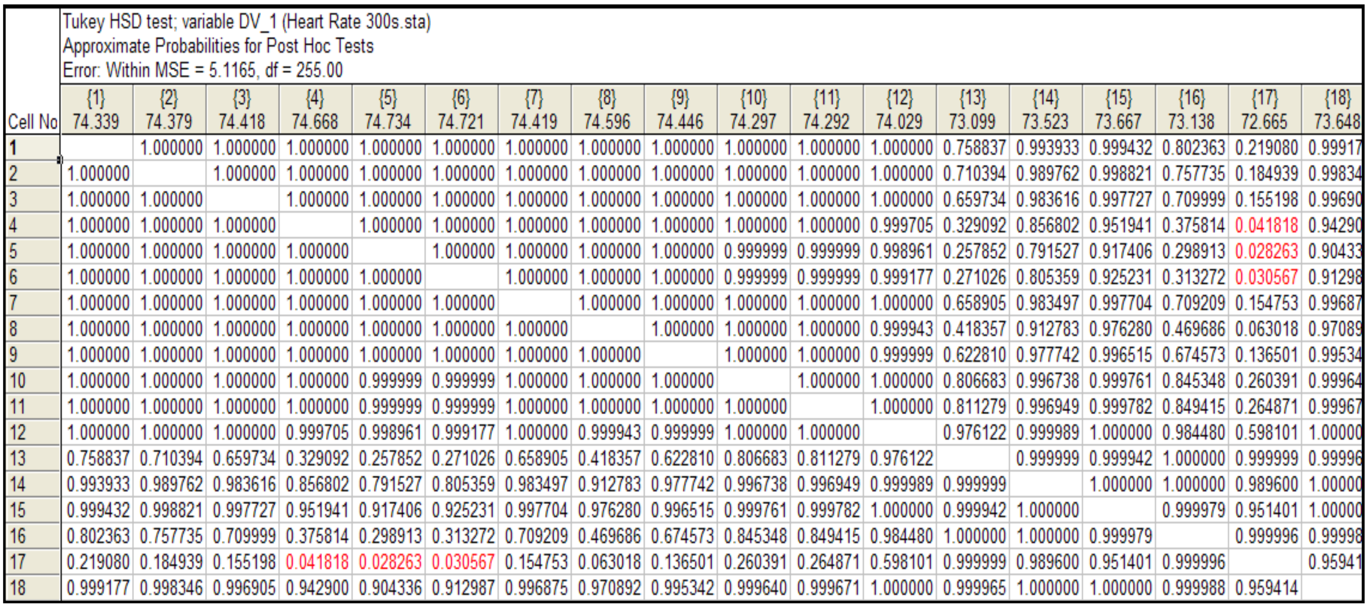
Percentage of missed responses for the two conditions, the six eccentricities and the task duration



Effect	SS	Degr. of Freedom	MS	F	p
Intercept	331610.6	1	331610.6	15.96231	0.001170
Error	311618.9	15	20774.6		
TIMES	2775.3	1	2775.3	2.00428	0.177284
Error	20770.1	15	1384.7		
INTERVAL	123172.6	5	24634.5	14.29336	0.000000
Error	129262.0	75	1723.5		
REP	17728.5	8	2216.1	8.07721	0.000000
Error	32923.1	120	274.4		
TIMES*INTERVAL	196.3	5	39.3	0.28706	0.918778
Error	10258.4	75	136.8		
TIMES*REP	1234.7	8	154.3	0.72430	0.669756
Error	25569.5	120	213.1		
INTERVAL*REP	3723.5	40	93.1	1.28934	0.113601
Error	43318.3	600	72.2		
TIMES*INTERVAL*REP	1885.6	40	47.1	0.92594	0.603107
Error	30546.3	600	50.9		

7.4.2 POST HOC ANALYSES

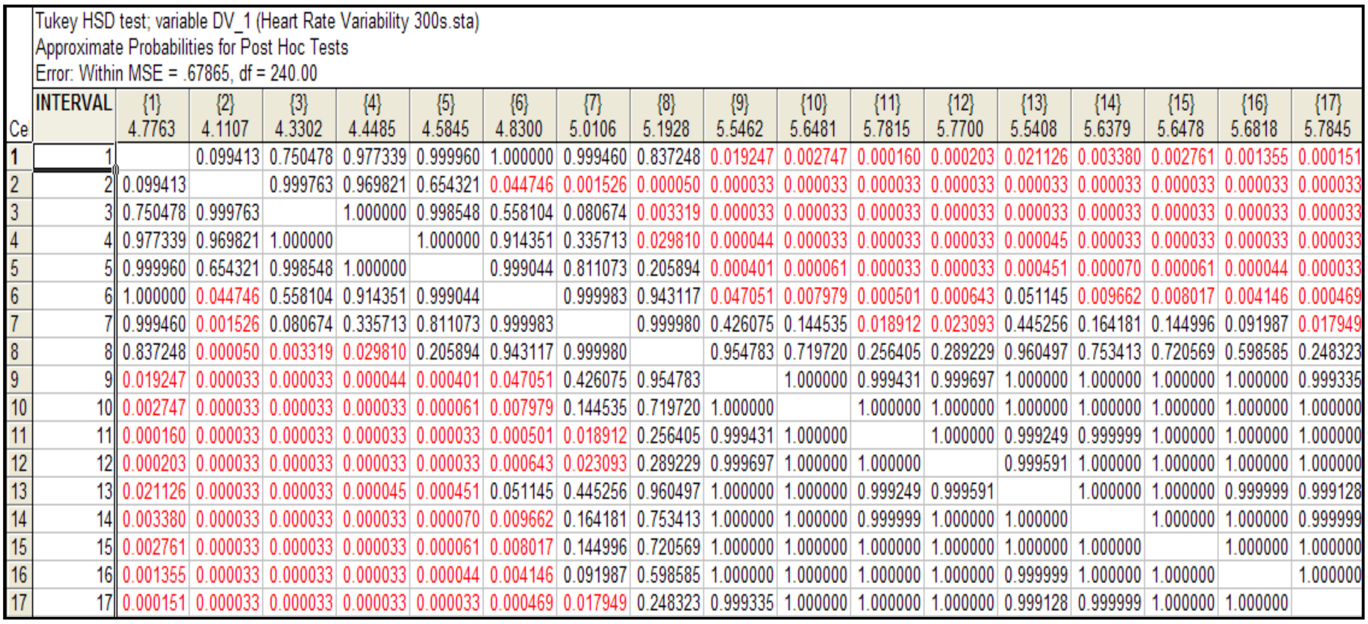
Heart Rate: Time on Task



Tukey HSD test; variable DV_1 (Heart Rate 300s.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 5.1165, df = 255.00

Cell No	{1} 74.339	{2} 74.379	{3} 74.418	{4} 74.668	{5} 74.734	{6} 74.721	{7} 74.419	{8} 74.596	{9} 74.446	{10} 74.297	{11} 74.292	{12} 74.029	{13} 73.099	{14} 73.523	{15} 73.667	{16} 73.138	{17} 72.665	{18} 73.648
1		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.758837	0.993933	0.999432	0.802363	0.219080	0.99917
2	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.710394	0.989762	0.998821	0.757735	0.184939	0.99834
3	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.659734	0.983616	0.997727	0.709999	0.155198	0.99690
4	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.999705	0.329092	0.856802	0.951941	0.375814	0.041818	0.94290
5	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	0.999999	0.999999	0.998961	0.257852	0.791527	0.917406	0.298913	0.028263	0.90433
6	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	0.999999	0.999999	0.999177	0.271026	0.805359	0.925231	0.313272	0.030567	0.91298
7	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	0.658905	0.983497	0.997704	0.709209	0.154753	0.99687
8	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	0.999943	0.418357	0.912783	0.976280	0.469686	0.063018	0.97089
9	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	0.999999	0.622810	0.977742	0.996515	0.674573	0.136501	0.99534
10	1.000000	1.000000	1.000000	1.000000	0.999999	0.999999	1.000000	1.000000	1.000000		1.000000	1.000000	0.806683	0.996738	0.999761	0.845348	0.260391	0.99964
11	1.000000	1.000000	1.000000	1.000000	0.999999	0.999999	1.000000	1.000000	1.000000	1.000000		1.000000	0.811279	0.996949	0.999782	0.849415	0.264871	0.99967
12	1.000000	1.000000	1.000000	0.999705	0.998961	0.999177	1.000000	0.999943	0.999999	1.000000	1.000000		0.976122	0.999989	1.000000	0.984480	0.598101	1.00000
13	0.758837	0.710394	0.659734	0.329092	0.257852	0.271026	0.658905	0.418357	0.622810	0.806683	0.811279	0.976122		0.999999	0.999942	1.000000	0.999999	0.99996
14	0.993933	0.989762	0.983616	0.856802	0.791527	0.805359	0.983497	0.912783	0.977742	0.996738	0.996949	0.999989	0.999999		1.000000	1.000000	0.989600	1.00000
15	0.999432	0.998821	0.997727	0.951941	0.917406	0.925231	0.997704	0.976280	0.996515	0.999761	0.999782	1.000000	0.999942	1.000000		0.999979	0.951401	1.00000
16	0.802363	0.757735	0.709999	0.375814	0.298913	0.313272	0.709209	0.469686	0.674573	0.845348	0.849415	0.984480	1.000000	1.000000	0.999979		0.999996	0.99998
17	0.219080	0.184939	0.155198	0.041818	0.028263	0.030567	0.154753	0.063018	0.136501	0.260391	0.264871	0.598101	0.999999	0.989600	0.951401	0.999996		0.95941
18	0.999177	0.998346	0.996905	0.942900	0.904336	0.912987	0.996875	0.970892	0.995342	0.999640	0.999671	1.000000	0.999965	1.000000	1.000000	0.999988	0.959414	

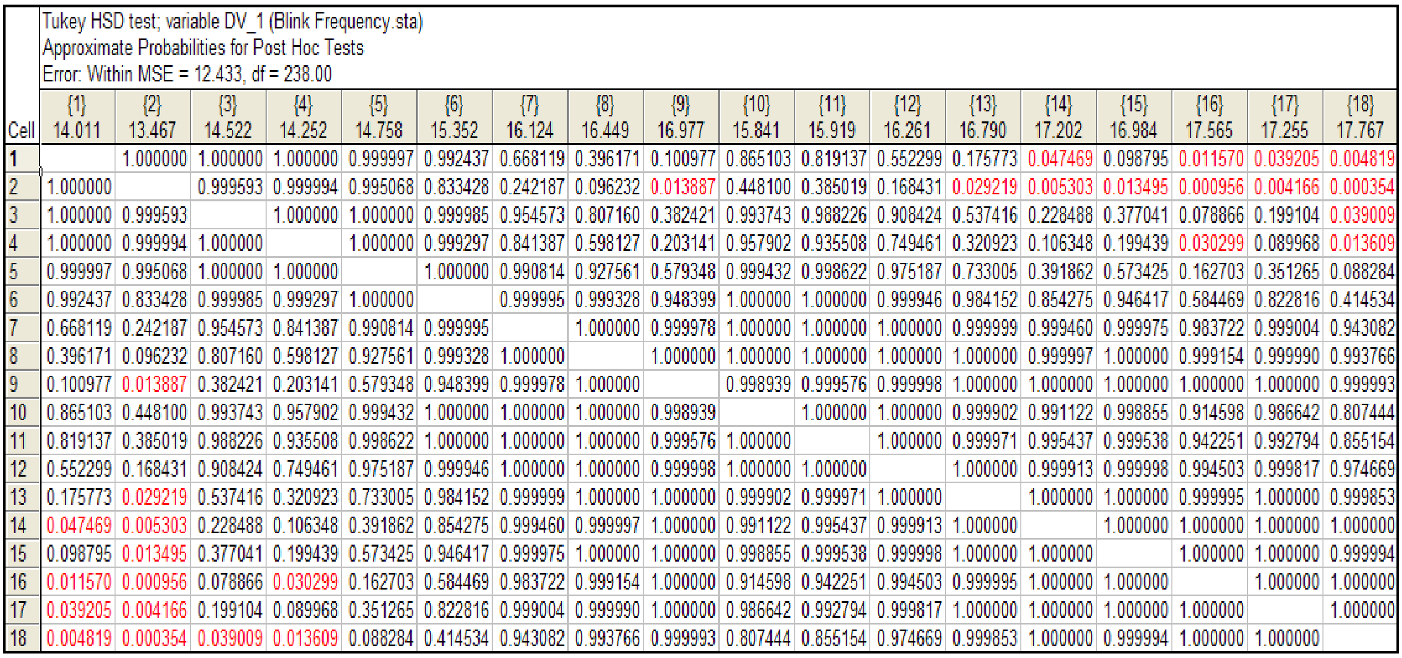
Heart Rate Variability: Time on Task



Tukey HSD test; variable DV_1 (Heart Rate Variability 300s.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = .67865, df = 240.00

Ce	INTERVAL	{1} 4.7763	{2} 4.1107	{3} 4.3302	{4} 4.4485	{5} 4.5845	{6} 4.8300	{7} 5.0106	{8} 5.1928	{9} 5.5462	{10} 5.6481	{11} 5.7815	{12} 5.7700	{13} 5.5408	{14} 5.6379	{15} 5.6478	{16} 5.6818	{17} 5.7845
1	1		0.099413	0.750478	0.977339	0.999960	1.000000	0.999460	0.837248	0.019247	0.002747	0.000160	0.000203	0.021126	0.003380	0.002761	0.001355	0.000151
2	2	0.099413		0.999763	0.969821	0.654321	0.044746	0.001526	0.000050	0.000033	0.000033	0.000033	0.000033	0.000033	0.000033	0.000033	0.000033	0.000033
3	3	0.750478	0.999763		1.000000	0.998548	0.558104	0.080674	0.003319	0.000033	0.000033	0.000033	0.000033	0.000033	0.000033	0.000033	0.000033	0.000033
4	4	0.977339	0.969821	1.000000		1.000000	0.914351	0.335713	0.029810	0.000044	0.000033	0.000033	0.000033	0.000045	0.000033	0.000033	0.000033	0.000033
5	5	0.999960	0.654321	0.998548	1.000000		0.999044	0.811073	0.205894	0.000401	0.000061	0.000033	0.000033	0.000451	0.000070	0.000061	0.000044	0.000033
6	6	1.000000	0.044746	0.558104	0.914351	0.999044		0.999983	0.943117	0.047051	0.007979	0.000501	0.000643	0.051145	0.009662	0.008017	0.004146	0.000469
7	7	0.999460	0.001526	0.080674	0.335713	0.811073	0.999983		0.999980	0.426075	0.144535	0.018912	0.023093	0.445256	0.164181	0.144996	0.091987	0.017949
8	8	0.837248	0.000050	0.003319	0.029810	0.205894	0.943117	0.999980		0.954783	0.719720	0.256405	0.289229	0.960497	0.753413	0.720569	0.598585	0.248323
9	9	0.019247	0.000033	0.000033	0.000044	0.000401	0.047051	0.426075	0.954783		1.000000	0.999431	0.999697	1.000000	1.000000	1.000000	1.000000	0.999335
10	10	0.002747	0.000033	0.000033	0.000033	0.000061	0.007979	0.144535	0.719720	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
11	11	0.000160	0.000033	0.000033	0.000033	0.000033	0.000501	0.018912	0.256405	0.999431	1.000000		1.000000	0.999249	0.999999	1.000000	1.000000	1.000000
12	12	0.000203	0.000033	0.000033	0.000033	0.000033	0.000643	0.023093	0.289229	0.999697	1.000000	1.000000		0.999591	1.000000	1.000000	1.000000	1.000000
13	13	0.021126	0.000033	0.000033	0.000045	0.000451	0.051145	0.445256	0.960497	1.000000	1.000000	0.999249	0.999591		1.000000	1.000000	0.999999	0.999128
14	14	0.003380	0.000033	0.000033	0.000033	0.000070	0.009662	0.164181	0.753413	1.000000	1.000000	0.999999	1.000000	1.000000		1.000000	1.000000	0.999999
15	15	0.002761	0.000033	0.000033	0.000033	0.000061	0.008017	0.144996	0.720569	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000
16	16	0.001355	0.000033	0.000033	0.000033	0.000044	0.004146	0.091987	0.598585	1.000000	1.000000	1.000000	1.000000	0.999999	1.000000	1.000000		1.000000
17	17	0.000151	0.000033	0.000033	0.000033	0.000033	0.000469	0.017949	0.248323	0.999335	1.000000	1.000000	1.000000	0.999128	0.999999	1.000000	1.000000	

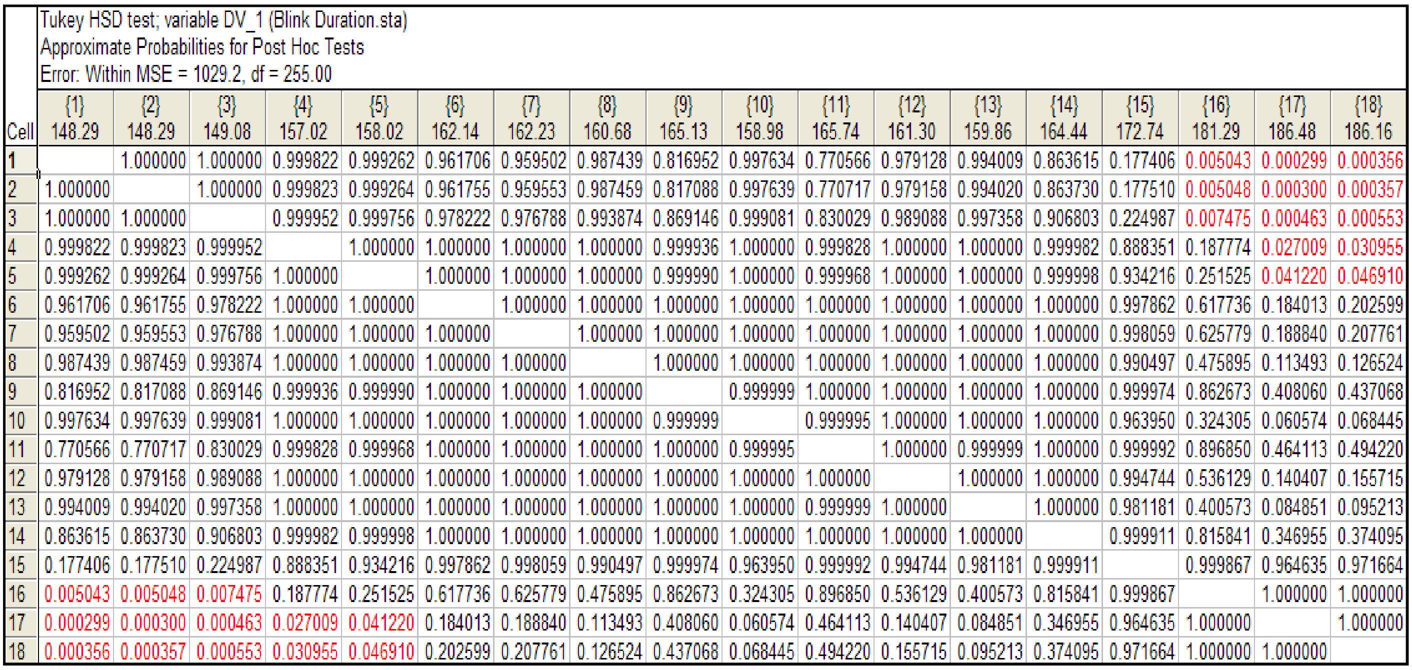
Blink Frequency: Time on Task



Tukey HSD test; variable DV_1 (Blink Frequency.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 12.433, df = 238.00

Cell	{1} 14.011	{2} 13.467	{3} 14.522	{4} 14.252	{5} 14.758	{6} 15.352	{7} 16.124	{8} 16.449	{9} 16.977	{10} 15.841	{11} 15.919	{12} 16.261	{13} 16.790	{14} 17.202	{15} 16.984	{16} 17.565	{17} 17.255	{18} 17.767
1		1.000000	1.000000	1.000000	0.999997	0.992437	0.668119	0.396171	0.100977	0.865103	0.819137	0.552299	0.175773	0.047469	0.098795	0.011570	0.039205	0.004819
2	1.000000		0.999593	0.999994	0.995068	0.833428	0.242187	0.096232	0.013887	0.448100	0.385019	0.168431	0.029219	0.005303	0.013495	0.000956	0.004166	0.000354
3	1.000000	0.999593		1.000000	1.000000	0.999985	0.954573	0.807160	0.382421	0.993743	0.988226	0.908424	0.537416	0.228488	0.377041	0.078866	0.199104	0.039009
4	1.000000	0.999994	1.000000		1.000000	0.999297	0.841387	0.598127	0.203141	0.957902	0.935508	0.749461	0.320923	0.106348	0.199439	0.030299	0.089968	0.013609
5	0.999997	0.995068	1.000000	1.000000		1.000000	0.990814	0.927561	0.579348	0.999432	0.998622	0.975187	0.733005	0.391862	0.573425	0.162703	0.351265	0.088284
6	0.992437	0.833428	0.999985	0.999297	1.000000		0.999995	0.999328	0.948399	1.000000	1.000000	0.999946	0.984152	0.854275	0.946417	0.584469	0.822816	0.414534
7	0.668119	0.242187	0.954573	0.841387	0.990814	0.999995		1.000000	0.999978	1.000000	1.000000	1.000000	0.999999	0.999460	0.999975	0.983722	0.999004	0.943082
8	0.396171	0.096232	0.807160	0.598127	0.927561	0.999328	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	0.999997	1.000000	0.999154	0.999990	0.993766
9	0.100977	0.013887	0.382421	0.203141	0.579348	0.948399	0.999978	1.000000		0.998939	0.999576	0.999998	1.000000	1.000000	1.000000	1.000000	1.000000	0.999993
10	0.865103	0.448100	0.993743	0.957902	0.999432	1.000000	1.000000	1.000000	0.998939		1.000000	1.000000	0.999902	0.991122	0.998855	0.914598	0.986642	0.807444
11	0.819137	0.385019	0.988226	0.935508	0.998622	1.000000	1.000000	1.000000	0.999576	1.000000		1.000000	0.999971	0.995437	0.999538	0.942251	0.992794	0.855154
12	0.552299	0.168431	0.908424	0.749461	0.975187	0.999946	1.000000	1.000000	0.999998	1.000000	1.000000		1.000000	0.999913	0.999998	0.994503	0.999817	0.974669
13	0.175773	0.029219	0.537416	0.320923	0.733005	0.984152	0.999999	1.000000	1.000000	0.999902	0.999971	1.000000		1.000000	1.000000	0.999995	1.000000	0.999853
14	0.047469	0.005303	0.228488	0.106348	0.391862	0.854275	0.999460	0.999997	1.000000	0.991122	0.995437	0.999913	1.000000		1.000000	1.000000	1.000000	1.000000
15	0.098795	0.013495	0.377041	0.199439	0.573425	0.946417	0.999975	1.000000	1.000000	0.998855	0.999538	0.999998	1.000000	1.000000		1.000000	1.000000	0.999994
16	0.011570	0.000956	0.078866	0.030299	0.162703	0.584469	0.983722	0.999154	1.000000	0.914598	0.942251	0.994503	0.999995	1.000000	1.000000		1.000000	1.000000
17	0.039205	0.004166	0.199104	0.089968	0.351265	0.822816	0.999004	0.999990	1.000000	0.986642	0.992794	0.999817	1.000000	1.000000	1.000000	1.000000		1.000000
18	0.004819	0.000354	0.039009	0.013609	0.088284	0.414534	0.943082	0.993766	0.999993	0.807444	0.855154	0.974669	0.999853	1.000000	0.999994	1.000000	1.000000	

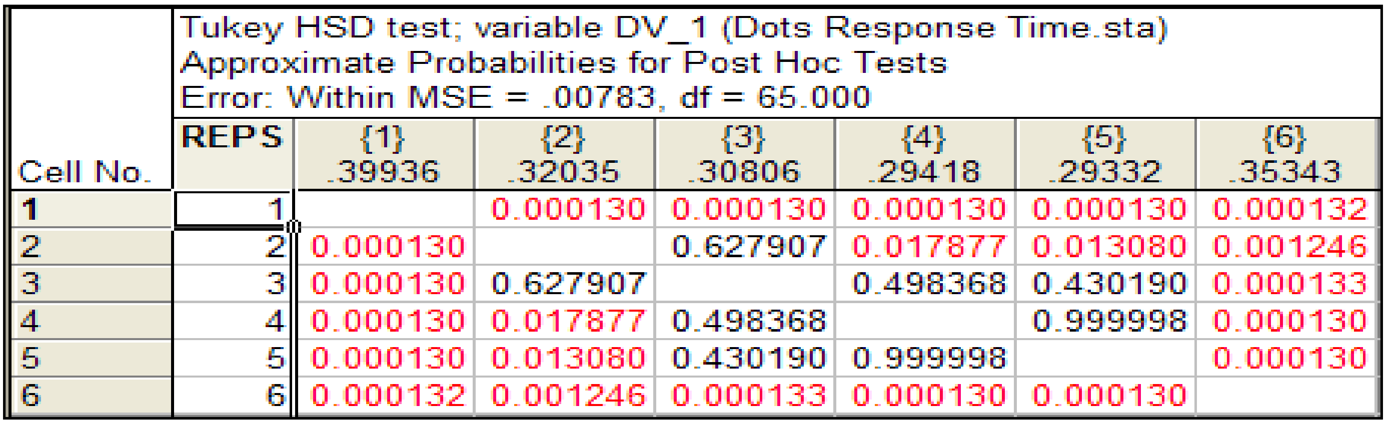
Blink Duration: Time on Task



Tukey HSD test; variable DV_1 (Blink Duration.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 1029.2, df = 255.00

Cell	{1} 148.29	{2} 148.29	{3} 149.08	{4} 157.02	{5} 158.02	{6} 162.14	{7} 162.23	{8} 160.68	{9} 165.13	{10} 158.98	{11} 165.74	{12} 161.30	{13} 159.86	{14} 164.44	{15} 172.74	{16} 181.29	{17} 186.48	{18} 186.16
1		1.000000	1.000000	0.999822	0.999262	0.961706	0.959502	0.987439	0.816952	0.997634	0.770566	0.979128	0.994009	0.863615	0.177406	0.005043	0.000299	0.000356
2	1.000000		1.000000	0.999823	0.999264	0.961755	0.959553	0.987459	0.817088	0.997639	0.770717	0.979158	0.994020	0.863730	0.177510	0.005048	0.000300	0.000357
3	1.000000	1.000000		0.999952	0.999756	0.978222	0.976788	0.993874	0.869146	0.999081	0.830029	0.989088	0.997358	0.906803	0.224987	0.007475	0.000463	0.000553
4	0.999822	0.999823	0.999952		1.000000	1.000000	1.000000	1.000000	0.999936	1.000000	0.999828	1.000000	1.000000	0.999982	0.888351	0.187774	0.027009	0.030955
5	0.999262	0.999264	0.999756	1.000000		1.000000	1.000000	1.000000	0.999990	1.000000	0.999968	1.000000	1.000000	0.999998	0.934216	0.251525	0.041220	0.046910
6	0.961706	0.961755	0.978222	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.997862	0.617736	0.184013	0.202599
7	0.959502	0.959553	0.976788	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.998059	0.625779	0.188840	0.207761
8	0.987439	0.987459	0.993874	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.990497	0.475895	0.113493	0.126524
9	0.816952	0.817088	0.869146	0.999936	0.999990	1.000000	1.000000	1.000000		0.999999	1.000000	1.000000	1.000000	1.000000	0.999974	0.862673	0.408060	0.437068
10	0.997634	0.997639	0.999081	1.000000	1.000000	1.000000	1.000000	1.000000	0.999999		0.999995	1.000000	1.000000	1.000000	0.963950	0.324305	0.060574	0.068445
11	0.770566	0.770717	0.830029	0.999828	0.999968	1.000000	1.000000	1.000000	1.000000	0.999995		1.000000	0.999999	1.000000	0.999992	0.896850	0.464113	0.494220
12	0.979128	0.979158	0.989088	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	0.994744	0.536129	0.140407	0.155715
13	0.994009	0.994020	0.997358	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.999999	1.000000		1.000000	0.981181	0.400573	0.084851	0.095213
14	0.863615	0.863730	0.906803	0.999982	0.999998	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		0.999911	0.815841	0.346955	0.374095
15	0.177406	0.177510	0.224987	0.888351	0.934216	0.997862	0.998059	0.990497	0.999974	0.963950	0.999992	0.994744	0.981181	0.999911		0.999867	0.964635	0.971664
16	0.005043	0.005048	0.007475	0.187774	0.251525	0.617736	0.625779	0.475895	0.862673	0.324305	0.896850	0.536129	0.400573	0.815841	0.999867		1.000000	1.000000
17	0.000299	0.000300	0.000463	0.027009	0.041220	0.184013	0.188840	0.113493	0.408060	0.060574	0.464113	0.140407	0.084851	0.346955	0.964635	1.000000		1.000000
18	0.000356	0.000357	0.000553	0.030955	0.046910	0.202599	0.207761	0.126524	0.437068	0.068445	0.494220	0.155715	0.095213	0.374095	0.971664	1.000000	1.000000	

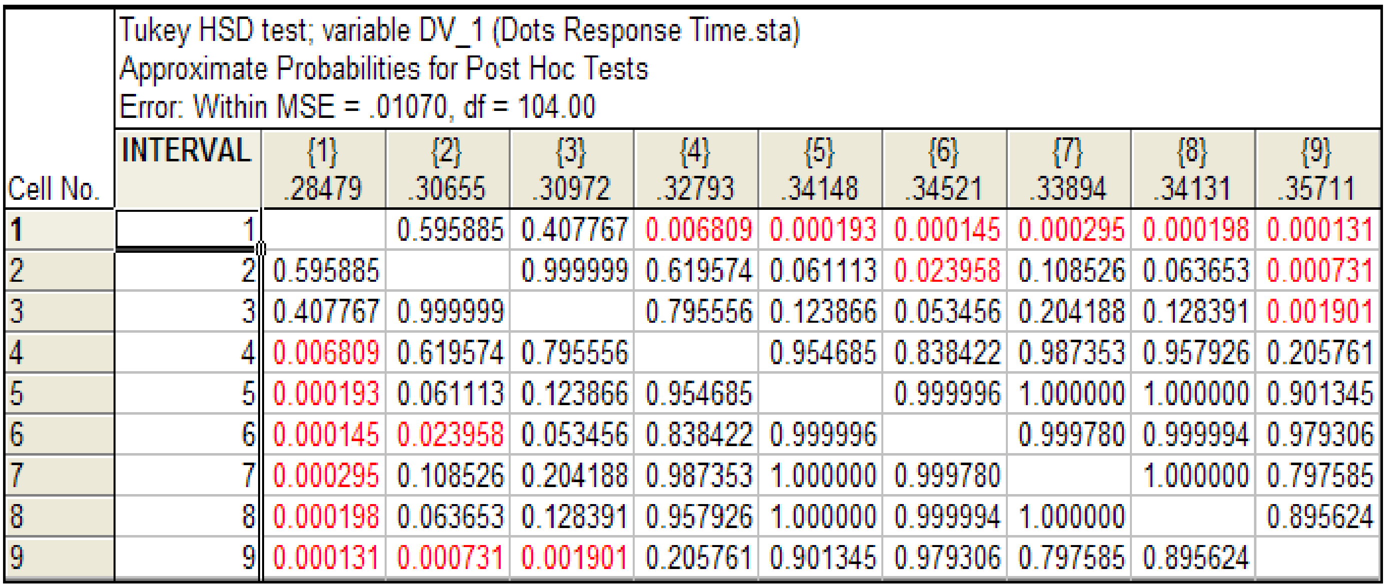
Peripheral Response Time: Eccentricity



Tukey HSD test; variable DV_1 (Dots Response Time.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = .00783, df = 65.000

Cell No.	REPS	{1} .39936	{2} .32035	{3} .30806	{4} .29418	{5} .29332	{6} .35343
1	1		0.000130	0.000130	0.000130	0.000130	0.000132
2	2	0.000130		0.627907	0.017877	0.013080	0.001246
3	3	0.000130	0.627907		0.498368	0.430190	0.000133
4	4	0.000130	0.017877	0.498368		0.999998	0.000130
5	5	0.000130	0.013080	0.430190	0.999998		0.000130
6	6	0.000132	0.001246	0.000133	0.000130	0.000130	

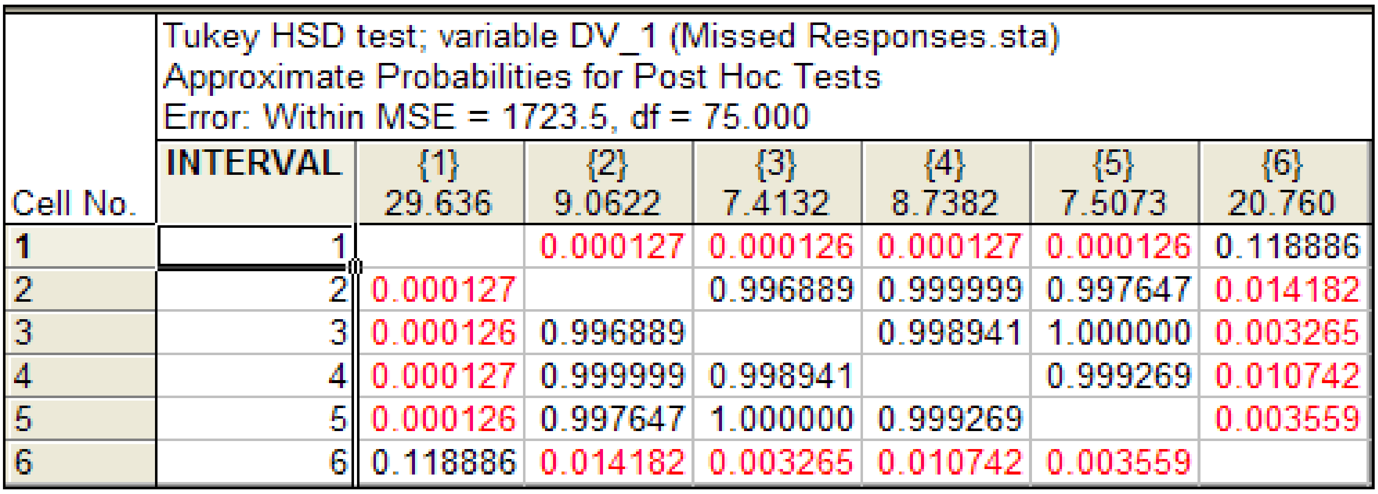
Peripheral Response Time: Time on Task



Tukey HSD test; variable DV_1 (Dots Response Time.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = .01070, df = 104.00

Cell No.	INTERVAL	{1} .28479	{2} .30655	{3} .30972	{4} .32793	{5} .34148	{6} .34521	{7} .33894	{8} .34131	{9} .35711
1	1		0.595885	0.407767	0.006809	0.000193	0.000145	0.000295	0.000198	0.000131
2	2	0.595885		0.999999	0.619574	0.061113	0.023958	0.108526	0.063653	0.000731
3	3	0.407767	0.999999		0.795556	0.123866	0.053456	0.204188	0.128391	0.001901
4	4	0.006809	0.619574	0.795556		0.954685	0.838422	0.987353	0.957926	0.205761
5	5	0.000193	0.061113	0.123866	0.954685		0.999996	1.000000	1.000000	0.901345
6	6	0.000145	0.023958	0.053456	0.838422	0.999996		0.999780	0.999994	0.979306
7	7	0.000295	0.108526	0.204188	0.987353	1.000000	0.999780		1.000000	0.797585
8	8	0.000198	0.063653	0.128391	0.957926	1.000000	0.999994	1.000000		0.895624
9	9	0.000131	0.000731	0.001901	0.205761	0.901345	0.979306	0.797585	0.895624	

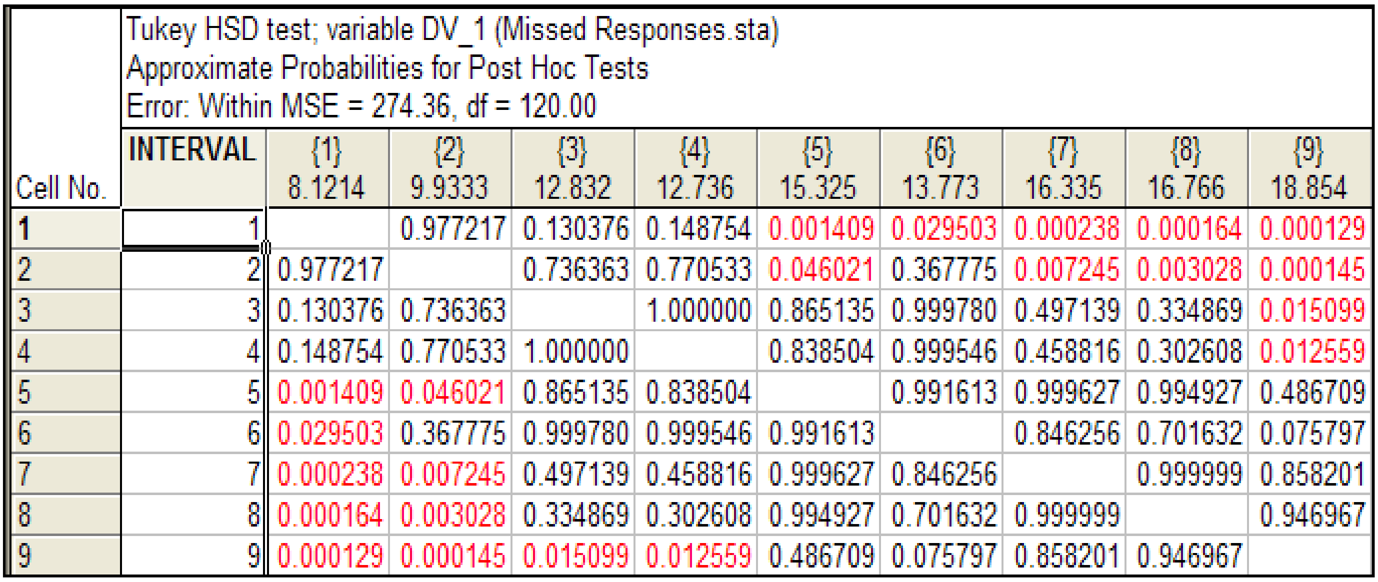
Percentage of Missed Peripheral Stimuli: Eccentricity



Tukey HSD test; variable DV_1 (Missed Responses.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 1723.5, df = 75.000

Cell No.	INTERVAL	{1} 29.636	{2} 9.0622	{3} 7.4132	{4} 8.7382	{5} 7.5073	{6} 20.760
1	1		0.000127	0.000126	0.000127	0.000126	0.118886
2	2	0.000127		0.996889	0.999999	0.997647	0.014182
3	3	0.000126	0.996889		0.998941	1.000000	0.003265
4	4	0.000127	0.999999	0.998941		0.999269	0.010742
5	5	0.000126	0.997647	1.000000	0.999269		0.003559
6	6	0.118886	0.014182	0.003265	0.010742	0.003559	

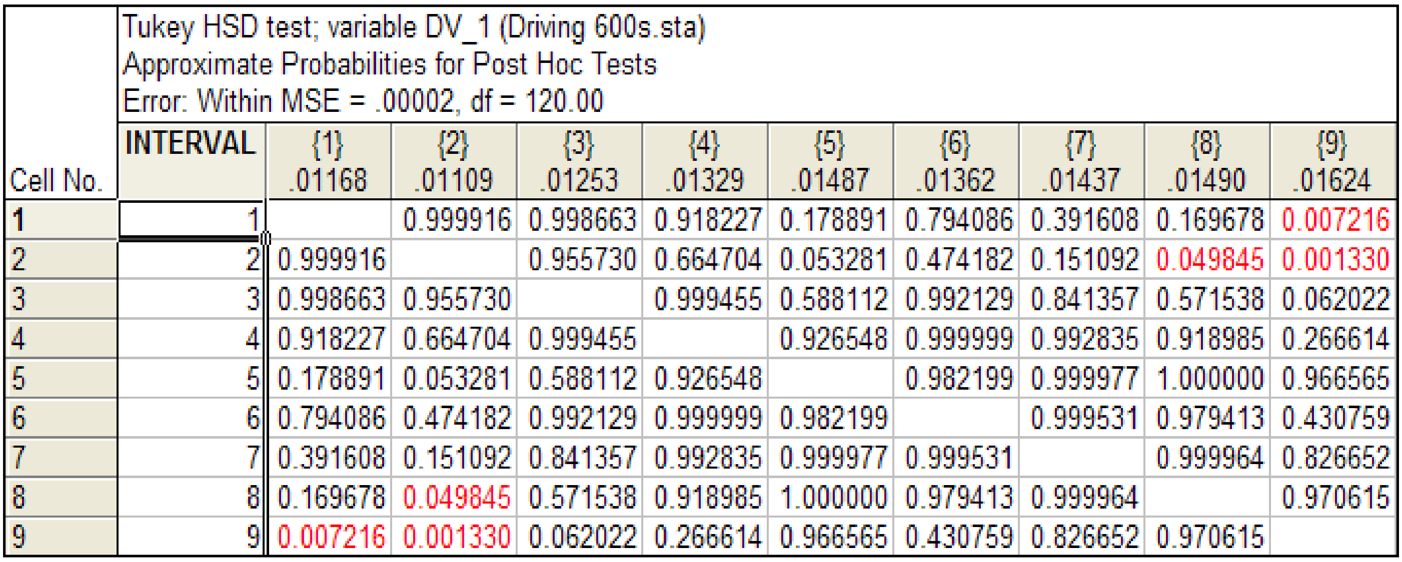
Percentage of Missed Peripheral Stimuli: Time on Task



Tukey HSD test; variable DV_1 (Missed Responses.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 274.36, df = 120.00

Cell No.	INTERVAL	{1} 8.1214	{2} 9.9333	{3} 12.832	{4} 12.736	{5} 15.325	{6} 13.773	{7} 16.335	{8} 16.766	{9} 18.854
1	1		0.977217	0.130376	0.148754	0.001409	0.029503	0.000238	0.000164	0.000129
2	2	0.977217		0.736363	0.770533	0.046021	0.367775	0.007245	0.003028	0.000145
3	3	0.130376	0.736363		1.000000	0.865135	0.999780	0.497139	0.334869	0.015099
4	4	0.148754	0.770533	1.000000		0.838504	0.999546	0.458816	0.302608	0.012559
5	5	0.001409	0.046021	0.865135	0.838504		0.991613	0.999627	0.994927	0.486709
6	6	0.029503	0.367775	0.999780	0.999546	0.991613		0.846256	0.701632	0.075797
7	7	0.000238	0.007245	0.497139	0.458816	0.999627	0.846256		0.999999	0.858201
8	8	0.000164	0.003028	0.334869	0.302608	0.994927	0.701632	0.999999		0.946967
9	9	0.000129	0.000145	0.015099	0.012559	0.486709	0.075797	0.858201	0.946967	

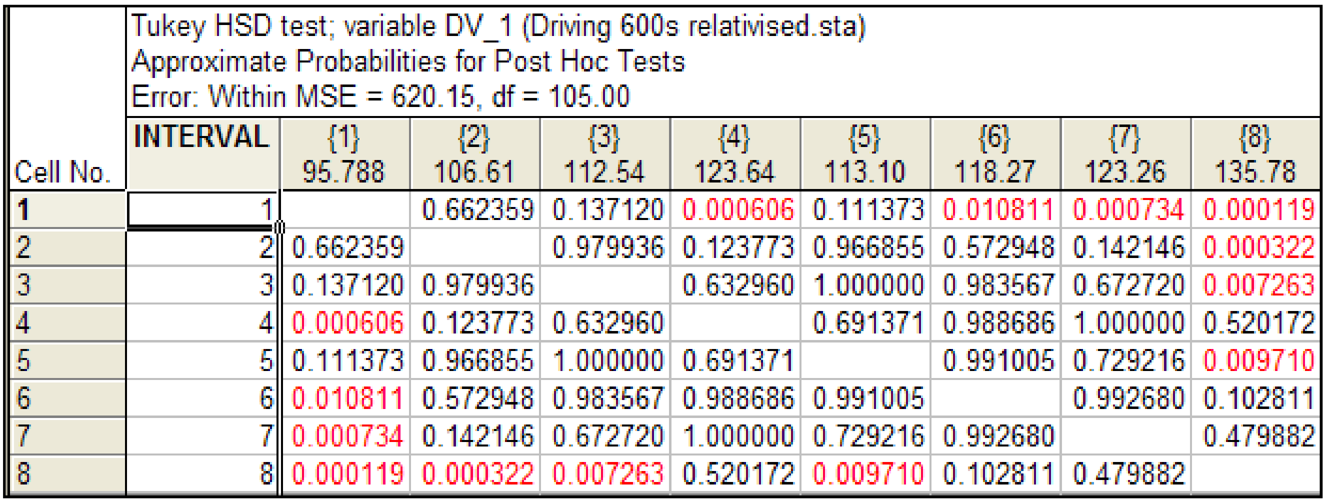
Lane Deviation: Time on Task



Tukey HSD test; variable DV_1 (Driving 600s.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = .00002, df = 120.00

Cell No.	INTERVAL	{1} .01168	{2} .01109	{3} .01253	{4} .01329	{5} .01487	{6} .01362	{7} .01437	{8} .01490	{9} .01624
1	1		0.999916	0.998663	0.918227	0.178891	0.794086	0.391608	0.169678	0.007216
2	2	0.999916		0.955730	0.664704	0.053281	0.474182	0.151092	0.049845	0.001330
3	3	0.998663	0.955730		0.999455	0.588112	0.992129	0.841357	0.571538	0.062022
4	4	0.918227	0.664704	0.999455		0.926548	0.999999	0.992835	0.918985	0.266614
5	5	0.178891	0.053281	0.588112	0.926548		0.982199	0.999977	1.000000	0.966565
6	6	0.794086	0.474182	0.992129	0.999999	0.982199		0.999531	0.979413	0.430759
7	7	0.391608	0.151092	0.841357	0.992835	0.999977	0.999531		0.999964	0.826652
8	8	0.169678	0.049845	0.571538	0.918985	1.000000	0.979413	0.999964		0.970615
9	9	0.007216	0.001330	0.062022	0.266614	0.966565	0.430759	0.826652	0.970615	

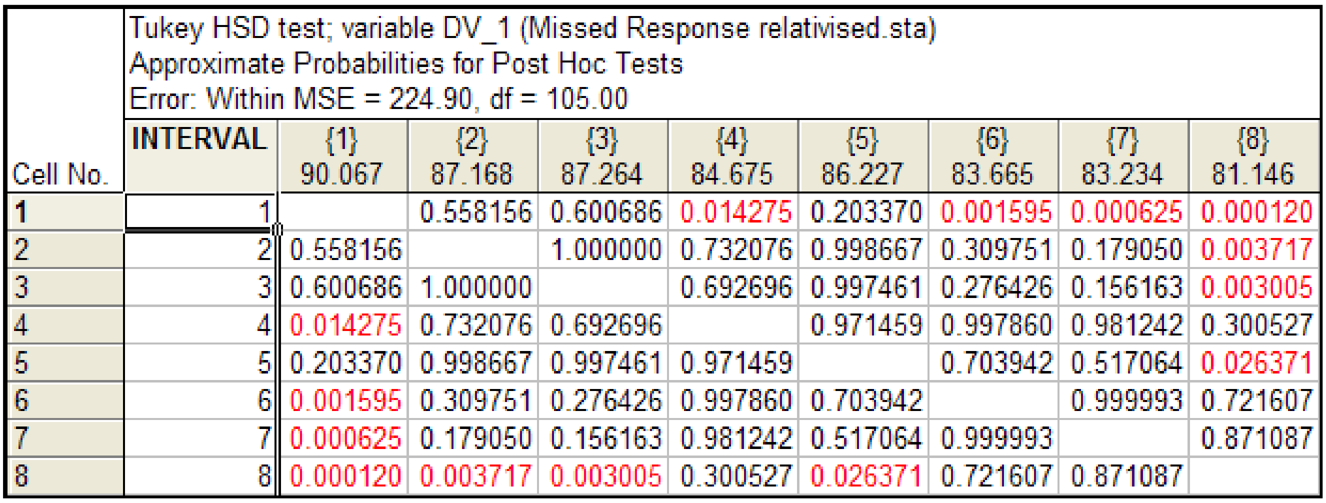
Percentage Rate of Decrement: Driving Performance



Tukey HSD test; variable DV_1 (Driving 600s relativised.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 620.15, df = 105.00

Cell No.	INTERVAL	{1} 95.788	{2} 106.61	{3} 112.54	{4} 123.64	{5} 113.10	{6} 118.27	{7} 123.26	{8} 135.78
1	1		0.662359	0.137120	0.000606	0.111373	0.010811	0.000734	0.000119
2	2	0.662359		0.979936	0.123773	0.966855	0.572948	0.142146	0.000322
3	3	0.137120	0.979936		0.632960	1.000000	0.983567	0.672720	0.007263
4	4	0.000606	0.123773	0.632960		0.691371	0.988686	1.000000	0.520172
5	5	0.111373	0.966855	1.000000	0.691371		0.991005	0.729216	0.009710
6	6	0.010811	0.572948	0.983567	0.988686	0.991005		0.992680	0.102811
7	7	0.000734	0.142146	0.672720	1.000000	0.729216	0.992680		0.479882
8	8	0.000119	0.000322	0.007263	0.520172	0.009710	0.102811	0.479882	

Percentage Rate of Decrement: Percentage of Missed Peripheral Stimuli



Tukey HSD test; variable DV_1 (Missed Response relativised.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 224.90, df = 105.00

Cell No.	INTERVAL	{1} 90.067	{2} 87.168	{3} 87.264	{4} 84.675	{5} 86.227	{6} 83.665	{7} 83.234	{8} 81.146
1	1		0.558156	0.600686	0.014275	0.203370	0.001595	0.000625	0.000120
2	2	0.558156		1.000000	0.732076	0.998667	0.309751	0.179050	0.003717
3	3	0.600686	1.000000		0.692696	0.997461	0.276426	0.156163	0.003005
4	4	0.014275	0.732076	0.692696		0.971459	0.997860	0.981242	0.300527
5	5	0.203370	0.998667	0.997461	0.971459		0.703942	0.517064	0.026371
6	6	0.001595	0.309751	0.276426	0.997860	0.703942		0.999993	0.721607
7	7	0.000625	0.179050	0.156163	0.981242	0.517064	0.999993		0.871087
8	8	0.000120	0.003717	0.003005	0.300527	0.026371	0.721607	0.871087	