VALIDATION OF AN ASSESSMENT TOOL FOR MENTAL FATIGUE APPLIED TO ROTATIONAL SHIFT WORK

BY

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THESIS

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ABSTRACT

Mental fatigue has been proven to be highly prominent during shift work, due to long, irregular working hours and disruption of the circadian rhythm. Measuring mental fatigue has been a challenge for many years, where commonly cognitive test tasks are used to assess mental fatigue. Moreover, these test tasks do not isolate where fatigue is occurring during human information processing. The human information processing system consists of four core stages, each of which requires numerous cognitive functions in order to process information.

The Human Kinetics and Ergonomics Department at Rhodes University has developed six cognitive test tasks where each isolates a cognitive function: an accommodation test task, a visual detection test task, a reading test task, a memory test task, a tapping test task and a neural control test task. The cognitive functions include: eye accommodation, visual discrimination, visual pattern recognition, memory duration, motor programming and peripheral neural control. General task-related effect can also be examined for each of these cognitive test tasks which include choice reaction time, visual detection, reading performance, short-term memory, motor control and tracking performance. Additionally, a simple reaction time test task has been developed to analyse simple reaction time. This test task does not isolate a cognitive function. One or more parameters can be examined for each cognitive function and task-related effect.

The first aim of this study was to validate numerous cognitive test tasks for mental fatigue in a simulated shift work laboratory setting. The second aim was to assess the validated cognitive test tasks in Phase 1 in a field-based rotational shift work setting. Parameters revealing sensitivity to mental fatigue would be validated for mental fatigue applied to rotational shift work and would be inserted into an assessment tool.

In the laboratory setting, the seven cognitive test tasks were examined on four different types of shift work regimes. The first regime was a standard eight-hour shift work system, and the other three were non-conventional shift work regimes. Participants (n = 12 per regime) were required to complete one day shift followed by four night shifts,

where testing occurred before and after each shift and four times within each shift. The cognitive test tasks revealing sensitivity to fatigue included: visual detection test task, reading test task, memory test task, tapping test task, neural control test task and simple reaction time test task.

The testing of Phase 2 was conducted in three different companies, where each performed a different type of rotational shift work. The six cognitive test tasks validated for mental fatigue in Phase 1 were tested before and after work for each shift type within the rotational shift work system adopted by each company. Company A (n = 18) and Company B (n = 24) performed two-shift rotational shift work systems, where the shift length of Company A was 12-hours and the shift length of Company B was irregular hours. Company C (n = 21) performed an eight-hour three-shift rotational shift work system.

Nine parameters revealed fatiguing effects and were inserted into the assessment tool, five of which provided information on a specific cognitive function: error rate for visual discrimination, processing time for visual pattern recognition, error rate for visual pattern recognition, impact of rehearsal time on memory recall rate for memory duration and the high-precision condition for motor programming time. The remaining four parameters provided information on general task-related effects: reading speed for reading performance, recall rate for short-term memory, reaction time for motor control and simple reaction time.

Therefore, an assessment tool comprising nine parameters was validated for mental fatigue applied to rotational shift work, where five of the parameters were able to isolate exactly where fatigue was occurring during human information processing and the other four parameters were able to assess fatigue occurring throughout the human information processing chain.

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CHAPTER I

INTRODUCTION

1.1 BACKGROUND TO STUDY

Fatigue is an acute or chronic state of tiredness that leads to mental or physical exhaustion and prevents people from functioning within their normal boundaries (Bridger, 2003). The effects of fatigue at work have been associated with comprised worker well-being and poor work performance, all of which impacts negatively on productivity and the efficiency of a company (Darby and Wells, 1998). By preventing early-onset fatigue indicators, worker well-being and performance is enhanced which ultimately impacts positively on productivity and efficiency (Darby and Wells, 1998).

Shift work and specifically night shift work is globally prevalent and has increased rapidly over the past two decades due to simultaneous expansion of global, social and economic demands (Rajaratnam and Arendt, 2001). Shift work refers to work patterns that extend beyond the conventional eight-hour work day in which individuals have to work atypical hours, usually on a rotational basis (Åkerstedt, 1998, Verster *et al*., 2009).

Shift work has been proven to be a potent cause of mental, emotional and physical fatigue (Darby and Wells, 1998). Fatigue experienced during shift work, especially night shift work, is inevitable. This is due to the combination of two factors: irregular work hours and task-related factors. Irregular work hours cause an increase in sleepiness and sleep loss which is due to individuals shifting their usual sleep periods out of their natural circadian rhythm (Darby and Wells, 1998; Blatter and Cajochen, 2007). This is referred to as disruption of the circadian rhythm or circadian disruption (Haus and Smolensky, 2013). Task-related factors such as time-on-task and task-demand contribute to fatigue, as performing a physically or mentally demanding task for a long duration will result in the early onset of fatigue (Brown, 1982; Meijman, 1996).

The onset of fatigue during shift work has been associated with impaired or reduced human performance, increased accidents and errors, lowered levels of production and efficiency, increased absenteeism and decreased health as well as social and psychological problems (Åkerstedt, 2004; Härmä *et al*., 2006). The negative effects associated with shift work are enhanced during night shift work due to the circadian disruption and working whilst circadian rhythm activity is low (Dawson *et al*., 2011). Additionally, these fatiguing effects are exacerbated during rotational shift work due to cumulative sleep loss as the circadian rhythm is being constantly disrupted from repeatedly changing work hours, which leads to a decrease in physical performance, cognitive performance and alertness (Vidacek *et al*., 1986; Dula *et al*., 2001).

Over the past decade, work has changed largely from demanding physical effort to demanding mental effort (Boksem and Tops, 2008). This has resulted in a substantial increase in complaints related to mental fatigue in the workplace, especially during shift work (Ricci *et al*., 2007; Boksem and Tops, 2008). Mental fatigue has shown to have a profound and negative impact on cognitive functioning, cognitive ability and cognitive processing, where many incidents, accidents and errors have been related to mental fatigue in industry which has resulted in a decrease in productivity, efficiency and reduced worker well-being (Baker *et al*., 1994; Van der Linden *et al*., 2003; Boksem and Tops, 2008).

Thus, reducing mental fatigue experienced during shift work is of vital importance. This can be done via an intervention such as altering the working task or adjusting the shift work regime. In order to evaluate any type of adjustment or intervention, an assessment tool is required to ensure the changes are effective and mental fatigue is reduced.

In previous literature, cognitive test tasks have been used to assess the rate of mental fatigue experienced during shift work by evaluating cognitive performance decrements (Meijman, 1996; Ahsberg *et al*., 2000; Fletcher and Dawson, 2001; Dula *et al*., 2001; Murzur *et al*., 2002; Fenn *et al*., 2003; Van der Linden *et al*., 2003; Boksem *et al*., 2006; Van der Linden *et al*., 2006; Bogdan *et al*., 2008; Babenko and Ermakov, 2008; Tyagi *et al*., 2009; Chaplin, 2010). However, the majority of these cognitive test tasks have not been validated to ensure that they measure mental fatigue during shift work. Additionally, numerous studies measure cognitive performance during shift work in a laboratory setting and apply this information to an actual real-life shift work setting. This has occurred even though it has been documented that laboratory experimentations in isolation are necessarily limited in relevance for predicting field behaviour (Harrison and List, 2004; Kantermann *et al*., 2012).

Over and above these issues, these test tasks used to assess mental fatigue do not isolate where fatigue is occurring during human information processing. The human information processing chain consists of four core stages (Wickens, 1992); where each stage requires numerous cognitive functions in order to process information. It has been suggested that different resources are required for the different stages (Wickens, 2002; Matthews *et al*., 2010). Thus, depletion of one resource (fatigue) does not necessarily mean depletion of all resources (Wickens, 2002). It suggests that one or more cognitive functions of a particular stage in human information processing are fatigued. If we are able to determine where this fatigue is occurring, workplace design or tasks can be adapted.

1.2 STATEMENT OF THE PROBLEM

There is no creditable evidence-based assessment tool to measure mental fatigue during shift work in the workplace. As a result, companies are unable to determine, monitor or control the amount of mental fatigue a worker is experiencing. Thus, the negative consequences of mental fatigue experienced during shift work are not being alleviated or minimized, which places workers and companies at a potential risk. An assessment tool measuring mental fatigue during shift work would help to identify and prevent onset fatigue indicators experienced during shift work, so that worker well-being and performance can be enhanced, which ultimately will increase productivity and efficiency (Darby and Wells, 1998).

Additionally, methods available to measure mental fatigue do not isolate where fatigue is occurring during human information processing. The Human Kinetics and Ergonomics

Department at Rhodes University has developed numerous cognitive test tasks, each of which isolates a cognitive function activated during a stage of human information processing. Additionally, general task-related effects can also be analysed from these cognitive test tasks.

Thus, the first objective of this study was to validate various cognitive test tasks in a laboratory setting, where shift work was simulated. Each cognitive test task was aimed at isolating a specific cognitive function activated during human information processing and provided information on the general task-related effect. Cognitive test tasks revealing significant fatiguing effects in the laboratory setting were added to an assessment tool. The second objective was to validate the assessment tool from the laboratory setting for mental fatigue in a rotational shift work field-based setting.

1.3 RESEARCH HYPOTHESIS

The first research hypothesis suggested that cognitive performance in a simulated shift work laboratory setting would either differ between the five consecutive shifts examined or within each of the five shifts examined. The second research hypothesis suggested that cognitive performance in a rotational shift work field-based setting would differ before and after work or between the shift types examined in each rotational shift work system under investigation.

CHAPTER 2

REVIEW OF LITERATURE

2.1 INTRODUCTION

This chapter aims to provide the necessary background for understanding and assessing the relationship between mental fatigue and shift work, as well as the factors known to influence it.

The first section examines the complex nature and various types of fatigue. This is followed by the explanation of the human information processing chain and the fatigue processes associated with information processing. Chapter 2.5 focuses on shift work and unpacks the different types and negative consequences associated with it. After that, mental fatigue in the workplace is explored. This is followed by the mechanisms causing mental fatigue during shift work and the tools used to measure this. Lastly, the relationship between fatigue occurring during shift work and the effects of living in a third world country will be discussed.

2.2 FATIGUE

2.2.1 General concepts

Fatigue is a highly elusive concept from which researchers have yet to provide a precise definition (Saxby, 2007). This has been challenging due to the complex interaction of the biological processes, psychosocial phenomena and behavioural manifestation involved (Aaronson *et al.,* 1999). Additionally, fatigue has a non-specific aetiology, there are vast individual differences in susceptibility and adaptation to it and there is no consensus regarding its measurement (Hitchcock and Matthews, 2005; Louw, 2013).

According to Bridger (2003) fatigue can be defined as an acute and/or on-going state of tiredness that leads to mental or physical exhaustion and prevents people from functioning within their normal boundaries (Bridger, 2003). Bridger (2003) suggests that fatigue occurs due to the rate of resource demand exceeding the rate of resource replenishment. Fatigue can be defined as a complex, multi-causal, multi-dimensional, non-specific and subjective phenomenon where a combination of underlying causative factors causes one to reduce performing an activity (Lucas *et al*., 2008). Fatigue tends to occur after long durations of performing a particular task and presents itself as a disinclination to continue a task coupled with discomfort of some sort (Brown, 1982; Chaplin, 2010). The onset of fatigue can also be interpreted as a subjective response as the body informs the brain to slow down performance which acts as a protective mechanism (Brown, 1982; Chaplin, 2010). The onset of fatigue can occur at different rates and can be eradicated quickly (Zinchenko *et al*., 1985). Fatigue has been described as involving an increase in resistance in order to carry on with a task (Bridger, 2003). Thus, a greater effort is required to continue performing the task as the resistance must be overcome (Bridger, 2003).

2.2.2 Types of fatigue

<u>Physical and mental fatigue</u>

Physical fatigue is commonly referred to in literature as physiological fatigue and mental fatigue as psychological fatigue (Aaronson *et al*., 1999; Chaplin, 2010). Physical fatigue is defined as the inability to maintain optimal or maximal physical exertion or activity (Aaronson *et al*., 1999). This is attributed to excessive energy consumption and can be characterised by the depletion of hormones, neurotransmitters or essential substrates of physiological functioning (Aaronson *et al*., 1999).

Mental fatigue refers to a state of tiredness, where motivation to complete the task is reduced (Chaplin, 2010). It occurs after or during prolonged periods of cognitive activity (Boksem and Tops, 2008). These feelings are common in everyday modern life and generally involve tiredness or even exhaustion, an aversion to continue with the present activity and a decrease in the level of commitment to the task at hand (Boksem and Tops, 2008). In addition, mental fatigue has been associated with impaired cognitive and behavioural performance (Boksem *et al*., 2005; Lorist *et al*., 2005; Van der Linden and Eling, 2006).

Work-related fatigue and circadian fatigue

Work-related fatigue occurs when the rate of resource demands exceeds the rate of resource replenishment, thus depleting the particular resource needed to continue to perform (Bridger, 2003). This results in a decline in performance over time. The particular resource can either be a resource required to perform a physical task (physical fatigue) or a resource required to perform a mental task (mental fatigue) (Bridger, 2003).

Circadian fatigue is controlled by the activity of the circadian rhythm, where levels of alertness and activation fluctuate throughout the day (Van Dongen and Dinges, 2000). The circadian rhythm is a roughly 24-hour cycle physiological process of living beings, also known as the human internal biological clock (Kelly, 1996). Circadian rhythm activity, displayed in Figure 1, increases throughout the day and decreases with the onset of evening (Blatter and Cajochen, 2007; Valdez *et al*., 2008). Homeostatic drive for wakefulness is activated with the increase in circadian rhythm activity, whereas the homeostatic drive for sleeping is activated with the decrease in circadian rhythm activity (Blatter and Cajochen, 2007; Valdez *et al*., 2008).

Circadian rhythm activity increases during the day as melatonin, which causes drowsiness and a decrease in body temperature, is inhibited (Brzezinski, 1997) and sympathetic nervous system activity is increased, which is associated with an increase in alertness and wakefulness (Montemurro *et al*., 2012). Conversely, the decrease in circadian rhythm activity during the evening is due to melatonin being released (Brzezinski, 1997) and parasympathetic nervous system activity being increased, which causes a decrease in alertness and an increase in sleepiness (Montemurro *et al*., 2012). Sympathetic nervous system (SNS) and parasympathetic nervous system (PSN) are branches of the autonomic nervous system (ANS) and act as antagonists to each other (Acharya *et al*., 2005). Activation of the ANS is influenced by light and darkness (Brzezinski, 1997; Acharya *et al*., 2005; Montemurro *et al*., 2012). The presence of light increases SNS activity, whereas the presence of darkness increases PSN activity (Brzezinski, 1997; Acharya *et al*., 2005; Montemurro *et al*., 2012).

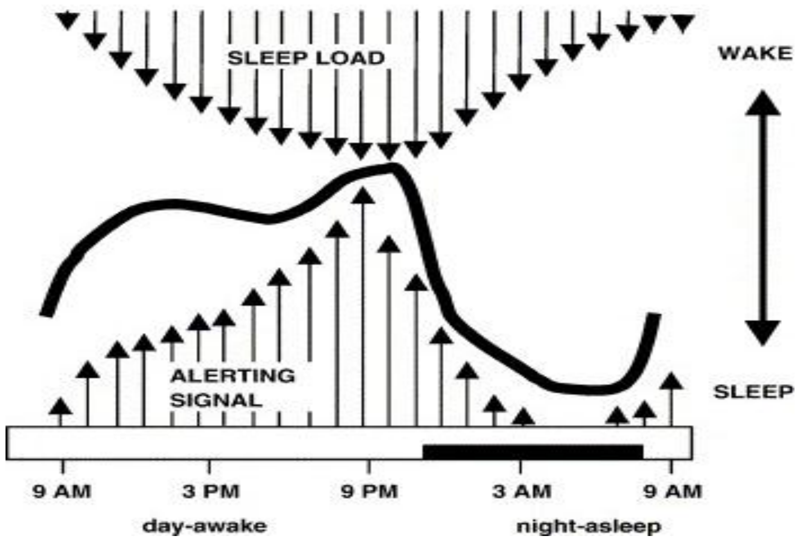

Figure 1: Circadian rhythm activity, also indicating alertness and sleep load (Blatter and Cajochen, 2007, pg. 202).

Thus, fatigue caused by circadian rhythm activity is increased in the evening and minimised during the day. It has been well-documented that circadian rhythm activity is mimicked by alertness, physical performance, body temperature and cognitive performance (Blatter and Cajochen, 2007; Valdez *et al*., 2008). Therefore, these factors deteriorate and become impaired during the evening due to circadian fatigue and, conversely, improve during the day. Additionally, circadian fatigue also influences the perception of workload, thus the same task may be perceived as harder during the night compared to during the day.

<u>Acute and chronic fatigue</u>

Acute fatigue occurs after performing a strenuous or repetitive activity for a prolonged duration (Shen *et al*., 2006). It is a protective mechanism that is linked to a single cause (Aaronson *et al*., 1999). It occurs in healthy individuals and is perceived as normal (Aaronson *et al*., 1999). The onset of acute fatigue occurs quickly and is eradicated quickly (Shen *et al*., 2006). It is reversible and generally disappears with rest, change in activity, exercise, diet and stress management (Aaronson *et al*., 1999; Shen *et al*., 2006). Most importantly, it has little effect on an individual’s life (Shen *et al*., 2006).

In contrast, chronic fatigue is a poorly-understood condition characterised by unremitting and debilitating fatigue (Aaronson *et al*., 1999). This type of fatigue is a result of many causes over time and is not alleviated by rest (Aaronson *et al*., 1999). Furthermore, chronic fatigue is often experienced with no relation to activity or exertion and is often perceived as abnormal, unusual or excessive (Aaronson *et al*., 1999). This kind of fatigue has a major effect on the individual's activities in day-to-day living and quality of life (Aaronson *et al*., 1999).

2.3 HUMAN INFORMATION PROCESSING

Humans are constantly interacting with the environment, by processing stimuli and responding to them (Huysamen, 2011). Activities of daily living require humans to respond to stimuli presented by the external environment in an efficient and effective manner (Huysamen, 2011). This is most commonly required in the work place, as workers need to process and respond to stimuli in a manner that produces goal-directed behaviour in order to obtain desirable responses suited for the task at hand.

The human information processing system will be explained through application of the Wickens model (Figure 2), which displays a sequence of information processing stages (Wickens, 1984).

Wickens' model incorporates stages used to perceive sensations, transform data and choose action responses. The different stages of information processing are short-term sensory store, perception, decision-making/response selection and response execution/motor control. Processing at each stage takes time and requires mental resources (Wickens, 1984) which are believed to be limited in nature. Processing time can be prolonged due to uncertainty, fatigue or overload.

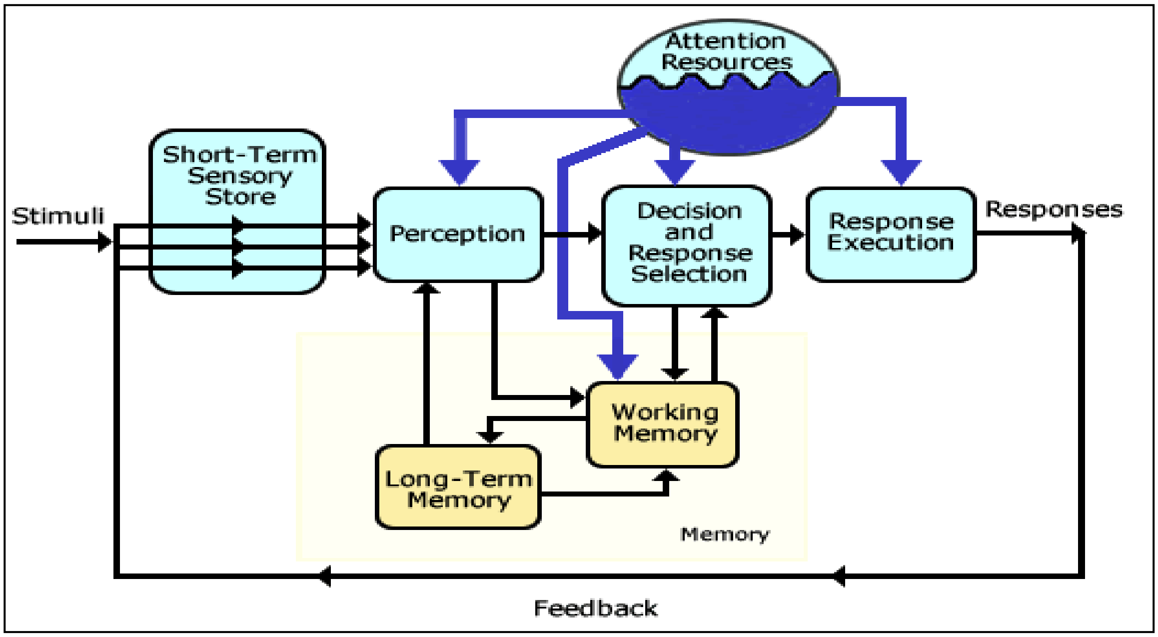

Figure 2: Model for human information processing (adapted from Wickens, 1984, pg.12).

Information from our external environment is picked up by receptor cells in the sensory channels (Wickens, 1992). These senses range from visual, auditory, touch, gustation, smell, vestibular system, proprioception, pain, time, temperature, and so on. The sensation/stimuli enter the short-term sensory store via afferent nerve impulses, where the information is transformed into a form that the perceptual processes within the brain can understand (Wickens, 1992).

Once the stimulus is processed, the information regarding the stimuli is sent to the perceptual stage (Wickens, 1984). Here, the information from the environment must be interpreted (Wickens, 1992). Our interpretation of sensory information requires retrieval from long-term memory (Wickens, 1992), a process often determined by our perceptions of prior experiences, knowledge, emotional states and value systems. This stage is generally processed automatically and requires minimal attention (Wickens, 1992).

Following recognition, information is passed to the decision-making and response-selection stage (Wickens, 1992), which is concerned with selecting an appropriate response for the stimuli presented (Wickens, 1992). This stage is also known as cognition and requires substantially more processing time, mental effort and attention than the perception stage (Wickens, 1992). These central processes are therefore intimately related to memory. Long-term memory is accessed in order to view previous decisions, experiences and knowledge which influences our response selected (Wickens, 1992). The process of selecting a response will be delayed if the stimulus has never been encountered before. Once an appropriate response has been selected, it is executed by sending efferent nerve impulses to the relevant muscles (Wickens, 1992). Thereafter, feedback is returned to the system with information regarding the decision that has been made (Wickens, 1992).

It is important to note that any task performed uses the whole information-processing chain (Wickens, 1992). However, different tasks may tax the components of human information processing differently (Wickens, 1992).

2.4 FATIGUE PROCESSES IN INFORMATION PROCESSING

Past research has failed to pinpoint the specific human information processing mechanisms responsible for fatigued-induced performance decrements (Hitchcock and Matthews, 2005). This may be due to the complex nature of fatigue and the lack of consensus as to what fatigue actually is. Matthews (2001) categorises the process models for fatigue and stress into two broad types: biocognitive and cognitive-adaptive. The biocognitive perspective is also known as Resource Theory (Kahneman, 1973) and the cognitive adaptive perceptive is also known as Effort-Regulation Theory (Hancock and Warm, 1989). Biocognitive models refer to mechanisms that reflect changes in parameters of neural and cognitive architecture and include changes in resource availability (Kahneman, 1973). Cognitive adaptive mechanisms reflect changes in the subject’s goals and intentions (Helton *et al*., 2009). This may lead to strategy changes, such as regulating task directed effort (Helton *et al*., 2009).

<u>Resource Theory</u>

In order to process information effectively, each process activated during human information processing needs to be completed efficiently (Wicken, 1984; Staal, 2004). For this to occur, resources need to be utilised in each process. This theory assumes that the resources are a fixed quantity and facilitate human information processing, which allows individuals to perform a task (Kahneman, 1973; Matthews *et al*., 2010). With regards to this research, workload typically refers to the amount of resources required to meet task demands. The Resource Theory suggests that the effort required for maintaining prolonged work activity leads to the depletion of resources (Warm *et al*., 2008). This leads to an increase in workload, which ultimately results in performance breakdown, as there are insufficient resources to meet task demands (Warm *et al*., 2008).

There are two main concerns with this theory. Firstly, there is a lack of a precise definition and secondly, resources may be multiple and not unitary (Wickens, 2002). The Multiple Resource Theory emerged to account for this, but mainly due to dual task settings (Wickens, 2002). Dual tasks are not relevant to this study, however, the suggestion of multiple resources is. This theory suggests that different resources are utilised for the different human information processing stages (Figure 3) (Wickens, 2002). Thus, depletion of one resource (fatigue) does not necessarily mean depletion of all resources. It merely suggests that one particular stage in human information processing is fatigued. With regards to the workplace, this would be very useful if measurable. If we are able to determine where fatigue is occurring in human information processing, workplace design or tasks can be adapted.

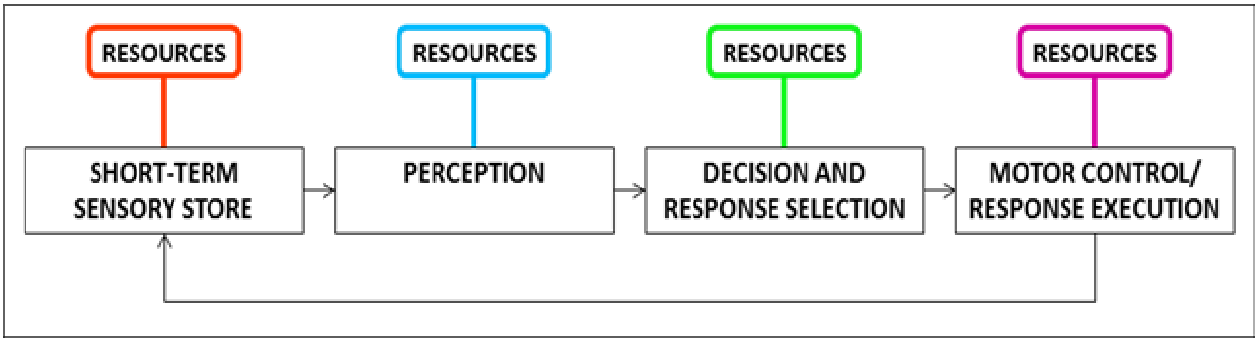

Figure 3: Adapted Wickens Human Information Processing Model (adapted from Wickens, 2002, pg.164).

Effort-Regulation theory

As with Resource Theory, the concept of resources is an integral element in Effort-Regulation theory. However, this theory suggests that decrements in performance are due to the inability to allocate resources, i.e. match effort to environmental demands. It has been suggested that effort-regulation can occur via both sub-conscious and conscious control (Rissler and Jacobsen, 1987; Hockey, 1993). Thus, a person will either voluntarily or involuntarily reduce engagement in a task (Van der Linden *et al*., 2003), especially when the task is perceived to be simple and require minimal attention or effort (Matthews and Desmond, 2002).

2.5 SHIFT WORK

Shift work is an industrial and commercial activity that operates outside normal work hours. Thus, shift work requires employees to continue work during the "conventional day-time third of the 24-hour cycle" (Åkerstedt, 1998: 118). Shift work is an increasingly common form of work organisation due to a simultaneous expansion of global, social and economic demands (Rajaratnam and Arendt, 2001; Bambra *et al.*, 2008). Approximately, one fifth of workers across the globe engage in some kind of shift work (Bambra *et al*., 2008). Shift work has expanded into a variety of sectors and socio-economic work groups; however, shift work is still highly prevalent among lower socio-economic groups (Bambra *et al*., 2008). Thus, these groups more commonly experience the adverse consequences of shift work on health and work-life balance.

2.5.1 Negative consequences of shift work

Shift work has been proven to impact negatively on both the employer and employee. The negative consequences associated with shift work can be divided into three main sections; health problems, social problems and fatigue. Health problems are common and are caused by the disruption in the circadian rhythm, disturbed socio-temporal patterns and unhealthy behaviour (Boggild and Knutsson, 1999; Knutsson and Boggild, 2000). Disruption in the circadian rhythm leads to sleep/wake disturbances, desynchronisation of internal processes, gastrointestinal problems, sleep disorders and increased susceptibility to diseases (Boggild and Knutsson, 1999; Knutsson and Boggild, 2000). Disturbed socio-temporal patterns is a result from atypical work and leads to family and social problems, reduced social support and increased stress (Boggild and Knutsson, 1999; Knutsson and Boggild, 2000). Unhealthy behaviour refers to increased smoking, poor diet, lack of exercise and irregular meals, which increases susceptibility to cardio-vascular diseases (Boggild and Knutsson, 1999; Knutsson and Boggild, 2000).

Shift work has been associated with social problems, particularly if working night shift. Night shift work requires workers to sleep during the day and work through the night. This has led to interactions with family and friends being disturbed and challenging (Demerouti *et al*., 2004). Additionally, normal day-time activities such as shopping, banking, paying bills, domestic obligations, etc. become challenging (Demerouti *et al*., 2004). These factors have led to non-work conflict (Demerouti *et al*., 2004).

The onset of fatigue occurs during prolonged working hours and occurs due to circadian disruption and work-related factors (discussed further in Chapter 2.7) (Rosa, 1993; Åkerstedt, 2004; Härmä *et al*., 2006; Shen *et al*., 2006). The onset of fatigue leads to a decrease in productivity and efficiency (Åkerstedt, 2004; Härmä *et al*., 2006), mainly due to human performance and alertness being impaired and reduced, which leads to an increase in accidents and errors and a decrease in worker well-being, work rate, productivity, efficiency and quality of work (Rosa, 1993; Åkerstedt, 2004; Härmä *et al*., 2006; Shen *et al*., 2006; Ellingsen *et al*., 2007).

2.5.2 Types of shift work

There are numerous types of shift work systems and patterns applied in practice. It is important to note that the length of a shift in such work systems is commonly either eight- or 12-hours (Smith *et al*., 1998). Those shifts that do not coincide with the lengths mentioned above are referred to as irregular shift work systems (Smith *et al*., 1998; Härmä *et al*., 2002). In these systems, workers are expected to work at unconventional shift times (Härmä *et al*., 2002), as is commonly seen with train drivers and in third world countries (Härmä *et al*., 2002).

The different types of shift work systems include day work, permanently-displaced work, rotational shift work and roster work (Åkerstedt, 1998). Day work involves work periods that falls between 07h00 to 19h00 (Åkerstedt, 1998). Workers participating in permanently-displaced work will have a permanent shift, where the starting time and ending time of the shift is fixed and does not alter (Åkerstedt, 1998). If the permanent shift is eight hours in length, the permanent shift can be a morning shift, an afternoon shift or an evening shift, where the starting and ending times are commonly from 06h00 to 14h00, 14h00 to 22h00 and 22h00 to 06h00 respectively (Åkerstedt, 1998, Smith *et al*., 1998). If the permanent shift is 12-hours in length, it can be either a day shift or a night shift, where the starting and ending times are commonly from 06h00 to 18h00 and 18h00 to 06h00 respectively (Smith *et al*., 1998).

A rotational shift work system involves the alteration between shifts (Åkerstedt, 1998, Smith *et al*., 1998). This system can be divided into either a two-shift or a three-shift rotational shift work system (Smith *et al*., 1998). The three-shift system consists of eight-hour shifts and is the rotation between a morning, an afternoon and an evening shift (Åkerstedt, 1998, Smith *et al*., 1998).The two-shift system consists of 12-hour shifts and is the rotation between a day and a night shift (Smith *et al*., 1998). Thus, rotational shift workers will rotate between shifts in a 24-hour cycle where the starting and ending times of these shifts commonly correspond with the starting and ending times mentioned for permanently displaced work (Smith *et al*., 1998). The direction and speed of rotation varies substantially between companies (Åkerstedt, 1998).

The three-shift rotational system uses direction, which can either be clockwise or anti-clockwise. Clockwise refers to shifts rotating from a morning to an afternoon and lastly to an evening shift, after which the cycle starts again (Knauth, 1995; Åkerstedt, 1998). Anti-clockwise refers to the three shifts rotating in the opposite direction (Knauth, 1995; Åkerstedt, 1998). It has frequently been claimed that rotation should occur clockwise as sleep duration increases, sleep quality is improved and work-family conflict is decreased (Barton and Folkard, 1993; Amelsvoort *et al*., 2004). However, there is no solid evidence that sleep or work performance will differ depending on direction of rotation (Knauth, 1995; Åkerstedt, 1998).

Speed of rotation is used for both two- and three-shift rotational shift work systems. This refers to the number of shifts worked consecutively and this frequently differs amongst shift schedules (Knauth, 1995; Åkerstedt, 1998). The speed of rotation can either rotate rapidly (every one, two or three days) or on a weekly basis (Knauth, 1995; Åkerstedt, 1998). Rest days are also be included into the speed of rotation as commonly, rest days are implemented in-between the transition into the next shift (Tucker *et al*., 1999). According to Tucker (1999), rest days incorporated between shifts revealed a decrease in negative consequences associated with shift work. Once again, there is no solid evidence regarding the speed of rotation or the most optimal amount of rest days (Knauth, 1995; Åkerstedt, 1998, Tucker *et al*., 1999).

Finally, roster work is similar to rotating shift work but is less regular, more flexible and less geared to specific teams (Åkerstedt, 1998). In contrast to other shift work systems, roster work is not used in industry but rather service-oriented occupations such as transport, health care and law enforcement (Åkerstedt, 1998).

2.6 MENTAL FATIGUE IN THE WORKPLACE

Fatigue in the workplace has been linked to an imbalance between the intensity, duration and timing of work with recovery time (Dawson *et al*., 2011). This imbalance is often related to working for extended periods and the subsequent inability to sustain the required level of performance on a task (Dawson *et al*., 2011).

Over the past decade, work has changed to a large extent from demanding physical effort to demanding mental effort (Boksem and Tops, 2008). This has resulted in a substantial increase in complaints related to mental fatigue. In the Netherland, half of the women and a third of the men in the working population complained about being mentally fatigued, where 15 years ago only 38% of women and 24% of men complained of being mentally fatigued (Boksem and Tops, 2008). Thirty-eight percentage of the US work force reported being mentally fatigued, where 66% of these workers lost productivity time (Ricci *et al*., 2007). Ricci and colleagues (2007) estimated that lost productivity time from mentally-fatigued workers costs employees in excess of a hundred billion dollars annually.

Mental fatigue experienced in the workplace is a result of working on cognitively demanding tasks for a considerable amount of time (Van der Linden *et al*., 2003). This is not only attributed to working on a singular task, but can extend over different tasks that require mental effort (Van der Linden *et al*., 2003). In industry, many incidents and accidents have been related to mental fatigue as the result of sustained cognitive performance (Baker *et al*., 1994; Van der Linden *et al*., 2003). Mental fatigue has shown to have a profound and negative impact on cognitive functioning (Boksem and Tops, 2008). Van der Linden and colleagues (2006) showed that fatigued participants had difficulties in focusing their attention, planning and adaptively changing strategies in the face of negative outcomes. Boksem *et al*. (2006) found that fatigued participants had difficulties in adequately preparing their responses, in sustaining attention and suffered from increased distractibility. Additionally, fatigued participants corrected their mistakes less often and decision-making was impaired (Boksem and Tops, 2008). According to Van der Linden *et al.* (2003) mental fatigue results in an increased resistance against further effort, increased tendency towards less analytical information processing and changes in mood. According to Lorist *et al*. (2000), mental fatigue affects the cognitive control of behaviour, thus the organisation of actions is impaired.

However, performance on simple or well-learned tasks, which can be executed in an automatic way, can be upheld over long periods of time, after sleep deprivation or after mentally demanding activities (Van der Linden *et al*., 2003). In contrast, complex tasks that require deliberate control of behaviour are generally difficult to perform under such circumstances (Sanders, 1998).

Reduced cognitive functioning is enhanced and amplified via shift work (Dawson *et al*., 2011). This is mainly a result of sleep loss and sleepiness, combined with prolonged work time duration at irregular working times (Dawson *et al*., 2011). Sleepiness and sleep loss are exacerbated during shift work due to the irregular working times which disrupts the circadian rhythm. Sleepiness and sleep loss caused by shift work results in an increase in the amount of accidents and errors in the workplace (Åkerstedt and Lanström, 1998). Furthermore, it has been proven that productivity and quality of work is further decreased with regards to performing shift work (Åkerstedt and Lanström, 1998).

Both functional performance testing and imaging studies such as positron emission tomography (PET) in humans demonstrate that the prefrontal cortex of the brain region is severely affected by sleep loss and sleepiness (Harrison and Horne, 1998; Maquet, 2000; Harrison *et al*., 2007). This negatively affects tasks requiring executive cognitive functions, such as verbal fluency, response inhibition, innovative and flexible thinking and emotional control (Harrison and Horne, 1998; Maquet, 2000; Harrison *et al*., 2007). Additionally, there has been evidence that sleep loss and sleepiness also impacts the hippocampus, resulting in memory and learning being impaired and impacts the motor functioning component of the body (Fenn *et al*., 2003, Patel *et al*., 2007).

Evidence from laboratory studies found that shift work has adverse effects on executive functioning, temporal memory, attention processes and working memory (Harrison and Horne, 1998; Harrison and Horne, 2000; Drummond *et al*., 2001; Kim *et al*., 2001). Data from field and laboratory studies also strongly suggest that disruption of circadian rhythms due to shift work induces deteriorating short-term effects on cognitive performance (Rogers *et al*., 1989; Folkard, 1996). A study conducted by Rouch *et al*. (2005) found that cognitive functioning tends to be impaired by long-term exposure to shift work. Additionally, it has been indicated that neuropsychological performance tends to decrease with the increase in duration of exposure to shift work (Cho, 2001; Rouch *et al*., 2005).

According to a study performed by Meijman (1996), working an eight-hour shift combined with sleep loss resulted in human information processing breaking down, resulting in impairment of cognitive functioning. Meijman (1996) suggested performance could no longer be protected by invested effort. Additionally Meijman (1996) stated that a breakdown in human information processing is a serious sign of mental fatigue.

Thus, cognitive functioning during shift work is not only impaired from mental fatigue from working on cognitively demanding tasks for long duration, but also from sleepiness and sleep loss associated with working irregular hours.

2.7. MECHANISMS OF FATIGUE DURING SHIFT WORK

Fatigue in the workplace can be caused by a variety of factors such as: roster patterns, length of shifts, poor work scheduling and planning, length of time worked, timing of shifts, insufficient recovery time between shifts, long periods of being awake, harsh environmental conditions, type of work being undertaken, inadequate rest breaks, poor quality of sleep, sleep loss, social life, family needs, other employment, travel time and sleep disorders (Harrington, 2001; CAA, 2007; Department of Labour, 2007; WorkSafe Victoria, 2008; Åkerstedt and Wright, 2009; Health and Safety Authority, 2012).

These factors all attribute to fatigue in the work place, however, there are two main factors that attribute to fatigue occurring during shift work: irregular work hours and task-related factors (time-on-task and task-demand).

<u>Irregular work hours</u>

Irregular work hours are experienced during rotational shift work, as workers work throughout the 24-hour day cycle. These hours have been proven to cause sleep loss and sleepiness in the workplace, which have been proven to increase the risk of accidents and errors (Dula *et al*., 2001; Åkerstedt *et al*., 2004). Sleep loss is due to sleeping during the day and sleepiness is attributed to either working throughout the night or insufficient sleep.

Sleepiness and sleep loss have been identified as the major risk factors behind accidents at work and elsewhere and is suspected to cost society up to US$50 billion per year (Åkerstedt *et al*., 2002). The US National Transportation Safety Board estimates 20-30% of all transportation accidents with injury are due to fatigue caused by sleepiness and sleep loss (Åkerstedt *et al*., 2002). Numerous studies have demonstrated high levels of sleepiness during night/evening shifts, as well as during morning shifts; whereas day work is associated with no or marginal sleepiness (Åkerstedt *et al*., 2002). Additionally, the occurrence of involuntary sleep at work has been found in several questionnaire studies and EEG studies (Åkerstedt *et al*., 2002).

Furthermore, it has been well documented that cumulative sleep loss leads to decreased alertness, poor performance and negative mood and that repeatedly changing hours of work disrupts an individual's sleep and circadian rhythm (Dula *et al*., 2001). This is experienced during rotational shift work, where Vidacek *et al*. (1986), found that workers tend to lose one to four hours of sleep each night for approximately three days following shift rotation. Additionally, it is suggested that a number of accidents are due to both reduced sleep and extended work periods (Dula *et al*., 2001).

The sleepiness and sleep loss experienced during rotational shift work amplifies and exacerbates fatigue in the workplace, especially with regards to mental fatigue (Chapter 2.6) (Åkerstedt and Lanström, 1998). Sleepiness and sleep loss is caused by disruption of the circadian rhythm combined with the onset of circadian fatigue discussed above (Åkerstedt and Lanström, 1998). The circadian rhythm becomes disrupted due to extended hours of wakefulness and unfavourable times of day for working.

Sleep loss and sleepiness occurs during night/evening shifts and morning shifts, as workers are expected to work contrary to their natural circadian rhythm (Åkerstedt *et al*., 2002). Night-shift workers are expected to perform at the same levels they would during the daytime, however, the body has down-regulated in order to rest and sleep (Figure 4) (Åkerstedt and Lanström, 1998; Kuhn, 2002; Louw, 2013). This leads to impaired wakefulness (sleepiness) during work hours; which ultimately leads to the negative fatigue consequences associated with shift work (Åkerstedt and Lanström, 1998; Kuhn, 2002). Additionally, the workers on night/evening shift and morning shift are required to sleep during the day (Figure 4). This sleep is fragmented and causes sleep loss; an individual attempts to sleep during the period whereas the homeostatic drive for wakefulness is activated (Åkerstedt and Lanström, 1998; Kuhn, 2002). As sleep loss occurs during the day, it contributes to the sleepiness experienced during the night shift, thus enhancing the fatigue (Åkerstedt and Lanström, 1998; Kuhn, 2002). Thus, disruption of the circadian rhythm amplifies and enhances the fatigue being experienced during shift work.

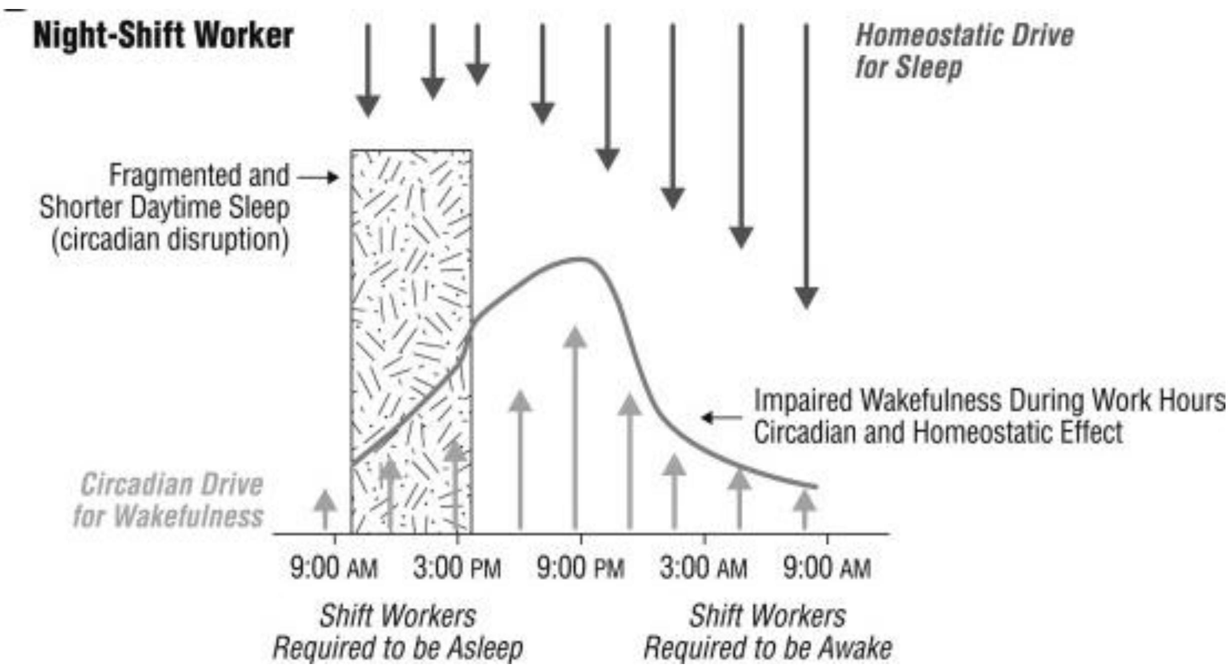

Figure 4: The effect of shift work on the circadian rhythm (Adapted from Wright *et al*., 2013).

<u>Task-related factors</u>

Task-related factors are further broken down into time-on-task and task-demanding factors.

Time-on-task

In the workplace, time-on-task is usually used to refer to time on duty or time into the work shift (Williamson *et al*., 2011). In terms of shift work, time-on-task is also known as task or shift duration (Williamson *et al*., 2011). Time-on-task has a strong correlation with fatigue (Williamson *et al*., 2011). It has been well established that cognitive performance deteriorates over time whilst performing a task in the workplace (Virtanen *et al*., 2008). A cross-sectional study of 248 automotive workers found an association between working time/hours and impaired performance on tests of attention and executive functioning (Virtanen *et al*., 2008). Deterioration in cognitive performance, including impaired grammatical reasoning and alertness, has been found among employees working nine- to 12-hour shifts compared with a traditional eight-hour shift (Macdonald and Benddak, 2000). Virtanen and colleagues (2008) examined cognitive performance in workers working a 40-hour week compared to workers working a 55-hour week. Both vocabulary and reasoning scores were significantly lower for those working a 55-hour week. Additionally Meijman (1996) discovered that, over long periods of working time, memory performance decreases and reaction time and error rate increases. Furthermore, Meijman (1996) suggested that this also results in the breakdown of the human information processing system. In contrast, Todd *et al*. (1991) and Reid *et al*. (1993) found no significant difference for cognitive performance and functioning between eight-hour and 12-hour shifts.

Task-demand

A physically or mentally demanding task results in the onset of fatigue (Louw, 2013). Additionally, boredom, monotony and under-stimulation may also contribute to the onset of fatigue (Louw, 2013). This is explained by the Arousal Theory showed in Figure 5. The inverted-U relationship between performance and arousal, or Arousal Theory, suggests that fatigue will develop in conditions of under-stimulation and low task demand (Grandjean and Kogi, 1975). Associated with this is low performance efficiency, decreased attention and diminished cortical arousal. Hancock and Verwey (1997) argue that high levels of stimulation and high task demand can also bring about fatigue. As revealed in Figure 5, a simple (easy) task will result in higher performance efficiency than a more difficult task, thus a more complex task result in a greater degree of fatigue.

Authors have differing views as to the mechanisms underlying performance decrements in these situations. Some attribute it to the depletion of resources, while others relate it to extended and excessive effort (Louw, 2013). The Arousal Theory has been criticized by many authors in terms of its ability to predict performance impairment (Matthews *et al*., 2000). However, what is important about task demand is that it is a critical factor in the aetiology and evolution of fatigue states.

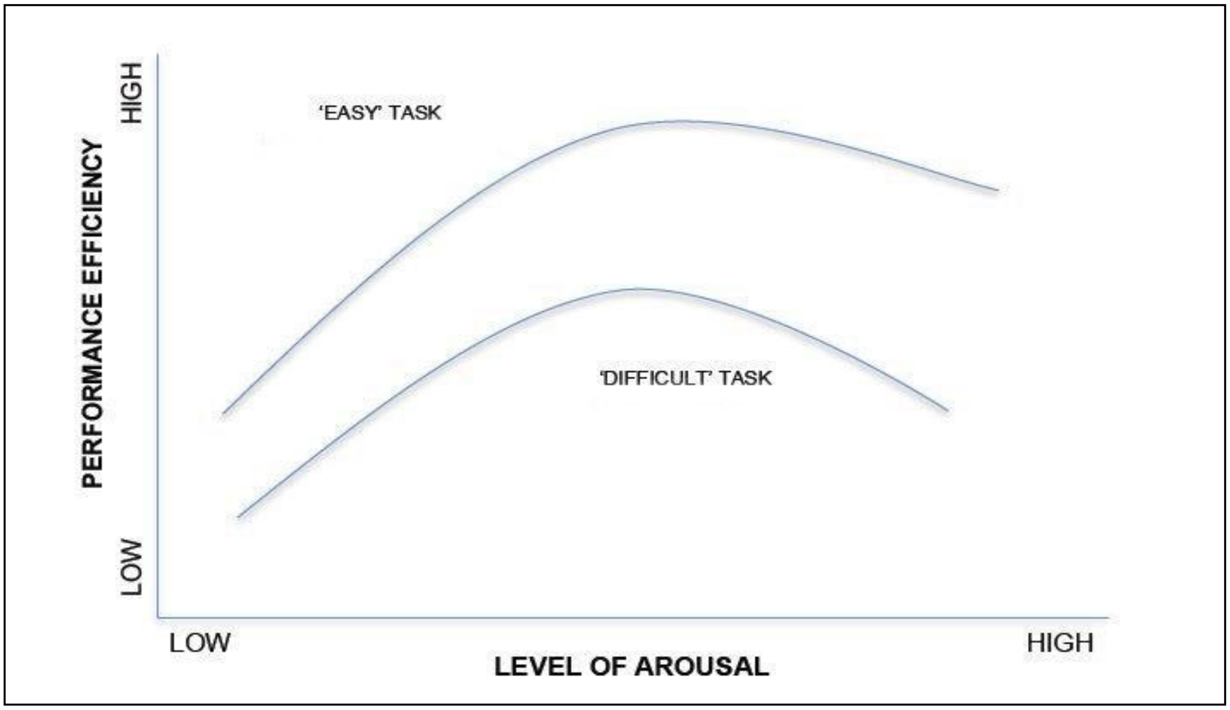

Figure 5: Performance as a function of arousal (Inverted-U/Arousal Theory; adapted from Brown, 1982, pg. 86).

2.8 MEASURING MENTAL FATIGUE

Due to its complex nature, there is no direct assessment tool to measure mental fatigue. For this reason, measuring fatigue has challenged scientists for decades (Aaronson *et al*., 1999). Aaronson *et al*. (1999) suggests that a valid and reliable tool is desperately needed. There are, however, various methods used for assessing mental fatigue. These include: behavioural measures, subjective measures and psycho-physiological measures.

Subjective measure are commonly used to measure fatigue via uni-dimensional rating scales, surveys and questionnaires; however these ratings do not quantify fatigue and are based on the perception of fatigue (Ahsberg *et al*., 2000). Both behavioural measures and psycho-physical measures attempt to quantify fatigue. Psycho-physiological measures include: eye movements, electro-encephalography (EEG), heart rate, heart rate variability, energy expenditure, cerebral blood flow and biochemical changes associated with chronic fatigue states (Akin *et al*., 2008). These measures were excluded from this study as they are not able to isolate where fatigue is occurring during human information processing. Therefore, this project will only focus on behavioural measures of fatigue. This methodology refers to deducing the presence of a fatigue state based on the performance of either a primary or secondary task (Eggemeier *et al*., 1991).

There is general consensus that mental fatigue causes decrements in cognitive performance, which has led to researches using cognitive test tasks in its assessment (Åkerstedt and Lanström, 1998; Lorist *et al*., 2000; Boksem *et al*., 2006; Van der Linden *et al*., 2006; Boksem and Tops, 2008; Dawson *et al*., 2011). A decrease in cognitive performance translates into the increase of mental fatigue. However, according to Hitchcock and Matthews (2005), one cannot assume that loss of performance can be directly attributed to fatigue due to the multi-faceted nature of the phenomenon. Additionally, Hitchcock and Matthews (2005) suggest that fatigue may not result in performance decrements. This theory is supported by Mascord and Heath (1992) and Hockey (1997).

A number of cognitive test tasks have been developed and used to measure cognitive performance. Some of these test tasks will be mentioned in Table I and will be discussed with regards to what they measure instead of what the task is called. This is because some cognitive test tasks measure the same performance parameter, but have different test task names. For instance, a verbal memory test task and an auditory memory test task both measure short-term memory performance.

Table i: Measures commonly used to asses cognitive performance.

Cognitive performance	**Task design**	**Literature**
Simple reaction time	Respond to an expected stimulus as quickly as possible (minimal decision-making is required)	Axelsson *et al*. (1998), Bogdan *et al*. (2008),Cote *et al*. (2009)
Choice/Complex reaction time	A stimulus will be presented where a choice/decision must be made among several possible responses as quickly as possible	Dula *et al.*(2001), Lorist *et al*. (2005), Bogdan *et al*. (2008), Sunshine (2010)
Auditory reaction time	Respond to an auditory stimulus as quickly as possible	Namita *et al*. (2010)
Visual reaction time/Vigilance	Respond to a visual stimulus as quickly as possible	Schweitzer *et al*. (2006),Tyagi *et al*. (2009), Namita *et al*. (2010)
Attention	Performance of a particular mental activity requiring substantial attention over a given time	Hancock and Warm (1989), Schweitzer *et al*. (2006), Bogdan *et al.* (2008), Murtagh *et al*. (2009)
Selective attention	Involves attending to a specific stimulus in the presence of competing stimuli	Downing (2000)
Working memory	Retain spatial information and manipulate remembered items in working memory	Downing (2000), Schweitzer *et al*. (2006), Thompson (2006), Murtagh *et al*. (2009), Tyagi *et al*. (2009)
Short-term memory	Remember either a number of digits, pictures, letters, words, etc. for a short duration, after which the participants must recall	Meijman (1996), Louw (2013), Özdemir *et al.*(2013)
Long-term memory	Remember either a number of digits, pictures, letters, words, etc. for a long duration, after which participants must recall	Özdemir *et al.* (2013)
Motor control	Tap or respond to a randomly presented stimulus as quickly as possible OR perform a test task where movement must be continuously controlled (i.e. driving)	Fletcher and Dawson (2001), Folkard and Tucker (2001), Fenn *et al*. (2003), Boksem *et al*. (2006)
Verbal/Word fluency	Mention as many words as possible from a particular chosen category in a given time	Murzur *et al*. (2002), Schweitzer *et al*. (2006), Murtagh *et al*. (2009)
Grammatical reasoning	Carry out mental operations involving chains of logical reasoning	Schroeder *et al*. (1998), Macdonald and Benddak (2000)
Problem solving and abstract ability	Example of this type of test task consists of sorting tasks as quickly as possible or solving problems	Murzur *et al*. (2002), Van der Linden *et al*. (2003), Schweitzer et al. (2006)

The issue that arises for these cognitive test tasks is that they have not all been validated to measure mental fatigue. Additionally, these test tasks do not isolate where fatigue occurs during human information processing. Numerous cognitive test tasks attempt to isolate a process activated during human information processing by making a cognitive test task specific to one of the processes involved in the chain such as a memory test task or decision-making test task. However other processes in the information-processing system are utilised and activated whilst performing the specific cognitive test task. Thus, performance decrements noted may be due to one of these other processes. For instance, a choice-reaction time test task aims at providing information on the decision-making stage; however, performance decrements in choice reaction time may not be attributed to decision-making, but may be attributed to perception or motor control.

Furthermore, there is an insufficient amount of assessment tools developed to measure mental fatigue. Additionally, there are a number of concerns with these. Firstly, they comprise cognitive test tasks, thus share the same limitations as those discussed above. Secondly, large quantities of these assessment tools are psychological test batteries that are used to measure cognitive functioning in a clinical setting. Thus, these test tasks have not been validated to measure fatigue, but rather psychological performance as is the case with the Automated Neuropsychological Assessment Metrics (ANAM) (Reeves *et al*., 1993). The ANAM consists of 22 sub-tests that provide information on attention, concentration, memory, simple reaction time, processing speed, decision-making and executive functioning (Reeves *et al*., 1993). Lastly, numerous assessment tools claim to be analysing a specific process in the human information processing chain such as the Wechsler Memory Scale-Revised (WMSR) (D'Elia *et al*., 1989). The WMSR is an advanced memory tool which consists of 13 sub-tests (D'Elia *et al*., 1989). This tool has been used to measure fatigue of short-term memory; however, fatiguing effects noted may be attributed to other processes activated during human information processing. Thus, these inferences are not accurate.

Lastly, inferences from a laboratory setting regarding mental fatigue via cognitive test task performance are commonly applied to actual real-life shift work settings. According to Harrison and List (2004), laboratory experimentations in isolation are necessarily limited in relevance for predicting field behaviour. By contrast, Lieberman *et al*. (2006) revealed that cognitive performance in a laboratory setting produces similar results in a field-based setting. However, Schweitzer *et al*. (2006) found that the statistical power of data in a field-based study was reduced compared to a controlled laboratory setting where performance and alertness was examined with regards to shift work. According to Waggoner *et al*, (2012), field and laboratory investigations should not be tested in isolation, but rather in combination in order to bridge the gap between the realism of shift work and the control of laboratory performance testing. This has proved to be a useful approach for addressing the relationship between shift work-induced fatigue and task performance (Waggoner *et al*., 2012). According to Kantermann *et al*. (2010), all instruments and tests that are used in the field should be developed and validated in controlled laboratory experiments to ensure their reliability.

2.9 SOUTH AFRICAN CONTEXT

Shift work has increased globally in the last decade and has increased substantially in developing countries, where it is most prevalent in low socio-economic work groups (Bambra *et al*., 2008). These work groups generally live in under-developed urban areas known as townships or locations (Co-operative Governance and Traditional Affairs, 2009). These workers are not only exposed to the negative consequences associated with fatigue occurring during shift work, but also have to manage the difficulties of living in a developing country.

Workers living in townships are required to travel long distances to work (Ong and Blumenberg, 1998; Bookwalter and Dalenberg, 2002), either walking or making use of public transportation (Ong and Blumenberg, 1998). Workers will travel up to two hours to get to work (Ong and Blumenberg, 1998). Furthermore, dwellings are extremely close together in townships, which lead to workers' sleep being continuously disrupted (Bookwalter and Dalenberg, 2002). These factors contribute to the onset of fatigue in shift workers as they do not get sufficient sleep, resulting in increased sleep loss and sleepiness which leads to decrements in performance and impaired alertness.

It is important to note that working conditions in South Africa are well below international standards and contributes to the onset of fatigue as workers expend unnecessary energy (Jafray and O'Neill, 2000; Goswami *et al*., 2005). Additionally, the majority of shift workers are uneducated and computer illiterate (Modisaotsile, 2012).

CHAPTER 3

EXPERIMENTAL CONCEPT

3.1 INTRODUCTION

Mental fatigue has been shown to be highly prevalent in the workplace, especially with regards to rotational shift work due to cumulative sleep loss and sleepiness, where decrements in cognitive performance, ability and functioning have been noted (Van der Linden *et al*., 2006; Boksem and Tops, 2008). The negative consequences associated with mental fatigue in the workplace are heightened during shift work due to the combination of irregular working hours, disrupted circadian rhythm, long working hours and excessive task demand (Dula *et al*., 2001; Åkerstedt *et al*., 2004; Shen *et al*., 2006; Ellingsen *et al*., 2007 Dawson *et al*., 2011). Therefore, reducing or preventing mental fatigue in the workplace whilst performing rotational shift work is vitally important.

In order to reduce or prevent mental fatigue, this phenomenon needs to measurable and quantifiable. However, there is no creditable behavioural assessment tool available to measure mental fatigue applied to shift work (Aaronson *et al*., 1999; Hitchcock and Matthews, 2005; Louw, 2013). It is well established that cognitive test tasks are used to measure mental fatigue (Ahsberg *et al*., 2000; Dula *et al*., 2001; Murzur *et al*., 2002; Fenn *et al*., 2003; Van der Linden *et al*., 2003; Boksem *et al*., 2006; Van der Linden *et al*., 2006; Bogdan *et al*., 2008; Babenko and Ermakov, 2008; Tyagi *et al*., 2009). However, there are some concerns regarding these test tasks. Firstly, not all of them have been validated to measure mental fatigue. Secondly, the cognitive test tasks used to measure mental fatigue do not isolate where fatigue is occurring during human information processing. Lastly, inferences regarding mental fatigue in a simulated laboratory setting have been applied to real-life situations despite the literature stating its irrelevance.

According to the Resource Theory, in order to process information effectively, each stage activated during human information processing needs to be completed efficiently.

In order for this to occur, resources need to be utilised in each process, as these allow for the performance on a task (Wickens, 1984; Staal, 2004; Matthews *et al*., 2010). The depletion of these resources results in the onset of fatigue (Bridger, 2003; Warm *et al*., 2008). Additionally, there may be different resources utilised for the different stages of human information processing (Wickens, 2002). Therefore fatigue of one stage does not necessarily suggest fatigue of the entire processing chain (Wickens, 2002). It must be noted that each stage requires numerous cognitive functions in order to process information. Thus, fatigue being experienced within a stage can be due to either a single cognitive function or multiple cognitive functions being fatigued. Thus, it is imperative to attempt to isolate the individual cognitive functions within each stage of the human information processing chain in order to determine where fatigue is occurring and to broaden our understanding regarding the topic.

3.2 EXPERIMENTAL CONCEPT

The aim of this project was to validate an assessment tool for mental fatigue applied to rotational shift work, where it will comprise various cognitive test tasks intended to isolate numerous cognitive functions activated during human information processing in order to identify where fatigue is occurring within the processing chain.

According to Kantermann *et al*. (2010), all instruments and tests that are used in the field should be validated in controlled laboratory experiments to ensure their reliability. Therefore, this project was split into two phases: Phase 1 and Phase 2.

In Phase 1, numerous cognitive test tasks isolating specific cognitive functions activated during human information processing were validated for mental fatigue in a simulated shift work laboratory setting. The general task-related effects of these test tasks were also examined. Cognitive test tasks revealing significant fatiguing effects due to simulated shift work comprised an assessment tool.

In Phase 2 the validated assessment tool from Phase 1 was validated for mental fatigue in a field-based setting. The validation occurred at three different companies where each participated in a different form of rotational shift work. Parameters of the cognitive test tasks revealing significant fatiguing effects in the field-based study were validated for measuring mental fatigue occurring during rotational shift work and were included into the final assessment tool.

This chapter will discuss the methods behind isolating the processes activated during human information processing and the cognitive test tasks; the equipment and experimental set-up. The results and discussion of Phase 1 and 2 will be discussed in Chapters 4 and 5, respectively.

3.3 ISOLATION OF COGNITIVE FUNCTIONS

Cognitive test tasks used to assess mental fatigue do not isolate where fatigue is occurring during human information processing. These cognitive test tasks apply emphasis to a particular process such as a memory test task, but the other processes activated in human information processing are still activated and contribute to test task performance. Thus, inferences of these results may not be attributed to the process under investigation. Therefore, it is imperative to isolate these processes.

There are four core stages in the human information processing chain: short-term sensory store, perception, decision-making/response selection and response execution/motor control. These stages require various cognitive functions in order to function. For instance, during the response execution stage numerous cognitive functions are activated and are required in order to process information such as motor programming, peripheral neural control, motor control, etc. Thus, when attempting to isolate the stages of information processing, the cognitive functions are the aspects that need to be isolated. If not, then the interpretation of the results will not isolate where exactly fatigue is occurring as numerous cognitive functions are being utilised and activated during one stage of information processing.

Isolating cognitive functions is achieved by constructing two versions of the same test {i.e. Task 1 (simple) and Task 2 (complex) in Figure 6}, where both tests are the same, except for a specific difference that affects the demand of a single cognitive function within the human information processing chain. The performance difference between both versions tested will then exclusively reflect the impact of the changed demand of this single cognitive function (complex minus simple conditions). Effects occurring in other cognitive functions will affect both test versions in the same way and thus do not contribute to the difference between both test versions. This allows isolation of the performance of a specific cognitive function from the performance of all other cognitive functions involved. This approach was developed at the Human Kinetics and Ergonomic department at Rhodes University and is called the ‘Differential Approach’.

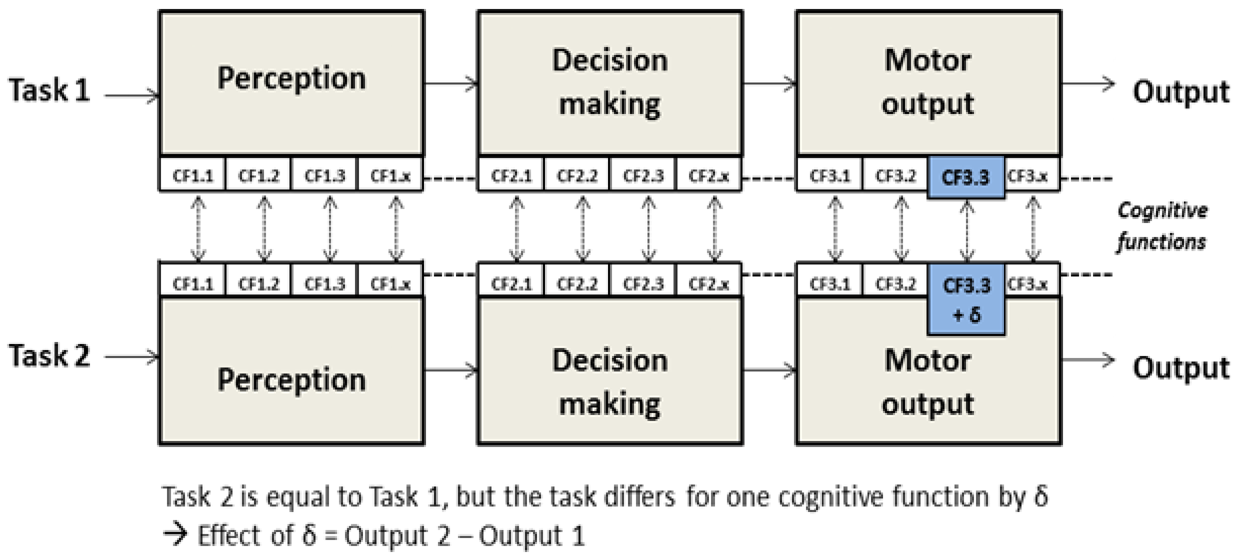

Figure 6: Basic concept of the Differential Approach, applied to the human information processing system (Human Kinetics and Ergonomics Department; 2013).

In order to reveal whether a fatiguing effect is occurring for a particular test task, the difference between the two tests, i.e. levels of difficulty of a particular test task will be analysed. If the difference between these two levels increases over time then the cognitive function is fatiguing (Figure 7), as the complex condition (increased demand of a particular aspect of the test task) deteriorates over time, whereas the simple condition should remain fairly constant over time (Sanders, 1998; Van der Linden *et al*., 2003).

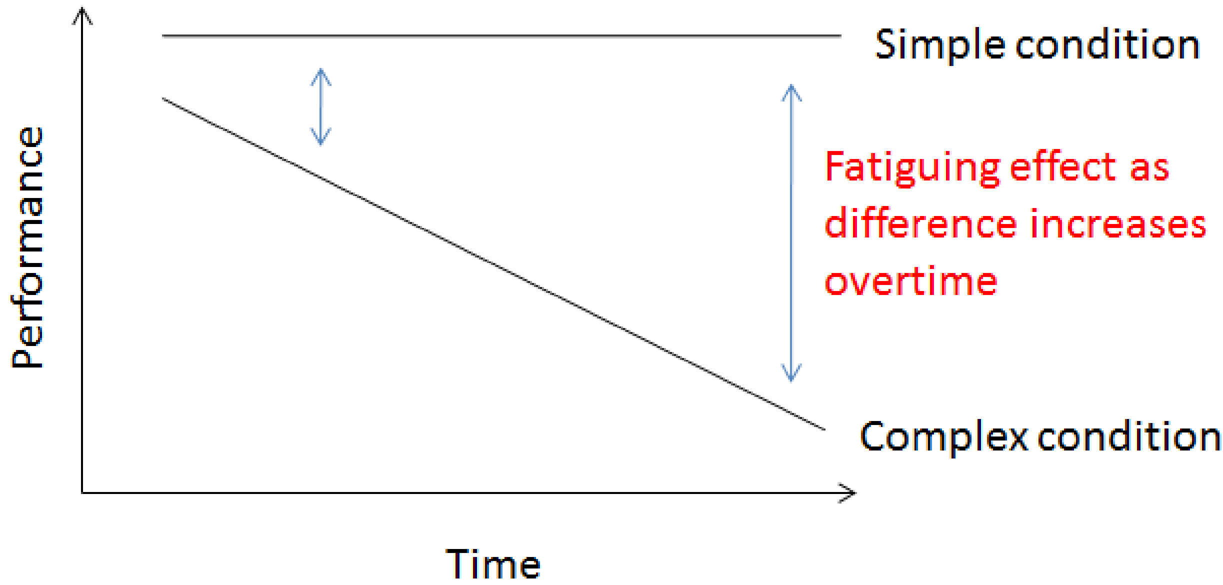

Figure 7: Identifying the fatiguing effect using the Differential Approach.

Therefore, the complex condition will be subtracted from the simple condition in order to isolate the particular cognitive function under investigation. This will result in a singular line presented on a graph. The trend of the line will determine whether a fatiguing effect is present or not. A trend that does not change over time suggests no fatigue is occurring, as the difference between the simple and complex conditions remains the same over time. However, a trend that significantly changes over time will either represent fatigue occurring or an improvement in performance over time. This depends on whether the difference between the two levels of difficulty increased (fatiguing) or decreased (improving) over time. The slope of the fatiguing trend line is dependent on the parameter under investigation. This will be discussed in Chapter 3.5 after the explanations of each cognitive function.

3.4 COGNITIVE FUNCTIONS AND TASK-RELATED EFFECTS

The Human Kinetics and Ergonomics department at Rhodes University has developed numerous cognitive tests tasks which isolate various cognitive functions activated during human information processing (Figure 8). Thus, each test task was tested at two levels of difficulty in order to apply the Differential Approach. It must be noted that not all cognitive functions activated during human information processing have been isolated. This is due to test tasks not being developed yet. Additionally, general task-related effects can be examined for these cognitive test tasks. This is the most common method for analysing cognitive performance. Task-related effects of cognitive test tasks do not isolate cognitive functions, thus these effects provide information regarding the entire information processing chain. The cognitive test tasks will be discussed below, where the isolated cognitive functions and task-related effects will be mentioned.

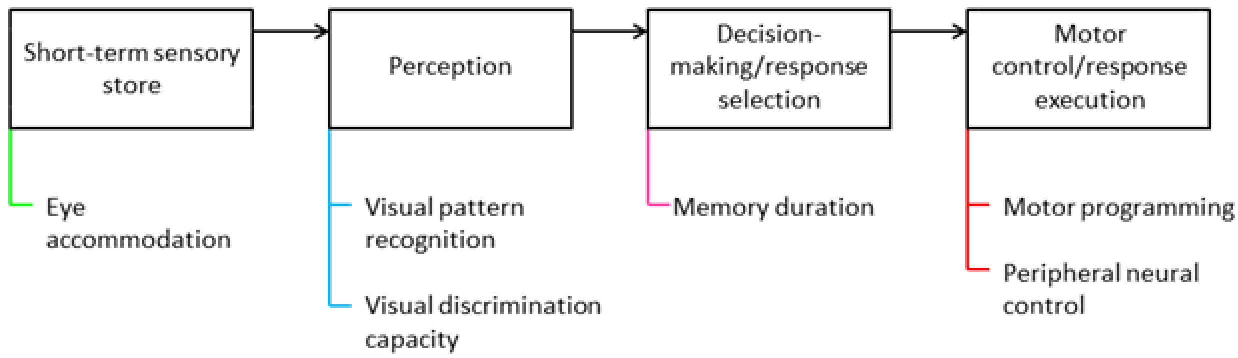

Figure 8: The cognitive functions isolated during human information processing via the Differential Approach.

3.4.1 Accommodation test task

The accommodation test task measures human eye accommodation by alteration of the viewing distance during the test task. This test task required participants to respond to a stimulus presented 50cm away (near) and 3m away (far). This consisted of a white square, where a black dot was presented either on the right hand side of the square or on the left-hand side of the square. On presentation of the stimulus, participants were required to click the corresponding button on the mouse. The simple condition consisted of participants responding to a stimulus, where the previous one presented was the same distance away from the participants (near vs. near; far vs. far). The complex condition consisted of participants responding to a stimulus where the previous one presented was not the same distance away from the participant (near vs. far; far vs. near).

The cognitive function isolated for this test task was eye accommodation. This is utilised during the short-term sensory store stage of human information processing. This cognitive function was isolated as the only aspect that changes between the simple condition (near vs. near; far vs. far) and complex condition (near vs. far; far vs. near) was the accommodation of the eye. Therefore, other cognitive functions activated during human information processing remain the same for both levels of difficulty. Two parameters were measured for eye accommodation: eye accommodation time [s] (speed) and error rate for eye accommodation [%] (quality).

The task-related effect of this test task was choice reaction time, as participants were required to choose a motor response according to the stimulus presented. Only the simple condition was analysed in order to eliminate the effects of eye accommodation. Both reaction time [s] (speed) and error rate [%] (quality) will be examined for choice reaction time.

3.4.2 Visual detection test task

The visual detection test task measures visual discrimination by altering the amount of distractions presented in the environment. This test task required participants to identify a single moving red dot amongst numerous moving white dots by clicking the right-hand side button on a computer mouse. The simple condition required participants to identify the moving red dot amongst 40 moving white dots and the complex condition required participants to identify the moving red dot amongst 80 moving white dots. The red dot appeared randomly, where participants were required to respond as quickly as possible.

The cognitive function isolated via the visual detection test task was visual discrimination. This is activated during the perceptual process of human information processing. It occurred as only the discrimination factor was changed for both levels of difficulties (40 dots vs. 80 dots), thus being able to discriminate between the white dot and the single red dot became more challenging as the degree of difficulty increased. All other cognitive functions activated during human information processing remained constant for both levels of difficulty. This test task analysed the processing time [s] (speed), error rate [%] (quality) and impact of detection workload on tunnel view [Δr] for visual discrimination. Tunnel view, also known as tunnel vision, is the loss of peripheral vision with retention of central vision, resulting in a constricted tunnel-like field of vision.

The task-related effect analysed for this test task was visual detection, as participants were required to detect the single moving red dot amongst the numerous moving white dots. The average of the simple and complex conditions was examined. The average was chosen as the two levels of difficulty were similar in nature. Additionally, this was to ensure a more robust analysis, as more samples would be taken under consideration, especially as the duration of this test task was short (45 seconds). Three parameters were measured for this test task: reaction time [s] (speed), error rate [%] (quality) and tunnel view index [Δr] for visual detection.

3.4.3 Reading test task

The reading test task measures visual pattern recognition by changing the demand on pattern recognition. This test task required participants to read a text in both high and low resolution. Spelling errors in the form of double letters (i.e. saafe) were inserted into the text.

The cognitive function isolated by this test task was visual pattern recognition which is utilised during the perceptual stage of human information processing. The isolation of this cognitive function occurs as only the resolution of the texts changes between the simple and complex conditions. Thus, the other cognitive functions activated during human information processing do not alter for both levels of difficulty. Processing time [words/min] (speed) and error rate [%] (quality) for visual patter recognition were analysed.

The task-related effect for this test task was reading performance. Only the high resolution reading text was analysed, Low resolution was excluded from analysis as visual recognition was compromised, thus not giving a clear indication on reading performance. Two parameters were measured with regards to reading performance: reading speed [words/min] and error rate [%] (quality).

3.4.4 Memory test task

The memory test task measures memory duration by changing the duration of rehearsal time. This test task required participants to remember and recall a number of digits presented to them on a computer screen. Participants in Phase 1 were required to remember seven numbers, where the participants in Phase 2 were required to remember five numbers. In the laboratory-based study, participants were required to remember seven numbers, as humans are able to recall numbers in chunks below six extremely easily, beyond seven is deemed challenging (Mueller, 2010). However, when seven numbers were tested in the field, the participants found it too challenging and could not complete the test task, causing a misrepresentation of the test task. This was mainly due to the level of education (students vs. lower socio-economic work group). Thus, the amount of numbers participants needed to remember in the field-based study was set to five. The difference between the two levels of difficulty was the waiting period before recalling the digits. For the simple condition, the waiting period was two seconds and for the complex condition the waiting period was four seconds. As the waiting period was different for the two levels of difficulty, the rehearsal time varied. The rehearsal time was longer for the complex condition compared to the simple condition.

The cognitive function isolated via the memory test task was memory duration. This is activated during the decision-making stage of human information processing. Memory duration was isolated, as the only aspect of the test task that changed between the simple and complex conditions was the waiting period. Thus, only the duration demand of memorisation was changed. All other cognitive functions activated during human information processing were kept constant for both levels of difficulty. The impact of rehearsal time on memory recall rate was analysed [%].

The task-related effect analysed was short-term memory performance. The average of the simple and complex conditions was examined. This was to ensure a more robust analysis, as more samples would be taken under consideration. This was possible, as the structure of both levels of difficulty remained the same. Recall rate [%] for short-term memory was analysed.

3.4.5 Tapping test task

The tapping test task measured motor programming by examining both predictable and non-predictable target locations. The tapping test task required participants to respond by touching a round stimulus presented on a touch screen. The simple and complex conditions were embedded into one single test task. The stimulus was presented in the middle of the screen for the simple condition and presented anywhere on the screen for the complex condition. Additionally, the round stimulus was either large (low-precision) or small in size (high-precision).

The cognitive function isolated by this test task was motor programming which is activated during the motor control stage of human information processing. This cognitive function was isolated, as the only difference between the simple and complex condition was the motor programming of the arm movement, all other human information processing components remained the same. Motor programming time for both high and low precision [s] was analysed for this test task.

The task-related effect analysed was motor control. This was examined as participants were controlling their motor functioning in order to respond to the presented stimuli. Only the complex condition was analysed. The simple condition was excluded as the presentation of the stimuli was predictable and too similar to the simple reaction time test task discussed below. Reaction time for motor control [s] was analysed.

3.4.6 Neural control test tasks

The neural control test task measured peripheral neural control by altering movement sensitivity. Two neural control test tasks will be discussed: driving simulator test task and neural control test task.

The driving simulator test task was a simple driving task, where the participants were required to drive on a curving road displayed on a computer screen. The aim of this test task was to stay as close as possible to the white line in the centre of the road. The steering wheel was set at two levels of sensitivity; high and low.

The neural control test task required participants to respond to a round stimulus presented on a computer screen by moving the cursor of a computer mouse onto the stimulus and clicking the right-hand side button. The computer mouse was set at two levels of sensitivity: high and low.

For both the driving simulator and neural control test tasks, the cognitive function isolated was peripheral neural control which is activated during the motor control stage of human information processing. This cognitive function was isolated as only the level of sensitivity was altered between the two complexities. All other cognitive functions activated during information processing were kept constant for both levels of difficulty. The impact of movement sensitivity on reaction time for peripheral neural control [s] was analysed.

For the driving simulator test task, the task-related effect was tracking performance, as participants were required to stay as close as possible to the white line presented on the road. The average of the simple and complex conditions was analysed, as the two levels of difficulty were similar in nature and this allowed for a greater number of samples, especially due to the short duration of testing (one minute). Reaction time for tracking performance [s] was measured.

The task-related effect for the neural control test task was motor control. This was not analysed as it was being investigated via the task-related effect of the tapping test task.

It must be noted that the results from the driving simulator test task in Phase 1 were inconclusive due to the amount of excluded and variable data. This was the result of driving inexperience coupled with high sensitivity of the steering wheel and falling asleep during testing. Thus, the neural control test task was developed in order to examine peripheral neural control in a field-based setting. The neural control test task was simpler to learn and complete, especially as the sample tested in Phase 2 were inexperienced drivers and uneducated.

A pilot test was performed on the neural control test task before being taken into Phase 2 on three participants at a security company in Grahamstown, where testing took place before and after work on one eight-hour day shift. The impact of movement sensitivity demands on reaction time for peripheral neural control was worse after work compared to before work (Figure 9). Even though there was a limited sample, this test task seemed to be sensitive to fatigue experienced in the workplace and thus this test task would be examined into Phase 2.

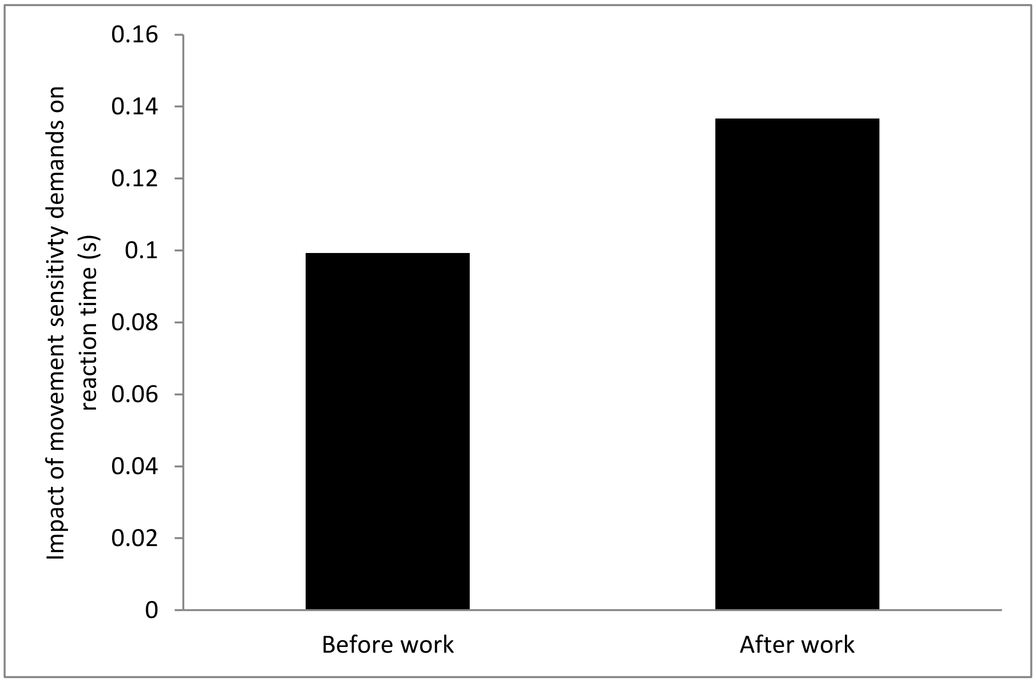

Figure 9: Impact of movement sensitivity demands on reaction time for peripheral neural control before and after work on a one eight-hour day shift.

3.4.7 Simple reaction time test task

This test task was included into testing as it is a common tool used to assess mental fatigue occurring during shift work. Participants were required to respond to a large round stimulus presented in the middle of a computer screen by clicking the right button on a computer mouse. This test task was only tested at one level of difficulty, thus only the task-related effect was analysed which consisted of simple neural reflex (motor control), where simple reaction time [s] was measured.

3.4.8 Summary

Table ii: Summary of cognitive test tasks assessed and corresponding isolated cognitive functions and general task-related effects.

	Cognitive functions	**Task-related effects**
Accommodation test task	Eye accommodation	Choice-reaction time
Visual detection test task	Visual discrimination	Visual detection
Reading test task	Visual pattern recognition	Reading performance
Memory test task	Memory duration	Short-term memory
Tapping test task	Motor programming	Motor control
Driving simulator test task	Peripheral neural control	Tracking performance
Neural control test task	Peripheral neural control	
Simple reaction time test task		Simple reaction time

3.5 FATIGUING EFFECTS

In order to isolate the cognitive functions, the simple conditions had to be subtracted from the complex ones (complex minus simple). Performance values of complex conditions are generally lower than those of simple conditions. If fatigue occurs, the performance values will decline over time for complex conditions, where the values for simple conditions will remain fairly constant. Thus, when these high constant values were subtracted from the low declining values, a decreasing trend was present (Figure 10). Thus, if fatigue is present in the following parameters, the trend would decrease over time: processing time and error rate for visual pattern recognition, impact of detection workload on tunnel view and memory duration.

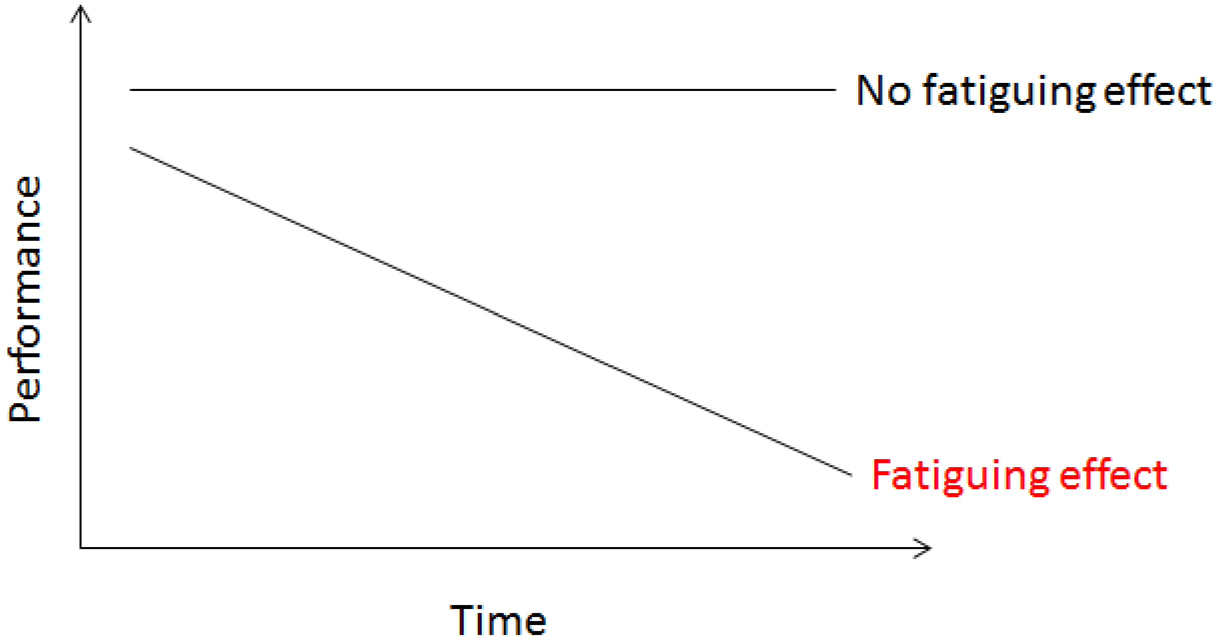

Figure 10: Fatiguing effect and non-fatiguing effect for the following cognitive functions: processing time and error rate for visual pattern recognition, impact of detection workload on tunnel view and memory duration.

For some cognitive functions, the performance values of the complex condition and simple condition act inversely. For instance, reaction time values are worse for a complex condition compared to a simple condition. These slower times resulted in a higher value compared to the simple condition. Thus, if fatigue occurred the values would get higher over time for the complex condition (worse), where the values for the simple condition would remain fairly constant. Thus, when subtracting these low constant values from the high inclining values, an increasing trend was present. If fatigue was present in the following parameters over time, the trend would increase: eye accommodation time, error rate of eye accommodation, motor programming time, impact of movement sensitivity on reaction time for peripheral neural control, processing time and error rate of visual discrimination.

3.6 EQUIPMENT AND EXPERIMENTAL SET-UP

This section examines the equipment and experimental set-up required for each individual cognitive test task examined. All cognitive test tasks assessed in this project were designed within the Human Kinetic and Ergonomics department at Rhodes University and were performed on the in-house developed software.

3.6.1 Accommodation test task

The white square was 4mm x 4mm in dimension and the stimulus was presented between 100ms to 300ms after the previous response. The simple and complex condition was embedded into one single test task of 120 seconds in duration. In order for accommodation of the eye to occur, vision must switch from near to far and vice versa. To facilitate this during the accommodation test task the stimulus was presented near (50cm) and far away (3m). Half of the screen was covered on the laptop and on the projector in order to make one screen (half being near, half being far). The presentation of the stimulus was random but was equally distributed amongst the simple and complex conditions. This was also the case for the presentation of the dot on the stimulus.

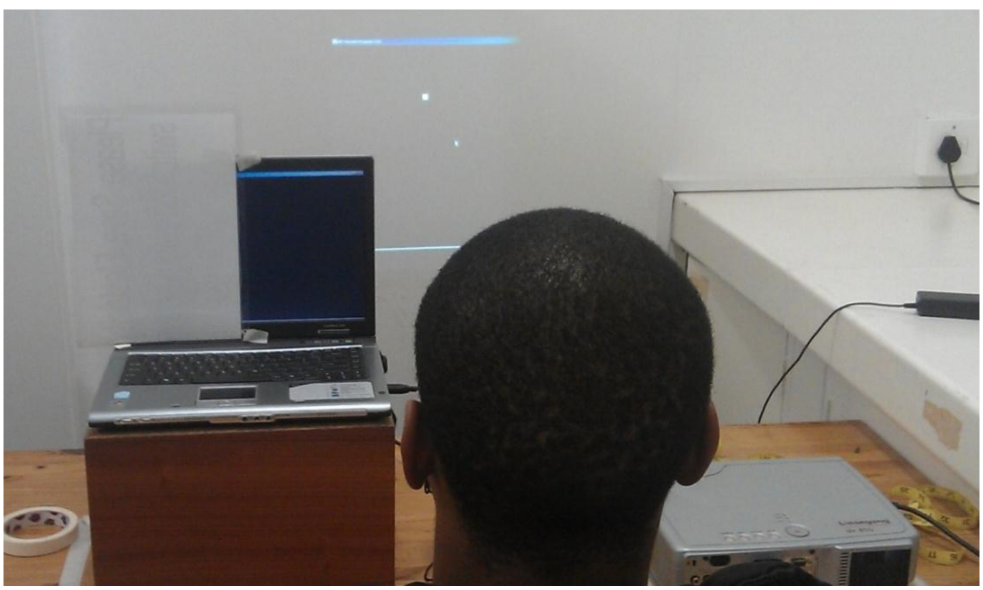

Figure 11: Accommodation test task conducted in this study.

3.6.2 Visual detection test task

The moving red dot and white dots were 2mm in size and moved at a speed of 50mm per second. Each level of difficulty was tested for 45 seconds, where testing occurred on a large computer screen (550mm X 300mm) in order to examine tunnel view. This was important as tunnel vision is the loss of peripheral vision with retention of central vision.

Figure 12: Visual detection test task conducted in the study.

3.6.3 Reading test task

The high resolution reading text was set at 300 dpi where the low resolution reading text was set at 60dpi (Appendix B3). Participants were required to identify the spelling errors inserted into the texts by circling the error with a pen. One error was inserted within every 20 words. Each level of difficulty was tested for 90 seconds. The reading texts used for this test task were newspaper articles which were chosen as they are designed to be read by all types of individuals with different interests and expertise.

In the laboratory-based study, the texts used were only in English, as all participants were fluent in English. However, in the field-based study, the texts were offered in four languages: English, Afrikaans, Zulu and Xhosa. South Africa has eleven official languages, of which these are the four most common. This was to ensure that all workers participating in the field-based study were able to complete the test task efficiently and accurately, with no added pressure from not understanding the language or being able to identify the errors. Additionally, all texts used during testing were permutated between the testing sessions. This was to eliminate any effects due to easy or difficult newspaper articles.

Figure 13: Reading test task conducted in this study.

3.6.4 Memory test task

The memory test task was a modified version of digit span memory task, which forms part of the PEBL psychological test battery (Meuller, 2010). For both levels of difficulty, the participants were required to remember and recall, via a computer keyboard, a number of digits displayed to them on a computer screen. The numbers appeared on the computer screen one at a time. Once all the numbers had appeared, the participants were required to wait, after which a line would appear on the screen, where participants recalled the numbers by typing on a keyboard. Once these had been inserted, the participants were required to press the enter key, after which the next numbers would appear.

The duration of the simple condition was 60 seconds and the complex condition was 90 seconds. The complex condition continued for longer, as the waiting time was longer.

This was to ensure the same amount of remembered and recalled numbers was evenly distributed for both conditions.

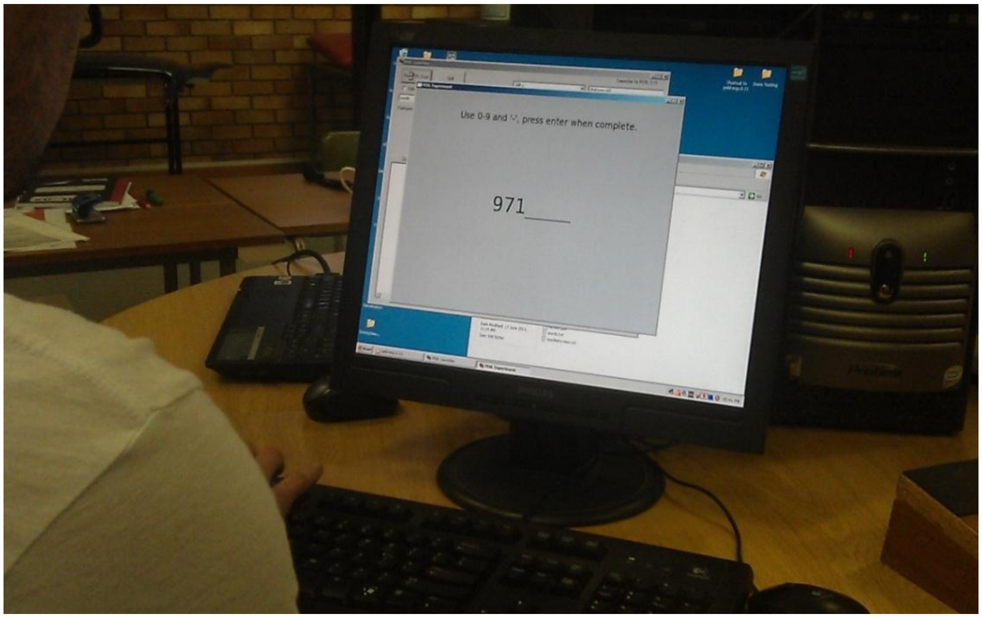

Figure 14: Memory test task conducted in this study.

3.6.5 Tapping test task

The small round stimulus was 12mm in diameter and the large round stimulus was 24mm. The two levels of difficulty were embedded into one single test task, of 90 seconds in duration. The complex and simple condition and the two dot sizes alternated between each stimulus in order to equally distribute the level of difficulty and dot size. The presentation of each stimulus occurred between 250ms and 500ms after the previous response. Participants were required to use their dominant hand throughout testing. The touch screen was calibrated before each testing to ensure the accuracy of data throughout testing.

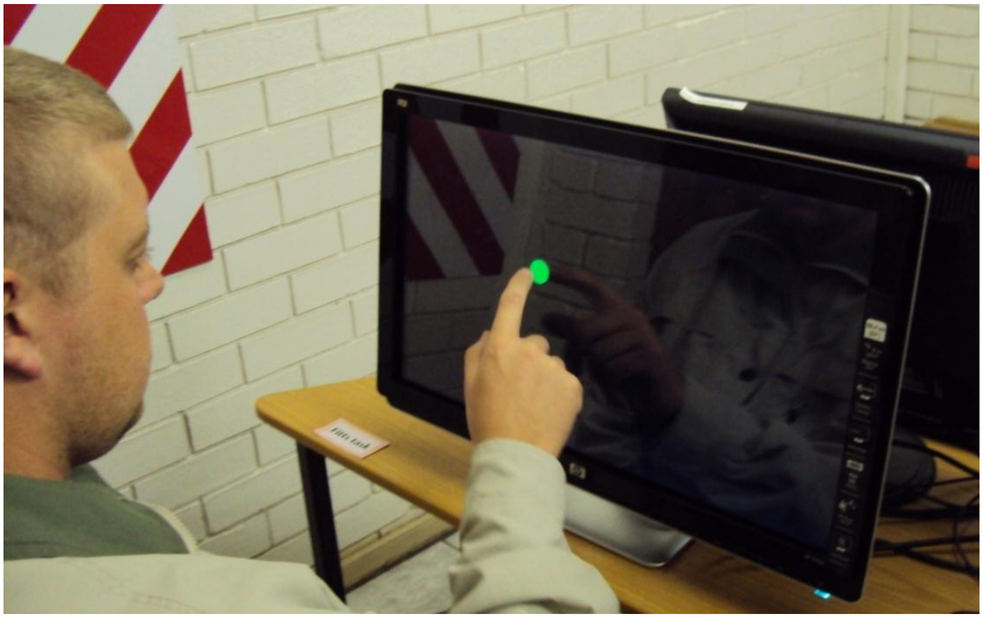

Figure 15: Tapping test task conducted in the study.

3.6.6 Driving simulator test task

This was a simple driving task, where the steering wheel was set at two levels of sensitivity. The duration for each level of difficulty (high vs. low sensitivity) was 60 seconds.

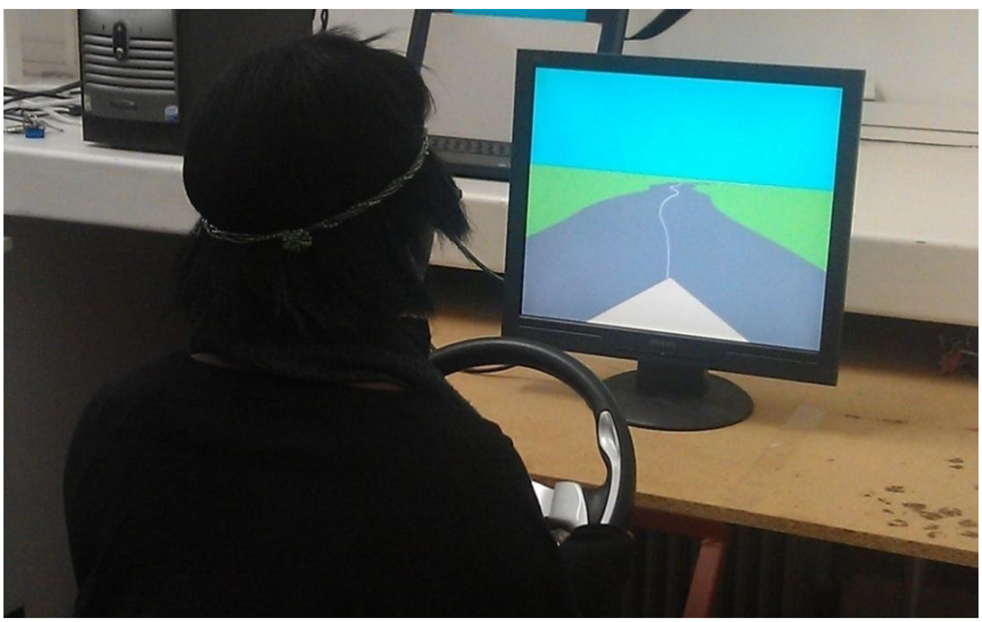

Figure 16: Driving simulator test task conducted in this study.

3.6.7 Neural control test task

The round stimulus varied in size, as the index of difficulty was set at four. Thus, if the stimulus was presented close to the previous one, the stimulus was small in size, but if it was presented far away from the previous one, the stimulus was large in size. This allowed for reaction time to be constant between stimuli, as an individual would respond at the same speed for the large stimuli far away (fast as large surface area of stimulus) as for the small stimuli close to the cursor (slow as small surface area of stimulus). The presentation of the stimulus was 250ms to 500ms after the previous response. The duration for each level of difficulty was 60 seconds.

Figure 17: Neural control test task conducted in this study.

3.6.8 Simple reaction time test task

The round stimulus was 5cm in size, where the presentation of the stimulus occurred 500ms to 1500ms after the previous response. This test task was 20 seconds in duration.

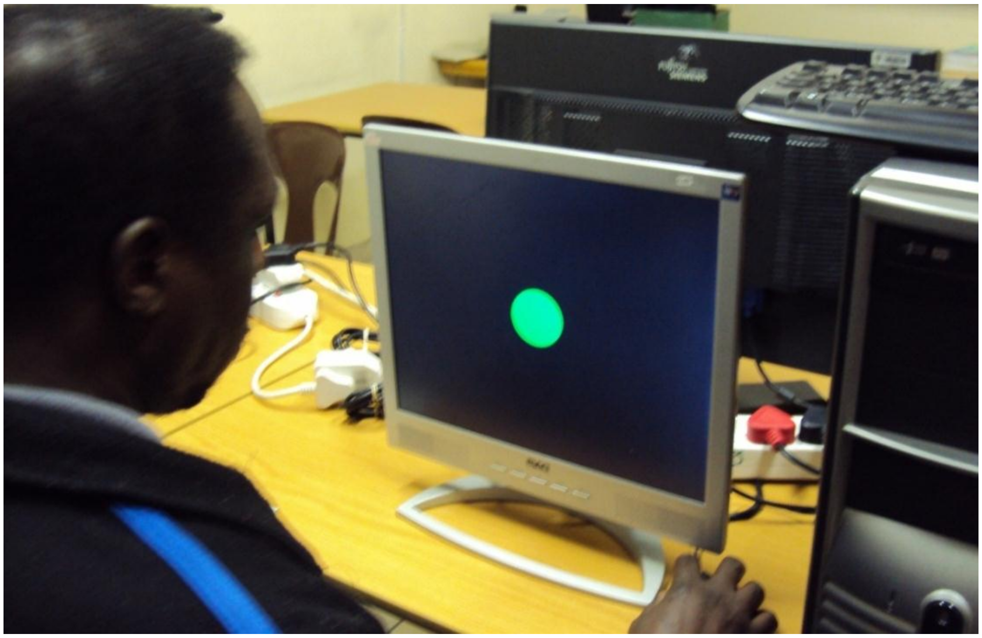

Figure 18: Simple reaction time test task conducted in this study.

Throughout all tests, participants were required to sit 50cm – 60cm away from the computer screens used during testing and have their eye in line with the top of the screen (Ankrum, 1996; Sommerich *et al*., 2000). This follows the ergonomical set-up of a workplace and ensures posture and eye strain are controlled throughout the testing sessions (Ankrum, 1996; Sommerich *et al*., 2000). Additionally, all test tasks using reaction time or processing time analysed the median values, as these values are more robust and eliminate outliers.

CHAPTER 4

PHASE 1

4.1 INTRODUCTION

The aim of Phase 1 was to assess various cognitive test tasks in a simulated shift work laboratory setting. Each test task was examined at two levels of difficulty in order to apply the Differential Approach which provides information on a specific cognitive function activated during human information processing. The analysis of each cognitive test task also provides information on the general task-related effect. Cognitive functions and task-related effects revealing significant fatiguing effects and shift work-related effects comprised an assessment tool which was validated in a rotational shift work field-based setting in Phase 2. This chapter will explain the methodology undertaken in Phase 1. After which the results of this phase will be analysed and discussed.

4.2 METHODOLOGY

4.2.1 Experimental design

Cognitive test tasks were evaluated in a simulated shift work laboratory setting at Rhodes University, where each provided information on a particular cognitive function and task-related effect (refer to Chapter 3 for more information). These cognitive test tasks were applied to four different types of shift work regimes, with the main focus on night shift work. One of the shift work regimes was a standard eight-hour rotational shift work system and the additional three shift work regimes were non-conventional systems. The duration of each shift for the unconventional shift work system was eight hours in length.

Each shift work regime consisted of one standard day shift followed by four night shifts. Participants were required to perform the cognitive test tasks before and after each shift. Additionally, the cognitive test tasks were tested four times within each shift (equally distributed across each shift). Thus, six testing session were performed per shift. Rest breaks were added into each shift every two hours, where participants were offered food and beverages. The food and beverage were controlled as much as possible, by only having a limited variety of these available. Additionally, any food or beverages that either increased or decreased alertness or arousal were excluded, such as caffeine.

The shift work task performed for the eight hours was a beading task. Participants were required to thread beads onto a string continuously, where cessation was only allowed during the provided rest breaks. This task was used in order to ensure the same level of alertness and activation was experienced across participants as it is automatic and repetitive, requiring minimal attention or cognitive effort. Additionally, the task only required limited skills and learning, thus participants would perform on the same level throughout testing.

Seven cognitive test tasks were tested in total and comprised the test battery (refer to Chapter 3 for more details). Each test task was performed at its own work station, except for the tapping and simple reaction time test tasks. These two were performed on the same computer, thus comprising one work station, due to the short duration of the simple reaction time test task (20 seconds). Therefore, testing of the cognitive test tasks occurred at six different work stations, where each hosted a different test task being investigated. These workstations were set up in a circular formation and participants were required to rotate in a clockwise direction from test task to test task (Figure 19 and Figure 20). This set-up allowed for six participants to be tested at a time, where each started at a different cognitive test task. As each participant started at a different workstation, the order of testing regarding the cognitive test tasks was equally distributed amongst participants (Appendix B1). Additionally, the two levels of difficulty were also equally distributed amongst participants (Appendix B1).

Figure 19: Experimental set-up of test battery and participants (driving simulator task test was not captured in this picture).

Each cognitive test task at both levels of difficulty did not exceed three minutes (refer to Chapter 3 for more detail; Figure 20). This was to ensure the test battery did not take too long, as monotony might set in, especially as the participants performed the test battery six times per shift (30 times during the testing duration). Also, this was to ensure that the fatigue experienced was not due to the test battery being performed for a long duration. The durations chosen for each cognitive test task allow for sufficient samples to be collected, thus the duration was not too short (Goble, 2013). This also explains the reason for the different test task durations (Goble, 2013), i.e. reading test task needs at least 90 seconds to obtain sufficient data, whereas the visual detection test task only needs 45 seconds.

The total test battery time was 12 minutes and 50 seconds; however, the time taken to complete the entire test battery in a testing session (gross time) was 18 minutes (Figure 20). This was due to the reading test task taking three minutes to complete. Participants could only rotate to the next test task after this test task was finished.

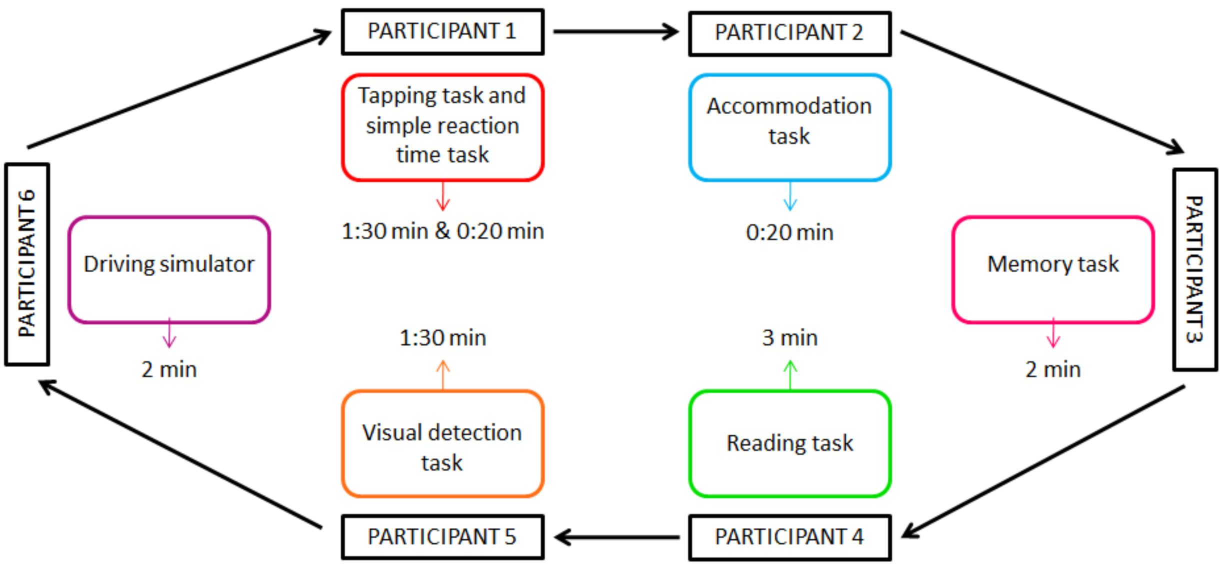

Figure 20: Layout of cognitive test tasks, rotation of participants and total duration of each individual cognitive test task.

The following confounding variables were controlled: lighting, temperature, food intake, rest breaks and noise. Chronotype of each participant and gender was equally distributed amongst the four shift work regimes. In an attempt to control sleeping patterns and duration of wakefulness amongst participants, participants were requested to maintain normal sleeping patterns before the commencement of testing and were requested to sleep after each consecutive shift. This was monitored via sleep diaries however it must be noted that this may be a confounding variable as data presented was not monitored by the researcher.

4.2.2 Independent variables

This phase consisted of three independent variables: the consecutive shifts, the testing sessions and the shift work regimes.

Testing occurred over five consecutive shifts, where the first shift was a standard eight-hour shift from 14h00 to 22h00 and the remaining four shifts were night shifts. Six testing sessions were performed during each shift tested, where each testing session comprised the test battery. Four shift work regimes were examined consisting of a standard rotating shift system, rolling shift system, split shift-nap system 1 and split shift-nap system 2.

These shift work regimes were chosen as testing coincided with a research project that aimed at developing a shift work system that eases into night shift work. Thus, the testing of the two projects was combined. Testing the cognitive test tasks on the three unconventional shift work regimes still provides information regarding fatigue occurring during shift work, as participants performed work during the night and at irregular hours, where shift duration was eight hours in length. Thus the effects of shift work were still experienced, especially as the participants had never been exposed to prior shift work.

Testing mainly focused on night shift work which may be seen as a limitation, as the effects of the morning shift are not taken under consideration or the transition into day shift work from morning shift.

Standard rotating shift system

The first shift performed was the standard eight-hour day shift, which was followed by four consecutive eight-hour night shifts from 22h00 to 06h00 (Figure 21). Three 15-minute breaks were inserted into the shifts every two hours.

Rolling shift system

The system involved gradually introducing the workers to a night shift from an afternoon shift. This was achieved by delaying the start (and end) of each shift by two hours. Thus the participants were required to perform a day shift followed by 4 night shifts where the start of the shift was continuously delayed by two hours (Figure 21). Therefore, the last shift performed was a standard night shift from 22h00 to 06h00 (Figure 21). Three 15-minute breaks were inserted into the shifts every two hours.

Split-shift nap system

Both split-shift nap systems required the participants to perform a day shift followed by four shifts where the participants were required to work for four hours, nap for fours hour and then work for another four hours. Participants slept in a designated sleeping area in the lab, thus remaining in the laboratory for 12 hours. The difference between these two shift work systems is the start and end time of the four night shifts. The first split-shift nap system started at 20h00 and ended at 08h00 and, the second started at 24h00 and ended at 12h00 (Figure 21). Two rest breaks were allowed during this shift work system, two hours after starting the shift and two hours before ending the shift. The elimination of sleep inertia was hopefully accomplished by testing the participants only approximately one hour and 40 minutes after being woken up.

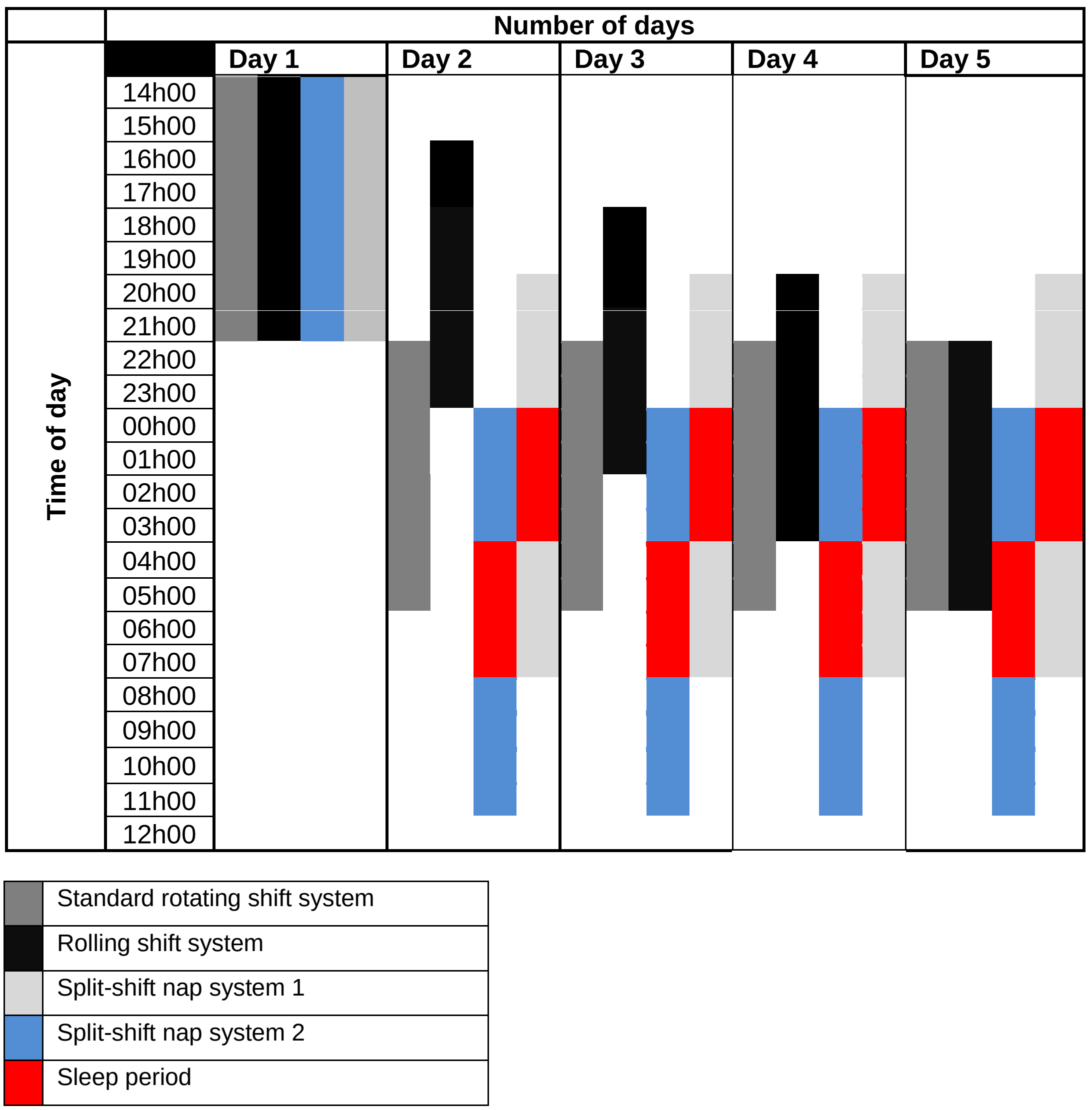

Figure 21: Table displaying the timing of all four shift work regimes tested in Phase 1.

For the standard rotating shift work system and rolling shift work system, participants were paid R500 (US$48), whereas for the two split nap shift systems the participants were paid R700 (US$67), the difference being due to the amount of hours kept in the laboratory, 40 hours vs. 56 hours respectively.

4.2.3 Dependent variables

The dependent variables consisted of cognitive test task performance: cognitive functions and task-related effects. Seven cognitive test tasks were examined: accommodation, visual detection, reading, memory, tapping, driving simulator and simple reaction time. It must be noted that the driving simulator test task will not be discussed (Refer to Chapter 3.4.6 for more information).

In summary, the seven cognitive test tasks were performed six times within the five consecutive shifts examined for the four different types of shift work regimes assessed.

4.2.4 Participant characteristics

Forty-eight fluent English-speaking participants were recruited for this study, which consisted of both male (n=24) and female (n=24) participants. Participants were recruited from Rhodes University via advertisements and were required to be between the ages of 18 and 26, in order to eliminate an aging effect ($\bar{x}$=22). Twelve participants were assigned to each shift work regime, thus making the study a non-repeated design. Additionally, each shift work regime comprised six females and six males.

Participants were required to be non-smokers as nicotine has an arousing effect and has been found to improve attention, working memory performance and concentration (Kumari *et al*., 1997; Ernst *et al*., 2001). Participants were also required to have a fairly consistent sleeping pattern, while obtaining on average seven to eight hours sleep. This was to ensure data was consistent amongst shift work regimes, especially due to the fact that this was a non-repeated design. Additionally, participants were excluded if they were on any medication (increases arousal or sleepiness), performed rotational night shift work previously (impact data due to past adaptation to shift work), suffered from dyslexia (will not be able to perform the reading test task) or suffered from any sleep disorders and attention disorders, as these would influence the performance measures.

4.2.5 Ethics consideration

This phase was approved by the ethics committee of the Human Kinetics and Ergonomics Department of Rhodes University (Appendix A4), prior to any testing taking place. The participants voluntarily signed a consent form, in order to agree to participate in the study (Appendix A3). Each was identified using a participant code, rather than first names, in order to keep data confidential. Participants were reminded before and throughout testing that they were free to leave the testing at any point and there would be no negative consequences for them if this decision was made.

4.2.6 Experimental procedures

This section was divided into the habituation session and procedure.

<u>Habituation session</u>

In this section, the aims of the study, cognitive test tasks and experimental procedures were explained to the participants both verbally and in writing (Appendix A1). Those participants that were willing to perform the study then signed a consent form. After which, they were required to fill in a Morning-Evening Questionnaire (Horne and Ostberg; 1976) in order to obtain their chronotype and were required to fill in a demographic data sheet (age, gender, year of study, and so on). Once the relevant information was captured, participants were divided into their relative shift work regimes and the layout and requirements of their particular shift work system was explained to them. Once this was complete, each participant was required to perform the test battery. Participants needed to become familiar with the test tasks and test task requirements in order to ensure that the test tasks were performed correctly. This was also aimed at eliminating a learning effect. Additionally, each participant was given a code, with their particular cognitive test task and level of difficulty order (Appendix B1).

Participants were informed that no cell phones were to be used during the study, especially whilst performing the test battery as it may cause distraction, change mood or increase alertness. They were requested to not drink alcohol or digest caffeine 24 hours before and during testing, these substances are known to interfere with alertness, cognitive performance and attention (Goble, 2013). Participants were asked to sleep after testing in order to simulate a normal shift worker and to ensure effects found are due to the study and not due to voluntary sleep loss. Additionally, participants were requested to not perform vigorous or strenuous activity 12 hours before testing commenced and during testing as this type of exercise can cause an early onset of fatigue.

Procedure

Participants were required to arrive 15 minutes prior to the start of their relevant shift. Each participant completed five consecutive shifts in total, where the 18-minute test battery was performed six times per shift. During each shift, workers performed a continuous beading task, where cessation only occurred during rest breaks.

When performing the test battery, participants were required to remain silent and only rotate to the next work station once everyone had finished with their particular test task. Additionally the test battery only started once all participants were in the room and participants had to leave together.

4.2.7 Analysis, statistical analysis and statistical hypotheses

Analysis

For this phase only the overall effects were analysed: over the five shifts (SHIFTS), over the six testing sessions performed per shift (TESTS) and between the four shift work regimes (REGIMES). If a significant effect showing a decline in cognitive performance was found over the SHIFTS, TESTS or shift work REGIMES then the test task was added into the assessment tool, as a fatiguing effect of shift work was present. In contrast, an improvement in cognitive performance will represent a learning effect or adaptation to shift work, thus the test task will be excluded from the assessment tool.

If a significant effect was found for shift work influences (interaction effects) the test task would also be inserted into the assessment tool, as it revealed that fatigue behaved differently for different aspects of shift work. Additionally, if a cognitive test task only showed a significant effect for the cognitive function or task-related effect, it was added to the assessment tool, where both the cognitive function and task-related effect was analysed. Furthermore, if only one parameter of a cognitive function or task-related effect revealed a significant effect, all parameters of that test task were assessed in Phase 2.

The reason for this is that the cognitive test task has shown some indication of mental fatigue or indication of sensitivity towards shift work. Thus the other parameters and analyses need to be investigated in the field, as they might reveal a fatiguing significance or a unique shift work effect. Additionally, the laboratory and the field-based settings are different in nature and may yield different results.

Testing for Phase 1 was combined with a Doctor of Philosophy research project which assessed four different types of shift work designs, established vs. alternative, for easing the transition into night work. This project investigated and compared both within and between each shift work regime with regards to cognitive performance, shift work task and sleeping patterns. Therefore, this data: sleep diaries, shift work task performance and body temperature, will not be presented or discussed in this current research project.

Statistical analysis

In order to look at the overall effect, where performance can be analysed over the SHIFTS, TESTS and shift work REGIMES, a three-way ANOVA was performed, where SHIFTS was one factor, TESTS was the second factor and shift work REGIMES was the third factor. The statistical analyses were performed using Statistica software package 10 (Statistica©; Statsoft Inc.; Tulsa; Oklahoma, USA).

Statistical hypotheses

The hypotheses below are valid for all parameters of each cognitive function and task-related effect under investigation:

- Accommodation test task:
  - Eye accommodation: eye accommodation time (s) and error rate (%)
  - Choice reaction time: reaction time (s) and error rate (%)
- Visual detection test task:
  - Visual discrimination: processing time (s), error rate (%) and impact of detection workload on tunnel view (Δr)
  - Visual detection: reaction time (s), error rate (%) and tunnel view index (Δr)
- Reading test task:
  - Visual patter recognition: processing time (words/min) and error rate (%)
  - Reading performance: reading speed (words/min) and error rate (%)
- Memory test task:
  - Memory duration: impact of rehearsal time on memory recall rate (%)
  - Short-term memory performance: recall rate (%)
- Tapping test task:
  - Motor programming: motor programming time for the low precision condition and for the high precision condition (s)
  - Motor control: reaction time (s)
- Driving simulator test task:
  - Peripheral neural control: impact of movement sensitivity demands on reaction time (s)
  - Tracking performance: reaction time (s)
- Simple reaction time test task: reaction time (s)

Hypothesis 1: The null hypothesis proposed that there will be no significant difference between the SHIFTS.

Ho: $\mu_{S1} = \mu_{S2} = \mu_{S3} = \mu_{S4} = \mu_{S5}$

Ho: $\mu_{S1} \neq \mu_{S2} \neq \mu_{S3} \neq \mu_{S4} \neq \mu_{S5}$

Where: S1 = Shift 1, S2 = Shift 2, S3 = Shift 3, S4 = Shift 4, S5 = Shift 5

Hypothesis 2: The null hypothesis proposed that there will be no significant difference between the TESTS.

Ho: $\mu_{T1} = \mu_{T2} = \mu_{T3} = \mu_{T4} = \mu_{T5} = \mu_{T6}$

Ho: $\mu_{T1} \neq \mu_{T2} \neq \mu_{T3} \neq \mu_{T4} \neq \mu_{T5} \neq \mu_{T6}$

Where: T1 = Pre Test, T2 = Test 1, T3 = Test 2, T4 = Test 3, T5 = Test 4 = T6 = Post Test

Hypothesis 3: The null hypothesis proposed that there will be no significant difference between the shift work REGIMES.

Ho: $\mu_A = \mu_B = \mu_C = \mu_D$

Ho: $\mu_A \neq \mu_B \neq \mu_C \neq \mu_D$

Where: A = Standard shift work system, B = Rolling shift system, C = Split-shift nap system 1, D = Split-shift nap system 2

Hypothesis 4: The null hypothesis proposed that there will be no significant interaction effect between the four shift work regimes and five consecutive shifts tested.

Hypothesis 5: The null hypothesis proposed that there will be no significant interaction effect between the four shift work regimes and six testing sessions performed per shift.

Hypothesis 6: The null hypothesis proposed that there will be no significant interaction effect between the five consecutive shifts tested and six testing sessions performed per shift.

Hypothesis 7: The null hypothesis proposed that there will be no significant interaction effect between the four shift work regimes, five consecutive shifts tested and six testing sessions performed per shift.

4.3 RESULTS

In this section the significant effects for each parameter of each cognitive function and task-related effect for each cognitive test task will be investigated over the SHIFTS, over the TESTS, between the shift work REGIMES and the interaction effects.

Table iii: Key displaying the meanings of the statistical analyses.

	Definitions	**Abbreviations**
SHIFTS	Five consecutive shifts tested	Shift 1: Day shift Shift 2 – 5: Night shifts
TESTS	Six testing sessions performed per shift	Pre Test: Testing session before work Test 1 to 4: Testing sessions within each shift Post Test: Testing session after work
REGIMES	Four shift work regimes	A: Standard rotating shift work system B: Rolling shift system C: Split-shift nap system 1 D: Split-shift nap system 2

4.3.1 Accommodation test task

<u>Eye accommodation</u>

No significant effects were found for eye accommodation time and for error rate for eye accommodation (Tables IV and VI respectively).

<u>Choice reaction time</u>

A significant effect was found for choice reaction time over the SHIFTS (Table IV), where reaction time decreased from Shift 1 to Shift 5 (Figure 22). No other significant effects were found for choice reaction time (Table IV). Additionally, no significant effects were found for error rate for choice reaction time (Table VI).

Table iv: Statistical analysis of choice reaction time and eye accommodation time for the five consecutive shifts, six testing sessions and four shift work regimes.

	Choice reaction time			Eye accommodation time		
Effects	**DF**	**F**	**P**	**DF**	**F**	**P**
REGIMES	3, 34	0.94	0.42	3, 31	0.62	0.61
SHIFTS	12, 136	15.22	**< 0.01**	4, 124	0.75	0.55
TESTS	5, 170	0.55	0.73	5, 155	0.89	0.48
SHIFTS*REGIMES	12, 136	0.89	0.55	12, 124	0.77	0.66
TEST*REGIME	15, 170	1.46	0.12	15, 155	0.73	0.73
SHIFT*TESTS	20, 680	5.66	0.06	20, 620	0.69	0.83
SHIFT*TESTS*REGIMES	60, 680	1.15	0.20	60, 620	1.03	0.42

Table v: Statistical analysis of error rate for both choice reaction time and eye accommodation for the five consecutive shifts, six testing sessions and four shift work regimes.

	Error rate for choice reaction time			Error rate for eye accommodation		
Effects	**DF**	**F**	**P**	**DF**	**F**	**P**
REGIMES	3, 34	0.92	0.45	3, 31	1.09	0.38
SHIFTS	12, 136	1.50	0.22	4, 124	0.14	0.93
TESTS	5, 170	1.85	0.11	5, 155	0.88	0.49
SHIFTS*REGIMES	12, 136	0.83	0.58	12, 124	1.05	0.41
TEST*REGIME	15, 170	1.11	0.35	15, 155	0.90	0.56
SHIFT*TESTS	20, 680	1.48	0.11	20, 620	1.10	0.35
SHIFT*TESTS*REGIMES	60, 680	0.95	0.55	60, 620	1.13	0.27

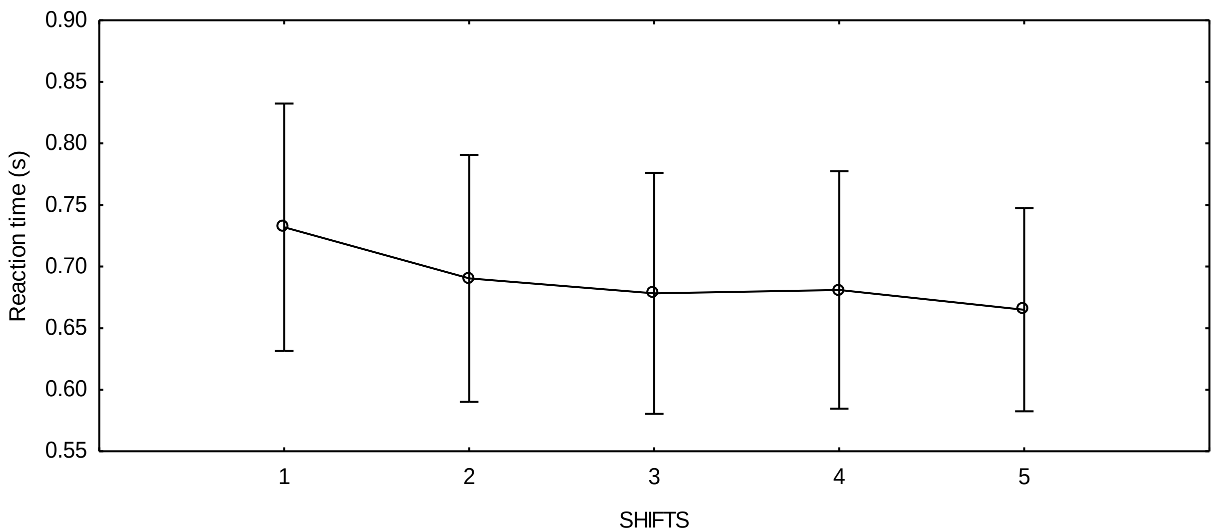

Figure 22: Choice reaction time over the five consecutive shifts tested ($p < 0.05$; error bars depict 95% confidence interval).

4.3.2 Visual detection test task

Visual discrimination

No significant effects were found for processing time, error rate or the impact of detection workload on tunnel view for visual discrimination (Tables VI, VII and VIII respectively).

Table vi: Statistical analysis of reaction time for visual detection and processing time for visual discrimination for the five consecutive shifts, six testing sessions and four shift work regimes.

	Reaction time for visual detection			**Processing time for visual pattern recognition**		
Effects	**DF**	**F**	**P**	**DF**	**F**	**P**
REGIMES	3, 40	1.34	0.27	3, 32	1.14	0.34
SHIFTS	4, 160	14.06	**< 0.01**	4, 128	0.21	0.92
TESTS	5, 200	2.15	0.06	5, 160	1.62	0.15
SHIFTS*REGIMES	12, 160	1.37	0.18	12, 128	0.45	0.93
TEST*REGIME	15, 200	2.61	**< 0.01**	15, 160	0.85	0.62
SHIFT*TESTS	20, 800	1.11	0.32	20, 640	0.93	0.54
SHIFT*TESTS*REGIMES	60, 800	1.487	**0.01**	60,640	1.23	0.12

Table vii: Statistical analysis of error rate for both visual detection and visual discrimination for the five consecutive shifts, six testing sessions and four shift work regimes.

	Error rate for visual detection			**Error rate for visual discrimination**		
Effects	**DF**	**F**	**P**	**DF**	**F**	**P**
REGIMES	3, 39	1,70	0.18	3, 32	1.68	0.19
SHIFTS	4, 156	11.88	**< 0.01**	4, 128	1.24	0.29
TESTS	5, 195	4.90	**< 0.01**	5, 160	0.28	0.91
SHIFTS*REGIMES	12, 156	1.17	0.30	12, 128	0.58	0.85
TEST*REGIME	15, 195	1.40	0.14	15, 160	0.90	0.56
SHIFT*TESTS	20, 780	0.73	0.79	20, 640	1.26	0.19
SHIFT*TESTS*REGIMES	60, 780	1.08	0.30	60, 640	1.29	0.07

Table viii: Statistical analysis of tunnel view index for visual detection and of the impact of detection workload on tunnel view for visual discrimination for the five consecutive shifts, six testing sessions and four shift work regimes.

	Tunnel view index for visual detection			**Impact of detection workload on tunnel view for visual discrimination**		
Effects	**DF**	**F**	**P**	**DF**	**F**	**P**
REGIMES	3, 26	0.60	0.61	3, 27	0.09	0.96
SHIFTS	4, 104	3.13	0.01	4, 108	0.34	0.84
TESTS	5, 130	1.47	0.20	5, 135	0.47	0.79
SHIFTS*REGIMES	12, 104	0.81	0.63	12, 108	1.22	0.27
TEST*REGIME	15, 130	0.90	0.55	15, 135	1.38	0.16
SHIFT*TESTS	20, 520	1.49	0.07	20, 540	0.86	0.63
SHIFT*TESTS*REGIMES	60, 520	1.09	0.29	60, 540	0.74	0.92

Visual detection

Reaction time

A significant effect was found for reaction time for visual detection over the SHIFTS, the interaction between TESTS and REGIMES and the interaction between SHIFTS, TESTS and REGIMES (Table VI). Reaction time decreased from Shift 1 to Shift 5 (Figure 23). Reaction time during each testing session was dependent on the shift work REGIME being performed (Figure 24). Furthermore, the reaction time for each shift work REGIME was dependent on the testing sessions being examined over the five consecutive shifts. There were no other significant effects found (Table VI).

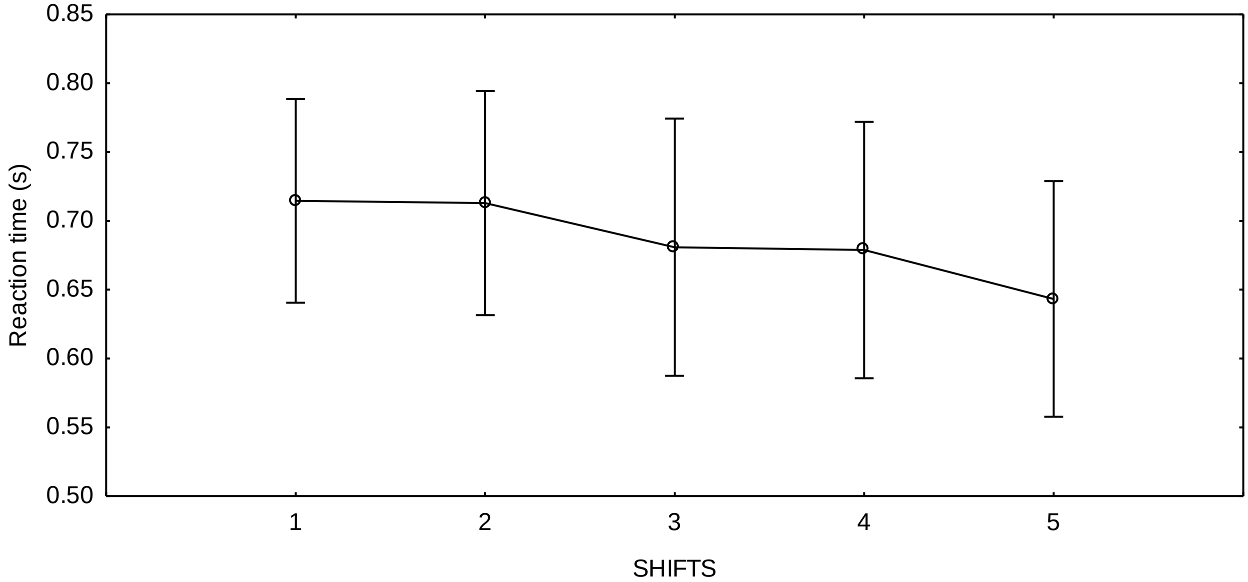

Figure 23: Reaction time for visual detection over the five consecutive shifts tested ($p < 0.05$; error bars depict 95% confidence interval).

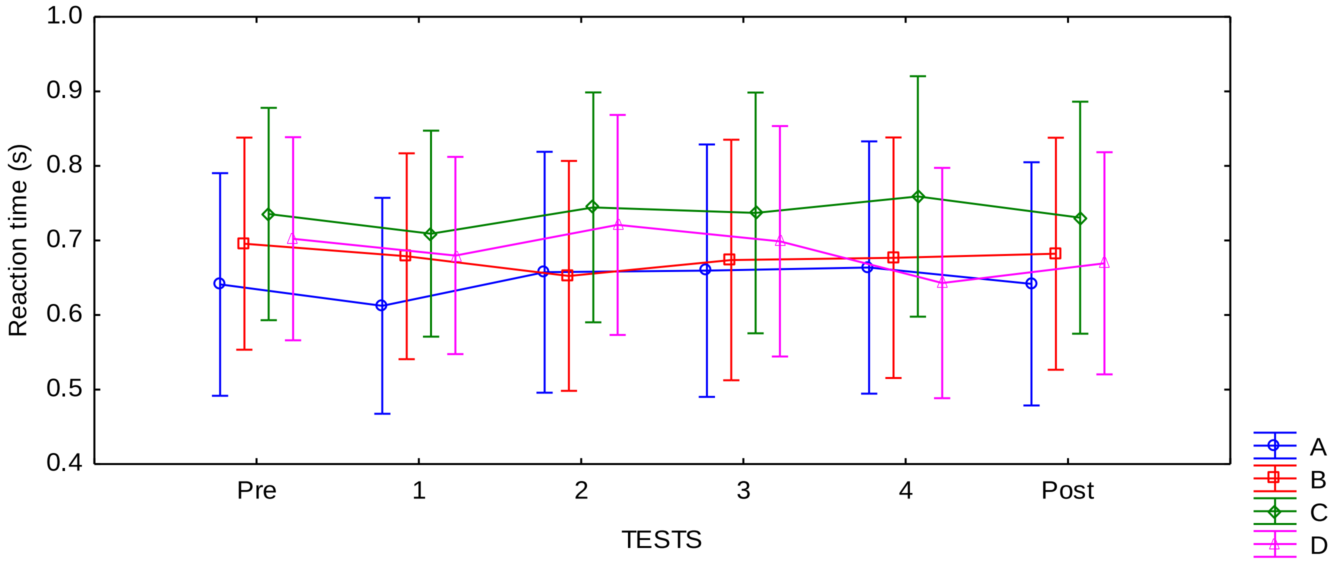

Figure 24: Interaction effect for reaction time for visual detection between the four shift work regimes and six testing sessions performed per shift ($p < 0.05$; error bars depict 95% confidence interval).

Error rate

A significant effect was found for error rate for visual detection over the SHIFTS (Table VII), where the percentage of overlooked stimuli decreased from Shift 1 to Shift 5 (Figure

25). Additionally, a significant effect was found over the TESTS (Table VII), where the percentage of overlooked stimuli decreased from Pre Test to Test 1, followed by an increase to Post Test (Figure 26). No other significant effects were found (Table VII).

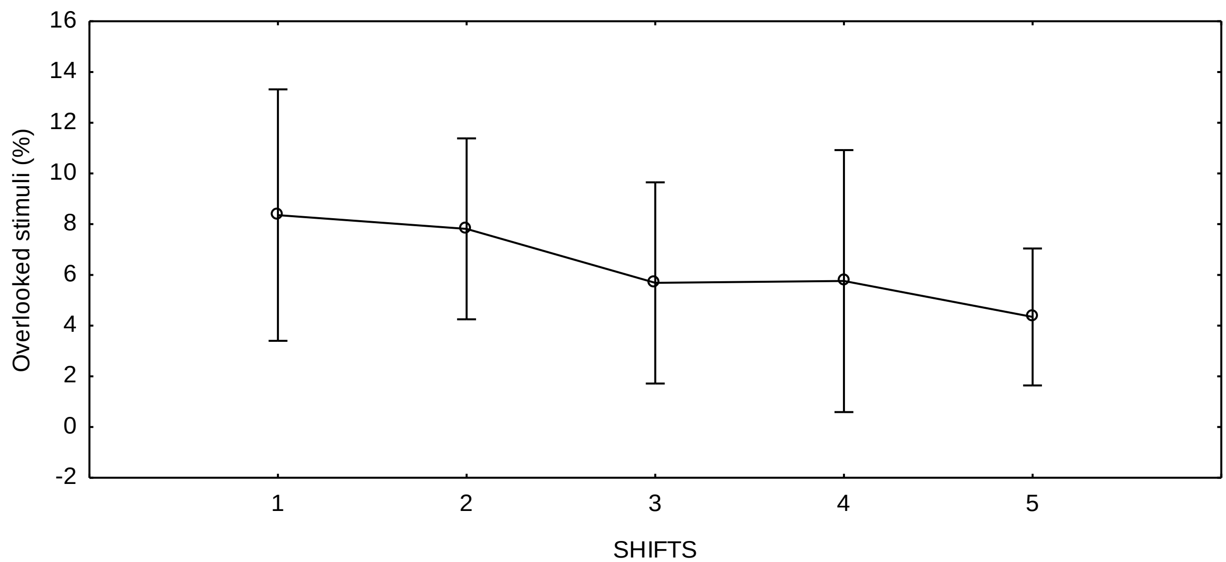

Figure 25: Error rate for visual detection over the five consecutive shifts tested ($p < 0.05$; error bars depict 95% confidence interval).

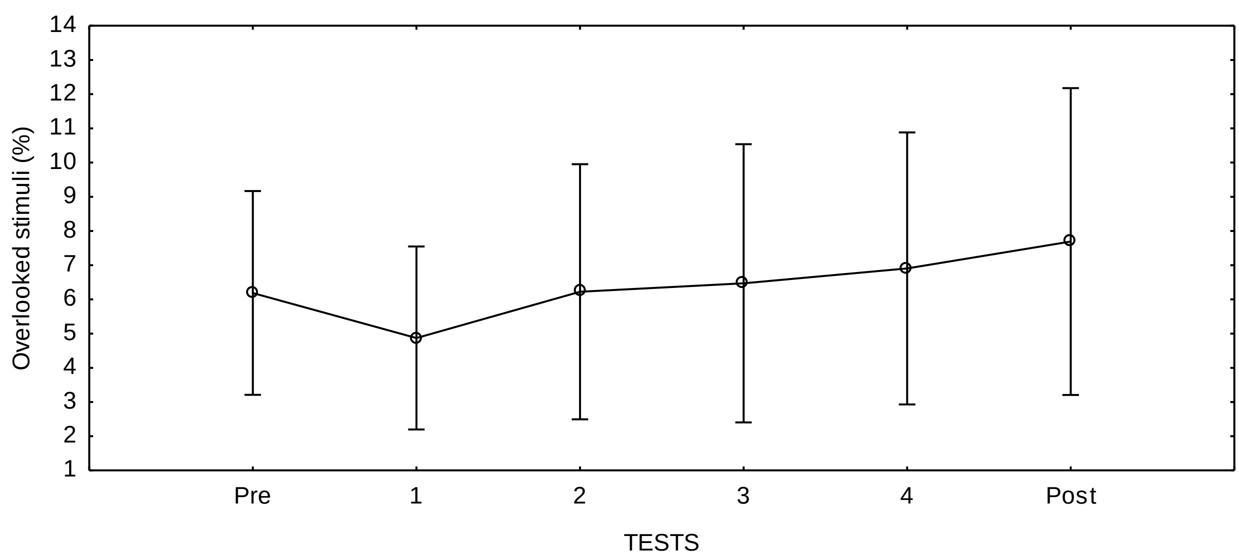

Figure 26: Error rate for visual detection over the six testing sessions tested per shift ($p < 0.05$; error bars depict 95% confidence interval).

Tunnel view index

A significant effect was found for tunnel view index for visual detection over the SHIFTS (Table VIII), where the tunnel view index decreased from Shift 1 to Shift 2, followed by an increase to Shift 3, after which a decrease is seen to Shift 5 (Figure 27). There were no other significant effects found (Table VIII).

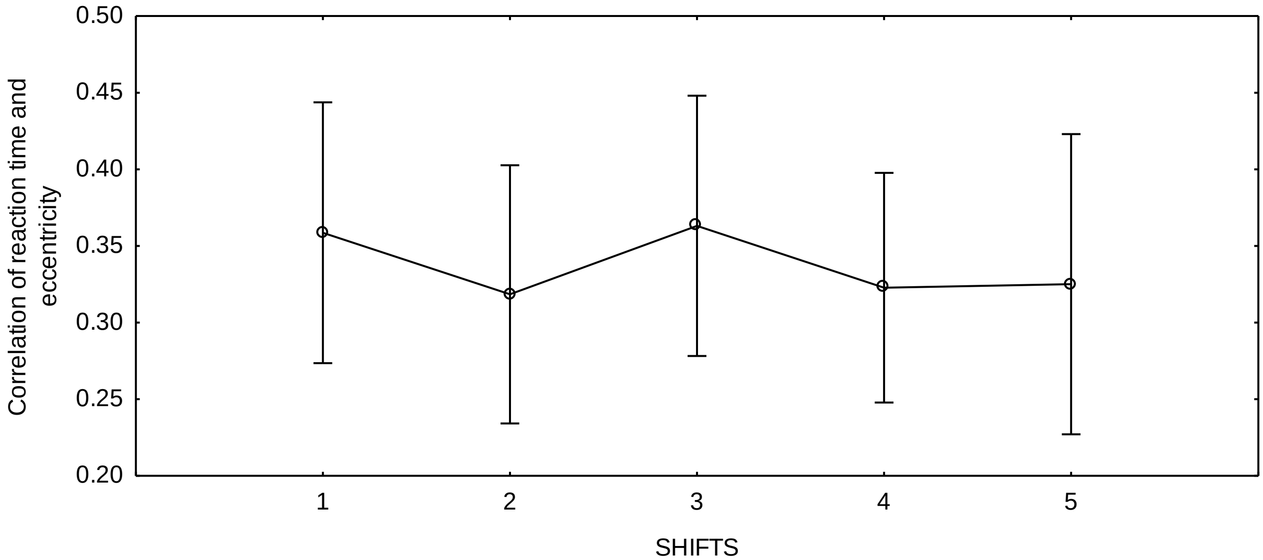

Figure 27: Tunnel view index for visual detection over the five shifts tested ($p < 0.05$; error bars depict 95% confidence interval).

4.3.3 Reading test task

Table ix: Statistical analysis of reading speed for reading performance and processing time for visual pattern recognition for the five consecutive shifts, six testing sessions and four shift work regimes.

	Reading speed for reading performance			**Processing time for visual pattern recognition**		
Effects	**DF**	**F**	**P**	**DF**	**F**	**P**
REGIMES	3, 40	0.91	0.44	3,40	0.47	0.70
SHIFTS	4, 160	0.13	0.96	4, 160	14.22	**< 0.01**
TESTS	5, 200	1.33	0.25	5, 200	3.49	**< 0.01**
SHIFTS*REGIMES	12, 160	0.58	0.84	12, 160	0.74	0.70
TEST*REGIME	15, 200	0.69	0.79	15, 200	1.31	0.19
SHIFT*TESTS	20, 800	4.94	**< 0.01**	20, 800	1.56	0.06
SHIFT*TESTS*REGIMES	60, 800	1.08	0.31	60, 800	1.05	0.36

Table x: Statistical analysis of error rate for both reading performance and visual pattern recognition for the five consecutive shifts, six testing sessions and four shift work regimes.

	Error rate for reading performance			**Error rate for visual pattern recognition**		
Effects	**DF**	**F**	**P**	**DF**	**F**	**P**
REGIMES	3, 18	0.59	0.62	3, 18	0.35	0.78
SHIFTS	4, 72	8.55	**< 0.01**	4, 72	6.65	**< 0.01**
TESTS	5, 90	3.63	**< 0.01**	5, 90	2.46	**0.03**
SHIFTS*REGIMES	12, 72	2.58	**< 0.01**	12, 72	0.85	0.59
TEST*REGIME	15, 90	1.62	0.08	15, 90	1.51	0.11
SHIFT*TESTS	20, 360	1.82	**0.01**	20, 360	3.65	**< 0.01**
SHIFT*TESTS*REGIMES	60, 360	1.14	0.23	60, 360	1.35	**0.04**

Visual pattern recognition

Processing time

A significant difference was found over the SHIFTS and over the TESTS for the processing time for visual pattern recognition (Table IX). Processing time declined in performance from Shift 1 to Shift 3, followed by a slight improvement to Shift 4 and then a further decline in performance was noted to Shift 5 (Figure 28). With regards to the TESTS, processing time improved from Pre Test to Test 1, followed by a decline in performance to Test 2, after which processing time remained constant to Post Test (Figure 29). No other significant effects were found (Table IX).

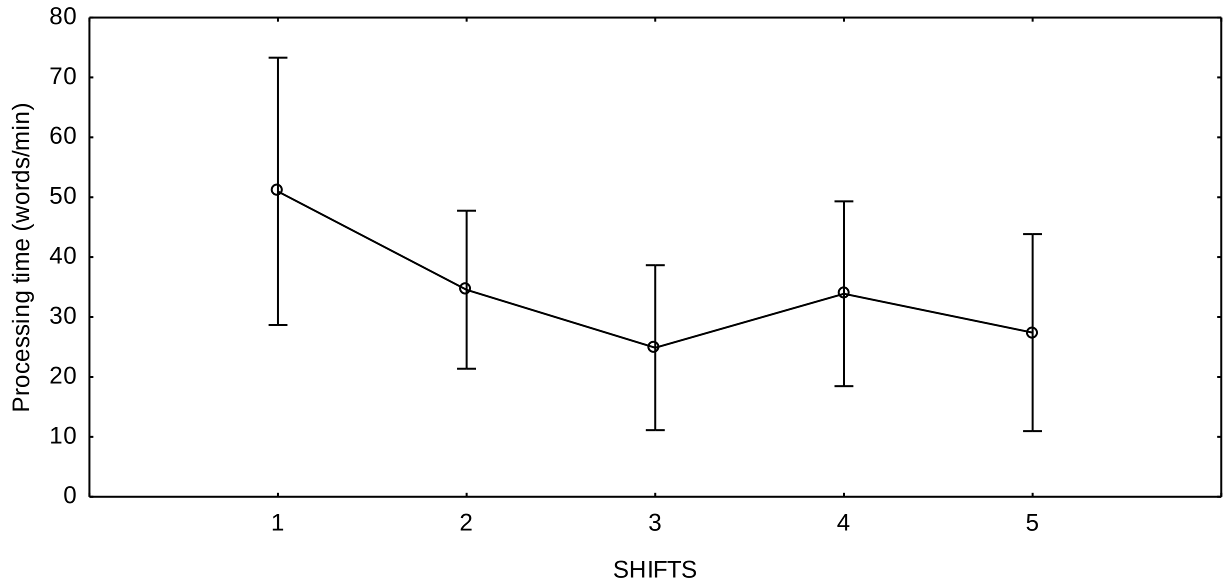

Figure 28: Processing time for visual pattern recognition over the five consecutive shifts tested ($p < 0.05$; error bars depict 95% confidence interval).

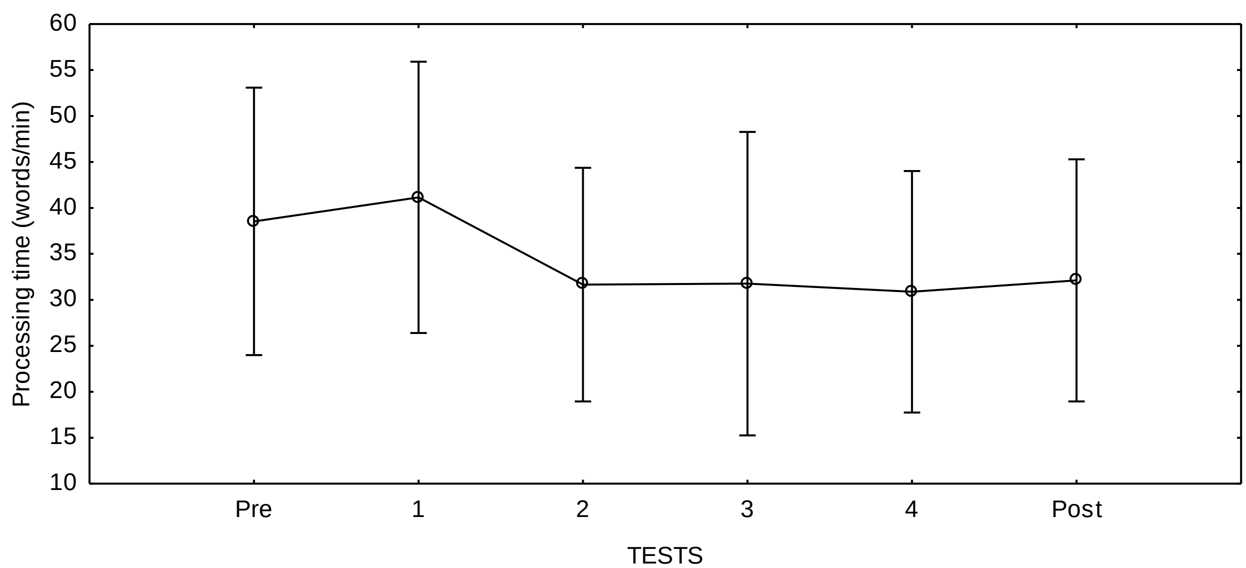

Figure 29: Processing time for visual pattern recognition over the six testing sessions tested per shift ($p < 0.05$; error bars depict 95% confidence interval).

Error rate

A significant effect was found for error rate for visual pattern recognition over the SHIFTS, over the TESTS, the interaction between SHIFTS and TESTS and the interaction between SHIFTS, TESTS and REGIMES (Table X). Error rate worsened from Shift 1 to Shift 4, followed by a slight improvement in performance to Shift 5 (Figure 30). For the TESTS, performance of error rate declined from Pre Test to Test 1, followed by an improvement to Test 2, after which performance declined to Test 3, where it remained fairly constant to Post Test (Figure 31). Additionally, the error rate during each testing session was dependent on the shift being performed (Figure 32) and the error rate for each shift work regime was dependent on the testing session being performed over the five consecutive shift tested. No other significant effects were found (Table X).

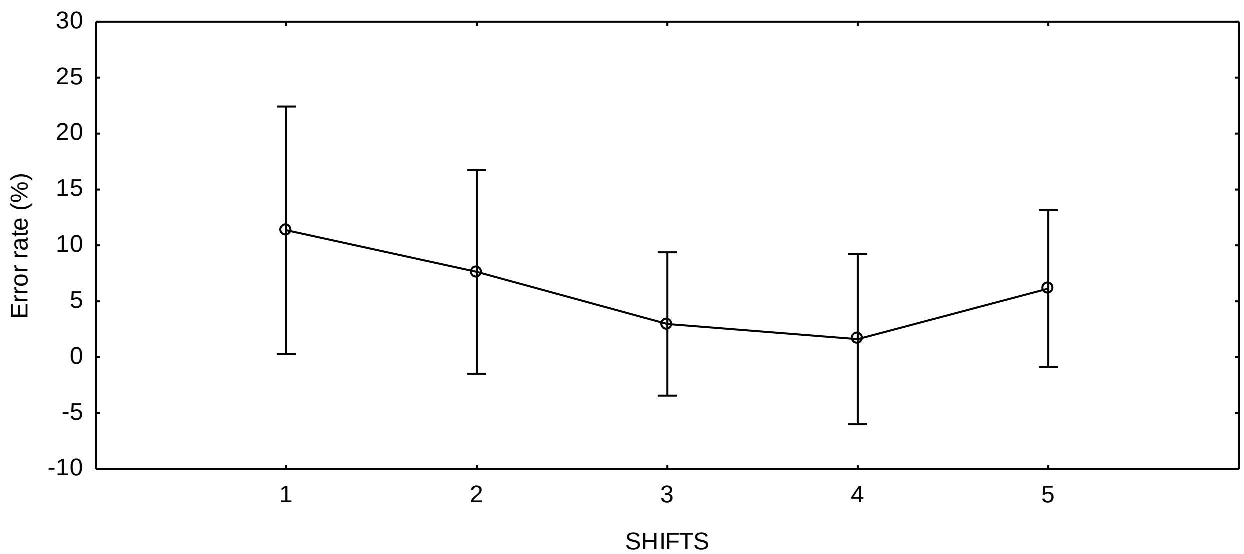

Figure 30: Error rate for visual pattern recognition over the five consecutive shifts tested ($p < 0.05$; error bars depict 95% confidence interval).

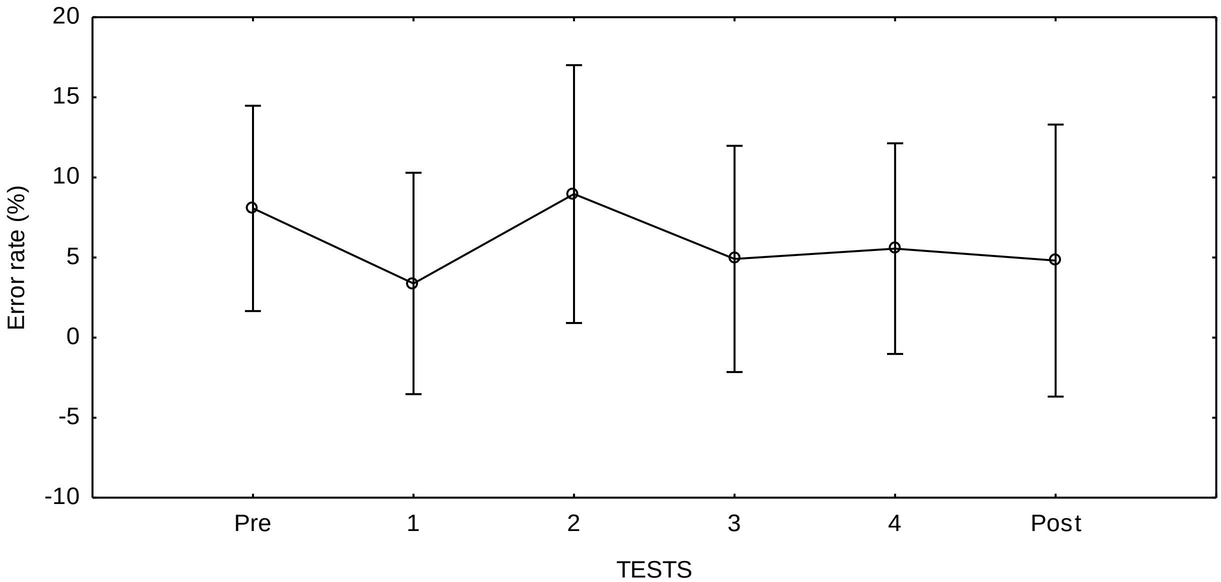

Figure 31: Error rate for visual pattern recognition over the six testing sessions tested per shift ($p < 0.05$; error bars depict 95% confidence intervals).

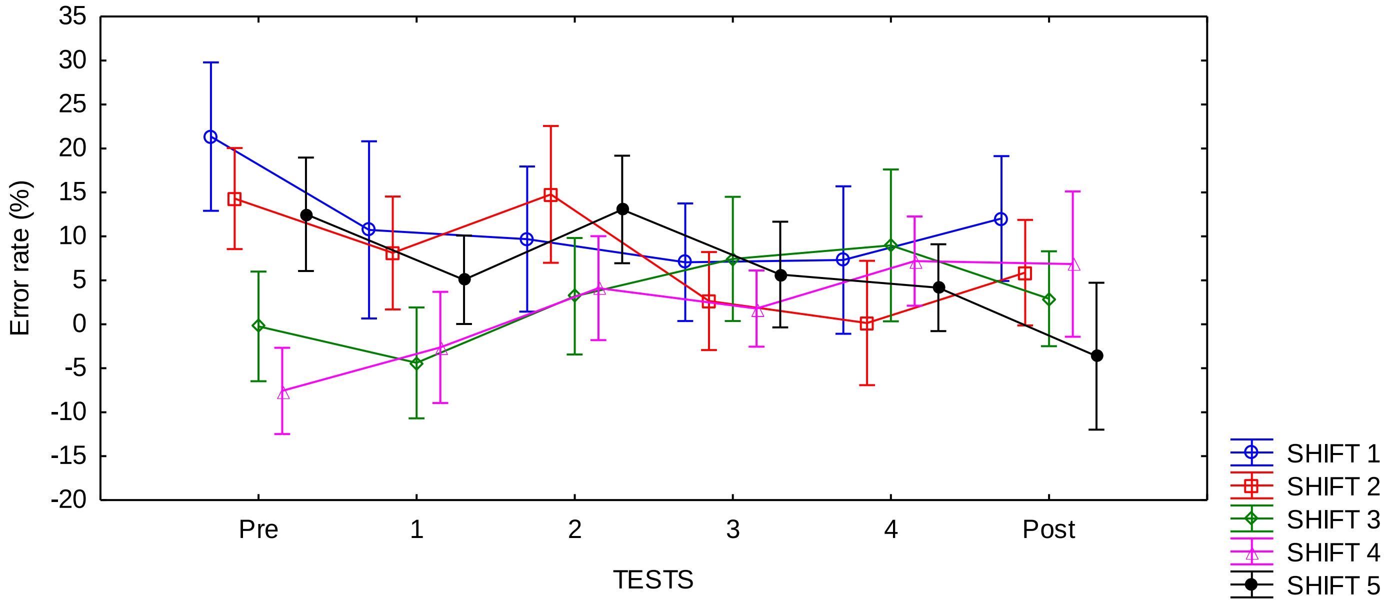

Figure 32: Interaction effect for error rate for visual pattern recognition between the six testing sessions and five consecutive shifts ($p < 0.05$; error bars depict 95% confidence interval).

Reading performance

Reading speed

A significant interaction effect was found for reading speed for reading performance between SHIFTS and TESTS (Table IX). Thus, reading speed during the testing sessions was dependent on the shift being performed (Figure 33). No other significant effects were found (Table IX).

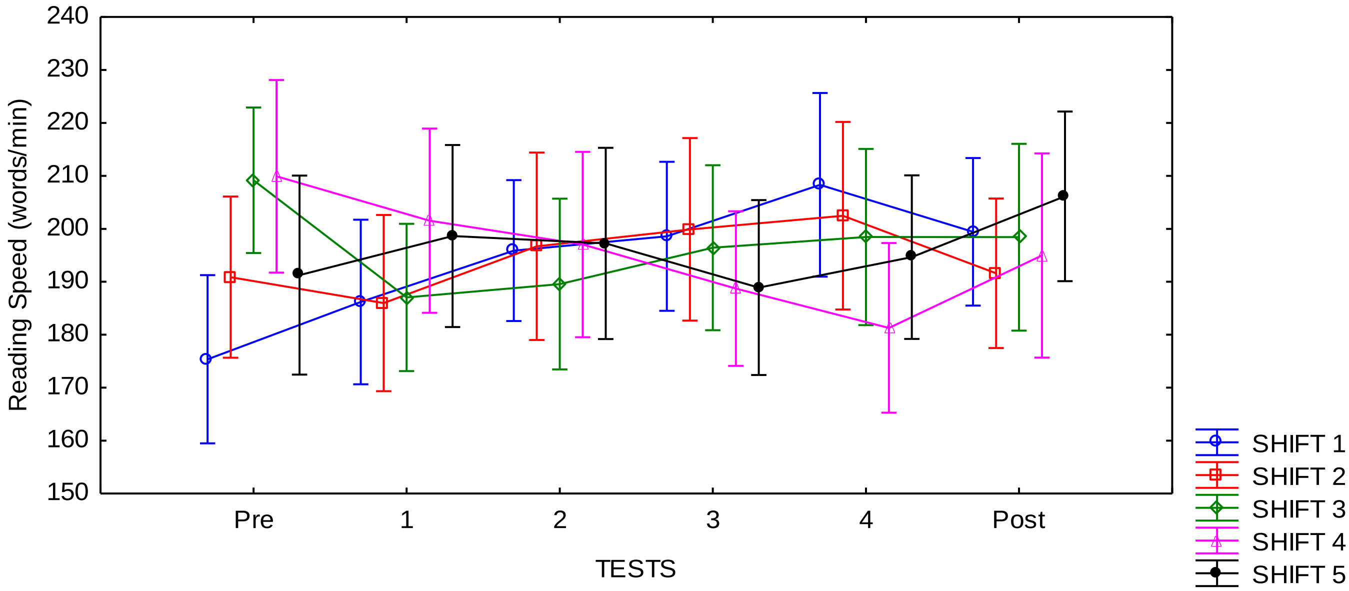

Figure 33: Interaction effect for reading speed for reading performance between the five consecutive shifts and six testing sessions ($p < 0.05$; error bars depict 95% confidence interval).

Error rate

A significant effect was found for the error rate for reading performance over the SHIFTS, over the TESTS, the interaction between SHIFTS and TESTS and the interaction between SHIFTS and REGIMES (Table X). The amount of identified spelling errors increased from Shift 1 to Shift 2, which was followed by a decline in performance to Shift 3, after which an improvement occurred to Shift 5 (Figure 34). With regards to the TESTS, the amount of identified spelling errors increased from Pre Test to Test 2, after which performance deteriorated to Post Test (Figure 35). The significant interaction effects revealed that error rate during the testing session was dependent on the shift being performed (Figure 36) and the error rate during the individual shifts was dependent on the shift work regime being performed (Figure 37). No other significant effects were found (Table X).

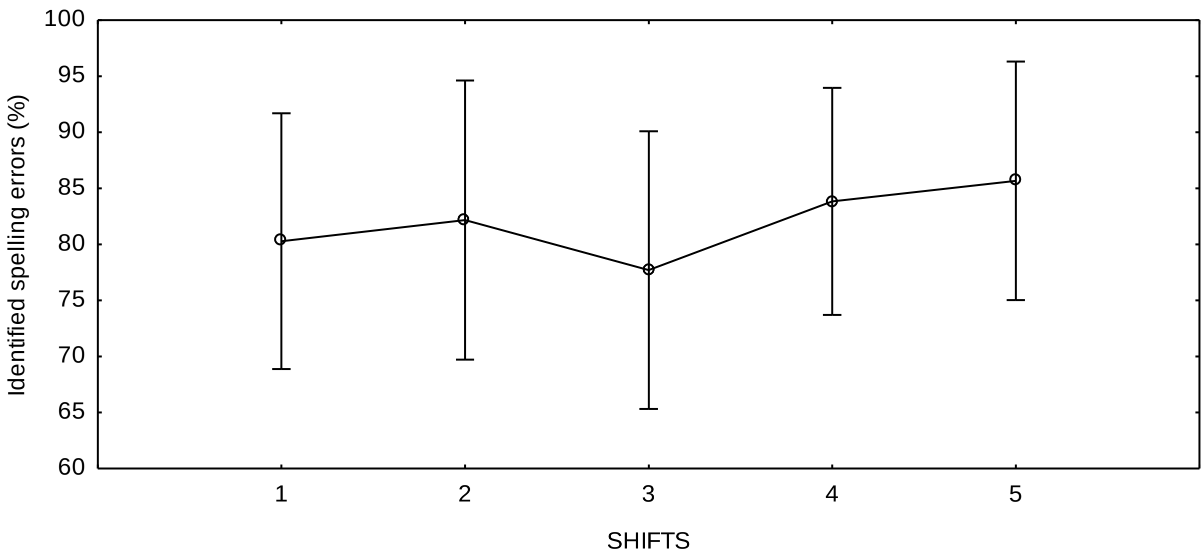

Figure 34: Error rate for reading performance over the five consecutive shifts tested ($p < 0.05$; error bars depict 95% confidence interval).

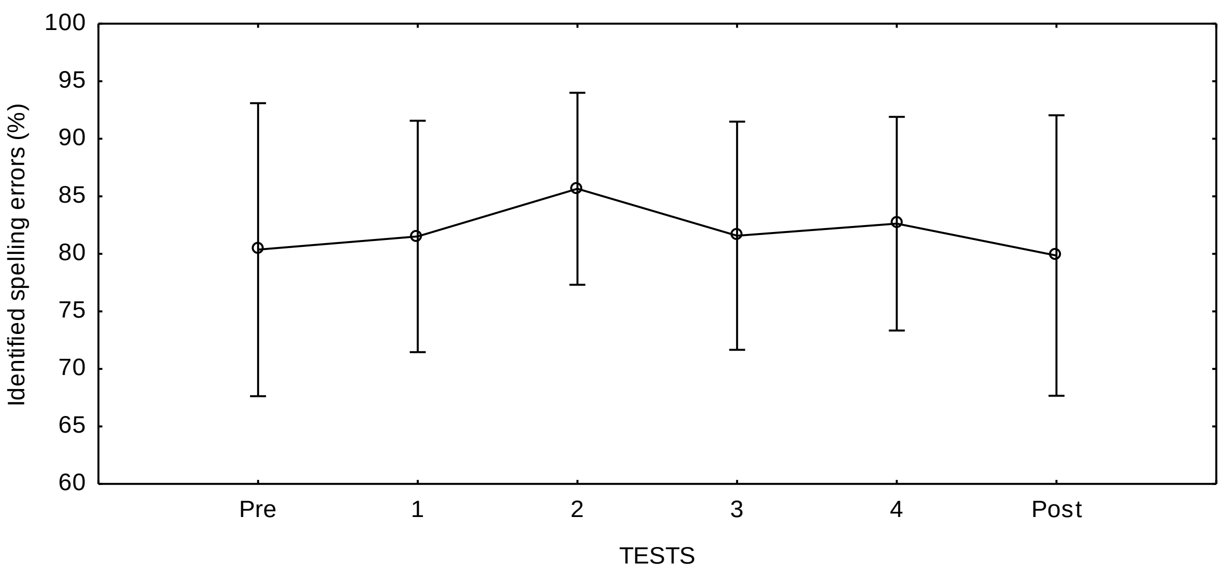

Figure 35: Error rate for reading performance over the six testing sessions performed per shift ($p < 0.05$; error bars depict 95% confidence intervals).

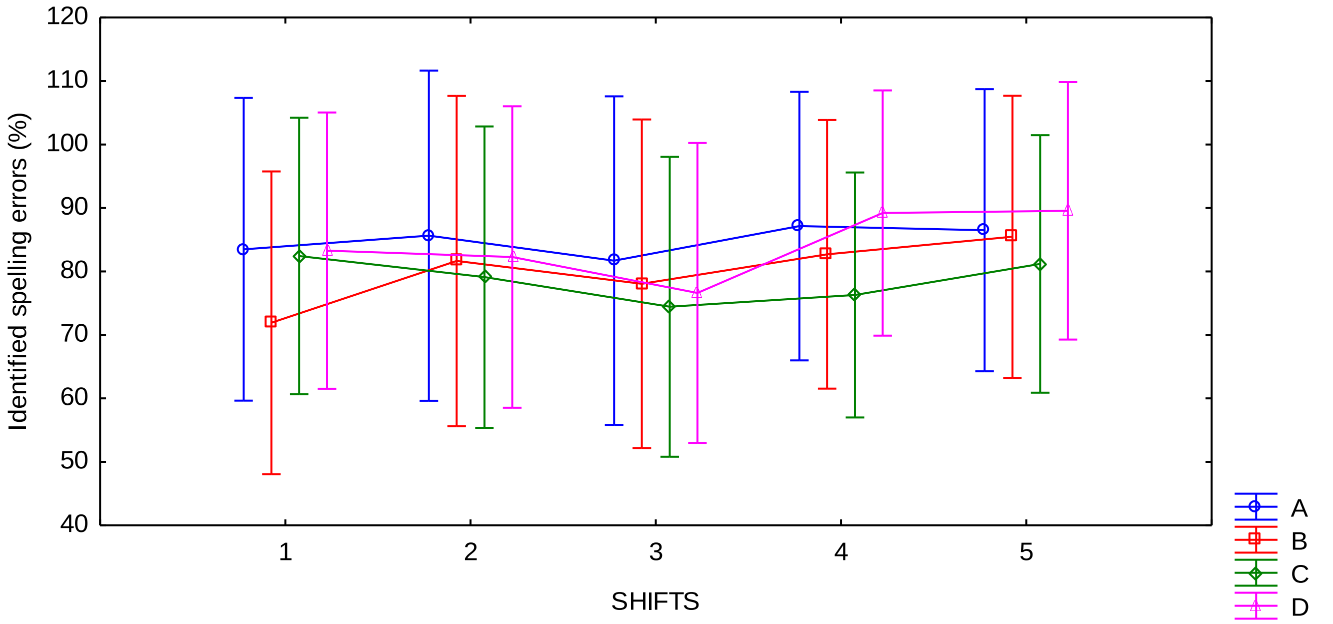

Figure 36: Interaction effect for error rate for reading performance between the four shift work regime and five consecutive shifts ($p < 0.05$; error bars depict 95% confidence interval).

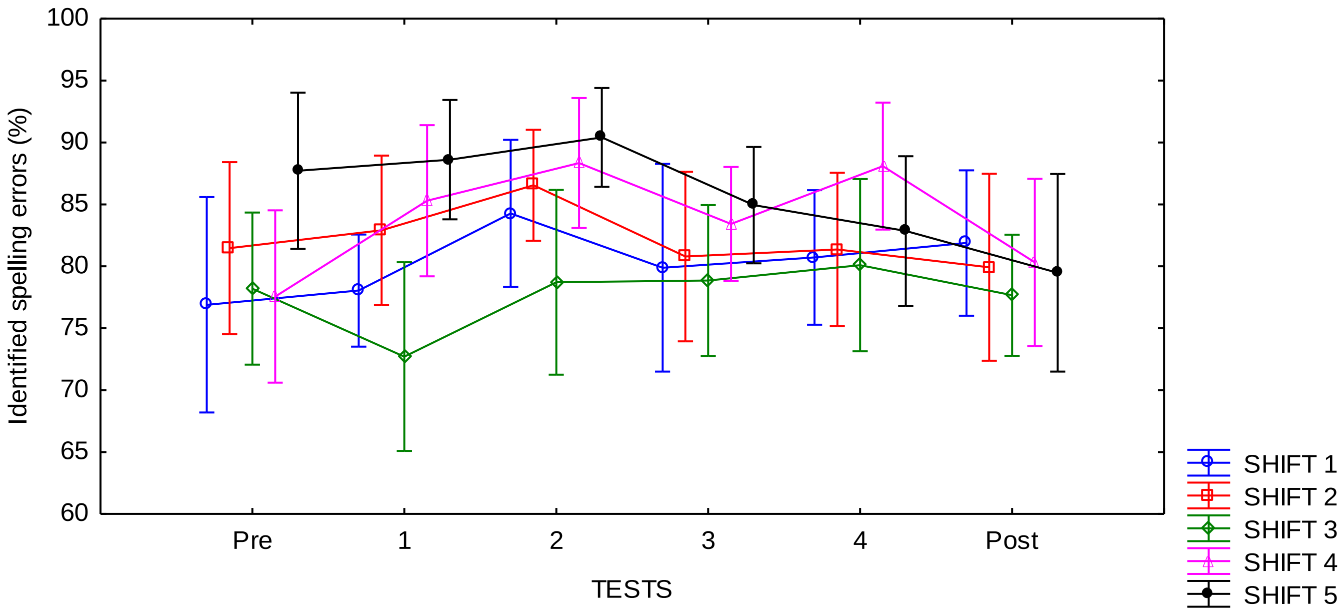

Figure 37: Interaction effect for error rate for reading performance between the six testing sessions and five consecutive shifts ($p < 0.05$; error bars depict 95% confidence interval).

4.3.4 Memory test task

Table xi: Statistical analysis of the recall rate of short-term memory and the impact of rehearsal time on memory recall rate for memory duration for the five consecutive shifts, six testing sessions and four shift work regimes.

	Recall rate for short-term memory			**Impact of rehearsal time on memory recall rate for memory duration**		
Effects	**DF**	**F**	**P**	**DF**	**F**	**P**
REGIMES	3, 35	3.23	**0.03**	3, 34	0.28	0.83
SHIFTS	4, 140	21.43	**< 0.01**	4, 136	2.74	**0.03**
TESTS	5, 175	1.34	0.24	5, 170	1.04	0.39
SHIFTS*REGIMES	12, 140	0.76	0.69	12, 136	1.08	0.37
TEST*REGIME	15, 175	0.71	0.76	15, 170	0.76	0.71
SHIFT*TESTS	20, 700	3.25	**< 0.01**	20, 680	1.28	0.18
SHIFT*TESTS*REGIMES	60, 700	1.06	0.35	60, 680	1.17	0.18

<u>Memory duration</u>

Only one significant effect was found for the impact of rehearsal time on memory recall rate for memory duration. This significance was found over the SHIFTS (Table XI), where performance declined from Shift 1 to Shift 5 (Figure 38). No other significant effects were found (Table XI).

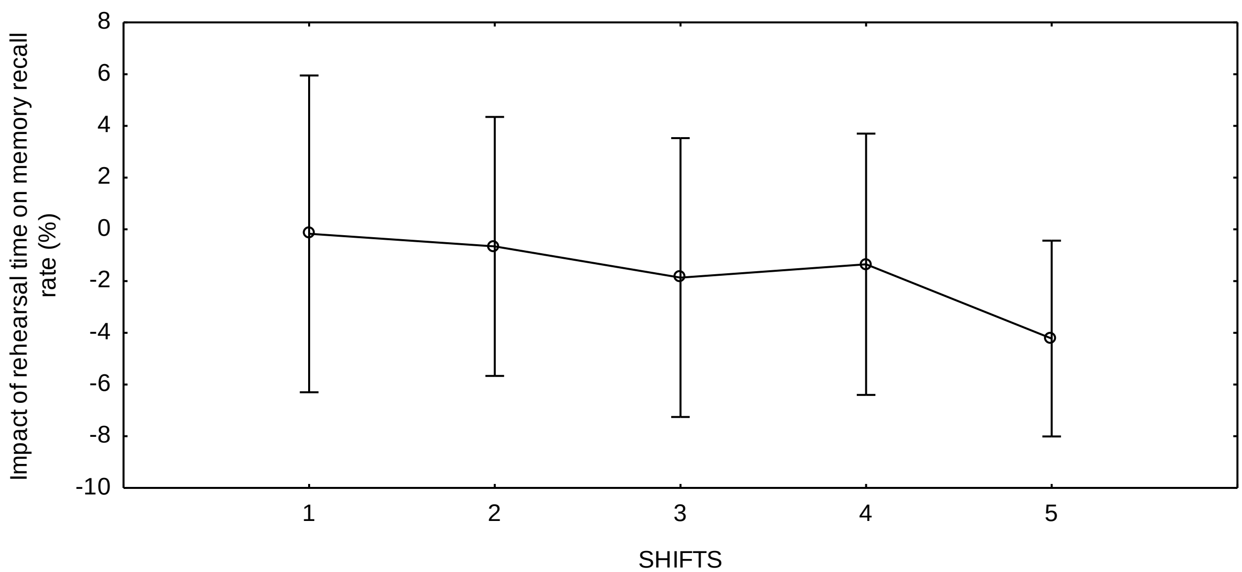

Figure 38: The impact of rehearsal time on memory recall rate for memory duration over the five consecutive shifts tested ($p < 0.05$; error bars depict 95% confidence interval).

Short-term memory

A significant effect was found for the recall rate for short-term memory between the shift work REGIMES, over the SHIFTS and for the interaction between the SHIFTS and TESTS (Table XI). The recall rate was similar for shift work REGIME A and C, where recall rate was lower for REGIME C and the worst for REGIME D (Figure 39). The recall rate increased over the five shifts (Figure 40). The interaction effect revealed that the recall rate during each testing session was dependent on the shift being performed (Figure 41). No other significant effects were found (Table XI).

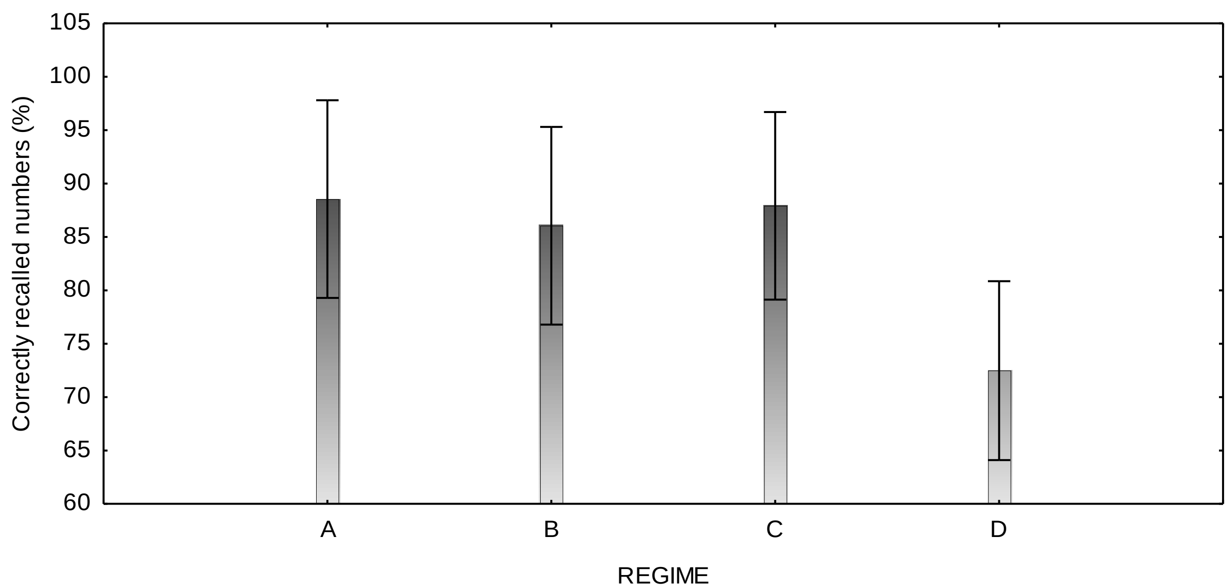

Figure 39: Recall rate for short-term memory across the four shift work regimes examined ($p < 0.05$; error bars depicts 95% confidence interval).

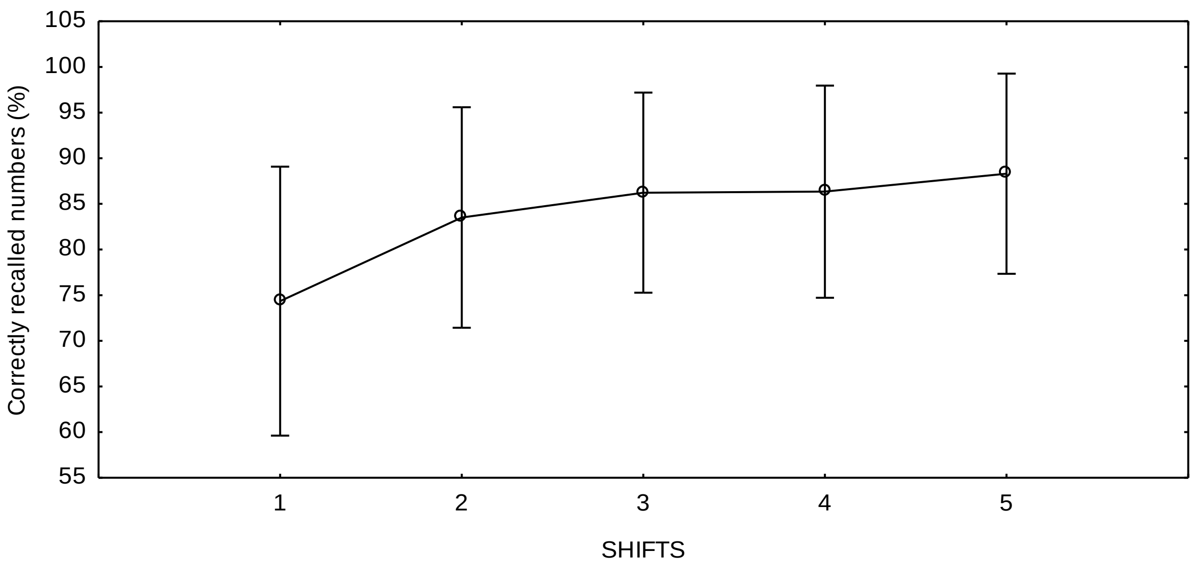

Figure 40: Recall rate for short-term memory over the five consecutive shifts tested ($p < 0.05$; error bars depict 95% confidence intervals).

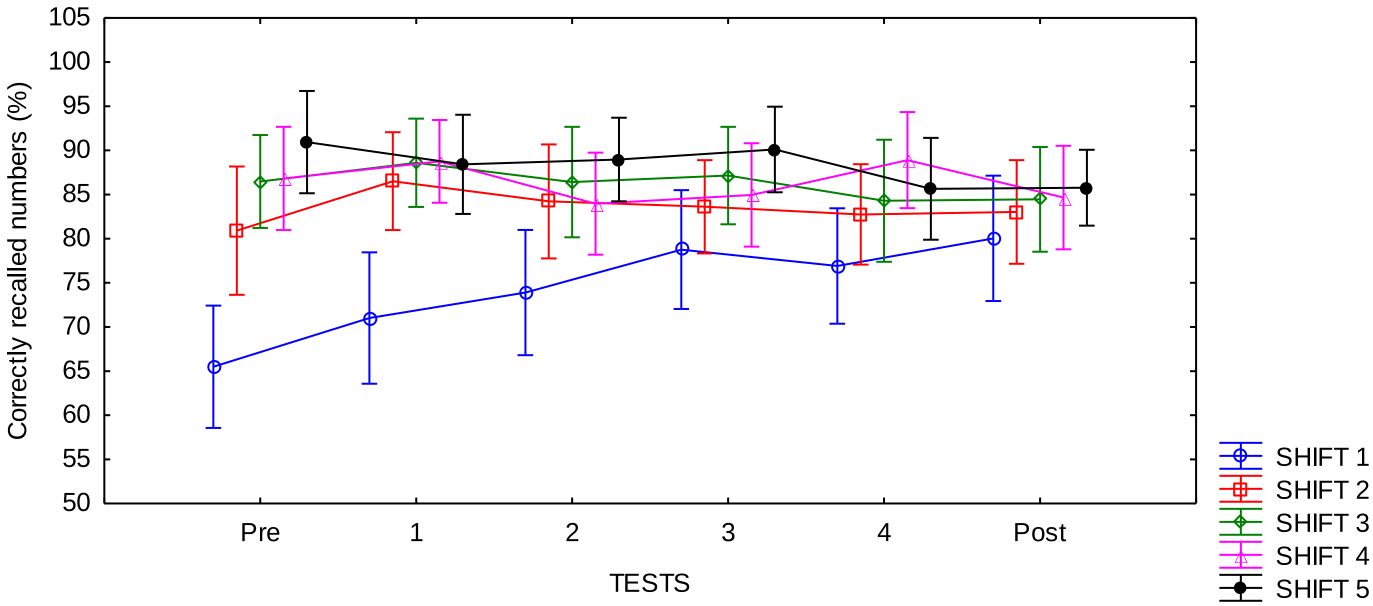

Figure 41: The interaction effect between the six testing sessions and five consecutive shifts for the recall rate for short-term memory ($p < 0.05$; error bars depict 95% confidence interval).

4.3.5 Tapping test task

Table xii: Statistical analysis of reaction time for motor control and of low precision and high precision motor programming time for the five consecutive shifts, six testing sessions and four shift work regimes.

		Reaction time for motor control		**Motor programming time – low precision**		**Motor programming time – high precision**	
Effects	**DF**	**F**	**P**	**F**	**P**	**F**	**P**
REGIMES	3, 39	1.34	0.27	1.55	0.21	1.28	0.29
SHIFTS	4, 156	3.37	**0.01**	49.10	**< 0.01**	48.09	**< 0.01**
TESTS	5, 195	1.87	0.31	9.24	**< 0.01**	9.23	**< 0.01**
SHIFTS*REGIMES	12, 156	1.16	0.10	0.49	0.917	1.15	0.31
TEST*REGIME	15, 195	1.37	016	1.13	0.32	1.20	0.27
SHIFT*TESTS	20, 780	1.05	0.39	1.57	0.053	1.23	0.21
SHIFT*TESTS*REGIMES	60, 780	0.96	0.54	0.96	0.55	0.93	0.61

Motor programming

A significant effect was found for motor programming time over the SHIFTS and over the TESTS for both high precision and low precision conditions (Table XII). Motor programming time increased from Shift 1 to Shift 5 and increased from Pre Test to Post Test for both conditions (Figure 42, 43, 44 and 45). No other significant effects were found (Table XII).

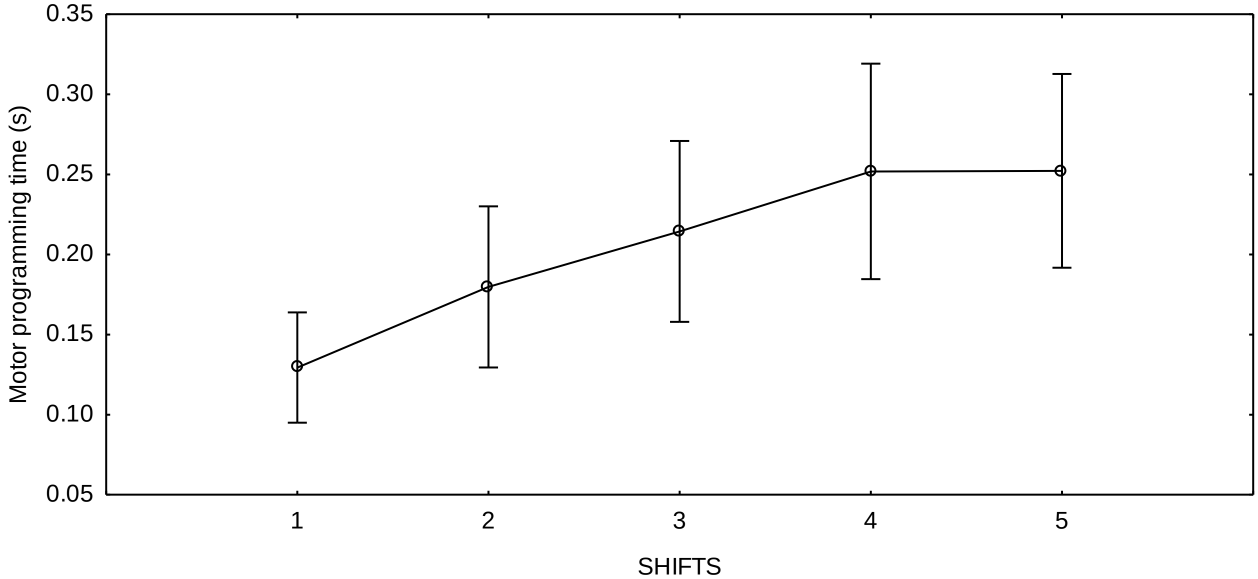

Figure 42: Motor programming time over the five consecutive shifts tested for the low precision condition ($p < 0.05$; error bars depict 95% confidence interval).

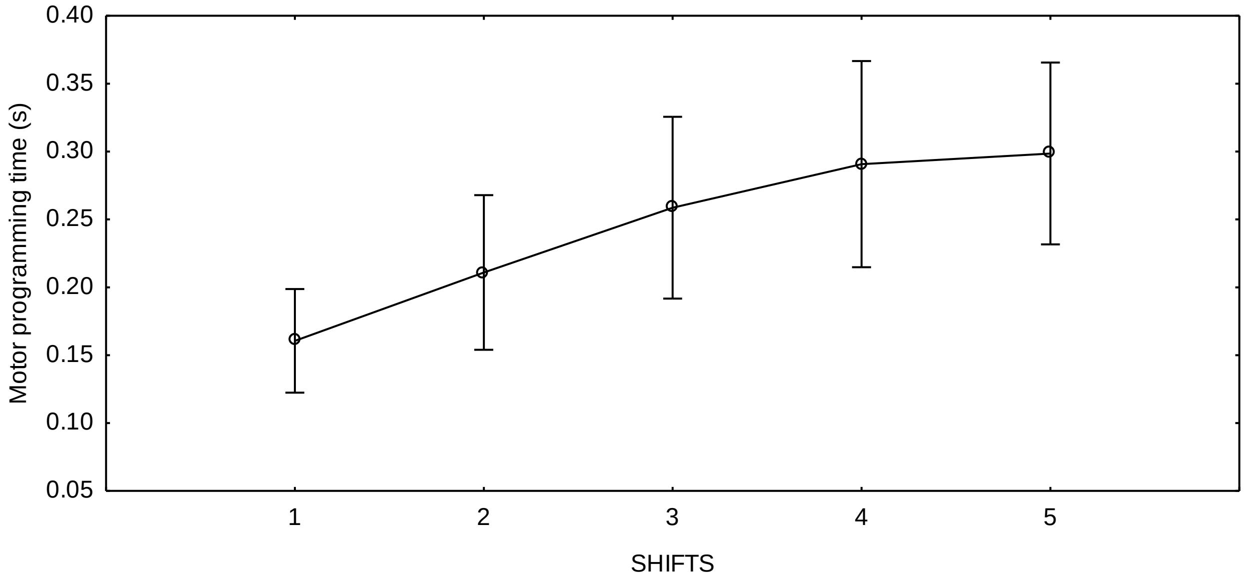

Figure 43: Motor programming time over the five consecutive shifts tested for the high precision condition ($p < 0.05$; error bars depict 95% confidence intervals).

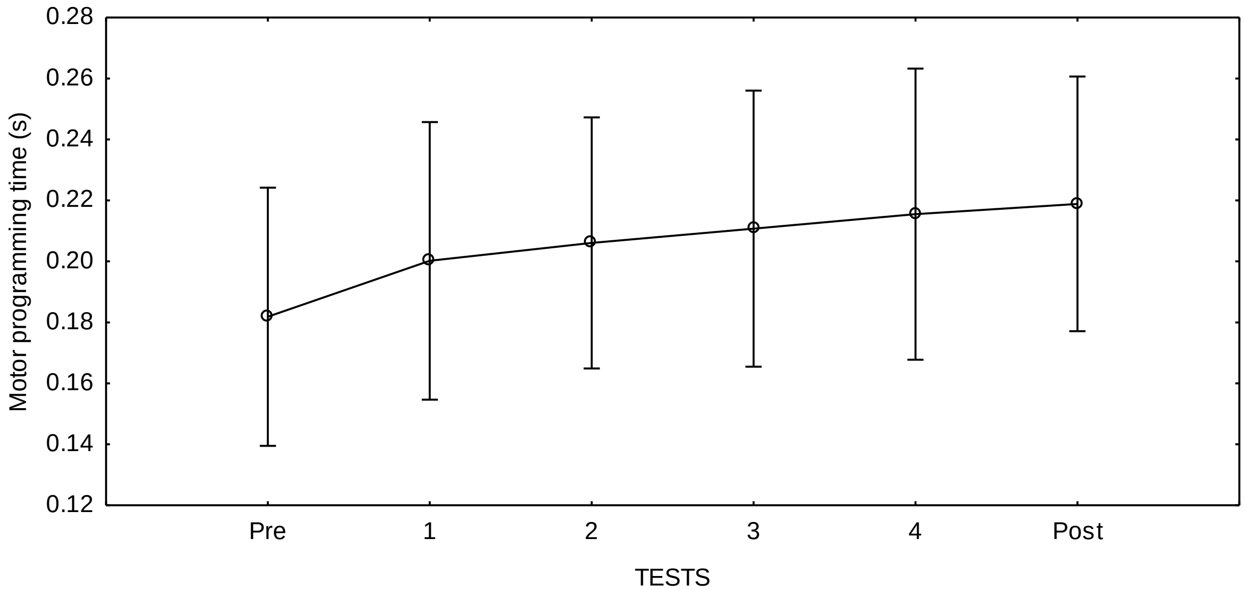

Figure 44: Motor programming time over the six testing sessions tested per shift for the low precision condition ($p < 0.05$; error bars depict 95% confidence interval).

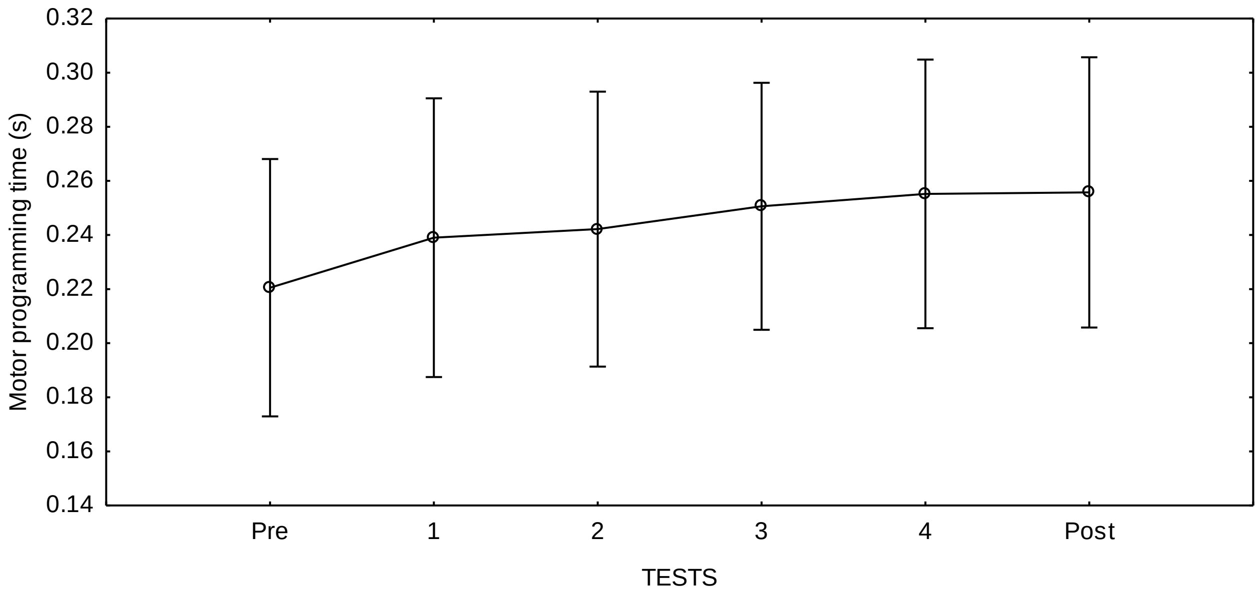

Figure 45: Motor programming time over the six testing sessions tested per shift for the high precision condition ($p < 0.05$; error bars depict 95% confidence interval).

Motor control

A significant effect was found for reaction time for motor control over the SHIFTS (Table XII), where reaction time decreased from the Shift 1 to Shift 5 (Figure 46). No other significant effects were found for reaction time of motor control (Table XII).

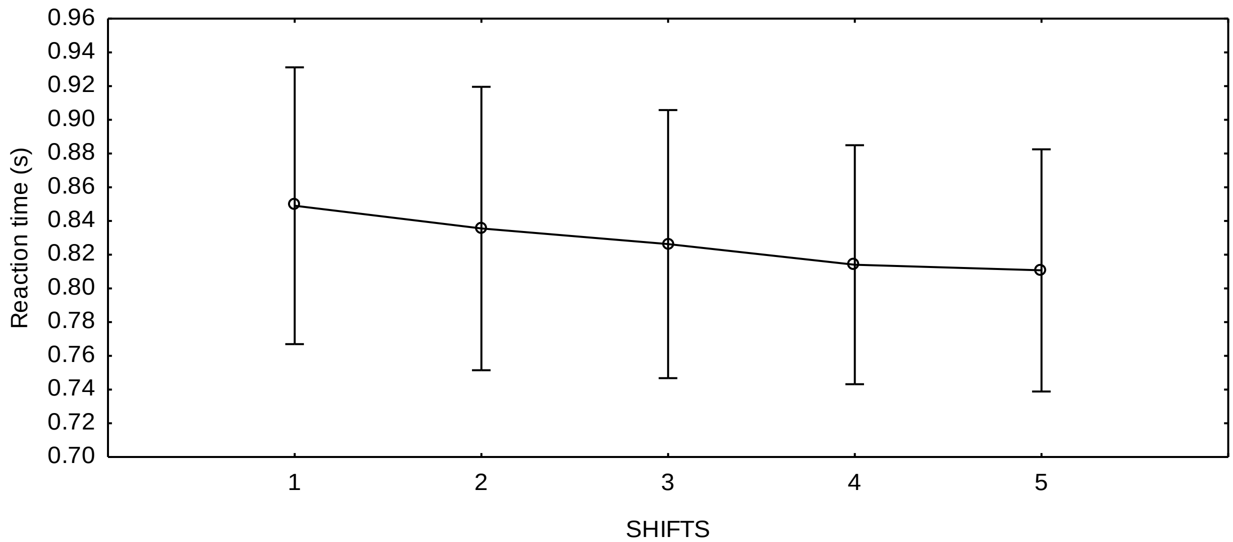

Figure 46: Reaction time for motor control over the five consecutive shifts tested ($p < 0.05$; error bars depict 95% confidence interval).

4.3.6 Simple reaction time test task

Table xiii: Statistical analysis of simple reaction time for the five consecutive shifts, six testing sessions and four shift work regimes.

Effects	Degrees of Freedom	F	P
REGIMES	3, 39	0.53	0.66
SHIFTS	4, 156	0.82	0.51
TESTS	5, 195	2.84	**0.01**
SHIFT*REGIMES	12, 156	0.35	0.97
TESTS*REGIMES	15, 195	1.17	0.29
SHIFTS*TESTS	20, 780	1.75	**0.02**
SHIFTS*TESTS*REGIMES	60, 780	0.81	0.83

A significant effect was found for simple reaction time over the TESTS and for the interaction between SHIFTS and TESTS (Table XIII). Reaction time increased from Pre Test to Test 4, followed by a decrease from Test 5 to Post Test (Figure 47), where reaction time was slower Post Test compared to Pre Test. The interaction effect revealed that reaction time during each testing session was dependent on the shift being performed (Figure 48). Except for Shift 1, reaction time was faster in the Pre Test compared to the Post Test for all shifts (Figure 48). There were no other significant effects found (Table XIII).

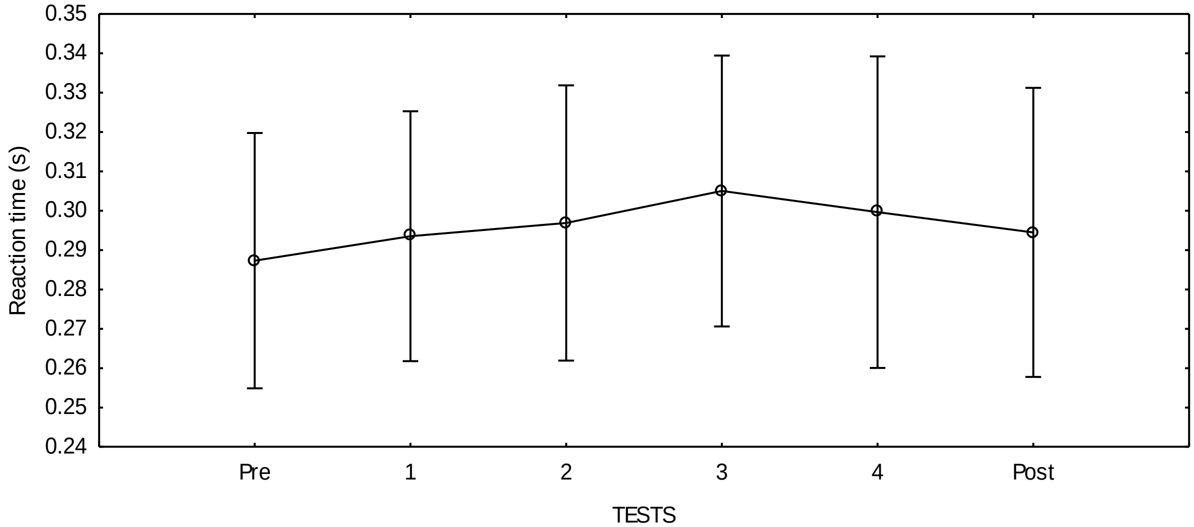

Figure 47: Simple reaction time over the 6 testing sessions tested per shift ($p < 0.05$; error bars depict 95% confidence interval).

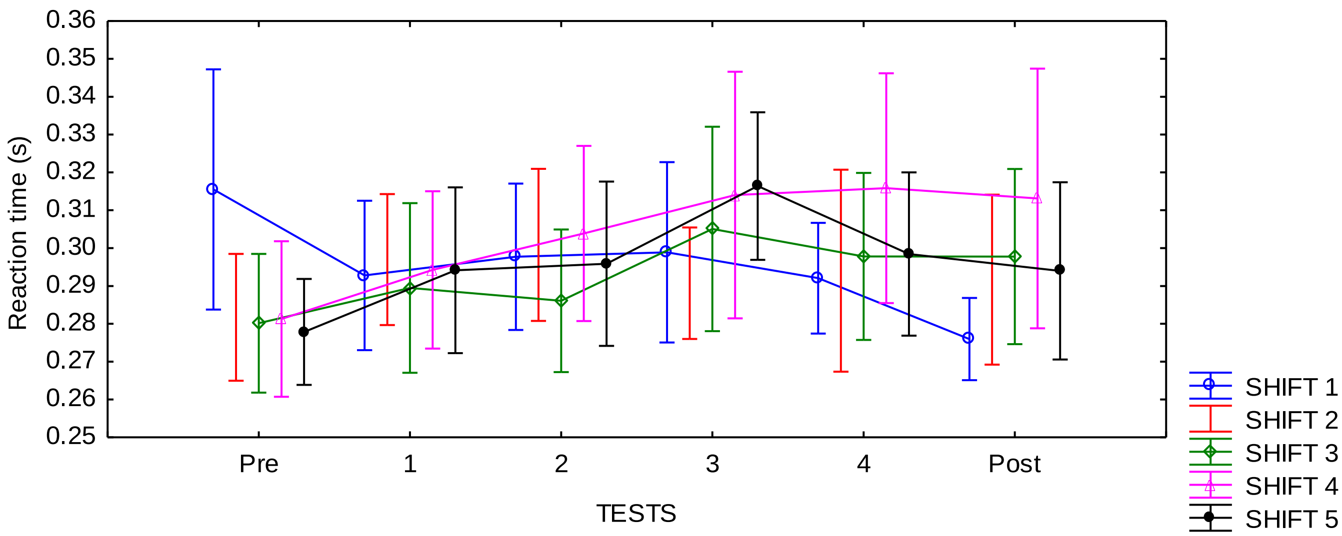

Figure 48: Interaction effect for simple reaction time between the five consecutive shifts and six testing sessions ($p < 0.05$; error bars depict 95% confidence interval).

4.4 DISCUSSION

A cognitive test task that showed a significant fatiguing effect for any parameter for either the cognitive function or task-related effect was taken into the field study, where both the cognitive function and task-related effect were examined for all parameters under investigation for the particular cognitive test task.

4.4.1 Accommodation test task

No significant effects were noted for eye accommodation time and error rate for eye accommodation. This revealed that eye accommodation was not sensitive to fatigue occurring during the simulated shift work. Choice reaction time revealed a learning effect or adaptation to shift work, as reaction time improved from Shift 1 to Shift 5. As this effect does not reveal a fatiguing effect and no other effects for choice reaction time were found, it was clear that choice reaction time was not sensitive to fatigue occurring during the simulated shift work. As no fatiguing effects were found for the accommodation test task, it was not included into the assessment tool.

4.4.2 Visual detection test task

There were no significant effects found for processing times, error rate and the impact of detection workload on tunnel view for visual discrimination. Thus, visual discrimination was not sensitive to fatigue occurring during the simulated shift work.

Reaction time and error rate for visual detection revealed either a learning effect or adaptation to shift work, as performance improved over the five consecutive shifts. However, there were three relevant findings found for visual detection. Firstly, there was a significant interaction effect for reaction time between the six testing sessions and the four shift work regimes. This suggests that fatigue within a shift was behaving differently for different types of shift work regimes investigated in the laboratory setting. Secondly, with regards to error rate, a significant fatiguing effect was found over the six testing sessions. Therefore, the quality of visual detection became impaired during each shift. Thirdly, there was a significant effect found over the five consecutive shifts for tunnel view, where tunnel view was worse during the night shifts (except shift 3) compared to the day shift. This reveals that tunnel vision was more prominent at night and peripheral vision became impaired.

As both error rate and tunnel view for visual detection revealed sensitivity to fatigue occurring within the shifts and between the five consecutive shifts respectively, during the simulated shift work and fatigue within each shift behaved differently for the different shift work regimes, the visual detection test task was added to the assessment tool.

4.4.3 Reading test task

A significant effect for processing time and error rate for visual pattern recognition was identified both over the five consecutive shifts and over the six testing sessions performed per shift. Processing time and error rate were worse during the night shifts compared to during the day shift and was worse after each shift compared to before each shift (Figure 28 and Figure 29). Thus, both speed and quality of visual pattern recognition were being impaired. This reveals that processing time and error rate for visual pattern recognition were both sensitive to fatigue occurring during the simulated shift work. Additionally, error rate during the six testing sessions varied with the shift being performed. This reveals that fatigue behaves differently within each shift. This effect was also noted for reading speed.

In terms of error rate for reading performance, a learning effect or adaptation to shift work was evident over the five consecutive shifts, as the amount of identified spelling errors increased over the five consecutive shifts. However, a fatiguing effect was noted for error rate over the six testing sessions, as more errors were identified before each shift compared to after each shift. Thus, the quality of reading performance was being compromised during each shift and was sensitive to fatigue occurring during the simulated shift work. In addition, the error rate during each shift varied with regards to the shift work regimes being performed, revealing that fatigue behaved differently for the different types of shift work regimes investigated. Also, the error rate for the six testing sessions depended on the shift being tested, which reveals that the different shifts elicited different fatiguing responses.

A number of fatiguing effects were noted for visual pattern recognition and reading performance, therefore the reading test task was inserted into the assessment tool.

4.4.4 Memory test task

Memory duration revealed a significant fatiguing effect over the five consecutive shifts examined, as the impact of rehearsal time on memory recall rate decreased from Shift 1 to Shift 5. Therefore, memory duration was sensitive to fatigue occurring across the five consecutive shifts in the simulated shift work laboratory setting.

Short-term memory performance was lower for shift work regime B and worst for shift work regime D compared to regimes A and C. This reveals that fatigue behaved differently for different types of shift work regimes. In contrast, short-term memory performance significantly improved over the five consecutive shifts. This improvement is likely attributed to a learning effect or adaptation to shift work. However, when examining the interaction effect between the five consecutive shifts and six testing sessions examined within each shift, it is obvious that the increase in performance over the shifts is due to Shift 1. The recall rate of Shift 1 improves over the five consecutive shifts, revealing a learning effect, whereas the night shifts reveal a slight decline in performance over the six testing sessions (Figure 41), where performance was worse after the shifts compared to before the shifts. Thus, short-term memory performance was fatiguing during simulated night shift work.

The memory test task was added to the assessment tool, as fatiguing effects were found across the five consecutive shifts for the impact of rehearsal time on memory recall rate for memory duration, amongst the shift work regimes as well as over the six testing session of the night shifts for short-term memory performance.

4.4.5 Tapping test task

Motor programming time for both the high and low precision conditions revealed significant fatiguing effects as motor programming time deteriorated over the six testing session performed per shift and across the five consecutive shifts examined for all shift work regimes under investigation. Thus motor programming time was sensitive to fatigue occurring both within and between the five consecutive shifts examined in the simulated shift work laboratory setting.

Motor control revealed a learning effect or adaptation to shift work as reaction time improved over the five consecutive shifts, which revealed that participants were responding faster from shift to shift. Thus, motor control did not reveal a fatiguing effect in the simulated shift work laboratory setting.

The tapping test task was added to the assessment tool as significant fatiguing effects were noted for motor programming time for both the high and low precision conditions.

4.4.6 Simple reaction time test task

A fatiguing effect was noted for simple reaction time between Pre test and Test 3, as performance decreased over the tests. However, this was followed by an improvement in performance to Post Test. Thus, the fatiguing effect noticed may be dominated by circadian fatigue. The important aspect to note for simple reaction time was that performance was worse after the shifts compared to before them. An interaction effect was found between the five consecutive shifts tested and the six tests examined per shift. This reveals that simple reaction time over the six testing sessions varies with the shift. The key characteristic to note from this effect was that reaction time for Shift 2, 3, 4 and 5 was faster before the shifts compared to afterwards. This reveals that during the simulated night shift work, simple reaction time was worse after the night shifts shift than prior to it, which reveals a fatiguing effect. This was supported by the significant effect found over the six tests, where reaction time was slower after the shifts compared to before them. Therefore, the simple reaction time test task was added to the assessment tool.

4.4.7 CONCLUSION

Fatiguing effects were evident for either the cognitive function or task-related effect for at least one parameter of all cognitive test tasks except the driving simulator test task and accommodation test task. Thus, visual detection, reading, memory, tapping and simple reaction time test tasks were added into the assessment tool, which will be taken into

Phase 2 in order to be tested in a field-based rotational shift work setting. Additionally, a neural control test task will be added to the assessment tool in order to replace the driving simulator test task, where analysis could not occur. After a pilot test, this test task revealed a fatiguing trend for peripheral neural control (refer to Chapter 3.4.6 for more details on this matter).

CHAPTER 5

PHASE 2

5.1 INTRODUCTION

The aim of this phase was to validate the assessment tool developed for mental fatigue in Phase 1 in a field-based setting where different types of companies, that undertake different types of rotational shift work regimes and working tasks, were assessed. Additionally, this phase would inform whether mental fatigue behaved differently for different types of rotational shift work regimes and working tasks. Cognitive functions and task-related effects revealing significant fatiguing effects for any company would be added to the assessment tool so as to be validated for measuring mental fatigue occurring during rotational shift work. This chapter will investigate the methodology undertaken, after which the results of this phase will be analysed and discussed.

5.2 METHODOLOGY

5.2.1 Experimental design

The assessment tool from Phase 1 was examined in three different companies in Johannesburg, South Africa, where each company performed a different type of rotational shift work system and manufactured different products. Rotational shift work was analysed as this system has been proven to cause the most amount of mental fatigue due to constant disruption of the circadian rhythm and cumulative sleep loss (Dula *et al*., 2001). Company A and Company B performed a two-shift rotational shift work system and Company C performed a three-shift rotational shift work system.

Each company was required to perform different types of rotational shift work systems and manufacture different products, as these two factors might elicit different fatiguing responses. A cognitive function or task-related effect may be more taxed due to extended work periods (longer shift duration); or a cognitive function or task-related effect may be fully utilised in one company, but not in another. Thus, the fatiguing responses may be different within the different companies under investigation.

The assessment tool was examined before and after work (pre-post tests) on each shift type in the rotational shift work system adopted by each company. It must be noted that shift type refers to the different shifts performed within each rotational shift work system, i.e. day shift and night shift.

The assessment tool comprised six cognitive test tasks which revealed sensitivity to mental fatigue in the simulated shift work laboratory setting (Phase 1). Therefore, the testing venue within each company consisted of six workstations, where each hosted a different cognitive test task. The workstations were set up in a circular formation in the testing venues, where participants were required to rotate in a clockwise direction from test task to test task (Figure 49 and 50). This set-up allowed for multiple workers to be tested at one time (maximum six). The order of testing regarding the cognitive test tasks and level of difficulty was equally distributed amongst participants (Appendix B2).

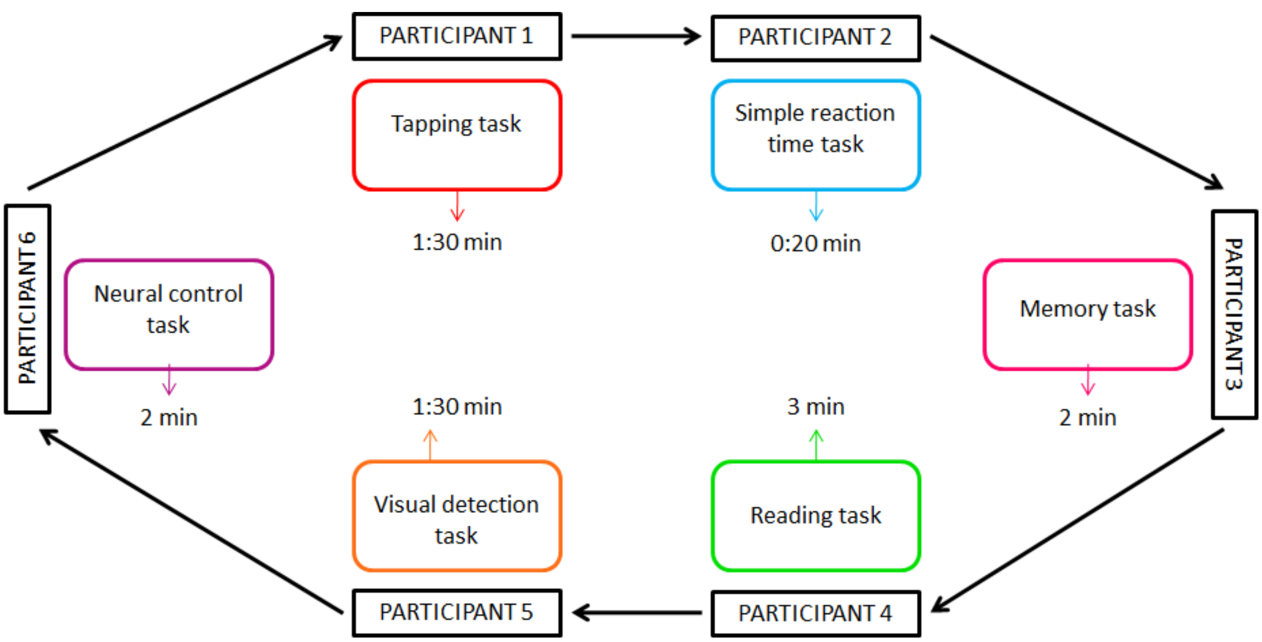

Figure 49: Layout of the assessment tool and total duration for each cognitive test task.

Figure 50: Testing venue in each company where testing was commenced. From right to left: Company A, Company B and Company C.

The total time taken to complete the assessment tool was 10:20 minutes; however, the maximum time taken was 18 minutes (Figure 50). This was due to the reading test task taking three minutes to complete. Participants could only rotate to the next test task once this was finished.

The testing venue was isolated from the factory and was kept constant throughout the testing process within each company; enabling the following co-founding variables to be controlled: lighting, temperature, distractions and noise.

The following elements were not able to be controlled in this study: sample size, age, gender, ethnicity and chronotype. This was due to three main factors: company restrictions, volunteers and literacy. Each company suggested the sample size. Workers volunteered for the study, where they were expected to come to work early and remain after work, which resulted in minimal volunteers. Additionally, all volunteers for the study were required to be literate.

In order to attempt to control sleep patterns and duration of wakefulness, participants were requested to maintain normal sleeping patterns throughout however it must be noted that was a confounding variable as sleep was not monitored by the researcher.

5.2.2 Companies where testing commenced

The companies were analysed independently as the rotational shift work regimes and working tasks differed between the companies. The working task of each worker within each company could not be controlled due to the limited sample and having insufficient workers participating in the same working task within each company. This could influence the data as some tasks were more manual in nature whilst others were more cognitive.

Company A

This company specialises in the manufacture of PET pre-forms, jars and bottles. This company performs stretch blow-moulding of containers, injection moulding of pre-forms and application of wraparound stretch labels. Within the factory, the workers perform tasks such as machine packer, quality control inspector, shift technician, general worker and supervisor.

Table xiv: Working tasks of participants in Company A.

Task	**Amount of workers tested**
Machine packer	6
Quality control inspector	4
Shift technician	2
General worker	4
Supervisor	2

Company B

This company specialises in the manufacture and supply of masterbatches and pigments to the plastics industry. These products are added during the manufacturing process to impart colour and/or performance properties to the end product. Masterbatch is manufactured in two stages. Firstly, the ingredients are combined in either high or low-speed mixers to ensure even distribution of materials. Secondly, the pre-mix is compounded on either a single or twin screw extruders and pelletised into the finished product. Working tasks include: mixers, extruder operators and bag weighers.

Table xv: Working tasks of participants in Company B.

Task	**Amount of workers tested**
Mixers	10
Extruder operators	8
Bag weighers	6

Company C

This company manufactures flour and sells it to bakeries nationally and globally. Wheat is harvested and brought to the mill, where it is cleaned, washed and ground into flour which is then separated from the wheat skin and packed into bags. This is sold to bakeries and other interested companies. Different types of working tasks within this company include: forklift drivers, machine operators, bag fillers, millers, plant sifters and supervisors.

Table xvi: Working tasks of participants in Company C.

Task	Amount of workers tested
Forklift driver	3
Machine operator	4
Bag filler	3
Miller	5
Plant sifter	3
Supervisor	3

5.2.3 Independent variables

Testing occurred before and after work for each shift type in the rotational system adopted by each company under investigation. It could not occur during the shifts as it would disrupt work. This was a limitation as testing during each shift type would broaden our understanding of mental fatigue behaviour occurring during shift work. Additionally, workers were only tested once before and once after each shift type. The ideal situation would consist of testing workers for all consecutive shifts for each shift type. However, this was not possible due to the intensive nature of the testing and company constraints. Thus, in order to eliminate the factors associated with rotating into a new shift and the fatiguing effects for the last consecutive shift, the participants were equally distributed over the consecutive working shifts. Additionally, workers had to perform testing on the same consecutive shift for all testing sessions of each shift type.

Thus, there were two independent variables tested in this phase: shift type and pre-post tests. It must be noted that each company had two 15-minutes rest breaks per shift and a 30-minute lunch/dinner break per shift. Additionally, participants were paid R50 ($5) per shift type.

Company A

This company adopted a 12- hour, two-shift rotational shift work system: rotation between day and night shifts: 06h00 to 18h00 and 18h00 to 06h00 respectively. Workers were required to work three consecutive shifts, followed by three consecutive days off. Rotation between the day shift and the night shift occurs every six days (three working shifts, three days off).

Table xvii: Structure of the rotational shift work system for Company A.

Shift	Day	Off	Night	Off
Amount of days	3	3	3	3

For Company A, 18 workers participated in the study, where each was required to perform testing before and after work on one day shift and on one night shift (four testing sessions). Nine participants started testing on a day shift and nine on a night shift. Additionally, they were equally distributed amongst the three consecutive shifts worked, thus three workers were tested per consecutive shift (3 days x 3 workers = 9 participants, Figure 51).

	Day Shift			**Days off**			**Night Shift**			
	18-May	19-May	20-May	21-May	22-May	23-May	24-May	25-May	26-May	
Shift system 1	Day 1	Day 2	Day 3	Off 1	Off 2	Off 3	Night 1	Night 2	Night 3	
Workers	3	3	3				3	3	3	9 workers

	Night Shift			**Days off**			**Day shift**			
	18-May	19-May	20-May	21-May	22-May	23-May	24-May	25-May	26-May	
Shift system 2	Night 1	Night 2	Night 3	Off 1	Off 2	Off 3	Day 1	Day 2	Day 3	
Workers	3	3	3				3	3	3	9 workers

Total workers	18

Each colour represents 3 participants and their relative testing sessions throughout the testing procedure

Figure 51: Testing layout and structure for Company A.

Company B

This company adopts an irregular two-shift rotational shift system between day and night shift. Workers are required to work from Monday to Thursday (four days), followed by three days off (Friday-Sunday). The rotation between day shift and night shift occurs on a weekly basis, where day shift starts at 07h00 and ends at 17h00 (10-hour shift) and night shift starts at 17h00 and ends at 06h00 (13-hour shift).

Table xviii: Structure of the rotational shift work system for Company B.

Shift	Day	Off	Night	Off
Amount of days	4	3	4	3

For Company B, 24 workers participated in the study, where each was required to perform testing before and after work on one day shift and on one night shift (four testing sessions). Twelve participants started testing on a day shift and 12 participants on a night shift. Additionally, they were equally distributed amongst the four consecutive shifts worked, thus three workers were tested per consecutive shift (4 days x 3 workers = 12 participants, Figure 52).

	Day Shift				**Day off**			**Night Shift**				
	3-Jun	4-Jun	5-Jun	6-Jun	7-Jun	8-Jun	9-Jun	10-Jun	11-Jun	12-Jun	13-Jun	
Shift system 1	Day 1	Day 2	Day 3	Day 4	Off 1	Off 2	Off 3	Night 1	Night 2	Night 3	Night 4	
Workers	3	3	3	3				3	3	3	3	12 Workers

	Night Shift				**Day off**			**Day Shift**				
	3-Jun	4-Jun	5-Jun	6-Jun	7-Jun	8-Jun	9-Jun	10-Jun	11-Jun	12-Jun	13-Jun	
Shift system 2	Night 1	Night 2	Night 3	Night 4	Off 1	Off 2	Off 3	Day 1	Day 2	Day 3	Day 4	
Workers	3	3	3	3				3	3	3	3	12 Workers

Total workers	**24**

Each colour represents 3 participants and their relative testing sessions throughout the testing procedure

Figure 52: Testing layout and structure of company B.

Company C

This company adopts an eight-hour, three-shift rotational shift system between evening, afternoon and morning shift, where the shift work rotation is anti-clockwise. Workers are required to work from Monday to Thursday (four days) with three days off (Friday - Sunday). The rotation between the shifts occurs on a weekly basis, where the morning shift is from 06h00 – 14h00, the afternoon shift is from 14h00 – 22h00 and the evening shift is from 22h00 – 06h00.

Table xix: Structure of the rotational shift work system for Company C.

Shift	Morning	Off	Evening	Off	Afternoon	Off
Amount of days	4	3	4	3	4	3

For company C, 21 workers participated in the study, where each was required to perform testing before and after work on one morning, on one afternoon and on one evening shift (six testing sessions). Seven of the participants started testing on a morning shift, seven on an afternoon shift and seven on an evening shift. Additionally, an attempt to equally distribute the participants over the four consecutive shifts was made; however, seven is a prime number and not divisible by four. Thus two participants were tested for consecutive shift 1, 2 and 4, and one participants was tested for consecutive shift 3 (seven participants in total, Figure 53).

	Morning Shift				Off	Afternoon Shift				Off	Evening Shift				
	24-Jun	25-Jun	26-Jun	27-Jun	28 - 30 Jun	1-Jul	2-Jul	3-Jul	4-Jul	5-7 Jul	8-Jul	9-Jul	10-Jul	11-Jul	
Shift System 1	Mor 1	Mor 2	Mor 3	Mor 4	Off 1 - 3	Aft 1	Aft 2	Aft 3	Aft 4	Off 1 – 3	Eve 1	Eve 2	Eve 3	Eve 4	
Workers	2	2	1	2		2	2	1	2		2	2	1	2	7 Workers

	Afternoon Shift				Off	Evening Shift				Off	Morning Shift				
	24-Jun	25-Jun	26-Jun	27-Jun	28 - 30 Jun	1-Jul	2-Jul	3-Jul	4-Jul	5-7 Jul	8-Jul	9-Jul	10-Jul	11-Jul	
Shift System 2	Aft 1	Aft 2	Aft 3	Aft 4	Off 1 - 3	Eve 1	Eve 2	Eve 3	Eve 4	Off 1 - 3	Mor 1	Mor 2	Mor 3	Mor 4	
Workers	2	2	1	2		2	2	1	2		2	2	1	2	7 Workers

	Evening Shift				Off	Morning Shift				Off	Afternoon Shift				
	24-Jun	25-Jun	26-Jun	27-Jun	28 - 30 Jun	1-Jul	2-Jul	3-Jul	4-Jul	5-7 Jul	8-Jul	9-Jul	10-Jul	11-Jul	
Shift System 3	Eve 1	Eve 2	Eve 3	Eve 4	Off 1 - 3	Mor 1	Mor 2	Mor 3	Mor 4	Off 1 - 3	Aft 1	Aft 2	Aft 3	Aft 4	
Workers	2	2	1	2		2	2	1	2		2	2	1	2	7 Workers

Each colour represents a group of participants and their relative testing sessions throughout the testing procedure

Workers	**21**

Figure 53: Testing layout and structure of Company C.

5.2.4 Dependent variables

The dependent variables consisted of cognitive test task performance: cognitive functions and task-related effects. Six cognitive test tasks were examined: visual detection, reading, memory, tapping, neural control and simple reaction time.

The six cognitive test tasks were performed before and after work for each shift type examined for each Company under investigation.

5.2.5 Participant characteristics

The number of participants tested within each company varied (Table XX). Male and female participants of any age were tested in this study. All participants were required to be literate (completed junior school) and to be able to read in English, Afrikaans, Xhosa or Zulu languages (please refer to Chapter 3 for more information).

Table xx: Participant characteristics for Company A, Company B and Company C.

		Company A	Company B	Company C
Total participants		18	24	21
Age (mean)		34	35	39
Gender	Males	10	22	20
	Female	8	2	2
Language	English	11	21	14
	Xhosa	0	0	3
	isiZulu	6	3	2
	Afrikaans	1	0	0
School	Yes	18	24	21
	No	0	0	0
School level completed	College	1	1	4
	Matric	11	12	8
	High school	5	11	3
	Junior School	1	0	6

Participants were excluded if they were on any medication (increases arousal or sleepiness), illiterate, suffered from dyslexia (will not be able to perform the reading test task) or suffered from any sleep and/or attention disorders, as these would influence the performance measures.

5.2.6 Ethical consideration

This phase was approved by the ethics committee of the Human Kinetics and Ergonomics Department of Rhodes University (Appendix A4) prior to any testing taking place. Each company informed its employees of the testing and requested volunteers for the study. Workers were also informed of the requirements necessary to participate in the study. Each participant was identified using a participant code, rather than their first name, in order to keep data confidential. Participants were reminded before and throughout the process that they were free to leave the testing at any point and there would be no negative consequences for them if this decision was made.

5.2.7 Experimental procedures

Habituation session

Before testing commenced, each participant was required to attend a habituation session where the study requirements, assessment tool, procedure and payment was explained to them both verbally and in writing (Appendix A2). After which, those that were willing to participate in the study signed a consent form (Appendix A3) and completed a form requesting details of age, gender, language preference and level of schooling. Once the relevant information was captured, each participant was given a code, with their particular cognitive test task and level of difficulty order (Appendix B2).

Each participant was required to perform the assessment tool in their particular given order. They were required to become familiar with the test tasks and the requirements of each to ensure that they were performed correctly. If participants were computer illiterate, they were taught how to use the computers and requested to come in for another habituation session. This was intended to eliminate learning effects.

After participants were familiar with the assessment tool, they were informed about project restrictions. It was explained that if these were not followed, it would impact upon the data collected by interfering with alertness, cognitive performance and attention (Goble, 2013). These included: not drinking alcohol or digesting caffeine 24 hours before testing commenced or during a testing shift. Participants were also asked to not perform vigorous activity 12 hours beforehand as this might cause an early onset of fatigue. They were informed to avoid the use of cell phones in the testing venue as it might cause distractions, alter mood or increase alertness. Additionally, workers were requested to arrive promptly at the testing venue, as testing could only commence once all participants were present. This was necessary to minimise distractions and to ensure the order of testing was not compromised.

Procedure

Participants were tested 20 minutes before work started and again after work for one shift of each respective type in the rotational shift work system adopted by the relevant company. During each testing session, the assessment tool, which consisted of six cognitive test tasks, was performed. Participants were required to remain silent and only rotate to the next work station once everyone had finished their particular test task.

5.2.8 Analysis, statistical analysis and statistical hypotheses

Analysis

As the rotational shift work systems and manufactured product were different in each company, each was analysed independently. Workers within each company were tested before and after work for each shift type, thus, this study was a repeated design within each company. In order to validate the assessment tool for mental fatigue during rotational shift work, the parameters of the cognitive functions and task-related effects will be compared before and after the shifts (PRE-POST) and will be compared between the different shift types (SHIFT TYPE) within each company.

A parameter of a cognitive function or a task-related effect will be added to the assessment tool, if a fatiguing effect was noted for any of the companies under investigation. The reason for this is that companies in general are different with regard to rotational shift work systems and manufactured products. This leads to fatiguing effects or behaviour of fatigue differing between companies. Thus, if these effects are noted in one company, the parameter has shown sensitivity to mental fatigue occurring during rotational shift work.

Statistical analysis

The data was analysed using a two-way ANOVA in order to examine performance between the PRE-POST tests and between the SHIFT TYPES for each company separately, where SHIFT TYPE was one factor and PRE-POST tests was the second.

The analysed data was either raw or via z-transformation; the latter is a mathematical equation that equals out variance between participants and equalises the amount of variance within them. Z-transformation was applied to the parameters in Table XXI, as the captured data was highly variable within and between each participant. This variability was due to computer illiteracy and the participants having varied levels of education. Additionally, variability increased as age and gender were not controlled. For all other parameters, the raw collected data was used (Table XXI). The statistical analyses were performed using Statistica software package 10 (Statistica©; Statsoft Inc.; Tulsa; Oklahoma, USA).

Table xxi: Data analysed using the raw collected data and using Z-transformation.

Raw Data	**Z-transformation**
Processing time for visual discrimination	Error rate for visual discrimination and visual detection
Reaction time for visual detection	Impact of detection workload on tunnel view for visual discrimination
Tapping test task	Tunnel view for visual detection
Neural control test task	Reading test task
Simple reaction time test task	Memory test task

<u>Statistical hypotheses</u>

These hypotheses below are valid for all parameters of each cognitive function and task-related effect under investigation:

- Visual detection test task:
    - Visual discrimination: processing time (s), error rate (%) and impact of detection workload on tunnel view (Δr)
    - Visual detection: reaction time (s), error rate (%) and tunnel view index (Δr)
- Reading test task:
    - Visual pattern recognition: processing time (words/min) and error rate (%)
    - Reading performance: reading speed (words/min) and error rate (%)
- Memory test task:
    - Memory duration: impact of rehearsal time on memory recall rate (%)
    - Short-term memory performance: recall rate (%)
- Tapping test task:
    - Motor programming: motor programming time for the low precision condition and for the high precision condition (s)

- Motor control: reaction time (s)

- Neural control test task:
  - Peripheral neural control: impact of movement sensitivity demands on reaction time (s)
- Simple reaction time test task: reaction time (s)

Hypothesis 1: The null hypothesis proposed that there will be no significant difference between the shift types for each company.

Company A and B

Ho: $\mu_{S1} = \mu_{S2}$

Ho: $\mu_{S1} \neq \mu_{S2}$

Where: S1 = Day Shift, S2 = Night Shift

Company C

Ho: $\mu_{S1} = \mu_{S2} = \mu_{S3}$

Ho: $\mu_{S1} \neq \mu_{S2} \neq \mu_{S3}$

Where: S1 = Morning Shift, S2 = Afternoon Shift, S3 = Evening Shift

Hypothesis 2: The null hypothesis proposed that there will be no significant difference between the Pre Tests and Post Tests for each company.

Ho: $\mu_{T1} = \mu_{T2}$

Ho: $\mu_{T1} \neq \mu_{T2}$

Where: T1 =Pre Test, T2 = Post Test

Hypothesis 3: The null hypothesis proposed that there will be no significant interaction effect between the shift types and pre-post tests.

5.3 RESULTS

In this section, the significant effects for each parameter of each cognitive function and task-related effect for each cognitive test task will be investigated between the PRE-POST tests and between the SHIFT TYPES for each company individually.

Table xxii: Key displaying the meanings of the statistical analyses.

SHIFT TYPE	Day shift vs. night shift OR morning shift vs. afternoon shift vs. evening shift
PRE-POST	Testing sessions performed before work and after work

It is important to note that Pre Test refers to the testing sessions occurring before the shifts and Post Test refers to the testing sessions occurring after the shifts.

5.3.1 Visual detection test task

Table xxiii: Statistical analysis of reaction time for visual detection and processing time for visual discrimination for the shifts types and pre-post tests for each individual company.

Company	Effects	DF	Reaction time for visual detection		Processing time for visual discrimination	
			F	P	F	P
A	**SHIFT TYPE**	1, 16	0.25	0.62	0.37	0.54
	PRE-POST	1, 16	0.28	0.60	0.02	0.88
	SHIFT TYPE*PRE-POST	1, 16	0.31	0.58	0.17	0.68
B	**SHIFT TYPE**	1, 21	0.30	0.58	1.06	0.31
	PRE-POST	1, 21	0.55	0.46	0.57	0.45
	SHIFT TYPE*PRE-POST	1, 21	0.02	0.88	0.02	0.87
C	**SHIFT TYPE**	2, 30	0.43	0.65	0.33	0.71
	PRE-POST	1, 15	0.61	0.44	0.94	0.34
	SHIFT TYPE*PRE-POST	2, 30	0.48	0.62	0.82	0.44

Table xxiv: Statistical analysis of error rate for both visual detection and visual discrimination for the shifts types and pre-post tests for each individual company.

Company	Effects	DF	Error rate for visual detection		Error rate for visual discrimination	
			F	P	F	P
A	SHIFT TYPE	1, 16	0.40	0.53	0.27	0.60
	PRE-POST	1, 16	0.09	0.76	0.63	0.43
	SHIFT TYPE*PRE-POST	1, 16	0.02	0.89	0.77	0.39
B	SHIFT TYPE	1, 20	0.04	0.83	0.01	0.97
	PRE-POST	1, 20	0.78	0.39	0.74	0.40
	SHIFT TYPE*PRE-POST	1, 20	0.04	0.83	4.90	**0.04**
C	SHIFT TYPE	2, 34	0.68	0.51	1.44	0.25
	PRE-POST	1, 17	1.94	0.18	0.33	0.56
	SHIFT TYPE*PRE-POST	2, 34	0.26	0.76	3.36	**0.04**

Table xxv: Statistical analysis of the tunnel view index and the impact of detection workload on tunnel view for visual discrimination for the shifts types and pre-post tests for each individual company.

Company	Effects	DF	Tunnel view index for visual detection		Impact of detection workload on tunnel view for visual discrimination	
			F	P	F	P
A	SHIFT TYPE	1, 16	< 0.01	0.84	0.52	0.48
	PRE-POST	1, 16	0.01	0.70	0.58	0.45
	SHIFT TYPE*PRE-POST	1, 16	0.06	0.80	1.58	0.22
B	SHIFT TYPE	1, 21	0.55	0.46	1.03	0.32
	PRE-POST	1, 21	0.03	0.85	3.09	0.09
	SHIFT TYPE*PRE-POST	1, 21	0.01	0.98	0.16	0.69
C	SHIFT TYPE	2, 34	0.16	0.85	0.36	0.69
	PRE-POST	1, 17	0.56	0.46	0.16	0.68
	SHIFT TYPE*PRE-POST	2, 34	0.62	0.54	1.53	0.22

Visual discrimination

There were no significant effects found for processing time for visual discrimination for any company under investigation (Table XXIII). In terms of error rate for visual discrimination, no significant effects were found for Company A (Table XXIV). There was a significant interaction effect found for both Company B and Company C between

SHIFT TYPES and PRE-POST tests for error rate for visual discrimination (Table XXIV). In terms of Company B, error rate was worse after the day shift compared to before the day shift, whereas error rate improved from Pre Test to Post Test for the night shift (Figure 54). After a paired t-test was conducted on each shift type separately for Company B, only the day shift ($p = 0.03$) revealed a significant effect between the PRE-POST tests, where error rate was worse after the shift. In terms of the interaction effect found for Company C, error rate before and after work depended on the shift type being performed. Error rate deteriorated during the afternoon shift and evening shift whereas error rate improved during the morning shift (Figure 55). No other significant effects were found for Company B and Company C (Table XXIV). Additionally, no significant effects were found for the impact of detection workload on tunnel view for any company under investigation (Table XXV).

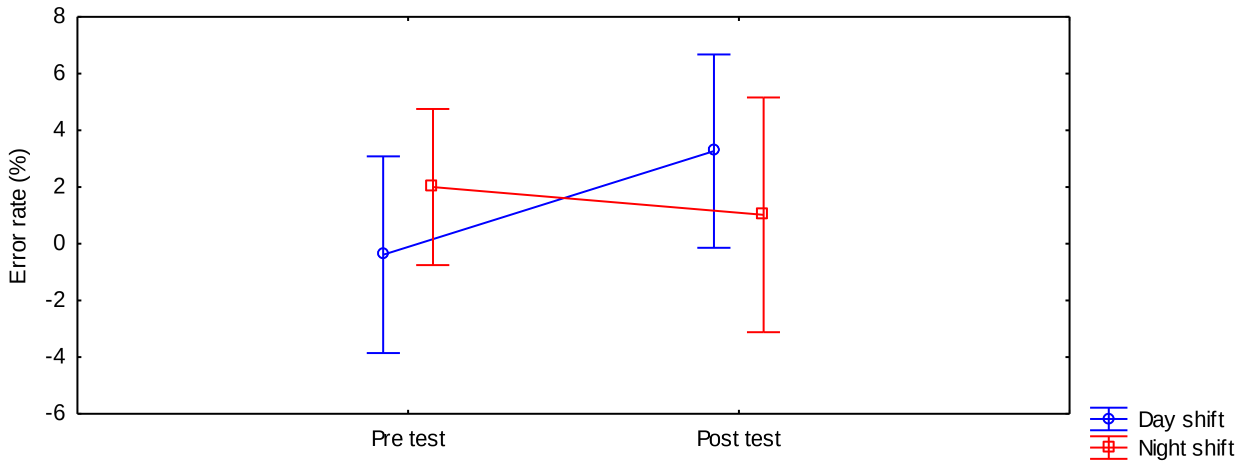

Figure 54: Interaction effect for error rate for visual discrimination between the shift types and pre-post tests of Company B ($p < 0.05$; error bars depict 95% confidence interval).

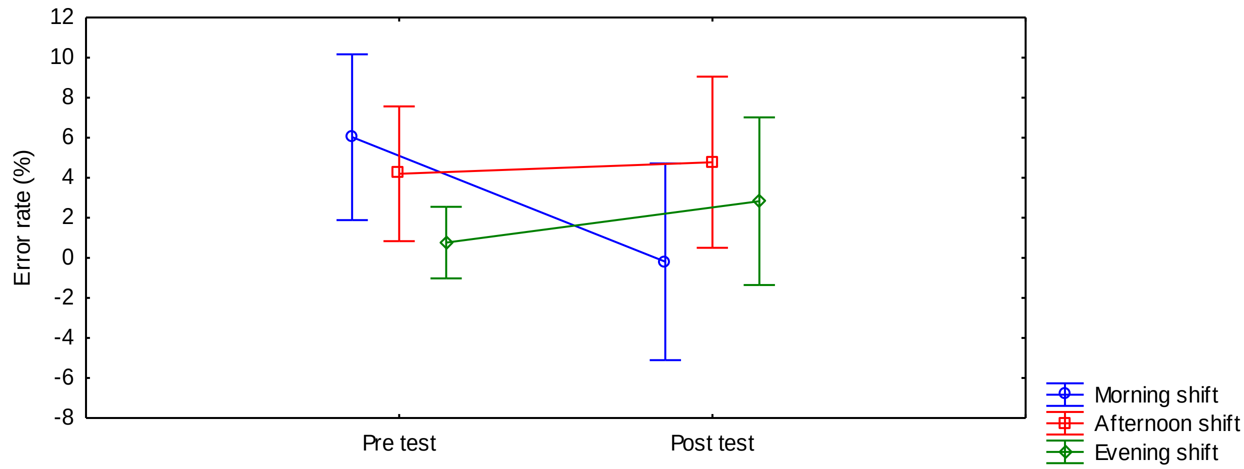

Figure 55: Interaction effect for error rate for visual discrimination between the shift types and pre-post tests of Company C (p < 0.05; error bars depict 95% confidence interval).

Visual detection

No significant effects were found for reaction time, error rate and tunnel view index for visual detection for any company under investigation (Table XXIII, XXIV and XXV respectively).

5.3.2 Reading test task

Table xxvi: Statistical analysis of reading speed for reading performance and processing time for visual pattern recognition for the shifts types and pre-post tests for each individual company.

Company	Effects	DF	Reading speed for reading performance		Processing time for visual pattern recognition	
			F	P	F	P
A	SHIFT TYPE	1, 16	0.06	0.80	0.05	0.82
	PRE-POST	1, 16	12.08	< 0.01	2.46	0.14
	SHIFT TYPE*PRE-POST	1, 16	0.05	0.83	0.50	0.49
B	SHIFT TYPE	1, 18	1.64	0.22	0.91	0.36
	PRE-POST	1, 18	36.83	< 0.1	6.73	0.02
	SHIFT TYPE*PRE-POST	1, 18	0.13	0.72	0.43	0.52
C	SHIFT TYPE	2, 28	4.78	0.02	0.48	0.62
	PRE-POST	1, 14	3.04	0.11	6.59	0.02
	SHIFT TYPE*PRE-POST	2, 28	7.88	< 0.01	2.95	0.06

Table xxvii: Statistical analysis of error rate for both reading performance and visual pattern recognition for the shifts types and pre-post tests for each individual company.

Company	Effects	DF	Error rate for reading performance		Error rate for visual pattern recognition	
			F	P	F	P
A	**SHIFT TYPE**	1, 15	0.02	0.88	0.12	0.72
	PRE-POST	1, 15	1.38	0.25	8.13	**0.01**
	SHIFT TYPE*PRE-POST	1, 15	0.82	0.37	0.54	0.47
B	**SHIFT TYPE**	1, 21	0.82	0.37	< 0.01	0.99
	PRE-POST	1, 21	1.78	0.19	4.75	**0.04**
	SHIFT TYPE*PRE-POST	1, 21	0.58	0.45	< 0.01	0.93
C	**SHIFT TYPE**	2, 34	< 0.01	0.99	2.18	0.12
	PRE-POST	1, 17	1.72	0.20	0.74	0.40
	SHIFT TYPE*PRE-POST	2, 34	1.52	0.23	1.61	0.21

Visual pattern recognition

Processing time

No significant effects were found for processing time for visual pattern recognition for Company A (Table XXVI). For both Company B and Company C a significant effect was found for processing time between the PRE-POST tests (Table XXVI), where processing time was slower after work compared to before work for each shift type (Figure 56 and 57 respectively). No other significant effects were found for Company B and Company C (Table XXVI).

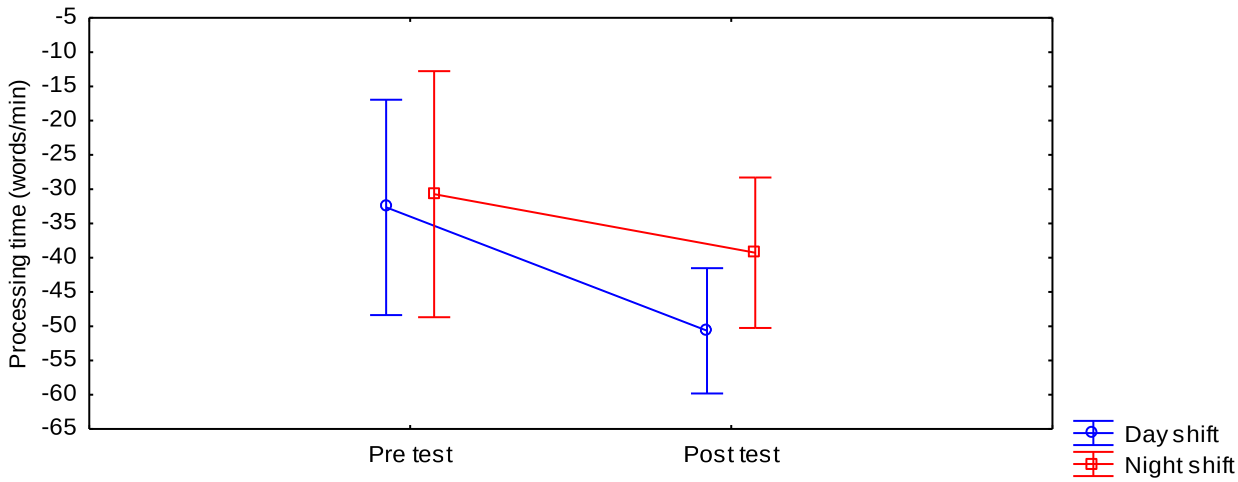

Figure 56: Processing time for visual pattern recognition before and after work for both the day and night shift of Company B (p<0.05 for PRE-POST tests; error bars depict 95% confidence interval).

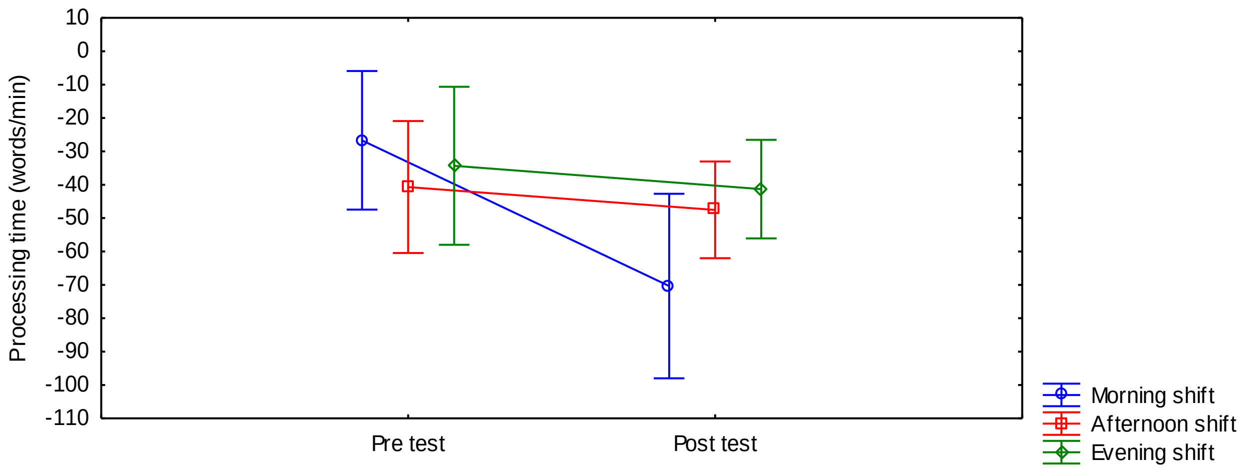

Figure 57: Processing time for visual pattern recognition before and after work for the morning, afternoon and evening shift of Company C (p< 0.05 for PRE-POST tests; error bars depict 95% confidence interval).

Error rate

A significant effect was found for the error rate for visual pattern recognition between the PRE-POST tests for Company A and Company B (Table XXVII), where error rate was worse after work compared to before work for each shift type (Figure 58 and 59 respectively). No other significant effects were found for Company A and Company B

(Table XXVII). Additionally, no significant effects were found for Company C (Table XXVII).

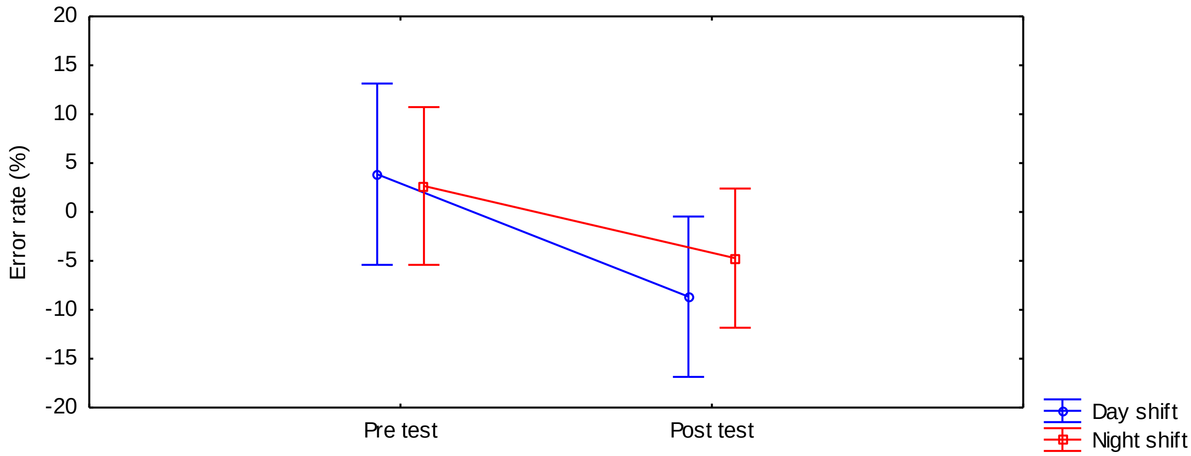

Figure 58: Error rate for visual pattern recognition before and after work for both the day and night shift of Company A ($p < 0.05$ for PRE-POST tests; error bars depict 95% confidence interval).

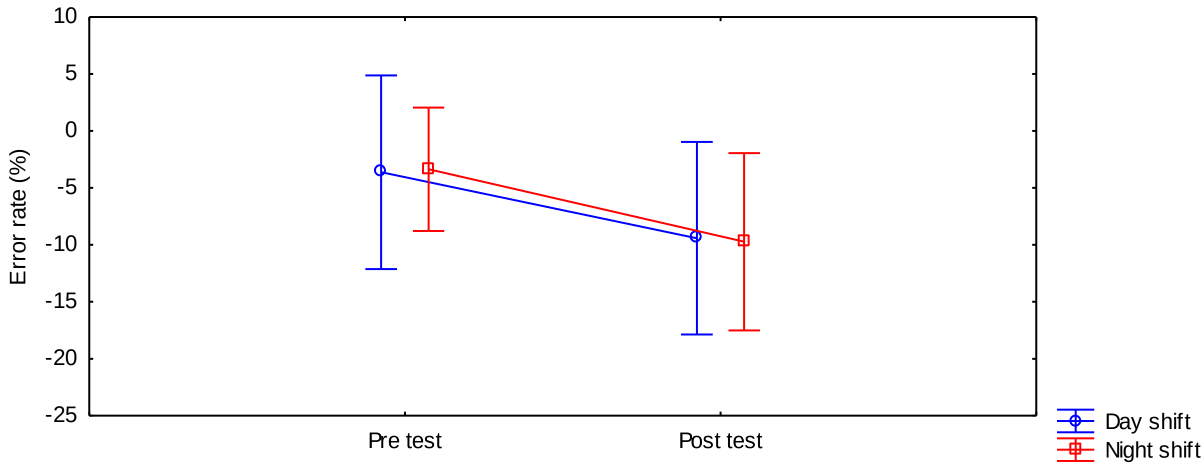

Figure 59: Error rate for visual pattern recognition before and after work for both the day and night shift of Company B ($p < 0.05$ for PRE-POST tests; error bars depict 95% confidence interval).

Reading performance

Reading speed

A significant effect was found for reading speed for reading performance between the PRE-POST tests for Company A and Company B (Table XXVI). Reading speed for both companies decreased from Pre Test to Post Test (Figure 60 and 61 respectively). Reading speed was slower after compared to before work for each shift type of both Company A and Company B. No other significant effects were found for Company A and Company B (Table XXVI).

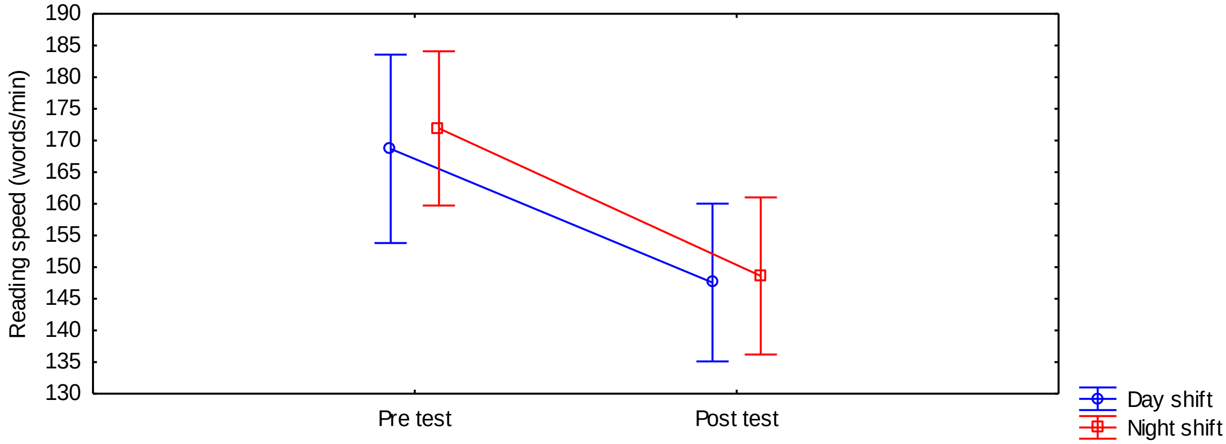

Figure 60: Reading speed for reading performance before and after work for both the day and night shift of Company A ($p < 0.05$ for PRE-POST tests; error bars depict 95% confidence interval).

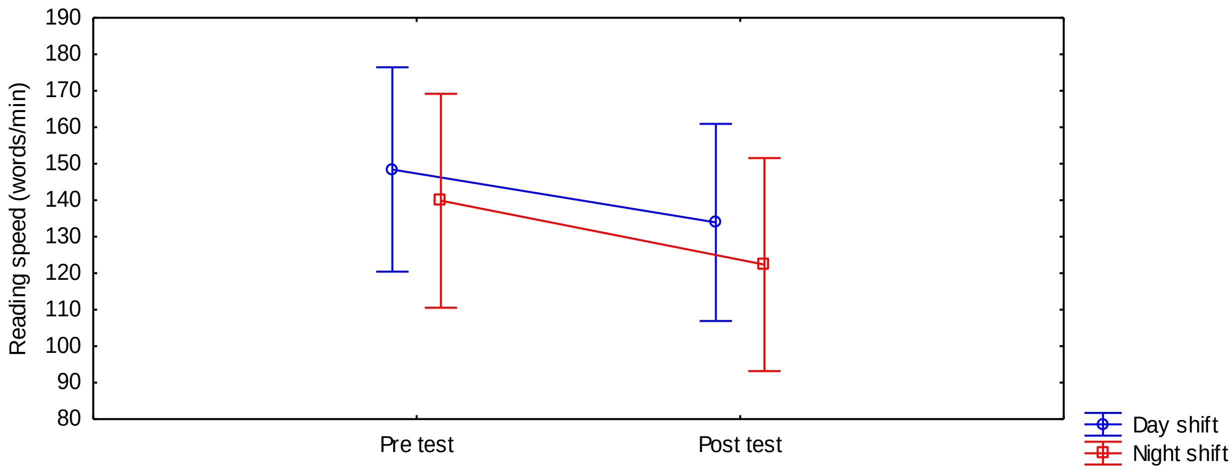

Figure 61: Reading speed for reading performance before and after work for both the day and night shift of Company B ($p < 0.05$ for PRE-POST tests; error bars depict 95% confidence interval).

A significant effect was found for reading speed for reading performance between the SHIFT TYPES and the interaction between SHIFT TYPE and PRE-POST tests for Company C (Table XXVI). Reading speed was slower during the evening shift compared to the morning and afternoon shift (Figure 62). Additionally, reading speed before and after work was dependent on the shift type being performed in Company C. Reading speed improved from Pre Test to Post test for the morning shift, whereas it slowed down from Pre Test to Post test for the afternoon and evening shift (Figure 63). No significant effect was found between the PRE-POST tests for Company C (Table XXVI).

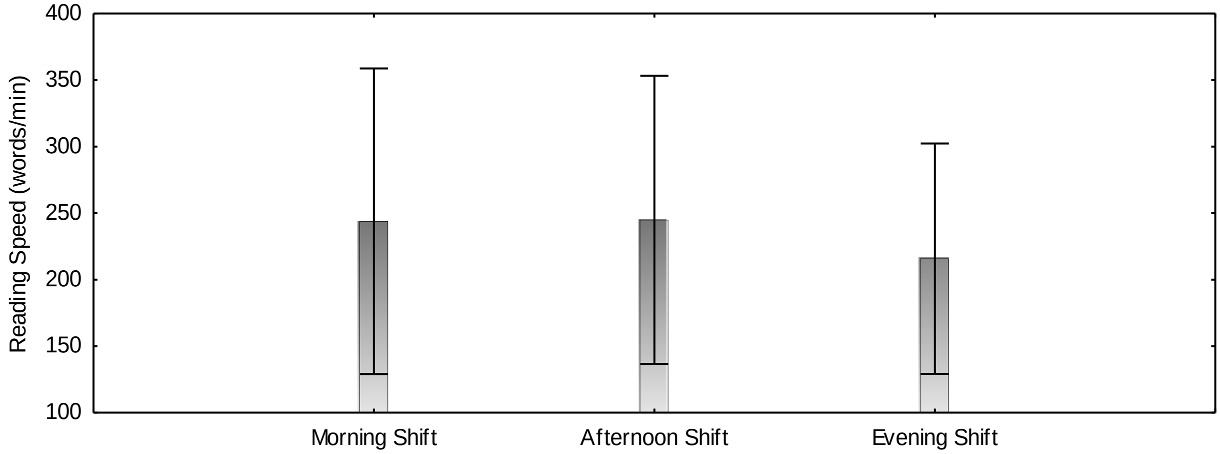

Figure 62: Reading speed for reading performance for the morning, afternoon and evening shift of Company C ($p < 0.05$; error bars depict 95% confidence interval).

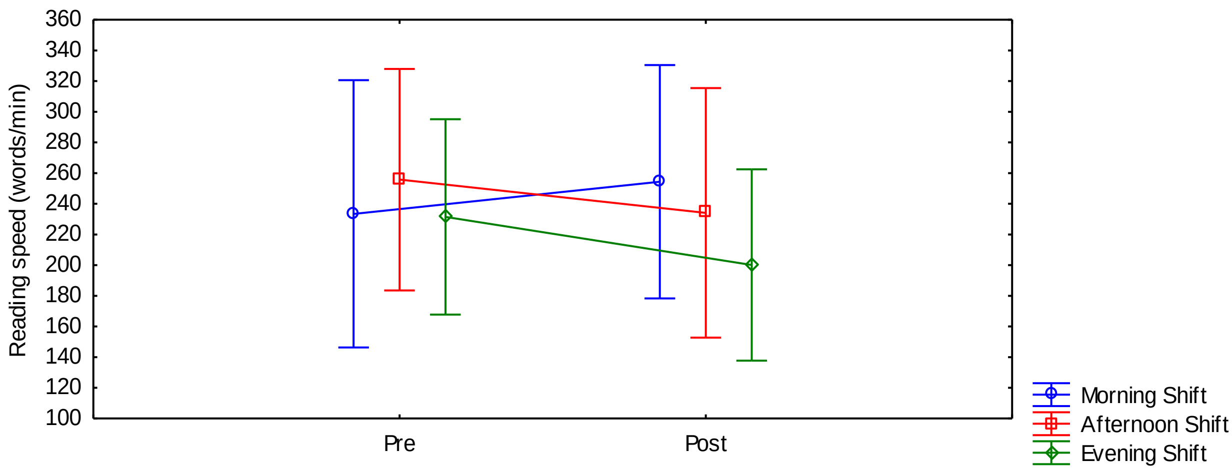

Figure 63: Interaction effect for reading speed for reading performance between the shift types and pre-post tests of Company C ($p < 0.05$; error bars depict 95% confidence interval).

Error rate

No significant effects were found for error rate for reading performance for any company under investigation (Table XXVII).

5.3.3 Memory test task

Table xxviii: Statistical analysis of recall rate for short-term memory and for the impact of rehearsal time on memory recall rate for memory duration for the shifts types and pre-post tests for each individual company.

Company	Effects	DF	Recall rate of short-term memory		Impact of rehearsal time on memory recall rate for memory duration	
			F	P	F	P
A	SHIFT TYPE	1, 14	<0.01	0.99	0.01	0.91
	PRE-POST	1, 14	3.00	0.10	0.02	0.87
	SHIFT TYPE*PRE-POST	1, 14	0.20	0.66	0.20	0.65
B	SHIFT TYPE	1, 16	5.00	**0.04**	0.12	0.73
	PRE-POST	1, 16	0.58	0.45	0.34	0.57
	SHIFT TYPE*PRE-POST	1, 16	0.90	0.35	0.06	0.79
C	SHIFT TYPE	2, 22	1.37	0.27	4.48	**0.02**
	PRE-POST	1, 11	0.80	0.39	7.18	**0.02**
	SHIFT TYPE*PRE-POST	2, 22	0.36	0.70	1.26	0.31

<u>Memory duration</u>

No significant effects were found for the impact of rehearsal time on memory recall rate for memory duration for both Company A and Company B (Table XXVIII). There was however, a significant effect found for the impact of rehearsal time on memory recall rate between the SHIFT TYPES and between the PRE-POST tests for Company C (Table XXVIII). Memory duration was worse during the evening shift compared to that of the morning and afternoon shift (Figure 64). Additionally, the impact of rehearsal time on memory recall rate during the afternoon shift was better than during the morning shift (Figure 64). In terms of the PRE-POST effect, memory duration deteriorated from Pre Test to Post Test (Figure 65). There was no interaction effect found for Company C (Table XXVIII).

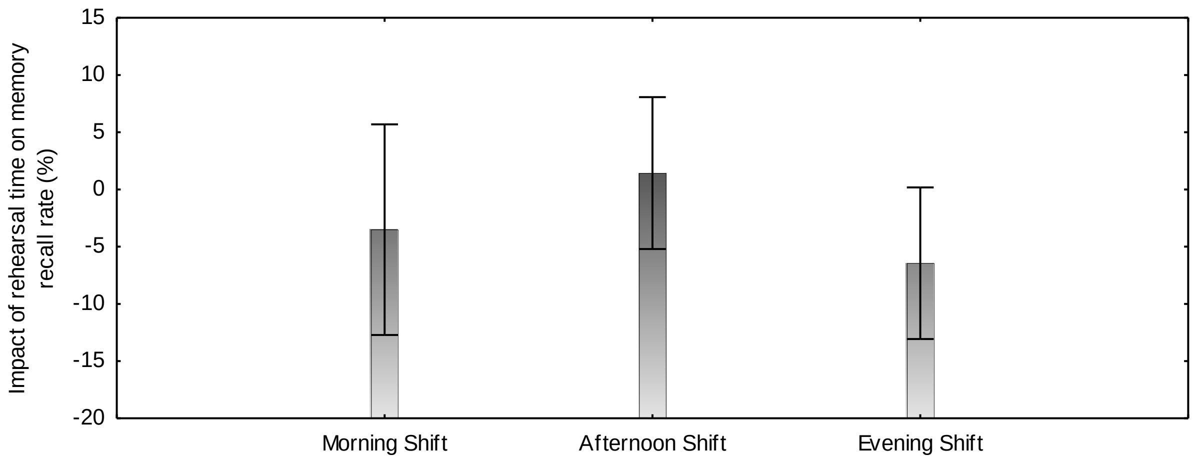

Figure 64: Impact of rehearsal time on memory recall rate for memory duration for the morning, afternoon and evening shift of Company C ($p < 0.05$; error bars depict 95% confidence interval).

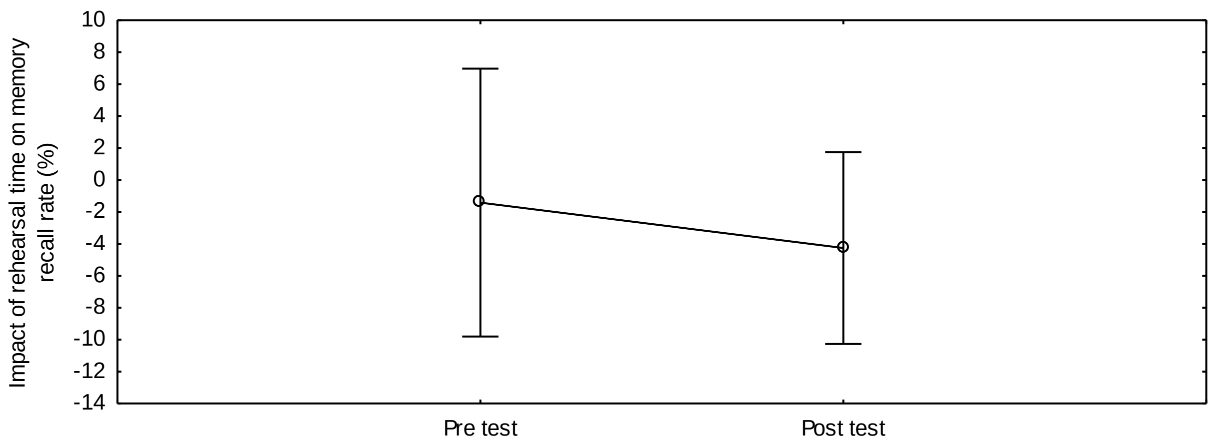

Figure 65: Impact of rehearsal time on memory recall rate for memory duration before and after work over the three shifts examined in Company C ($p < 0.05$; error bars depict 95% confidence interval).

<u>Short term memory</u>

There was only one statistically significant effect for recall rate for short-term memory after all three companies were analysed (Table XXVIII). This was found for SHIFT TYPE for Company B (Table XXVIII), where recall rate was worse during the night shift compared to that of the day shift (Figure 66).

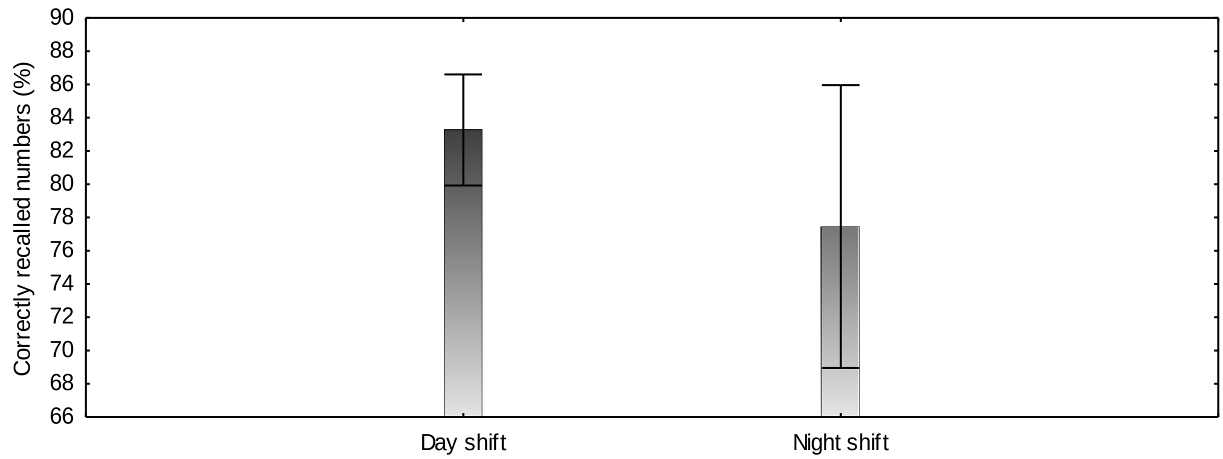

Figure 66: Recall rate for short-term memory for the day and night shift of Company B (p < 0.05; error bars depict 95% confidence interval).

5.3.4 Tapping test task

Table xxix: Statistical analysis of reaction time for motor control and motor programming time for both high and low precision conditions for the shifts types and pre-post tests for each individual company.

Company	Effects	DF	Reaction time for motor control		Motor programming time – low precision		Motor programming time – high precision	
			F	P	F	P	F	P
A	SHIFT TYPE	1, 15	1.159	0.29	0.09	0.76	0.93	0.18
	PRE-POST	1, 15	2.56	0.12	0.24	0.62	0.01	0.96
	SHIFT TYPE*PRE-POST	1, 15	4.01	**0.06**	0.40	0.53	0.01	0.89
B	SHIFT TYPE	1, 20	0.21	0.65	1.56	0.22	0.13	0.71
	PRE-POST	1, 20	6.27	**0.02**	0.86	0.36	0.04	0.82
	SHIFT TYPE*PRE-POST	1, 20	6.43	**0.02**	1.15	0.29	1.50	0.23
C	SHIFT TYPE	2, 30	0.05	0.94	1.88	0.16	0.04	0.95
	PRE-POST	1, 15	0.65	0.43	0.80	0.38	6.96	**0.01**
	SHIFT TYPE*PRE-POST	2, 30	2.42	0.11	0.08	0.91	0.79	0.45

Motor programming

There were no significant effects found for the high precision condition for motor programming time for any company under investigation (Table XXIX). In terms of the low precision condition for motor programming, there were no significant effects found for

Company A and Company B (Table XXIX). However, one was found for Company C between the PRE-POST tests (Table XXIX), where motor programming time was slower Post Test compared to Pre Test for each shift type (Figure 67). No other significant effects were noted for motor programming time for the low precision condition of Company C (Table XXIX).

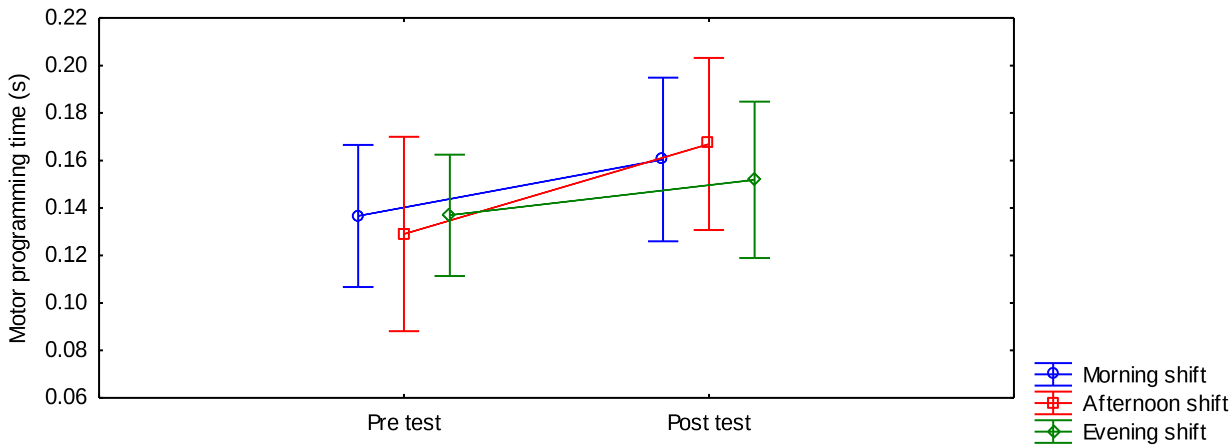

Figure 67: Motor programming time for the low precision condition before and after work for the morning, afternoon and evening of Company C ($p < 0.05$ for PRE-POST tests; error bars depict 95% confidence interval).

Motor control

No significant effects for reaction time for motor control were found for Company A (Table XXIX); however, the interaction effect between SHIFT TYPES and PRE-POST tests was close to being significant ($p = 0.06$). After a paired t-test was conducted on the day shift and night shift separately, only a significant effect was found for the night shift, where reaction time was slower after work compared to before work ($p = 0.04$; Figure 68).

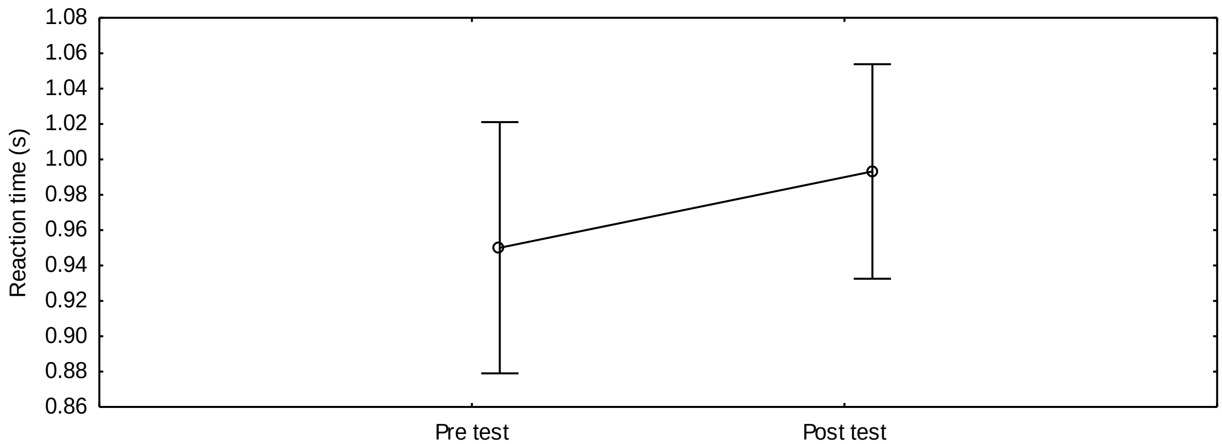

Figure 68: Reaction time for motor control before and after work for the night shift of Company A ($p < 0.05$; error bars depict 95% confidence interval).

A significant effect was found for reaction time for motor control between the PRE-POST tests and for the interaction between SHIFT TYPE and PRE-POST tests for Company B (Table XXIX). Reaction time improved from Pre Test to Post Test (Figure 69). However, when analysing the significant interaction effect it was evident that reaction time only improved from Pre Test to Post Test for the day shift, where reaction time decrements were evident from Pre Test to Post Test for the night shift (Figure 70). No other significant effects were found for Company B or for Company C (Table XXIX).

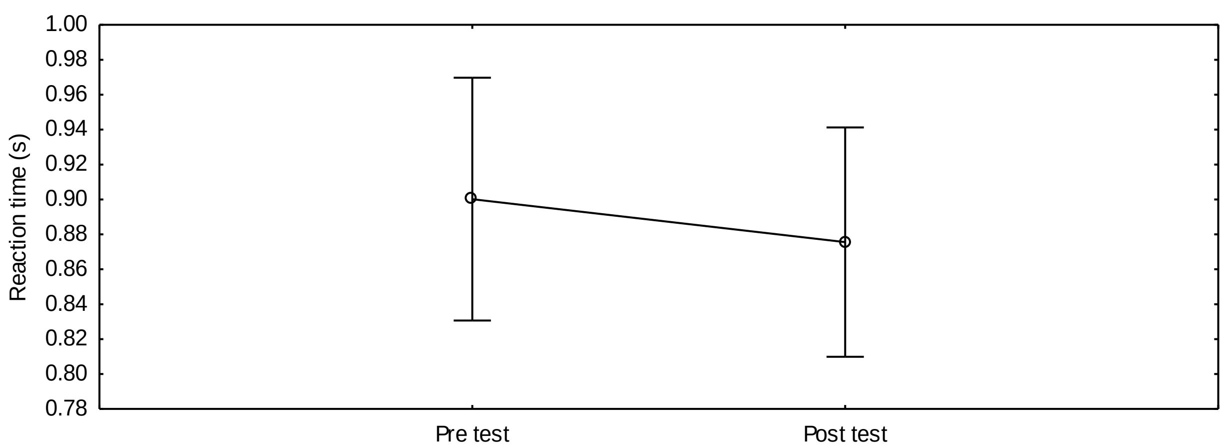

Figure 69: Reaction time for motor control before and after work for Company B over the two shifts tested ($p < 0.05$; error bars depict 95% confidence interval).

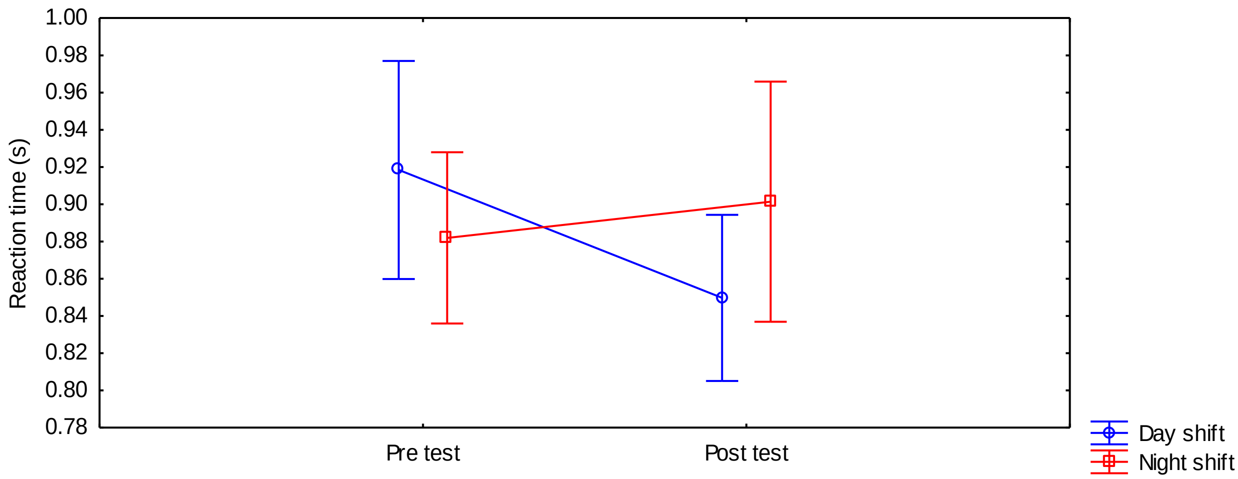

Figure 70: Interaction effect of reaction time for motor control between the shift types and pre-post tests of Company B ($p < 0.05$; error bars depict 95% confidence interval).

5.3.5 Neural control test task

No significant effects were found for the impact of movement sensitivity demands on reaction time for peripheral neural control for any company under investigation (Table XXX).

Table xxx: Statistical analysis of the impact of movement sensitivity demands on reaction time for peripheral neural control for the shifts types and pre-post tests for each individual company.

Company	Effects	The impact of movement sensitivity demands on reaction time for peripheral neural control		
		DF	**F**	**P**
A	**SHIFT TYPE**	1, 15	1.91	0.18
	PRE-POST	1, 15	0.92	0.35
	SHIFT TYPE*PRE-POST	1, 15	0.81	0.37
B	**SHIFT TYPE**	1, 18	0.06	0.79
	PRE-POST	1, 18	0.35	0.55
	SHIFT TYPE*PRE-POST	1, 18	0.12	0.72
C	**SHIFT TYPE**	2, 30	0.67	0.51
	PRE-POST	1, 15	< 0.01	0.95
	SHIFT TYPE*PRE-POST	2, 30	1.2	0.31

5.3.6 Simple reaction time test task

Table xxxi: Statistical analysis of simple reaction time for the shifts types and pre-post tests for each individual company.

Company	Effects	DF	F	P
A	**SHIFT TYPE**	1, 15	0.82	0.38
	PRE-POST	1, 15	22.10	**< 0.01**
	SHIFT TYPE*PRE-POST	1, 15	0.04	0.84
B	**SHIFT TYPE**	1, 16	0.03	0.85
	PRE-POST	1, 16	0.83	0.37
	SHIFT TYPE*PRE-POST	1, 16	6.01	**0.02**
C	**SHIFT TYPE**	2, 26	2.80	0.11
	PRE-POST	1, 13	6.22	**0.02**
	SHIFT TYPE*PRE-POST	2, 26	3.77	**0.03**

A significant effect was found for simple reaction time between the PRE-POST tests for Company A (Table XXXI), where reaction time was slower for both the day shift and the night shift after work compared to before work (Figure 71). No other significant effects were found for Company A (Table XXXI).

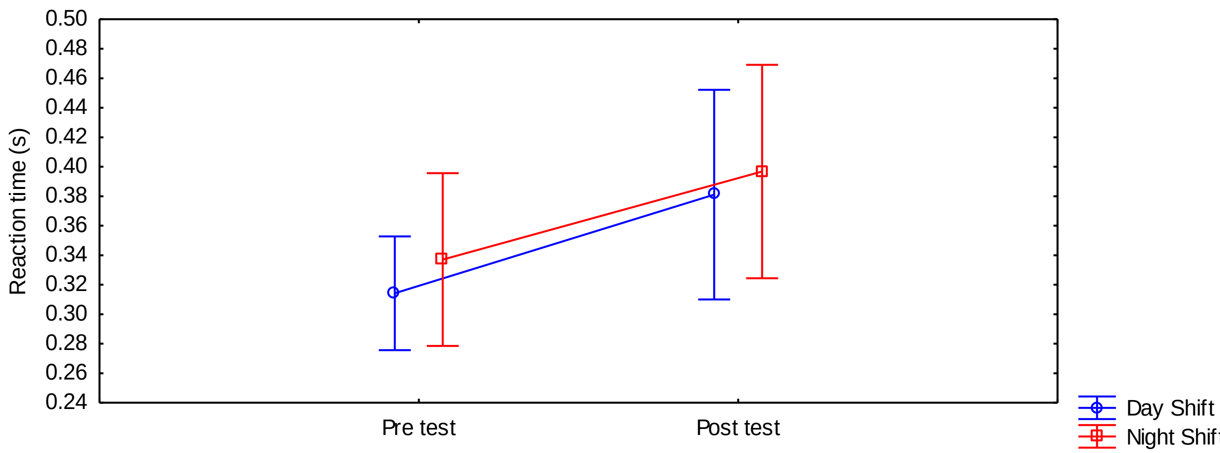

Figure 71: Simple reaction time before and after work for both the day and night shift of Company A ($p < 0.05$ for PRE-POST tests; error bars depict 95% confidence interval).

In terms of Company B, there was a significant interaction effect for simple reaction time between SHIFT TYPES and PRE-POST tests (Table XXXI). Thus, reaction time before and after work depended on the shift being performed. Reaction time was faster after work compared to before work for the day shift and slower after work compared to before work for the night shift (Figure 72). No other significant effects for simple reaction time were found for Company B (Table XXXI).

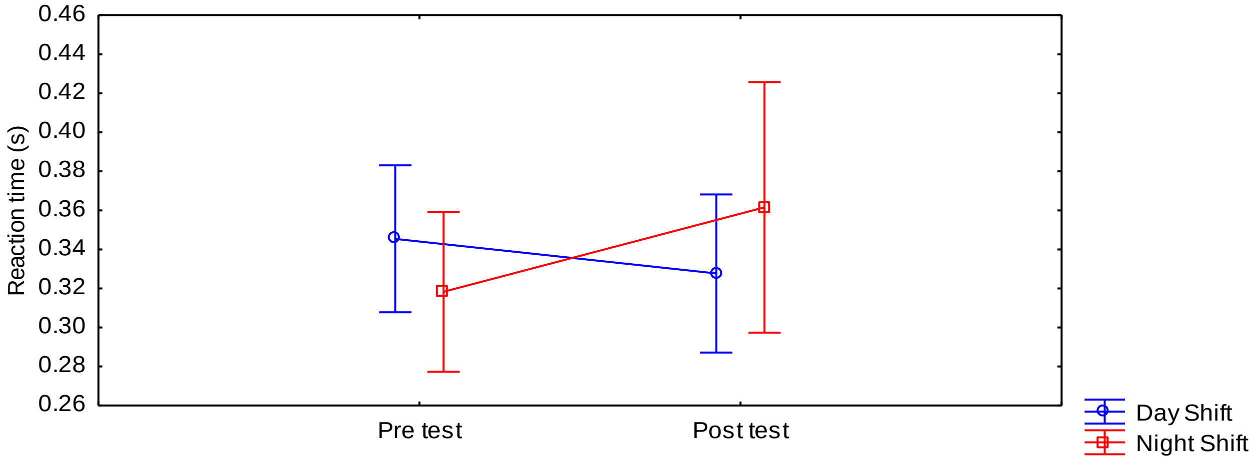

Figure 72: Interaction effect for simple reaction time between the shift types and pre-post tests for Company B ($p < 0.05$; error bars depict 95% confidence interval).

There was a significance found for simple reaction time between PRE-POST tests and the interaction between SHIFT TYPE and PRE-POST tests for Company C (Table XXXI). Reaction time increased from Pre Test to Post Test (Figure 73). When analysing the interaction effect, it is clear that performance was worse after work compared to before work for the morning and afternoon shift, whereas performance after work was only slightly worse compared to before work for the evening shift (Figure 74). No significant effect was found for SHIFT TYPES for Company C (Table XXXI).

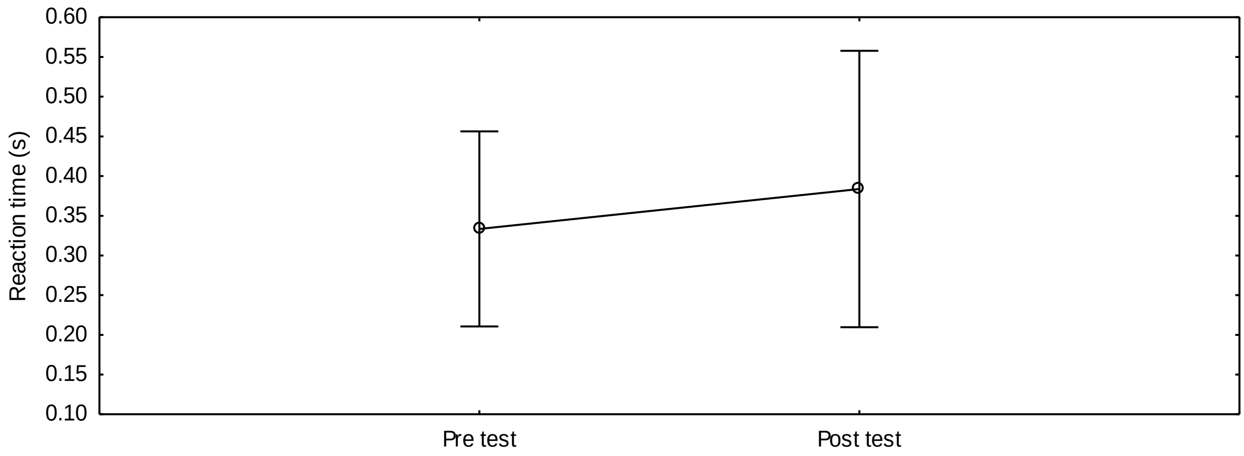

Figure 73: Simple reaction time before and after work over the three shifts of Company C ($p < 0.05$; error bars depicts 95% confidence interval).

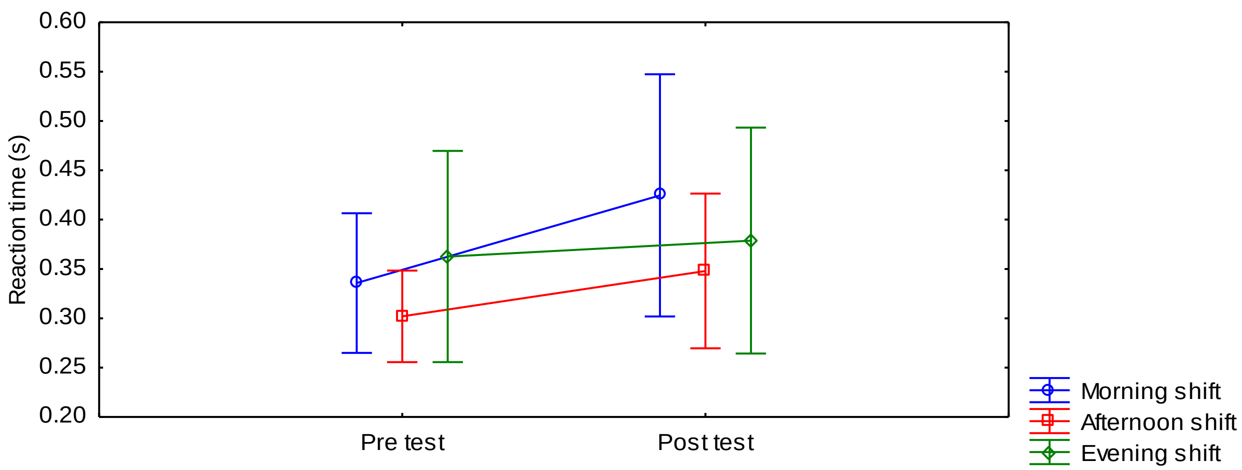

Figure 74: Interaction effect for simple reaction time between the shift types and pre-post tests for Company C ($p < 0.05$; error bars depict 95% confidence interval).

5.4 DISCUSSION

Parameters of cognitive functions and of task-related effects that revealed significant fatiguing effects for any company under investigation will be considered as validated for field-based assessment to measure mental fatigue during rotational shift work and will be inserted into the assessment tool. Parameters that did not reveal significant fatiguing effects will not be inserted as these have not been validated for mental fatigue in any company under investigation. This does not suggest that the parameters are not sensitive to mental fatigue occurring during rotational shift work. Fatiguing effects may be found in other companies where the rotational shift work and working tasks differ from the companies investigated in this study.

5.4.1 Visual discrimination

Processing time

No significant effects were found for processing time for visual discrimination for any company under investigation. This suggests that this parameter was not sensitive to fatigue occurring during the shifts or between the shift types for any of the companies.

Error rate

No significant effects were found for Company A and no significant effects were noted between the shift types of Company B and Company C. However, significant fatiguing effects were found for the day shift of Company B and for the interaction between the shift types and testing sessions performed before and after work for Company C.

In terms of Company B, a significant fatiguing effect was found for the day shift, where error rate deteriorated during the day shift, revealing that the quality of visual discrimination was becoming impaired during the shift. With regards to Company C, fatigue occurring during the shifts behaved differently for the individual shift types, where error rate was higher after compared to before work for the night shift and lower after work compared to before work for the day shift. These two significant effects reveal that error rate for visual discrimination was sensitive to fatigue occurring during the day shift of Company B and within the shifts for Company C.

Impact of detection workload on tunnel view

No significant effects were found for the impact of detection workload on tunnel view for visual discrimination for any company under investigation. Therefore, this parameter has not revealed sensitivity to fatigue occurring between the shift types or during the shifts for any company.

5.4.2 Visual detection

No significant effects were found for reaction time, error rate and tunnel view index for visual detection for any of the three companies under investigation. Despite visual detection revealing sensitivity to mental fatigue in the simulated shift work laboratory setting, it has not been affected by shift work performed in any of the companies investigated and therefore cannot be considered as validated for measuring mental fatigue.

5.4.3 Visual pattern recognition

Processing time

No significant effects for processing time for visual pattern recognition were found for Company A. Additionally, none were noted between the shift types for both Company B and Company C. However, a significant fatiguing effect was found between the testing sessions performed before and after work for both Company B and Company C, where processing time was slower after compared to before work for each shift type. This reveals that processing time was sensitive to fatigue occurring during the shifts for both Company B and Company C. Thus this parameter was considered to assess fatiguing effects experienced during rotational shift work.

Error rate

No significant effects were noted for error rate for visual pattern recognition for Company C and between the shift types for Company A and Company B. However, significant fatiguing effects were noted between the Pre Test and Post Test for both Company A and Company B, where error rate was higher after compared to before work. The decline in performance was noted for each shift type for both companies. Thus, error rate for visual pattern recognition was sensitive to fatigue occurring before and after work for each shift type of both Company A and Company B.

5.4.4 Reading performance

Reading speed

No significant effects were noted for reading speed between the day shift and night shift for both Company A and Company B. However, a significant fatiguing effect was found between the testing sessions performed before and after work for both Company A and Company B, where reading speed was slower after compared to before work for each shift type within both companies.

With regards to Company C, two significant fatiguing effects were found. Firstly, fatigue behaved significantly different amongst the shift types. Reading speed was worse during the evening shift compared to the morning and afternoon shift. Thus, fatigue was more prominent whilst working in the evening. According to Valdez *et al*., (2008), circadian rhythm activity is low during the evening due to the homeostatic drive for sleep being activated. This coincides with poor cognitive performance during the evening. Additionally, working irregular hours, especially night work, disrupts the circadian rhythm, which leads to an increase in sleepiness and sleep loss (Dula *et al*., 2001; Åkerstedt *et al*., 2004). Therefore, reading speed during the evening shift may be slower compared to the other two shifts due to one or a combination of these two factors coupled with work-related fatigue being experienced within the company. Secondly, fatigue before and after work varied significantly with the shift type being performed. Reading speed improved during the morning shift, whereas reading speed declined during the afternoon and evening shift.

Reading speed was sensitive to fatigue occurring before and after work for Company A and Company B, and fatigue behaved differently before and after work for each shift type of Company C.

Error rate

No significant effects were found for the quality of reading performance for any company under investigation. This suggests that it was not becoming impaired whilst performing shift work in any of the companies. Despite this parameter revealing sensitivity to mental fatigue in the simulated shift work laboratory setting, it has not been affected by shift work being performed within the three companies investigated and therefore cannot be considered as validated for measuring mental fatigue.

5.4.5 Memory duration

No significant effects were found for the impact of rehearsal time on memory recall rate for both Company A and Company B. Therefore, this parameter was not sensitive to fatigue occurring between the shift types and during the shifts for any of these companies. However, significant fatiguing effects were found between the shift types and between the testing sessions being performed before and after work for Company C.

With regards to the effect found between the shift types, performance was the worst for the evening shift, followed by the morning shift and best for the afternoon shift. The poor performance noted for the evening shift was likely attributed to either one or a combination of the following factors: circadian fatigue and disruption of the circadian rhythm (Dula *et al*., 2001; Åkerstedt *et al*., 2004; Valdez *et al*., 2008), as workers are expected to work whilst circadian rhythm activity is low and throughout the evening, causing an increase in sleepiness and sleep loss. These two factors, coupled with work-related fatigue, result in fatigue being amplified during the evening shift. Performance being worse during the morning compared to the afternoon shift suggests that workers were more fatigued during the morning shift. With regards to the effect found between the Pre Tests and Post Tests, performance was worse after work compared to before work.

Therefore, the impact of rehearsal time on memory recall rate for memory duration was sensitive to fatigue occurring amongst the shift types and during the shifts of Company C. Thus, this parameter for memory duration is considered valid to assess fatiguing effects experienced during rotational shift work.

5.4.6 Short term memory

No significant effects were found for recall rate between the testing sessions performed before and after work for any company under investigation and no significant effects were found between the shift types for Company B and Company C. This suggests that recall rate for short-term memory was not sensitive to fatigue occurring during the shifts for any company and was not sensitive to fatigue occurring between the shift types of both Company B and Company C. This may be due to the participants tested within each of these companies, a number of whom were computer illiterate and had never been previously exposed to a memory recall test. Thus, participants were required to memorise numbers whilst trying to remember how to use a computer. This may have resulted in fatigue being greater after work but was masked due to the fact that workers had developed skills to master memorisation from practicing and learning the test task in the Pre Test session. This hypothesis was supported by the laboratory phase where there were no significant fatiguing effects found due to the learning effect noted during the day shift.

There was a significant effect found for recall rate between the shift types of Company B. Short-term memory performance was worse during the night shift compared to the day shift. This decline in performance during the night shift may have been due to the increased sleepiness and sleep loss caused by working irregular hours and/or due to workers working during the night whilst circadian rhythm activity was low (Dula *et al*., 2001; Åkerstedt *et al*., 2002; Valdez *et al*., 2008). One or both of these factors, coupled with work-related fatigue, results in this amplified fatigue experienced during night shift work (Bridger, 2003). This parameter was sensitive to fatigue occurring amongst the shift types of Company B.

5.4.7 Motor programming

No significant effects were found for the low precision condition for motor programming for any company under investigation and no significant effects were found for the high precision condition for Company A and Company B. Therefore, motor programming time for the low precision condition was not found to be sensitive to mental fatigue for any of the companies investigated in this study and motor programming time for the high precision condition was not sensitive to mental fatigue for Company A and Company B.

In terms of the high precision condition for Company C, a significant fatiguing effect was found between the testing sessions performed before and after work. Motor programming time was slower after compared to before work for each shift type within Company C. Therefore, motor programming time for the high precision condition was sensitive to fatigue occurring during each shift type of Company C. This condition has been validated for mental fatigue before and after work for each shift type of Company C.

Motor programming time was significant for the high precision condition for Company C between the Pre Tests and Post Tests, but not for the low precision condition. This suggests that motor programming requiring high precision causes fatigue at a greater rate than tasks requiring low precision.

5.4.8 Motor control

No significant fatiguing effects for reaction time for motor control were found for Company A and Company C between the shift types or between the testing sessions performed before and after work. However, an almost significant fatiguing effect was found for the interaction between shift types and testing sessions performed before and after work for Company A ($p = 0.06$). Thus, a paired t-test was conducted on the day and night shift separately, where a significant fatiguing effect was found for the night shift, where reaction time was slower after compared to before work.

Additionally, a significant effect was found for Company B, where reaction time was faster after work compared to before it. This suggests a learning or habituation effect, however, a significant interaction effect was also noted. This revealed that reaction time was improving during the day but slowing down during the night shift. Thus, fatigue during a shift varies with the shift type being performed.

Therefore, reaction time for motor control was sensitive to fatigue occurring during the night shift of Company A and fatigue before and after work depends on the shift type being performed for Company B.

5.4.9 Peripheral neural control

No fatiguing effects were found for the impact of movement sensitivity demands on reaction time for peripheral neural control for any company under investigation. Thus, reaction time for peripheral neural control has not been validated for mental fatigue.

It must be noted that participants in this phase were computer illiterate which may have interfered with the results (Modisaotsile, 2012). They were required to use a computer for the first time, where they had to master manoeuvring a mouse at two levels of sensitivity. This could lead to improvements in performance from Pre Test to Post Test which hides the decrements in performance after work. Thus, fatigue may have been occurring after work, but could have been masked by a learning or habituation effect.

5.4.10 Simple reaction time

No significant effects were found between the shift types for any company investigated. However, significant fatiguing effects were noted for simple reaction time before and after work for Company A and Company C, where performance was worse after work compared to before work for each shift type. A significant interaction effect was found for Company B, where simple reaction time was faster after work compared to before work for the day shift and was slower after work compared to before work for the night shift. Thus, fatigue before and after work behaved differently within each shift type performed in Company B.

Thus, simple reaction time was sensitive to mental fatigue occurring between the testing sessions performed before and after work for both Company A and Company C and fatigue behaved differently within the individual shift types of Company B. This translates in simple reaction time being validated for mental fatigue within the individual shift types for all three companies.

5.4.11 Summary

From the data discussed above, it is evident that fatigue behaves differently in different companies (Table XXXII and XXXIII). This may be due to either the rotational shift work system adopted by each company or due to the different working tasks being performed within them. The tables below show the significant fatiguing effects found for each cognitive function and task-related effect for each company under investigation.

Table xxxii: Parameters of cognitive functions that revealed significant fatiguing effects ($p<0.05$). S refers to SHIFT TYPE, T refers to PRE-POST tests, SxT refers to the interaction effect between SHIFT TYPES and PRE-POST tests.

	Company A	**Company B**	**Company C**
Visual discrimination			
Processing time			
Error rate		SxT	SxT
Impact of detection workload on tunnel view			
Visual pattern recognition			
Processing time		T	T
Error rate	T	T	
Memory duration			
Impact of rehearsal time on memory recall rate			S, T
Motor programming			
Motor programming time			S, T
Peripheral neural control			
Impact of movement sensitivity demands on reaction time			

Table xxxiii: Parameters of task-related effects that revealed significant fatiguing effects ($p<0.05$). S refers to SHIFT TYPE, T refers to PRE-POST tests, SxT refers to the interaction effect between SHIFT TYPES and PRE-POST tests.

	Company A	**Company B**	**Company C**
Visual detection			
Reaction time			
Error rate			
Tunnel view index			
Reading performance			
Reading speed	T	T	S, SxT
Error rate			
Short-term memory			
Recall rate		S	
Motor control			
Reaction time	[SxT, p=0.06]	T, SxT	
Simple reaction time			
Reaction time	T	SxT	T

For Company A, only three significant fatiguing effects were found. Two of these, reading speed and simple reaction time, were also found in Company B and Company C, which reveals the sensitivity of these two parameters to rotational shift work. Seven and six parameters revealed significant fatiguing effects for Company B and Company C respectively, compared to two effects found in Company A. Thus, it would appear that minimal fatigue was occurring in Company A compared to Company B and Company C.

In terms of visual discrimination, a fatiguing effect was only found for the quality aspect (error rate). This effect was found for both Company B and Company C, where the quality of visual discrimination was being compromised during the day shift of Company B and for the night shift of Company C.

With regards to visual pattern recognition, its speed and quality was being comprised within the companies. Both parameters fatigued within Company B. Thus, recognizing visual pattern becomes more difficult whilst performing shift work in these companies. Similar effects were found for reading speed revealing that the resources required for reading was being depleted for each company under investigation. However, the quality of reading was not being comprised during the companies investigated in this study.

Memory duration was being more comprised during the evening shifts compared to the other shift types in Company C and was being comprised during each shift type. These effects were also noted for motor programming. Thus, both memorisation and programming of the hands were more compromised during the evening shift and deteriorated during each shift type of Company C. Additionally, short-term memory was being comprised at a greater rate during the night shift of Company B.

Motor control was found to be compromised by night shift work of Company B, as was simple reaction time, which was also compromised during each shift type of Company A and Company C. This suggests that motor skills were becoming impaired due to shift work performed within these relevant companies.

No significant fatiguing effects were found for either parameters of visual detection or for peripheral neural control. Thus, detecting stimuli in the environment and the control of movements was not found to be compromised by shift work performed within any company investigated.

For certain parameters, a decline in performance was noted for each shift type within the relevant companies (Table XXXIV). This reveals that fatigue was occurring within each shift type, which coincides with the effects of work-related fatigue. Thus, this was likely dominated by work-related factors, coupled with the negative consequences of performing rotational shift work (Bridger, 2003; Williamson *et al*., 2011).

Table xxxiv: Parameters where performance decreased within each shift type for the relevant companies.

Parameter	**Company**
Processing time for visual pattern recognition	B and C
Error rate for visual pattern recognition	A and B
Impact of rehearsal time on memory recall rate	C
Motor programming time	C
Reading speed	A and B
Simple reaction time	A and C

For certain parameters, fatigue behaved differently within each shift type for the relevant companies (Table XXXV). In these cases, performance increased during the day and decreased during the night, which coincides with the effects of circadian fatigue (Blatter and Cajochen *et al*., 2007; Valdez *et al*., 2008). This suggests that the effects noted are likely dominated by circadian fatigue. Additionally, the decline in performance experienced during the night was likely caused by both working whilst the circadian drive for sleeping was activated and working throughout the night which causes a disruption in the circadian rhythm (Dula *et al*., 2001; Valdez *et al*., 2008). Both these factors increase sleepiness and sleep loss which amplifies fatigue (Dula *et al*., 2001 Åkerstedt *et al*., 2004).

Table xxxv: Parameters where performance behaved differently within each shift type for the relevant companies.

Parameter	**Company**
Error rate for visual discrimination	C
Reading speed	C
Reaction time for motor control	B
Simple reaction time	B

Parameters which did not reveal a significant fatiguing effect during the shift suggests that either these parameters are not sensitive to fatigue or insufficient fatigue was being experienced whilst participating in shift work. Additionally, parameters which revealed similar cognitive performance amongst the shift types suggests that fatigue behaved similarly amongst the shift types and performance of these parameters was not influenced by the time of day.

In terms of fatiguing effects found in Phase 1 compared to those in Phase 2, visual discrimination and motor control revealed no significant fatiguing effects in the laboratory-setting, where both the quality of visual discrimination and reaction time for motor control revealed fatiguing effects in the field-based study. Similar effects were noted for all parameters of visual detection and error rate for reading performance, where significant effects were found in the laboratory study, but none were found in the field-based study. All other parameters examined in this project revealed both fatiguing effects in the laboratory and in the field. This suggests that making inferences regarding fatigue in a laboratory setting are not always accurate in predicting fatigue behaviour in a shift work setting.

The presence of fatigue varied for the different cognitive functions and task-related effects. Additionally, fatiguing effects noted were not present in all companies under investigation. If fatigue was measured via one parameter for any company, this was proven to be sensitive to mental fatigue occurring during rotational shift work. In total, nine parameters revealed sensitivity to fatigue in this phase, which results in these parameters being inserted into the assessment tool (Table XXXVI). Five of these provide information on a particular cognitive function activated during human information processing. Therefore, these parameters are able to isolate where fatigue is occurring during human information processing. The other four parameters provide information on a task-related effect and thus provide information on the entire human information processing chain. The parameters which revealed no significant fatiguing effects to shift work performed in any of the companies do not suggest that these cognitive functions or task-related effects are not sensitive to fatigue occurring during rotational shift work. These cognitive functions and task-related effects may well reveal sensitivity to mental fatigue in companies where different rotational shift work systems and working tasks are performed.

Table xxxvi: Assessment tool validated in this study for mental fatigue applied to rotational shift work.

Assessment tool	
Parameters providing information on a specific cognitive function	**Parameters providing information on a task-related effect**
1) Error rate for visual discrimination	1) Reading speed for reading performance
2) Processing time for visual pattern recognition	2) Recall rate for short-term memory
3) Error rate for visual pattern recognition	3) Reaction time for motor control
4) Impact of rehearsal time on memory recall rate for memory duration	4) Simple reaction time
5) Motor programming time for the high precision condition	

Fatiguing effects were noted within all stages of the Wickens' information processing model besides the short-term sensory store stage. Thus perception, decision-making and motor control can be analyzed individually, enabling the identification and isolation of mental fatigue occurring during shift work. This model has been proven to be suited for the isolation of cognitive functions and has been shown to be useful with regards to research in shift work and mental fatigue occurring during human information processing.

CHAPTER 6

CONCLUSION

6.1 INTRODUCTION

Mental fatigue has been proven to be highly prominent during rotational shift work, due to long, irregular working hours and disruption of the circadian rhythm. Mental fatigue is commonly measured via cognitive test tasks. However, not all of these have been validated for measuring mental fatigue during shift work. Moreover, these cognitive test tasks do not isolate where fatigue is occurring during human information processing. If we are able to determine this, workplace design or tasks can be adapted accordingly.

The human information processing system consists of four core stages, where each requires numerous cognitive functions in order to process information. It has been suggested that different resources are required for the different stages. Thus, depletion of one resource (fatigue) does not necessarily mean depletion of all resources. It merely suggests that one or more cognitive functions of a particular stage in human information processing are fatigued.

The Human Kinetics and Ergonomics Department at Rhodes University has developed various cognitive test tasks where each isolates a specific cognitive function activated during human information processing. This is achieved by constructing two versions of the same test task, in which the only difference between the two is the demand of a specific cognitive function. This difference will reflect the performance of the cognitive function. This method is called the 'Differential Approach'.

The cognitive test tasks developed and their respective isolated cognitive functions are displayed in Table XXXVII. Additionally, general task-related effects can be examined for these cognitive test tasks (Table XXXVII). This is the most common method for analysing cognitive performance and provides information regarding the entire information processing chain.

The aim of this study was to validate an assessment tool for mental fatigue applied to rotational shift work, where each cognitive test task isolated a cognitive function activated during human information processing by applying the Differential Approach and where each cognitive test task provided information on the general task-related effect.

Table xxxvii: The cognitive functions and task-related effects analysed for each cognitive test task under investigation.

	Cognitive functions	**Task-related effects**
Accommodation test task	Eye accommodation	Choice-reaction time
Visual detection test task	Visual discrimination	Visual detection
Reading test task	Visual pattern recognition	Reading performance
Memory test task	Memory duration	Short-term memory
Tapping test task	Motor programming	Motor control
Driving simulator test task	Peripheral neural control	Tracking performance
Neural control test task	Peripheral neural control	
Simple reaction time test task		Simple reaction time

6.2 SUMMARY OF PROCEDURES AND RESULTS

This project was split into two phases. In Phase 1, the cognitive test tasks were examined in a simulated shift work laboratory setting, where both the cognitive functions and task-related effects were analysed. Cognitive test tasks revealing significant fatiguing effect for either the cognitive function or task-related effect would be proven to be sensitive to mental fatigue occurring during simulated shift work and will be added to an assessment tool.

In Phase 2, this assessment tool was validated for mental fatigue applied to rotational shift work in a field-based setting. Parameters measured for each cognitive function and for each task-related effect revealing significant fatiguing effects in the field-based study were validated for measuring mental fatigue occurring during rotational shift work and were included into the final assessment tool.

6.2.1 Procedure of Phase 1

Seven cognitive test tasks were examined on four different types of shift work regimes, where three of these were unconventional shift work systems. The cognitive test tasks are listed in Table XXXVII; however, the neural control test task was not examined in this phase. The four shift work regimes consisted of a standard rotating shift system, rolling shift system and two split shift nap systems. Twelve participants were tested per shift work regime (non-repeated design), where they were required to attend five consecutive eight-hour shifts. The first shift consisted of a standard eight-hour day shift, which was followed by four night shifts relative to their assigned shift work regime, i.e. five consecutive shifts in total. Assessment of the cognitive test tasks occurred before and after work for each shift, with four testing sessions occurring within each shift, i.e. a total of six testing sessions per shift. The shift work task consisted of a beading task. Rest breaks were given every two hours.

6.2.2 Results of Phase 1

No significant fatiguing effects were found for the accommodation test task in the laboratory setting; thus, this test task was not given further consideration. With regards to the visual detection test task, error rate for visual detection deteriorated during each shift tested. Secondly, tunnel view index for visual detection was worse during the night compared to the day shift. Thirdly, reaction time within each shift responded differently for the various types of shift work regimes tested in the laboratory setting.

In terms of the reading test task, processing time and error rate for visual pattern recognition was significantly worse during the night shift compared to the day shift and was significantly worse after each shift when compared to before each shift. Additionally, reading speed during the six testing sessions behaved differently for the various shifts under investigation and the error rate for reading performance was significantly worse after each shift compared to before each shift.

In terms of the memory test task, the impact of rehearsal time on memory recall rate significantly deteriorated over the five consecutive shifts and short-term memory performance behaved differently for the various types of shift work regimes. With regards to the tapping test task, motor programming time significantly fatigued over the shift time and as well as over the five consecutive shifts. No significant fatiguing effects were noted for motor control.

For simple reaction time, performance was worse after shifts compared to before the shifts and simple reaction time over the six testing sessions varied with the shift being performed.

Five cognitive test tasks revealed significant fatiguing effects in at least one parameter for either the cognitive function or task-related effect. Therefore, five cognitive test tasks were validated for mental fatigue occurring during simulated shift work and were added into the assessment tool. These test tasks were: visual detection, reading, memory, tapping and simple reaction time.

It must be noted that the results from the driving simulator test task in Phase 1 were inconclusive due to the amount of excluded and variable data. This was the result of driving inexperience coupled with high sensitivity of the steering wheel and falling asleep during testing. Thus, another test task was developed in order to isolate peripheral neural control and was called neural control test task. A pilot test was conducted on this test task, where fatiguing effects were evident.

6.2.3 Procedure of Phase 2

The cognitive test tasks validated for mental fatigue in Phase 1 were examined in three different companies in Johannesburg, South Africa. Company A participated in a twelve-hour two-shift rotational shift work system, where workers worked four consecutive days, followed by four days off. Company B participated in an irregular two-shift rotational shift work system where the duration of the day shift and night shift differed. Company C participated in an eight-hour, three-shift rotational shift work system. For both Company B and Company C, employees worked four consecutive shifts followed by three days off. Eighteen participants were tested in Company A, 24 in Company B and 21 in Company C. Each participant was required to complete the cognitive test tasks within the assessment tool once before and once after work for each shift type within their relative company. Thus, this was a repeated design study within each company.

6.2.4 Results of Phase 2

The quality of visual discrimination was compromised during the day shift of Company B and during the night shift of Company C, where the quality of visual discrimination behaved differently within each shift type for Company C. Both the speed and quality of visual pattern recognition was being compromised within the companies. Speed slowed down during the shifts of Company C and Company B, and error rate deteriorated during the shifts of Company A and Company B. Similar effects were found for reading speed for Company A and Company B. Additionally, reading speed before and after work behaved differently within the individual shift types of Company C, where speed of reading performance was compromised during the night shift.

Memorisation was worst during the evening shift compared to the afternoon and morning shift of Company C and memory was being compromised during each of the shift types. These fatiguing effects were also noted for the high precision condition of motor programming. Additionally, short-term memory was being compromised at a greater rate during the night shift compared to during the day shift of Company B.

Motor control was compromised during the night shifts of Company A and Company B, and for the latter, reaction time before and after work varied with the shift type being performed. Fatiguing effects were noted in all three companies for simple reaction time, where performance was compromised during the night shift of Company B and during each shift type of Company A and Company C. Additionally, simple reaction time before and after work behaved differently for the individual shift types of Company B.

No significant fatiguing effects were found for visual detection or for peripheral neural control, which suggests that these two elements were not being compromised due to the shift work performed within any of the companies being investigated.

In total, nine parameters revealed sensitivity to mental fatigue occurring for one or more of the company's investigated. These included: error rate for visual discrimination; processing time and error rate for visual pattern recognition; reading speed; impact of rehearsal time on memory recall rate for memory; recall rate for short-term memory; motor programming time for high precision condition; reaction time for motor control; and simple reaction time.

6.3 CONCLUSIONS

This study revealed that the quality of discriminating between stimuli in the environment becomes challenging whilst performing rotational shift work. Additionally, both the speed and quality of recognising patterns deteriorates. This effect was also noted for the speed of reading. Furthermore, memorisation and programming of movements becomes compromised whilst partaking in rotational shift work and simple motor skills also become impaired.

The effects noted were measured by nine parameters which have been validated for mental fatigue applied to rotational shift work and have been inserted into an assessment tool. Five of these parameters provide information on a particular cognitive function activated during human information processing. These include: error rate for visual discrimination; processing time for visual pattern recognition; impact of rehearsal time on memory recall rate for memory duration; and the high precision condition for motor programming time. Thus these parameters are capable of isolating whereabouts fatigue is occurring during human information processing. The other four parameters provide information on a task-related effect, considering the whole human information processing chain. These include: reading speed for reading performance; recall rate for short-term memory; reaction time for motor control; and simple reaction time.

This assessment tool may prove useful as firstly, it has been validated in measuring mental fatigue and secondly, it is able to isolate where fatigue is occurring during human information processing. As fatigue is being isolated, working tasks and shift work regimes are able to be adapted and adjusted accordingly.

Additionally, mental fatigue behaves differently for different companies. This may be due to the different shift work systems adopted within each company or may be due to the different working tasks performed within each of them. Due to the complex interaction between these two factors, a further differentiation is required: is this is due to the shift work systems or to the working tasks? This must, however, remain a matter for some speculation.

6.4 LIMITATIONS OF THIS STUDY

Phase 1 was a non-repeated design where 12 participants were tested per shift work regime. This small sample size and experimental design reduces the statistical power of the data. Thus, effects that were not significant may have been due to the factors mentioned above rather than to fatigue not occurring sufficiently. Additionally, the sample was limited to students from Rhodes University which represents an educated population and these students have had no prior experience of shift work. Phase 1 was limited to four shift work regimes, three of which were unconventional shift work systems. Thus, the cognitive test tasks were validated for four regimes in the simulated shift work laboratory setting.

In Phase 2, the validation of the assessment tool occurred in South Africa, and has therefore only been validated for a South African population. Testing for Phase 2 was limited to three companies.

The sample tested within each company was rather small for a field-based study. Additionally, age, chronotype, ethnicity, gender, working task, computer literacy and level of education could not be controlled. These variables may have reduced the statistical power in such a way that effects that were not proved to be significant may, in fact, be due to the sampling and not to the insufficient amounts of fatigue occurring.

Participants were requested to not drink caffeine or drink alcohol during experimentation. If participants consumed these beverages on a daily basis, they may have experienced withdrawal during testing which would have interfered with the results. Additionally, the researcher was unable to monitor this beyond testing hours.

A limitation of this phase was that testing could not occur over all consecutive shifts, nor be conducted throughout the shifts. Thus the behaviour of fatigue during and amongst shifts could not be analysed. It is well documented that emotions, stress and distractions influence cognitive performance. This may have impacted upon the results found as testing only occurred once before and once after each shift type.

For both Phase 1 and Phase 2 there was no control group, which could be a limitation to this study. For instance, in Phase 1 participants were not experienced in shift work, this may translate into the data not representing fatigue occurring in the real-world setting. Additionally, in Phase 2 participants were computer illiterate which may have hindered the results and not be reflective of fatigue occurring during real-world shift work settings.

6.5 FURTHER WORK

More cognitive functions need to be isolated and validated for mental fatigue applied to rotational shift work. These must be related to shift work such as logical reasoning and situational awareness. If more cognitive functions reveal sensitivity to mental fatigue during shift work, the assessment tool will expand and more aspects of the human information processing system will be isolated. Additionally, other cognitive functions may be fatiguing and thus, not being eliminated or alleviated.

Some parameters analysed for the cognitive functions and task-related effects revealed no significant fatiguing effects. This does not suggest that they are not sensitive to mental fatigue occurring during rotational shift work. Fatiguing effects may be found in other companies where the rotational shift work and working tasks differ from those investigated in this study. Thus, these parameters have not yet been validated for mental fatigue applied to rotational shift work and should be examined in other companies in order to determine whether they are sensitive and relevant.

The different companies elicited different fatiguing responses. This may have been due to either the working tasks or the rotational shift work systems. Therefore, research should investigate which of these mechanisms was causing the different fatiguing responses. This will assist with interpretations of data found in field-based settings.

However, it must be noted that differentiating between these two factors is extremely challenging due to their complex interaction, a condition which may result in this research not being viable and purely speculative.

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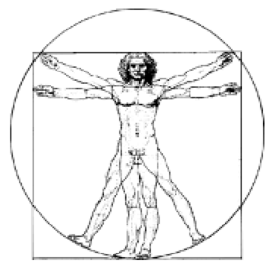
APPENDICES

APPENDIX A: ETHICAL CONSIDERATIONS

Appendix A1: Letter of information to the participant – Phase 1

* It must be noted that not all information presented in this letter of information is relevant to this research project. It must be reminded that the testing conducted in Phase 1 was combined with a PhD research project. Thus, not all collected data was presented in this research project such as comparison amongst shift work regimes, sleep diary and working task performance.



LETTER OF INFORMATION

Dear…………………………………………

Thank you for expressing an interest to participate in this project entitled:

“**Easing the transition into night work: a comparison between alternative and established shift system designs”**

AND

“Validation of an assessment tool for mental fatigue applied to rotational shift work”

BACKGROUND AND PURPOSE OF THE CURRENT STUDY

Shift work, and particularly that which occurs at night (anytime between 20h00 and 07h00) is practised globally, as a means for industries to provide round the clock services and production. Although such an arrangement increases output and contributes significantly to any company’s “bottom line”, the costs to the human operator are significant. Very often, night shift work is associated with circadian rhythm (body clock) and sleep problems, the disruptions of which have marked impacts on a person's ability to perform and stay safe at night. These problems stem from the fact that we are diurnal creatures and working at night essentially means that we are fighting our natural inclination to sleep during that time.

In an attempt to ease the difficulties associated with working at night, researchers have explored many different countermeasures. These include drinking coffee, exposing people to bright light, exercise, manipulating the way in which people move into and out of night work (shift system design) and strategic napping (short sleep opportunities at night).

When entering into night shift work from day or afternoon shifts, workers are forced to adjust their sleep wake cycle by as much as 8 hours, meaning that inevitably, they have to work at night and sleep during the day. This shift is similar to the effects of jet lag, in that you are forced to be awake when you should be asleep and trying to sleep when you should be awake. In an attempt to ease this transition, the current investigation will compare four different shift transition patterns to determine which one results in the least disruption to performance during the night time. The four conditions are a standard rotating night shift (one afternoon shift and four night shifts), an experimental rolling shift system (daily delay of 2 hours in the start and end times of each shift, for 5 shifts) and a two split shift nap systems (one afternoon shift and 4, 8 hour shift, split in to two four hour shifts that are separated by a four hour nap opportunity). All participants will also have to complete a 3 hour familiarisation session the day before the start of the actual data collection period.

PROCEDURE

During this introductory session, you will be briefed on the set up and procedures of the entire experiment. Additionally, and only after you have had all your questions answered and signed the consent form, you will have to complete a sleep disorders screening questionnaire and a morningness - eveningness questionnaire. The sleep disorder questionnaire will enable us to identify whether you have a sleep-related problem that could be worsened by the experiments, in which case you may be excluded from participating. The morningness - eveningness questionnaire will determine your chronotype (morning or evening type) and aid us in allocating you to an appropriate experimental group.

Basic demographic information such as age, sex, level of education, mass and stature will also be recorded. Following this session you will also receive a sleep diary, which I ask that you to complete for the next five days prior to starting your experimentation. Please also ensure that you complete it during the experimental period as well as the five days after you have completed the experiments.

As mentioned previously, in addition to this introduction session, you will be required to complete an additional familiarisation session of 1 to 1.5 hours, the day before the experiments begin. At this session, you will have the opportunity to become familiar with the task to be performed and the tests that you will be exposed to during each night shift. In total, you will all be required to complete five 8-hour shifts, the timings of which will differ depending on the system to which you will be allocated.

During each shift, you will be required to perform a very simple beading task; patterns to follow will be made available and the task will be completely self-paced. During the 8 hour shift, you will also receive three, 15-minute breaks during which you will be provided with a snack to ensure that you are not hungry during the night. The frequency of these breaks may differ, depending on which shift system you are allocated to. Water and toilet facilities will always be available to you.

The performance of this beading task will be interspersed with the completion of battery of tests. In total, each of you will complete at least 6 test batteries each shift, a pre and post shift test battery and four on shift test batteries, that will occur roughly every two hours and will take no longer than 20 minutes to complete. The timings of these tests will also depend on which shift system you are allocated to.

THE TEST BATTERY

The test battery will be comprised of 6 cognitive test tasks.

Reading test task

You will be required to read pieces of text at varying levels of clarity, scanning them for errors as you go. This will test your ability to visually scanning and recognise objects (in this, case errors such as book).

Memory test task

This task will require you to perform a short number memory recall task. During this task, you will be presented (visually) with a string of numbers, which you will have to remember and recite (in the correct order) after a 10 second delay. The simple version of the test is the presentation of 5 numbers, while the complex will be the presentation of 7 numbers.

Tapping test task

The Fitts' stimulus response test measures motor program formation (the planning and execution of different movement patterns in response to a stimulus). During this test, you will be required to respond to targets appearing in random positions on a touch screen as fast and as accurately as you can, using one finger.

Accommodation test task

This particular task will test your ability to accommodate (visually) to changes in your visual field. Two screens will be set up in front of you, one closer to you than the other. You will have to respond to small white squares that will appear between the different screens as quickly as possible.

Visual detection test task

This task will require you to be vigilant and to recognise a critical stimulus amongst many irrelevant ones. You will be required to sit in front of a large computer screen on which there will appear many white, randomly moving stars and one red star. You will be required to respond (by clicking the mouse) when you first see the red star.

Simple reaction time test task

This task measures simple reaction time, where you must respond as quickly as possible to a large round stimulus presented on the computer screen using a computer mouse.

Driving simulator test task

This is a simple driving task where you are required to drive on a curving road. The aim of the task is to stay as close as possible to the white line presented in the middle of the road.

In addition to these computer and paper based test tasks, you will also have to rate your subjective sleepiness (how sleepy you feel) using the Karolinksa sleepiness scale; this scale has 9 verbally anchored levels of sleepiness and is very easy to understand. Furthermore, roughly every 30 minutes, I or a research assistant will record your tympanic (inner ear) temperature. This will give us some insight into how your body clock (and therefore your alertness) changes over the course of each shift. Lastly, a heart rate monitor will be fitted around your chest, and will record your heart rate during each night shift.

RISKS AND BENEFITS

The proposed study may result in the following transient effects:

- acute sleep deprivation, which is typically accompanied by feelings of lethargy, fatigue, sleepiness and increased irritability.

- In addition, for a few days after the completion of the data collection period, you may feel “unadjusted” to being awake during the day. This is a perfectly normal response to working at night and results from your body clock having tried to adjust to working at night.

However, all of the abovementioned effects are easily reversible with sleep (obtained during the normal night time), with any effects of the sleep deprivation period disappearing within two or three days after the completion of the study. Furthermore, the test tasks that you will be exposed to are short in duration and simple and require very little in the way of physical effort to complete.

The proposed study will also afford you the opportunity of experiencing what so many of the shift working population have to deal with on a day to day basis, while giving you an idea of the effects of sleep loss on certain (critical) cognitive processes. This will hopefully increase your own awareness of the deleterious effects of sleep loss and circadian disruptions on your own work and lifestyle.

“DO”S AND “DON’T”S

In an attempt to limit the effects of factors out of the control of the researchers, we ask that you take note and adhere to (as much as is possible) the following requirements:

- Please ensure that you maintain a regular sleeping pattern during the 4 days prior to experimentation (at least 7 to 8 hours)
- Record your sleeping habits in the diary provided.

24 hours before the start of and during the actual experimentation, please do not:

- Consume any alcohol
- Engage in strenuous physical activity
- Take any medication or substances that promote alertness (caffeine (in normal or filter coffee and normal tea, high energy drinks) or sleep (sleep medication, melatonin) unless prescribed to you, in which case, please inform the researchers.

- Nap during the course of the day time: try as much as possible to avoid sleep during the day and just have one monophasic period of sleep during each night prior to the study.

<u>During the data collection, we ask that you:</u>

- Not have your cell phone on you as this may interfere with the equipment while also being a distraction to you and other participants

- Not consume any of the abovementioned substances

- Report any discomfort or problems that you may be experiencing.

- Ask any questions that you may have

CONFIDENTIALITY

Please also note that all information that is collected from you before and during the course of the study period will be coded in a form that is familiar only to the principal researcher. This will ensure that all personal data cannot be linked to you at any time. The data collected will need to be saved and backed up for analyses; this will be done on the principal researcher's personal computer and flash drives, while a copy will also be stored with the principal researcher's supervisor. This information will be stored indefinitely for use in future publications, but will remain coded as well to guarantee your anonymity.

Please note that your participation in the proposed study is voluntary and that you will receive some form of remuneration for participating. Furthermore, if at any stage, or for what ever reason you feel that you can no longer participate in the proposed research project, you are free to discontinue without prejudice. Additionally, if you have any questions regarding the project or need assistance in any way, please do not hesitate to contact the principal researcher (details provided below). Thank you again for your interest in the current project.

Yours sincerely,

Jonathan Davy
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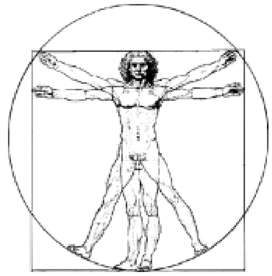
Rhodes University
Cell: 072 226 0430
Email:j.davy@ru.ac.za

Kirsten Huysamen
MSc Scholar
Department of Human Kinetics and Ergonomics
Rhodes University
Cell: 0846004702
Email: kirstenhuysamen@gmail.com

Appendix A2: Letter of information to the participant – Phase 2



LETTER OF INFORMATION

Dear ____________________

Thank you for your interest in participating in this study entitled:

"Validation of an assessment tool for mental fatigue applied to rotational shift work"

AIM OF STUDY

Fatigue is feeling mentally, physically or emotionally exhausted or drained. It has been proven that fatigue decreases your well-being and work performance. Shift work is a potent cause of fatigue, especially night shift work, as you shift your sleeping patterns out of your natural sleeping cycle. Therefore, you are awake when your body is trying to shut down in order for you to go to sleep. Many workers around the globe participate in shift work and suffer from fatigue, therefore preventing fatigue is essential. However, fatigue, especially mental fatigue, cannot be prevented, as there is no tool to measure it. Thus, this study will aim to develop an assessment tool to measure mental fatigue experienced during shift work

PROCEDURES

For this study, you will need to attend one habituation session and two testing session which will occur twenty minutes before work and twenty minutes after work for one day shift and for one night shift. During the testing sessions, you will complete an assessment tool which is discussed below.

In the habituation session, you will be introduced to the study and you will be given detailed information about what the study entails. You will become familiar with the equipment used in the study and you will become familiar with the methodology and procedures of the study. Once you fully understand the project aims and procedure, you will practice the assessment tool. If you have any question regarding the test tasks, please do not hesitate to ask any questions Basic personal information such as age, sex, language preference and level of education will need to be collected from you in this session. Language preference is needed in order to prepare the reading test task. If you are unable to read, please inform the principle researcher. The details collected will be kept private and confidential. If you agree to participate in the study, you will then sign the informed consent sheet. Once this has been done, you will be given your code with your testing days, testing order and testing times.

If you agree to participate in the study, testing will commence. Testing will take place at the company before and after work on one day shift and on one night shift. Further details will be given to you from the principal researcher. Each testing session will not take longer than 20 minutes and will consist of 6 different cognitive test tasks. When you arrive for your testing session, please inform the principal researcher of you arrival. You will be seated at your starting test task and will then rotate to the next test task, once you have completed the starting test task. After all testing sessions are complete, you will receive R100 cash, thanking for your participation in the study. If you wish to withdraw from the study at any point, you will be paid according to the sessions you have attended (R25 per session).

Assessment tool

The assessment tool is made up of 6 cognitive test tasks. Five of the cognitive test tasks are presented at two levels, simple and complex. These test tasks include a memory test task, a reading test task, a visual detection test task, a neural control test task and a tapping test task. Only one of the cognitive test tasks is presented at one level of difficulty, a simple reaction time test task. The assessment tool is 10 minutes and 50 seconds long in duration.

Memory Test Task

For both the simple and complex memory test task, you are required to remember and recall 7 numbers displayed to you on a computer screen, which you will enter into a computer via a keyboard. For the simple memory test task, which lasts 60 seconds, you will be required to wait 2 seconds before recalling the numbers. For the complex memory test task, which lasts 90 seconds, you will be required to wait 4 seconds before recalling the numbers. Your performance will be noted by the number of correctly recalled numbers.

Reading Test Task

The reading test task consists of reading different texts on a piece of paper in English, Zulu, Afrikaans or Xhosa at a high resolution (300dpi) and at a low resolution (60dpi. Spelling errors in the form of double letters (i.e. saafe) have been entered into the text, which you must identify. You must circle the various errors identified with a pen. Both the low resolution text and the high resolution text will be tested for 90 seconds each. Reading speed and the amount of correctly identified spelling errors are the performance indicators for this test task.

Visual Detection Test Task

In this test task, you will be required to identify, by clicking the right hand side button on a computer mouse, a moving red dot amongst numerous moving white dots across a computer screen. For the simple condition, there will 40 moving white dots and for the complex condition there will be 80 moving white dots, where each level of difficulty is tested for 45 seconds. The performance measurement for this test task is reaction time, percentage of overlooked stimuli and tunnel vision.

Neural Control Test Task

This test task requires you to respond to randomly situated green dots on a computer using a computer mouse. For the simple condition the computer mouse was set at a normal level of sensitivity. However, for the complex condition, the computer mouse was set at a high level of sensitivity. Each level of difficulty runs for 60 seconds where reaction time is the main performance measure.

Tapping Test Task

This test task run for 90 seconds and require you to respond, by tapping a green dot presented on a touch screen. One green dot is presented at a time in various places and in various sizes on the touch screen. Reaction time and target deviation are the performance measure in this test task.

Simple Reaction Time Test Task

This test task, which measures reaction time, only runs for 20 seconds, where you are required to right click with a mouse at the presentation of a 5cm green dot presented on a computer screen. This test task is used as a reference task.

REQUIREMENTS OF PARTICIPANTS

Prior to testing please adhere to the following requirements. If these requirements are not met, the data will be misrepresented and invalid. This will hinder and impact the quality of the study:

- Do not consume alcohol 24 hours before testing
- Do not participate in any vigorous activity 24 hours prior to testing
- Do not take caffeine 8 hours prior to testing
- Do not take medication (except chronic medication) or substances 24 hours before testing

If you are unable to adhere to these requirements, please inform the researcher on arrival.

RISKS AND BENEFITS

The risks associated with this protocol are minimal. If you should experience any discomfort during testing and wish to withdraw from the experiment, please inform the researcher immediately. There are two primary risks associated with this study, these include; eye strain and mental fatigue. Thus you may feel visual discomfort or you may feel drained. These symptoms are brief, reversible and easily eradicated once the protocol has been completed. It is therefore recommended that after the testing is complete you wait for 5 minutes before leaving the testing area. If the symptoms are still evident after 5 minutes of resting, you will be transported to receive immediate medical assistance.

By participating in the study, you are offered the chance to broaden your knowledge on mental fatigue in the workplace and you will gain an understanding of the effects felt during shift work. You will also be exposed to new equipment and test tasks which will enhance your technological knowledge. Furthermore, you will learn and be exposed to the benefits of Ergonomics in the workplace.

CONFIDENTIALITY AND FEEDBACK

Please be aware that your anonymity is guaranteed during this testing. All information will be coded according to your participant code to ensure your data is kept confidential. Once the data collection is complete all personal data will be deleted.

I am able to provide you with feedback on your performance directly after the testing session and if you would like to receive feedback of the study, please feel free to contact the primary researcher, however feedback can only be provided after the Master's Thesis is completed.

Thank you for showing an interest in this study. I hope you will learn a lot from this and that you enjoy the experience. If you have any further questions please do not hesitate to contact me directly.

Yours sincerely,

Kirsten Huysamen
MSc Scholar
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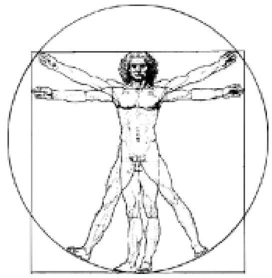
Rhodes University
Cell: 0846004703
Email: kirstenhuysamen@gmail.com

Appendix A3: Signed consent



LETTER OF INFORMED CONSENT

I, ______________________________having been fully informed of the research entitled:

VALIDATION OF AN ASSESSMENT TOOL FOR MENTAL FATIGUE APPLIED TO ROTATIONAL SHIFT WORK

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

I am fully aware of the procedures involved as well as the potential risks and benefits attendant to my participation as explained to me verbally. In agreeing to participate in this research, I waiver any legal recourse against the researchers of Rhodes University, from any and all injuries sustained. This waiver shall be binding upon my heirs and personal representatives. I realize that it is necessary for me to promptly report to the researchers any signs or symptoms indicating any abnormality or distress. I am aware that I may withdraw from participation, without consequences, at any time during the research. I was not pressured into participating in this research test and did so voluntary. I am aware that my anonymity will be protected at all times and that all the information collected, including photographs taken, may be used and published for statistical or scientific purposes. I have read this participant consent form and any questions that may have occurred to me have been answered to my satisfaction.

PARTICIPANT

______________ ________________ _____________
(Print name) (Signed) (Date)

RESEARCHER

______________ ________________ _____________
(Print name) (Signed) (Date)

WITNESS

______________ ________________ _____________
(Print name) (Signed) (Date)

Appendix A4: Ethical approval

Human Kinetics and Ergonomics
Ethics Committee Report

RHODES UNIVERSITY
Where leaders learn

Student Name: Kirsten Huysamen

Type of Research: Masters Research Project

Project Title: Validation of an assessment tool for human performance characteristics applied to shift work.

Supervisor: Prof Goebel

Application received: 08 April 2013

Report Compiled: 26 April 2013

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

Remarks:

Good luck for experimentation.

Signed

Al Todd
Chair: Human Kinetics and Ergonomics Ethics Committee

Confidential
HKE Ethical Committee Review Form

APPENDIX B: LOGISTICS

Appendix B1: Order of testing – Phase 1

Table xxxviii: Order of the level of difficulty and cognitive test tasks for each participant tested in Phase 1 and their relevant code.

Subjects	**Level of difficulty**	**Test task 1**	**Test task 2**	**Test task 3**	**Test task 4**	**Test task 5**	**Test task 6**
A1:A7	Simple - Complex	Tapping + SRT	Memory	Accommodation	Reading	Detection	Driving simulator
A2:A8	Complex - Simple	Memory	Accommodation	Reading	Detection	Driving simulator	Tapping + SRT
A3:A9	Simple - Complex	Accommodation	Reading	Detection	Driving simulator	Tapping + SRT	Memory
A4:A10	Complex - Simple	Reading	Detection	Driving simulator	Tapping + SRT	Memory	Accommodation
A5:A11	Simple - Complex	Detection	Driving simulator	Tapping + SRT	Memory	Accommodation	Reading
A6:A12	Complex - Simple	Driving simulator	Tapping + SRT	Memory	Accommodation	Reading	Detection
B1:B7	Simple - Complex	Tapping + SRT	Memory	Accommodation	Reading	Detection	Driving simulator
B2:B8	Complex - Simple	Memory	Accommodation	Reading	Detection	Driving simulator	Tapping + SRT
B3:B9	Simple - Complex	Accommodation	Reading	Detection	Driving simulator	Tapping + SRT	Memory
B4:B10	Complex - Simple	Reading	Detection	Driving simulator	Tapping + SRT	Memory	Accommodation
B5:B11	Simple - Complex	Detection	Driving simulator	Tapping + SRT	Memory	Accommodation	Reading
B6:B12	Complex - Simple	Driving simulator	Tapping + SRT	Memory	Accommodation	Reading	Detection
C1:C7	Simple - Complex	Tapping + SRT	Memory	Accommodation	Reading	Detection	Driving simulator
C2:C8	Complex - Simple	Memory	Accommodation	Reading	Detection	Driving simulator	Tapping + SRT
C3:C9	Simple - Complex	Accommodation	Reading	Detection	Driving simulator	Tapping + SRT	Memory
C4:C10	Complex - Simple	Reading	Detection	Driving simulator	Tapping + SRT	Memory	Accommodation
C5:C11	Simple - Complex	Detection	Driving simulator	Tapping + SRT	Memory	Accommodation	Reading
C6:C12	Complex - Simple	Driving simulator	Tapping + SRT	Memory	Accommodation	Reading	Detection
D1:D7	Simple - Complex	Tapping + SRT	Memory	Accommodation	Reading	Detection	Driving simulator
D2:D8	Complex - Simple	Memory	Accommodation	Reading	Detection	Driving simulator	Tapping + SRT
D3:D9	Simple - Complex	Accommodation	Reading	Detection	Driving simulator	Tapping + SRT	Memory
D4:D10	Complex - Simple	Reading	Detection	Driving simulator	Tapping + SRT	Memory	Accommodation
D5:D11	Simple - Complex	Detection	Driving simulator	Tapping + SRT	Memory	Accommodation	Reading
D6:D12	Complex - Simple	Driving simulator	Tapping + SRT	Memory	Accommodation	Reading	Detection

Appendix B2: Order of testing – Phase 2

Table xxxix: Order of the level of difficulty and cognitive test tasks for each participant tested in Phase 2 and their relevant code.

Code	**Start with**	**Test task 1**	**Test task 2**	**Test task 3**	**Test task 4**	**Test task 5**	**Test task 6**
A1: B1: C1	Simple	Tapping	SRT	Memory	Reading	Detection	modi. Tapping
A2: B2: C2	Complex	modi. Tapping	Tapping	SRT	Memory	Reading	Detection
A3: B3: C3	Simple	Detection	modi. Tapping	Tapping	SRT	Memory	Reading
A4: B4: C4	Complex	Reading	Detection	modi. Tapping	Tapping	SRT	Memory
A5: B5: C5	Simple	Memory	Reading	Detection	modi. Tapping	Tapping	SRT
A6: B6: C6	Complex	SRT	Memory	Reading	Detection	modi. Tapping	Tapping
A7: B7: C7	Simple	Tapping	SRT	Memory	Reading	Detection	modi. Tapping
A8: B8: C8	Complex	modi. Tapping	Tapping	SRT	Memory	Reading	Detection
A9: B9: C9	Simple	Detection	modi. Tapping	Tapping	SRT	Memory	Reading
A10: B10: C10	Complex	Reading	Detection	modi. Tapping	Tapping	SRT	Memory
A11: B11: C11	Simple	Memory	Reading	Detection	modi. Tapping	Tapping	SRT
A12: B12: C12	Complex	SRT	Memory	Reading	Detection	modi. Tapping	Tapping
A13: B13: C13	Simple	Tapping	SRT	Memory	Reading	Detection	modi. Tapping
A14: B14: C14	Complex	modi. Tapping	Tapping	SRT	Memory	Reading	Detection
A15: B15: C15	Simple	Detection	modi. Tapping	Tapping	SRT	Memory	Reading
A16: B16: C16	Complex	Reading	Detection	modi. Tapping	Tapping	SRT	Memory
A17: B17: C17	Simple	Memory	Reading	Detection	modi. Tapping	Tapping	SRT
A18: B18: C18	Complex	SRT	Memory	Reading	Detection	modi. Tapping	Tapping
B19: C19	Simple	Tapping	SRT	Memory	Reading	Detection	modi. Tapping
B20: C20	Complex	modi. Tapping	Tapping	SRT	Memory	Reading	Detection
B21: C21	Simple	Detection	modi. Tapping	Tapping	SRT	Memory	Reading
B22	Complex	Reading	Detection	modi. Tapping	Tapping	SRT	Memory
B23	Simple	Memory	Reading	Detection	modi. Tapping	Tapping	SRT
B24	Complex	SRT	Memory	Reading	Detection	modi. Tapping	Tapping

Appendix B3: Reading test task

High resolution reading text – 300dpi

Pistorius, the star of the London 2012 Paralympics, wass sensationally beaten into the silver medal position by Brazil's Alan Oliveira on Sunday, in a reesult that stunned the Olympic Stadium.The 25-year-old then hit out at the International Paralympic Committee (IPC), claiming it was not a fair racce and he was at a disadvantage caused by artificial leg length, as the regulations allowed athletes to makke themselves "unbelievably high".

Pistorius, who had both legs amputated below the knee, runs on carbon fibre blades, as does Oliveira."I would never want to detract fromm another athletes' moment of triumph and I want to apologise for the timing of my comments after yesterday's race," the South African saidd in a statement."I do believe that there is an issue hhere and I welcome the opportunity to discuss with the IPC but I accept that raising these concerns immediately as I stepped off the track was wrongg.

"That was Alan's moment and I would like to put on record the rrespect I have for him."I am a proud Paralympian and believe in the fairness of sport. I am happy to work with the IPC who obviously share thesse aims." After expressing his concerns publically, both before and after the final, about the length of the prosthetic blades usedd by Oliveira, IPC media director Craig Spence said the matter was noww being investigated.

"We've agreed we will meet again with our medical and scientific director Peter van de Vliet for Oscar to share his concerns with the IPC, without the emotions of ttonight's race," Spence said."That meeting will be set up in due course and we'll discuss what Oscar's got to sayy and then we'll take it from there." Pistorius, struggling to hhide his emotions expressed his gratitude to Spence and said his focus would now be on his other races.

"I would jjust like to say thanks very much to Craig for taking the time to listen to me," said the subdued Pistorius."I would also like to congratulate Alan. I shook his hhand outside on the track."He had a great performance tonight and I wish him all the bbest. My focus is going to be on my upcoming races now. I wasn't abble to defend my title in the 200m, but hopefully I'll be able to do it in the 400m and, maybe with a bit of luck, in the 100m."

"Thankk you very much for coming back out here, I appreciate it," he told reporters before being ushered away by Spence. Pistorius, who had sset a T43 world record of 21.30 seconds in the heats on Saturday, clocked 21.52 in the final, to lose hhis title to Oliveira by a fraction of a second in 21.45.In third place was Blake Leeper from the US, in 22.46."I've nnever seen a guy come back from eeight metres on the 100 metre mark, to overtake me on the finish line," said Pistorius, reeling from shock after conceding his huge lead to finish secondd.

Low resolution reading text – 60dpi

First man to step on moon dies

NEIL Armstrong was a qquiet, self-described "nerdy" engineer who became a global hero when, as a steely-nerved US pilot, he made "one giant leap for mankind" with the first step on the moon.

The modest man whho entranced and awed people on Earth has died. He was 82. Armstrong died on Saturday following complications resulting ffrom cardiovascular procedures, a statement from his family said. It didn't say where he died.

Armstrong commanded the Apollo 11 spacecraft thhat landed on the moon on July 20, 1969, capping the most daringg of the 20th century's scientific expeditions. His first words after setting foot on the surface are etched in history bookks and in the memories of those who heard them in a live broadcast. "That's one small step for man, one giant leap for mmankind," Armstrong said.

In those first few moments on the moon, during the climax of a heated space race with the then-Soviet Union, Armstrong stopped in whhat he called "a tender moment" and left a patch to commemorate Nasa astronauts and Soviet cosmonauts who had dieed in action. "It was special and memorable, but it was only instantaneous because there was work to ddo," Armstrong told an Australian television interviewer this year.

Armstrong and Buzz Aldrin spent nearly three hours walkinng on the lunar surface, collecting samples, conducting experiments and taking photographs. "The sights were simply magnificent, beyond any visual experience that I had ever been exposed to," Armstrong oncce said.

The moonwalk marked America's victory in the Cold War space race that began on October 4 1957, witth the launch of the Soviet Union's Sputnik 1, a satellite whose successful launch sent shock waves around the worldd.

An estimated 600 million people, a fifth of the world's population, watched and listened to the moonn landing, the largest audience for any single event in history. Parents huddled with their children in front of the ffamily television, mesmerised. Farmers abandoned their nightly milking duties, and motorists pulled off the highway and checked intto motels just to watch the TV.

APPENDIX C: PAIRED T-TEST TABLES

Visual discrimination – Company B

Paired t-test for the day shift of Company B

Repeated Measures Analysis of Variance (Spreadsheet23) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 6.790888					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	234.1034	1	234.1034	5.076386	0.037752
Error	783.9748	20	46.1162		
TESTS	110.1935	1	110.1935	5.667114	0.029252
Error	330.5544	20	19.4444		

Paired t-test for the night shift of Company B

Repeated Measures Analysis of Variance (Spreadsheet10) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 7.161670					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	74.4935	1	74.49349	1.452412	0.243747
Error	923.2113	20	51.28952		
TESTS	1.9083	1	1.90833	0.063653	0.803671
Error	539.6438	20	29.98021		

Motor control – Company A

Paired t-test for the day shift of Company A

Repeated Measures Analysis of Variance (Spreadsheet8) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .1528876					
	SS	**Degr. of – Freedom**	**MS**	**F**	**p**
Intercept	31.05949	1	31.05949	1328.769	0.000000
Error	0.37399	16	0.02337		
TESTS	0.00380	1	0.00380	2.598	0.126524
Error	0.02341	16	0.00146		

Paired t-test for the night shift of Company A

Repeated Measures Analysis of Variance (Spreadsheet8) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .1657180

	SS	Degr. of - Freedom	MS	F	p
Intercept	30.20879	1	30.20879	1100.003	0.000000
Error	0.41194	15	0.02746		
TESTS	0.01490	1	0.01490	4.585	0.049074
Error	0.04874	15	0.00325		