THE EFFECTS OF THE TYPE OF REST BREAKS ON RETURN-TO-TASK PERFORMANCE IN SEMI-AUTOMATED TASKS WITH VARYING COMPLEXITIES

BY

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ABSTRACT

Automation in the aviation industry is acknowledged as a useful tool in reducing pilot workload (Hoh, Smith & Hinton, 1987; Beringer & Harris Jr., 1999). Typically, the role of the pilot (operator) shifts from active participation in a process to a task of monitoring the system with the resumption of control should the automation 'fail' (Byrne & Parasuraman, 1996). Unfortunately, the skills necessary to do so would likely degrade from non-use, during this process (Landry, 2012). This project investigates the "attentional demands" for the human operator during interaction with semi-automated operations of the flight.

According to Dr Abbott (1996), FAA human factors specialist, one of the problems causing disharmony between crews and their automated systems is the incorrect upset recovery, owing to the human being out-of-the-loop (OOTL) from the system. Recovery, or rather return to task, is the ability of the pilot to loop back into control, once situational awareness has been decreased due to lack of alertness and a decrease in arousal. Different types of rest tasks are commonly prescribed fatigue countermeasures in the industrial setting and have been showed to elicit beneficial effects on prolonged human performance. Understanding the effects of different rest break activity and time out-of-the-loop during semi-automated flying on return to task performance has been adequately studied, thus highlighting its importance in the context of flight safety.

The present study requested participants to perform a tracking task in a laboratory where they changed from activity (30 minutes) to a break (2 vs. 30 minutes) and back to the activity (20 minutes). The task varied in the complexity of the activity (pure tracking vs. tracking plus memory plus rule-based decision making), the type of break (passive rest vs. actively supervising) and the duration of the break (2 minutes vs. 30 minutes). Performance was measured as effective response time in the tracking task and number of correct responses to secondary cognitive tasks. Physiological measures included heart rate (HR), heart rate variability (HRV- time and frequency-domain), eye blink frequency and duration. The Karolinska Sleepiness Scale was used as a subjective measure.

With regards to the most appropriate rest break tasks, the study concluded that active, administrative tasks, which allowed the operator to maintain some form of situational awareness by monitoring the automated system, achieved favourable effects of being more alert than the passive rest break of being disengaged from the system. In terms of the most appropriate rest break durations, the shorter duration of being out-of-the-loop from controlling the system proved to be more advantageous than the longer out-of-the-loop duration. In looking at the workload levels of arousal, the results suggest that the higher workload level is better at maintaining the alertness of operators. This study functions as a foundational framework for future investigations around the topic of human-automation interaction, looking specifically at return-to-task performance.

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CHAPTER I

INTRODUCTION

1.1 HUMAN-AUTOMATION INTERACTION CONTEXT

The use of automation is prevalent in our everyday lives, predominantly in industries such as the aviation industry (Lee & See, 2004). Automation, in its 'natural' form, is expressed as a means of technology that actively selects data, transforms information, makes decisions and/or controls processes (Parasuraman, Sheridan & Wickens, 2000). Thus, the objective of human interaction with automated systems is to increase operator performance, accuracy and reliability (Parasuraman, Sheridan & Wickens, 2000). Applied to the context of semi-automated flights, this means the introduction of automatics in the cockpit is aimed at reducing pilot workload in the name of operating the flight safely.

The design and introduction of such automated aids in the cockpit has brought, without a doubt, significant change to the operation of commercial transport aircraft. Numerous tasks that human pilots are required to perform in order to operate the aircraft safely and effectively, are heavily reliant on the automated system (Morris & Leung, 2006). These systems have in turn become 'addictive' so much that the pilot's flying skilled have regressed to a level upon which following system failures, their ability to handle the aircraft, has become doubtful in some cases. Landry (2012) further stipulates that such skills, necessary to resume control effectively and safely, would likely be degraded from non-use during the period of being out-of-the-loop (OOTL).

According to Barker (2012), the current automation design paradigm proposes that 'the less you give the pilot to do, the safer the system will be'. This has resulted in the majority of the control in the cockpit being shifted to the automation rather than to the pilot, however still maintaining some degree of shared control. The proposed control sharing approach is termed adaptive automation (AA) which is dependent upon situational demands and seeks to find ways of developing this understanding to increase human performance (Kaber & Endsley, 2004).

A series a questions in response to this kind of approach have arisen. In designing human error out of the cockpit, does this mean that the automation is to back up the pilots or is the pilot to back up the automation? What is the pilot role in such a setting? Contemporary research has shown the advantage of preserving a level of operator awareness of the various sub-tasks, even if they are performed in a fully automated mode (Parasuraman & Riley, 1997). Parasuraman, Mouloua & Molloy (1996) demonstrated that a task that is completely automated cannot simply be ‘forgotten’ but it is in reality itself transformed into an additional, obligatory monitoring task. Unfortunately, humans have proved to be relatively inefficient at such prolonged monitoring and any design rationale that advocates wholesale automation simply reduces operators to the monitors of multiple displays, a task which they are poorly equipped to perform (Bainbridge, 1983, Hancock *et al.*, 1991, 2013).

Pilots’ strategies for automation use will to a great extent be dependent on their perceptions of how a particular automated system in a particular situation will affect their cognitive and behavioural performance (Mosier *et al.*, 2013). Because operators make many decisions concerning automation use, it is important to understand their perceptions of how system and situational characteristics will affect their interaction with automation (Mosier *et al.*, 2013).

1.2 RESEARCH PROBLEM

There is growing apprehension about cockpit automation and its potential effects on pilot performance and alertness during automated flying, with the engagement of autopilot (Sarter & Woods, 2009). It is essential that pilots are capable of diagnosing troublesome situations in cases of different scenarios. The presence of automation has the ability to make commercial flying safer as it might reduce human error and exceed human capabilities. But, it also might largely reduce pilot control, which could induce pilot complacency, further resulting in decreased levels of alertness, arousal and situational awareness of pilots. The consequence of this is observable when pilots are expected to intervene (loop back into control); the return to task of flying needs to be quick and efficient. According to Dr Abbott (1996), FAA human factors specialist, one of the problems causing such disharmony between crews and their automated systems is the incorrect upset recovery, owing to the human being out-of-the-loop (OOTL) from the system.

Recovery, or rather return to task, is the ability of the pilot to loop back into control, once situational awareness has been decreased due to lack of alertness and a decrease in arousal. Different types of rest tasks are commonly prescribed fatigue countermeasures in the industrial setting and have been showed to elicit beneficial effects on prolonged human performance. Understanding the effects of different rest break activity and time out-of-the-loop during semi-automated flying on return to task performance has been adequately studied, thus highlighting its importance in the context of flight safety.

Thesis objectives

The main objectives of this research are to:

- provide analyses of rest break effects on the performance and alertness of human operators in the face of semi-automated tasks
- assess the impact of two types of rest tasks and two types of rest durations on performance and alertness immediately following a rest break
- assess the impression of various workloads on the performance and alertness of the human operators

The following chapter will look into the background of human operator interaction with automation, which is necessary to understand the work presented later in this thesis. It details the reasoning behind the interest of assessing return-to-task performance, in the face of semi-automated tasks.

CHAPTER II

LITERATURE REVIEW

This chapter aims to provide the background for understanding and assessing the relationship between human capabilities and automation developments in complex interactive spaces, as well as the factors that are known to influence the human-automation relationship.

The first section examines the concept of human factors in human-automation interaction, looking at how both agents in this interaction collaborate and how this relationship has transformed from the historic developments of automation as well as looking at the current knowledge around automation, specifically in the aviation industry. Section 2.2 unpacks the human performance aspect, entailing a description of the human information processing system as well as clarifying some of the basic concepts required to understand how humans interact with the automated system and the information in their environment. Section 2.3 looks at the impact of being out-of-the-loop in controlling a semi-automated system, outlining the various types of measures used to assess the breakdown of performance. These include behavioural measures, psychophysiological and subjective assessments.

2.1 HUMAN FACTORS IN HUMAN-AUTOMATION INTERACTION

One classic goal of human factors engineering is to ensure a good fit between the work environment and human capabilities (Wickens, 1992). In that same light, the traditional approach to task allocation describes the capabilities of the human versus the machine, and attempts to divide tasks upon the basis of this comparison (Scallen, Hancock & Duley, 1995). Deciding which functions (tasks, jobs) of a human-machine system should be allocated to the human and which to the machine has been an important activity within human factors research for years (Hancock & Scallen, 2009; Price, 1985), having the Fitts' list (Fitts, 1951) in the centre of this movement. This list went on to be cited majorly by most research on the topic of function allocation, gaining favour in the early 2000's. At the same time, the Fitts' list has received extensive criticism, ranging from it being considered an intrinsically flawed descriptive listing (Hancock & Scallen, 1997), to simply being insufficient, outdated, static and unable to acknowledge the organisational context and relationship of the human and machine (Bye *et al.*, 1999; Hoffman *et al.*, 2002).

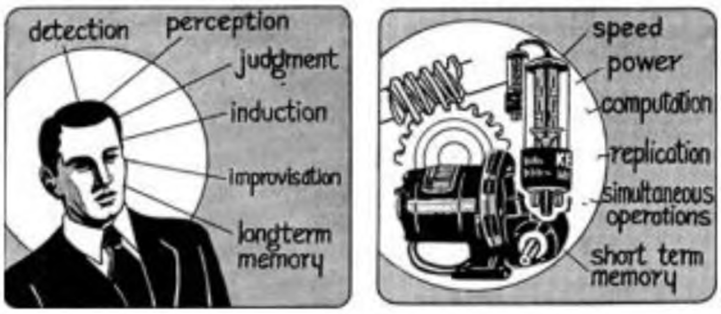

Figure 1: Illustrations of the Fitts' list taken from the original 1951 report (Fitts, 1951, pp. 7-8).

As progress of this interaction continues towards fully adaptive human-machine systems, a crucial concern remains to be resolved, looking at which is the appropriate degree of task partitioning (Sheridan, 2002; Hancock *et al.*, 2013). This deals with the division of a task into sequential actions controlled and shared by the two agents (human and automation). The tasks and intentions in cooperative scenarios (between automation and the human) may continuously change, as the level of interaction is typically dynamic, hence they are permanently reconfigured (Bengler *et al.*, 2012). According to the authors, from this cooperation, two aspects branch off, the first being an on-going arbitration between human and machine agents about a common course of action and the transition in the distribution of tasks and responsibilities. Contemporary research has shown the advantage of maintaining at least some degree of operator awareness of various sub-tasks, even if they are performed in a fully automated mode (Hancock *et al.*, 2013).

In various domains, the development and introduction of automated systems has been successful in terms of improving the precision and economy of operations (Woods, 1996). Inagaki (2003) suggests that, although some design conceptions advocate for a more holistic approach to 'human-in-the-loop' system operation, such that the human retains a more general picture overall operations, some designs bring about conflicts between the two agents in terms of authority sharing. These problems are related for the most part to breakdowns in the interaction between human operators and automated systems. This further results in costs to human performance, including impaired decision-making, manual skill degradation, loss of situational awareness and monitoring inefficiency (Byrne & Parasuraman, 1996). Hancock (2007), adds on in saying that by balancing the supposed advantages with the abovementioned disadvantages, this provides a fundamental rationale for considering how the transitions into and out of automation should occur.

2.1.2 History of automation in aviation

Automation, in its infant stages, was never thought to take over the world of technology like it has today. It represents one of the major trends of the 20th century (Endsley, 1996) which further developed into the 21st century. According to Mumaw *et al.* (2001), however, the introduction of these automatics to the aviation industry has been, a rather mixed blessing. Complex functions once performed by human pilots are now routinely performed by automated systems (Funk, Suroteguh, Wilson & Lyall, 1998). On one hand, it has led to an increased precision and efficiency of operations but it also involves the risk of breakdowns in the communication and coordination between pilots and their modern flight deck systems.

Sarter, Mumaw & Wickens (2007) have proposed several factors which are said to contribute to breakdowns in pilot-automation coordination on modern flight decks. These include: (a) low observability, attributed to poor automation feedback that fails to support pilots in managing their attentional resources and in assessing and interpreting system states and behaviours; (b) gaps and misconceptions in pilot mental model of highly complex flight deck automation, attributable to limited training, inappropriate manual and a problematic system image; (c) a high degree of system autonomy (the ability of the automation to initiate actions without immediately preceding pilot input); (d) a high degree of system coupling (a high level of interdependency between various components of the automation), which can lead to unexpected side effects of pilot input. Parasuraman and Riley (1997) define automation as the execution by a machine agent (usually a computer) of a function that was previously carried out by a human.

During the early days of aviation, automation was seen as a myth (Archer, Keno & Kwon, 2012). According to the authors, pilots controlled the aircraft by means of manual inputs, where the inputs were determined based on feedback from elementary cockpit instruments, such as a magnetic compass and the engine gauge. The first noticeable signs of aircraft automation were in 1914, a system designed to stabilize the aircraft attitude via mechanical manipulation of the aircraft control surfaces (Landry, 2009). An example of such a system was Sperry's autopilot, named after Lawrence Sperry, where it involved a gyroscopic mechanism capable of stabilizing an aircraft's flight without active participation from the human pilot (Mosier *et al.*, 2007; Landry, 2012).

There has been growing research based on examining the human capabilities involving working with automated systems (Parasuraman & Sheridan, 2000). It has been shown that automation does not simply supplant human activity but rather changes it, often in ways unintended and unanticipated by the designs of automation and thus as a result, pose new co-ordination demands on human operators (Parasuraman & Riley, 1997).

Over the years, automation has found its niche in many industries and has been viewed as the common 'perpetrator' in industrial accidents, placing the blame on 'over-reliance' on automation (Norman, 1990). A number of researchers, however, have disputed this notion by various means stating that automation is not the problem, but rather its inappropriate application (Norman, 1990; Parasuraman & Riley, 1997).

2.2.2 Current knowledge around automation in aviation

Considerable research has gone behind understanding human characteristics and limitations and such knowledge has been used to better designs of automated systems (Bainbridge, 1983; Billings, 1997; Jamieson & Vicente, 2005; Parasuraman & Mouloua, 1996; Parasuraman & Riley, 1997; Rasmussen, 1986; Sarter, Woods & Billings, 1997; Sheridan, 1992a, 2002; Wiener & Curry, 1980). The main goal of human-centred automation is to create systems that retain the human operator in control loops with meaningful and well-designed tasks that operators are capable of performing well in order to optimize overall human-machine functioning.

Research on automation has thus focused on factors that influence human behaviour and reliance on automation, looking at the operators level of trust in the system and level of automation (Hughes et al., 2009).

There has been research identifying two classes of errors that commonly emerge in highly automated decision environments (Mosier *et al.*, 1999). These are (1) errors of omission, defined as failure to respond to a system irregularities or events when automated devices fail to detect or indicate them and (2) errors of commission, which occur when people incorrectly follow an automated directive or recommendation, without verifying it against other available information or in spite of contradictions from other sources of information.

An example of such a scenario is the incident that occurred involving the TransAsia Airways Flight 235, taking off from Taipei Songshan Airport. Just moments after take-off, the pilots reported an engine 'flameout', which refers to the run-down of an engine, caused by the extinction of a flame. Ordinarily, the aircraft could function on one engine owing to the redundancy of aircraft automatics, however, the pilots mistook the functioning engine for the malfunctioning one, shutting it off, which lead to the plane being powerless and thus resulting to a crash into a nearby river. This gives light into the types of pilot errors present in the use of automatics without verifying the information correctly.

Levels of automation

More often than not, overreliance on automation by the aircrew can lead to 'automation bias', which is described by Mosier and colleagues (1999) as using automation as a form of heuristic replacement for vigilant information seeking and processing. The Amsterdam air crash occurrence, involving the Turkish Airlines Boeing 737 Flight 1951, confirms the dangers of pilots losing their basic flying skills due to the overreliance on automated aids. This resulted from a failure of a radio altimeter which led to the postponed attempts at stall recovery of the airline. Investigative reports ratify that the pilots allowed the automatic systems to decelerate the aircraft to a treacherously low speed on its approach at Schiphol Airport, Amsterdam. With very late detection and pilot response at only 450 feet (137.16m) above ground level, the pilots failed at preventing the aircraft to stall before crashing to the ground. This crash claimed the lives of three flight deck crew and six others on board.

Following the above mentioned incident, Boeing issued out a notice, bidding pilots 'to carefully monitor primary flight instruments', suggesting this be done at all levels of automation. Various levels of automation exist, and have been proposed by Sheridan and Verplank (1978), having a 10-point hierarchy scale. Higher levels represent increased autonomy of computer over human action whereas lower levels representing the human being superior to the computer.

In their definition of automation, Billings (1991) and Kaber (1997) suggest that level of automation (LOA) refers to the level of task planning and performance interaction maintained between a human operator and computer in controlling a complex system. Adding on, Parasuraman, Sheridan & Wickens (2000) as well as Endsley & Kaber (1999), explain that automation is not 'all or none', but can rather vary across a continuum of levels, from the lowest level of fully manual performance to the highest level of full automation. For example, at a low level 2, several options are provided to the human, but the system has no further say in which decision is chosen, whereas at a higher level 6, the system gives the human only little time to override the choice before carrying out the decision choice (Parasuraman, Sheridan & Wickens, 2000).

The levels are said to dictate the extent to which a human is involved in a system control and the degree of computer task aiding (Kaber & Endsley, 1999). The level of automation approach emphasises the interaction between the human operator and the computer (Endsley, 1995), in terms of shared control. The basic premise of this approach is to find a level of automation that is human-centred. Through the work of Endsley & Kiris, (1995) together with Parasuraman and colleagues, it is realised that the more support an automated system provides, the higher the risk of adverse effects are on human performance (e.g. complacency, loss of situational awareness, skill degradation). Onnasch *et al.* (2013) further agree with this statement elaborating that the probability of such events would be much more catastrophic in the face of automation failures.

Whist Sheridan & Verplank (1987) focused their model of automation mainly on the 'output' (decision making and action selection), Parasuraman, Sheridan & Wickens (2000) further extended this model, covering the different types of functions in Human-automation interaction, inclusive of input functions, which precede decision making and action selection. The expansion of this model included a four-stage view of human information processing (see Figure 2).

Table 1: Levels of automation proposed by Sheridan & Verplank (1978)

HIGH	10	The computer decides everything, acts autonomously, ignoring the human
	9	Informs the human only if it, the computer, decides to
	8	Informs the human only of asked
	7	Executes automatically, then necessarily informs the human
	6	Allows the human a restricted time to veto before automatic execution
	5	Executes that suggestion if the human approves
	4	Suggests one alternative
	3	Narrows the selection down to a few
	2	The computer offers a complete set of decision/action alternatives
LOW	1	The computer offers no assistance: human must take all decisions and actions

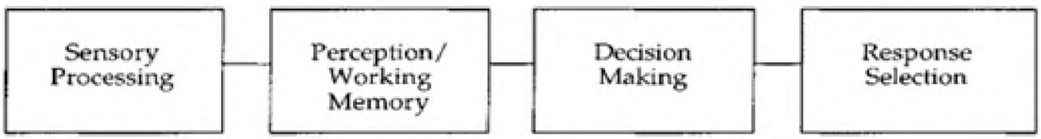

Figure 2: Simple four-stage model of human information processing (adopted from Parasuraman, Sheridan & Wickens, 2000)

Stage one of the 'simple four-stage model of human information processing' represents the acquisition and registration of multiple sources of information, whereas stage two involves the conscious perception and manipulation of processed and retrieved information in working memory. The former deals with the pre-processing of data prior to full perception and selective attention, involving sensory processing by the use of different sensory channels, visual and auditory, (Bonnel &

Hafter, 1998; Parasuraman, Sheridan & Wickens, 2000) and the latter involving cognitive operations such as rehearsal, integration and inference, all occurring prior to decision making (Baddeley, 1992). Stage three is where decisions are made based on the previously mentioned cognitive processes and the fourth and final stage involves the execution of a response or action consistent with the decision choice (Parasuraman, Sheridan & Wickens, 2000).

Adding to the delays in detecting a problem upon occurrence, necessitating an intervention, Endsley and Kaber (2004) submit that operators may require a significant period of time to reorient themselves to the current status of the system after a failure and in doing so, develop sufficient understanding of the state in order to act fittingly to the automation surprises. They continue in stating that this delay may either hinder operators from performing their required tasks or they may weaken the effectiveness of actions taken.

Laboratory studies carried out by Wickens & Kessel (1979, 1981) demonstrated longer system recovery times (return-to-task performance) and poor response accuracies for operators who had been removed from control loops in advance of critical events requiring intervention. Endsley & Kiris (1995) have hypothesised that for situational awareness problems to occur (namely, failure to detect and failure to understand the problem), there are three mechanisms. These include: (1) changes in vigilance and complacency associated with monitoring (further elaborated on below); (2) undertaking a passive role instead of an active role in controlling the system and (3) changes in the quality or form of feedback provided to the human operator. Certain levels of automation together with these above mentioned factors could contribute to the out-of-the-loop performance problem and a loss in situational awareness.

In order to overcome historic tribulations created by technology-centred approaches, Endsley (1999) suggests that, within the levels of automation, the use of intermediated level of automation may provide an approach to human-centred automation. This philosophy of a rather human-centred approach to automation was first proposed by Billings (1991, 1997). He defines human-centred automation as facilitating a cooperative relationship in the control and management of a complex system with potential benefits for performance. According to Sheridan (1997), this human-centred approach has many alternative meanings, ranging from the above explained Fitts' description of 'task allocation' between the human and the machine, through to 'achieve the best combination of human and automatic control, where "best" is defined by explicit system objectives'.

Human interaction with automation

The drive to try understand human interaction with automated systems is largely rooted from several accidents that have involved automation, this first observed by Wiener & Curry in a seminal paper in 1980. Looking particularly in the flight deck/cockpit, pilots are required to plan ahead, instruct the flight management system (FMS), monitor flight progress, correct and modify flight paths, and learn from the behaviour of their aircraft, (Billings, 1997; Chou, Madhavan & Funk, 1996; Wickens, 2002; Durso *et al.*, 2015;). Although the introduction of automated aids was first developed in aviation because of the potential benefits that they offer and the fact that they have extended system functionality well beyond the existing capabilities of the human, these advantages have come with a price (Archer, Keno & Kwon, 2012). A price of which a variety of human factor issues, inclusive of flight crew workload, reduced situational awareness, degradation of basic piloting skills, amongst many, play a huge role in.

A number of incidences that are 'automation-related' typically occur even though the automation did not malfunction. Rather, in some cases, the state of the automated system changed, but this change was not appropriately communicated to the human operator (Sheridan & Parasuraman, 2006). Parasuraman and colleagues (1996) effectively demonstrated that even a fully automated task is not simply 'forgotten' but is in reality itself transformed into a rather additional, obligatory monitoring task. Human factor limitations to this interaction are unfortunately rooted deeply in the fact that humans have proved to be relatively deficient at such prolonged monitoring tasks and according to Hancock *et al.* (1991, 2013), any design rationale advocating for full automation simply reduces operators to monitors, a task humans are simply poorly equipped to perform. Such challenges are accompanied by various other design related problems. It should be however noted that some designs promote for a more holistic approach to human-in-the-loop system operations, consistently giving the operator a general overview of operations (Hoc, Young & Bosseville, 2009).

Monitoring failures, as a human factors issue, have been reported and assumed to add further responsibility to breakdowns in pilot automation coordination (Hancock *et al.*, 2013). The mechanics of monitoring are complex and involve the selective application of mental resources to encode the sensory inputs whilst performing a goal directed task. According to the Civil Aviation Authority (CAA) (2013), there are many factors that hamper monitoring, including system and ergonomic design, however, the biggest concern relates to human vulnerabilities, which include complacency/inattention, distraction, low attentional, resources, low arousal, disorientation, tiredness, (amongst many others) and stressors, such as workload.

To place the above mentioned in a scenario, Sumwalt, Thomas and Dismukes (2002), in their paper looking at monitoring skills, reported on a fatal approach and landing accident, involving a corporate turbo-prop, where the surviving pilot (who was not flying) told the authors, “If I had been watching the instruments, I could have prevented the accident.” This statement alone gives insight to the many ways in which better monitoring strategies of flight instruments could have unfavourable effects on the operation of an automated system.

It is known and acknowledged by this study that equipment failures are infrequent in modern commercial air transport operations, however, it is also known that humans are inherently poor at monitoring for these infrequent events (CAA, 2013). High levels of trust on automation result in a feeling of well-being in the cockpit and important cues can be missed. Wickens (2013) suggests that the greatest benefit of automation is performance in routine circumstances, having the machine perform what it is expected to perform and in the manner of which it expected to do so. “Costs” result when there are automation surprises (‘failure’ of the system) and the human has to intervene by resuming control (Wickens, 2013). An example of such was the Air France 447 Airbus, flying from Rio de Janeiro, which was lost in the Atlantic in 2009.

In a space of four minutes, a series of twenty-four Aircraft Communication Addressing and Reporting Systems (ACARS) messages were sent habitually, signifying - amongst others - speed measurement inconsistencies, the disconnection of the autopilot and the airplane going into ‘alternate law’ flight control mode (a reconfiguration mode) suggesting multiple failures of redundant systems, killing all passengers and crew on board (228). Pilots first viewed this as a minor failure, unaware of the extent of problem which resulted with information overload and a total lack of situational awareness, further leading to a loss of control of the aircraft manually. The aircraft stalled and impacted into the ocean at high speed.

The inability of the human to respond promptly and effectively to the failure (‘return-to-task) is assumed to result jointly from complacency (the overreliance of the operator on automation) and from elimination of the so-called generation effect (this being when the operator is not involved in generating action alternatives) (Landry, 2012; Archer, Keno & Kwon 2012; Wickens, 2013). Combined, the previously mentioned effects define the loss of situational awareness at Level 1 (complacency) and Level 2 (the generation effect), this based on Endsley’s (1995) model of situational awareness in section 2.2.2, which will be elaborated on at a later stage.

Additionally, to the change in situational awareness, another inferred variable is the reduction of workload that comes with greater levels of automation. This meant that the operators were left with less work to perform, alluding to behaviour of a monotonous nature and ultimately boredom (Perkins & Hill, 1985). Wickens and colleagues (2010), however, reported that increased levels of automation, in order to improve routine performance, did not produce the degradation of failure response by the human operators (return-to-task). The question thus remains; what features can mitigate the loss in failure performance with higher levels of automation? Kaber and colleagues (2006) demonstrated that auditory and visual cuing of adaptive automation with supervisory control of a telerover served to improve operator performance and reduce decrements in situational awareness attributed from being ‘out-of-the-loop’.

2.2 HUMAN PERFORMANCE

In an era of constant change and development in automation, aviation experts call for a change in pilot culture and possibly, training regimes (Barker, 2016). At this point, according to Sarter & Woods (1995) amongst other researchers, a number of human-automation system errors have been documented, and these deficiencies are owing to numerous human operator issues such as vigilance decrements, complacency and loss of situational awareness (Endsley, 1987; Weiner, 1988; Endsley & Kiris, 1995, Parasuraman & Riley, 1997).

Human-automation interaction occurs in virtually every phase of flight (Sheridan & Parasuraman, 2006). Goudou & Tessier (2013) explain the process of operating the flight from a human factors perspective as requiring the crew's prediction capability to foresee the future state of the environment correctly (e.g. Air Traffic Controller (ATC) clearances). These capabilities involve both cognitive and emotional capabilities, where the former supports the rational process from the sensorial cues required for the task (Goudou & Tessier, 2013). According to Miyake *et al.*, (2000) this process is based on the activation of the prefrontal cortex, providing executive functions such as planning, working memory, focusing and shifting.

Subsequent research in the previous years has been focussing on understanding human characteristics and thus limitations which influence the appropriate or inappropriate use and management of automated systems (Norman, 1990; Sheridan & Parasuraman, 2002). Considering the reported Indian Airlines Airbus A320 accident on April 14, 1990 for instance, the flight crew suffered from a loss of situational awareness and resulted in the aircraft being destroyed, killing 90 people on board.

The aircraft was reported to have been caused by the pilots' failure to advance the throttles, even with radio communications of altitude call-outs, suggesting an increase in mental workload. Reports from this investigation and other related advanced technology aircraft accidents suggest that besides some of the obvious problems with the design of human-machine interfaces, the aircraft may pose substantial challenges to the flight-crew as they perform a crucial process termed task management (Funk *et al.*, 1998). According to the authors, task management is the process by which operators of complex situations prioritize and perform the multiple, concurrent tasks that compete for their attention.

2.2.1 Human information processing

Wickens' (1984) information processing model (Figure 3) describes a qualitative model of human information processing, incorporating stages used to perceive sensations, transform data and choose an action in response (Louw, 2013). The different stages of human information processing include sensory processing, perception, cognition and memory, and response selection and execution (Morris & Jones, 1990). The time it takes for a full processing at each stage is dependent on mental resources, with any additional considerations such as uncertainty and overload potentially extending processing time (Louw, 2013).

In the first phase of the model, sensory memory, this concerns itself with the visual and auditory senses of the eyes, ears and the proprioceptive or kinaesthetic sense of the body and limb position.

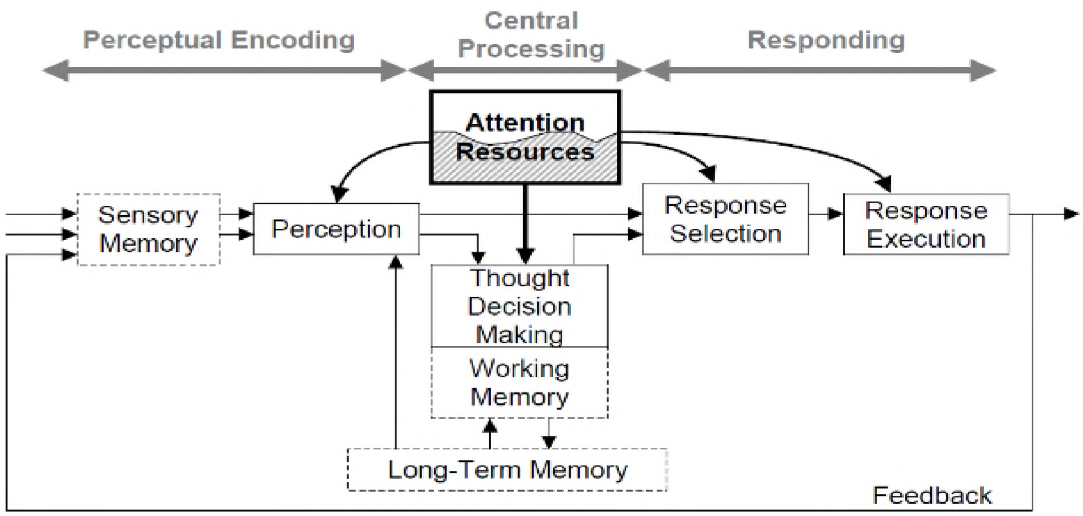

Figure 3: Model for human information processing (adapted from Wickens, 1984, pg. 12)

This information is then passed to stages of perceptions, typically requiring little to no attention, at which point the stimulus is identified or categorised in terms of previously learned or stored neural codes in the brain (Wickens, 2002; Louw, 2013).

This stage is typically driven by both sensory inputs (involving cues in the environment that attract attention such as glass displays in the cockpit) and long-term memory (which is user-directed attentional processing, being what the operator chooses to focus their attention to). The former takes a bottom-up processing approach whereas the latter takes a top-down processing approach (Louw, 2013).

Once information has been perceived and recognized, it is then passed on to decision- and respond-selection and execution processing, assessing the implications of the choice of a response. These central processes, according to Wickens (1984), are intimately related to memory. Eventually a response is selected, leading to the execution of the appropriate response by the human operator.

2.2.2 Workload

Humans receive information from the world around them through their senses: sight, hearing, touch, smell and taste (Felder & Silverman, 1988). When flying an aircraft, or operating any system, the human operator must observe and react to events both in the immediate or internal environment and in the external environment (Aviation academy, 2008). Research further stipulates that the information obtained from these environments must then be interpreted in order to make decisions and take actions to ensure safe and efficient operation of the system at all times. This can however be hindered by the presence or lack of workload.

According to Durso & Alexander (2010), workload is a vital construct in aviation. The potential for error caused by non-optimal levels of workload and the subsequent consequences of these errors make the value of understanding optimal and non-optimal workload unclear (Durso & Alexander, 2010). The study thus recognises that “non-optimal” levels can be either excessively high or excessively low levels of workload, as both are expected to contribute to pilot or controller error (Durso & Manning, 2008; Kantowitz & Casper, 1988). Given the inherent safety implications of ‘workers’ who are overworked or under-stimulated, it is no wonder that many studies in the previous years have focused on either measuring or manipulating workload (or both). According to Rantanan (2004), focusing on performance in Air Traffic Controller (ATC) literature, workload has been the construct of most scrutiny. This is due to the extreme presence of both high and low workload of the tasks.

2.2.3 Situational awareness

There is a long history of cases reporting supposed loss in awareness of automation failures and do not detect critical system state changes when taking up the role of monitoring automated systems (Endsley, 1995; Ephrath & Young, 1981; Kessel & Wickers, 1982; Wickens & Kessel, 1979; Young, 1969). The term *situational awareness* has been emphasized in the aviation industry owing to its prominent role in flight operations (Sohn & Doane, 2004). Maintaining a high level of situational awareness in the aviation industry is very crucial and challenging (Endsley, 1999). It is thus a continuous challenge to support the human operator in intensively mediated situations through automated designs, as the concerns for situational awareness are rooted in 'knowing what is going on' currently in the environment as well as 'knowing the future status of the flight' (Endsley, 1995; Kirlik & Strauss, 2006).

Situational Awareness (SA) is the term given to the awareness that an individual has of a certain state of affairs (Endsley, 1995). Furthermore, it is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1998, pg. 36). Situational awareness, according to Endsley (1999), therefore involves distinguishing critical factors in the environment (referred to as Level 1), understanding what these factors mean, especially in relation to the aircrew's goals (Level 2) and at the highest level, an understanding of what will happen with the system in the near future (Level 3). In order for pilots to function in a timely and effective manner, higher levels of situational awareness are required.

Many researchers have cited the glass cockpit (i.e. automation) as being responsible for psychologically distancing the pilots from their aircraft and the situation, leading to a dissonance between the human operators understanding of the system status and the actual system status (Norman, 1991; Woods, 1988). Adam and colleagues (1995) report on one pilot's experience, stating that although old cockpits placed high workload on the operator, one was always aware of what was going on, this being a critical part in operating the flight safely. Concerning situational awareness, Stanton *et al.*, (2001) proposes that three main theoretical approaches dominate the information processing approach, the activity approach as well as the ecological approach.

The information processing approach has been best described by Endsley's (1995) theoretical three-level model of situational awareness (briefly mentioned above). It presents an unfolding of situational awareness as higher-order cognitive processing is performed. This model follows a chain of information processing, from perception, through interpretation, to prediction; ranging from the lowest to the highest level of situational awareness. The lowest level of situational awareness (Level 1- Perception of the elements in the environment) is associated with the pilot's perception of information from aircraft instrumentation, the behaviour of the aircraft, other people in the cockpit, the terrain and air traffic control. At this stage, no interpretation of the data is performed, but rather the initial receipt of information in its raw nature. Level 2- comprehension of the current situation, may follow on from Level 1, however not necessarily. This level is said to be essential to understand the significance of the elements and to gain a general picture of what is going on (e.g. time and distance with fuel availability), necessary for pilots to be able to make judgements about whether their actions have the intended outcomes. Level 3- prediction of future status, is the highest level of situational awareness and is associated with the ability to project the future of the elements in the environment (e.g. projected potential aircraft conflicts). This approach describes situational awareness as a product, whist other models place emphasis on the processes that trigger situational awareness (Gartenberg *et al.*, 2014). According to Stanton and colleagues (2001), process refers to the perceptual and cognitive activities in revising the state of situational awareness whereas product refers to the state of situational awareness with regard to available information and knowledge.

The activity theoretic approach presents situational awareness as only one of many components of reflective-orientational activity (a process), as presented by Bedny & Meister (1999). This is an interactive, cognitive, sub-systems approach, which does not specify processes that are traditional to cognitive psychology, such as perception and memory but rather proposes that the extent to which processes are involved is dependent on the nature of the task and the goals of the individual. The last approach is the perceptual cycle model, which rather highlights the cognitive processes involved in situational awareness and the interaction between these processes and the environment (Gartenberg *et al.*, 2014). Adams *et* al., (1995) argue that the process-product dichotomy of situational awareness should be considered in the greater context of human information processing.

The maintenance of situational awareness in complex circumstances is frequently cited as a key to effective and efficient performance, especially in the aircraft context (Salmon et al., 2009). According to Salmon et al., (2009) the technological advances in the aviation industry resulted in profound changes in the tasks that human operators are responsible for in the cockpit, shifting from the dynamic “stick and rudder” control practice of flying an aircraft to involving supervision, programming, monitoring and decision making (Mosier, 2002).

A large portion of the aircrew’s job involves the development and maintenance of situational awareness in order to keep it ‘up to date’ in a rapidly changing environment (Woods, 1988; Endsley, 1998). Therefore, having a high degree of situational awareness can be seen as being the most critical aspect for achieving successful performance in aviation. In the case of automation, situational awareness may be negatively impacted as the aircrew is typically “out-of-the-loop” (Endsley, 1998), due to the efforts of automation alleviating the constant stresses from the human pilot that accompany operating a flight system. In accordance to Woods (1988), for operators to maintain an adequate awareness of the status of the system, they need to track the progress of events as they gradually unfold and thus change. He further argues that incidents evolve by the propagation of disturbances over time, where problems are further exacerbated if human controllers fail to adapt to new events in the environment.

Supervisory operators working with automation have been found to have a diminished ability to subsequently perform tasks manually in the case of automation failures as compared to manual performance on the same tasks (Billings, 1991). It has been documented that pilots who have lost situational awareness due to the effects of automation might be slower in detecting problems; furthermore, they will require extra time to re-orient themselves to relevant status of the system in order to proceed with problem diagnosis and resumption of manual performance when automation fails (Endsley, 1998). In their study, Endsley and Kiris (1995) suggest possible reasons as to why this may occur. These are; (1) a loss of vigilance and increase in becoming a monitor with the implementation of automation, (2) being a passive recipient of information rather than an active processor of information and (3) a loss or change in the type of feedback provided to the aircrew concerning the status of the system being automated. Although monitoring failures have typically been associated with simple, low-event tasks, Parasuraman (1987) and Endsley (1996) suggest that vigilance effects can be found in complex monitoring and concluded that humans may be poor passive monitors of an automated system, irrespective of the complexity of events being monitored.

2.2.4 Human supervisory role

In an automated setting, the human typically undertakes a central role, which is called *supervisory control* (Sheridan & Parasuraman, 2002). Sheridan, amongst many other key players in the field of human-automation interaction, has played a major role in the concept of *human supervisory control*, which is an area that has received ample reviews and theory based practical applications. In Figure 4, the role of the human is shown as a supervisor to the 'typically multiple' computer-controlled machines, whilst performing simultaneous tasks (labelled Task 1 – n). These 'task' boxes represent the different systems within an aircraft that the operator supervises (Sheridan & Parasuraman, 2006).

Showing the generic functions of human supervisory control, in Figure 4, function 1 which is to plan involves having some mental model of the physical system to be controlled, there being a trade-off between performance objectives that can be fulfilled and formulation of a strategy for performing the task (Sheridan & Parasuraman, 2006). Following this is function 2, to teach, where decision making plays a huge role in electing the desired control action and thus communicate that to the automation for the outcome of an action. Function 3 involves monitoring, which means allocating attention among the appropriate sources of information (enabling maintenance of situational awareness).

In the case of a failure of the automation being detected and successfully diagnosed, the human will either reprogram the automation or may intervene and exercise manual control, in function 4. The fifth and last function requires learning from knowledge of the results, which occurs in the form of the human having been out of the loop and thus receives feedback into planning the next phase of supervision.

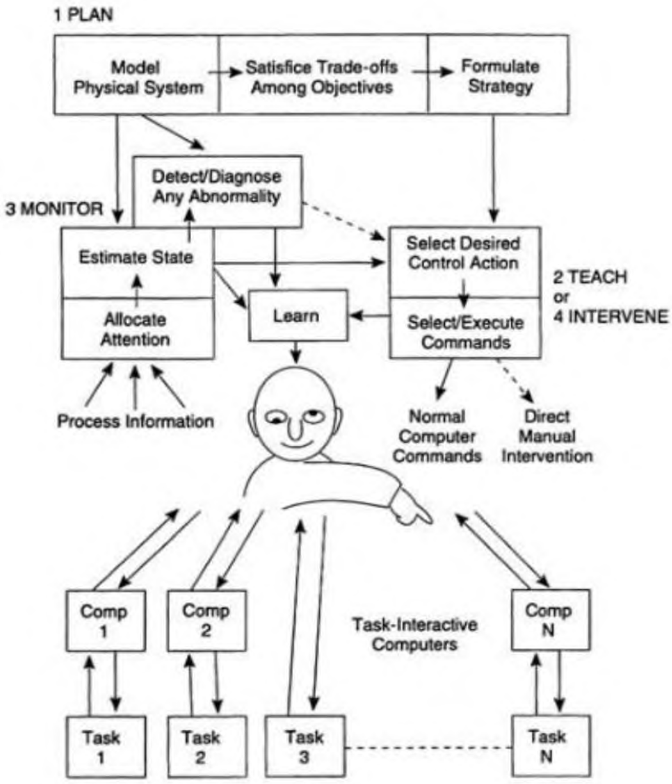

Figure 4: Generic functions of human supervisory control, adapted from Sheridan & Parasuraman (2006).

In the situation of supervising multiple parallel automated systems, as seen at the bottom of Figure 4, the human needs to employ whichever of the previously mentioned function is appropriate. According to Sheridan and Parasuraman (2006), the most appropriate functions will typically differ from one task to another.

2.2.5 Working memory

The working memory model put forward by Baddeley & Hitch (1974) consists of three components: an articulatory loop (‘speech-like’ representation), a visuo-spatial scratch pad (imaginal representation) and a central executive (which acts as an overseer directing attention and coordinating the activities of the other components).

There lies ample research in the field of aviation that supports the criticality of memory processes in situational awareness (Endsley & Bolstad, 1994; Endsley, 1999; Sohn & Doane, 2004), also speaking to the nature of individual differences in using memory processes in situational awareness. This is further elaborated on in the next section of *Human performance* (section 2.2.5).

Durso and Gronlund (1999) agree with Endsley (1995) in viewing memory as being in the centre when performing tasks that require dynamic and complex processing, as one would find in situational awareness. According to Wickens (1999), all content relevant to situational awareness is processed and stored in memory. Sohn and Duone (2004) go on to state that having a clear picture of situational awareness is dependent on incoming information which is integrated into a comprehensible understanding and prediction of aircraft status, which occurs in memory.

According to Endsley (1999), working memory capacity can alternatively act as a limit on situational awareness. She further stipulates that in the absence of other mechanisms, active information processing of a person must occur in the working memory. This then means that new information needs to be consolidated with existing knowledge in order for form an overall picture of the situation. The occurrence of such integration could be taxing, resulting on an overload on the pilot's already limited working memory and attention, leaving a lesser capacity for acquiring new information (Endsley, 1999). Conferring Wickens' (1984) model, the prediction of future states (Level 3 Situational awareness) imposes a strong load on working memory by requiring the conservation of present conditions, future conditions as well as rules used to generate the latter from the former, to carry out actions that are applicable to the future conditions of flight operations.

Carretta and colleagues, in 1996, looked at cognitive factors based solely on working memory predictors of situational awareness and showed that these factors, such as verbal working memory, spatial working memory, spatial reasoning and divided attention, were reliable predictors of situational awareness after controlling for the effects of flight experience. Subsequently, Stokes, Kemper and Kite (1997) used Long-term memory based knowledge representations alongside working memory based information processing abilities to predict decision making performance on a simulated flight situation.

2.2.6 Individual differences

Motowidlo, Borman & Schmit (1997), in their paper predicts that individual differences in personality and cognitive ability variables, in combination with learning experiences, lead to variability in knowledge, skills and work habits that affect general task performance. Thiffault & Bergeron (2003a) further identified three different mediating factors shown to amplify performance decline. The first looks at the extremes of the introversion/extraversion dimension. According to Louw (2013), extraverts appear to require more stimulation from performing monotonous tasks to stave off vigilance decline. In contrast, introverts tend to not require as much stimulations if at all, and may be resistant to certain forms of fatigue induced by the monotonous nature of the task. The second factor deals with sensation seeking, which shares similarities with extraversion. This is a personality trait expressed in the generalized tendency to seek complex and intension experiences, also known as arousal seeking (Zuckerman, 1972). The third and last factor deals with field dependence, which refers to an individual's ability to distinguish between task-relevant objects and task-irrelevant objects (Roge, 1996), factoring in decision-making which is crucial in the cockpit setting.

The development of fatigue therefore appears to be influenced by a range of both task and individual specific factors (Ackerman, 2011; Louw, 2013). Tasks that offer high levels of challenge and intrinsic interest, however, have been observed to be highly fatigue-resistant (Holding, 1983) as opposed to high workload and monotonous tasks. By examining the core human information processing functions, these situations can be understood further (Louw, 2013). Certainly, Ziedner (1998) observed cognitive disturbances to be a better predictor of performance decrement than physical symptoms, where Hitchcock and Matthews (2005) also explain this to mean that fatigue expressed as a physical discomfort may not be equivalent to fatigue expressed as loss of concentration.

2.2.7 Arousal theory

Monotony and thus under-stimulation may contribute to the development of fatigue and performance decrements. In contrast, high workload and over-stimulation may also contribute to the same effects on the human operators' responses. Both these extremes are conceptualised by the framework that is the Arousal Theory (Thiffault and Bergeron, 2003b). This shows the Inverted-U relationship between performance and arousal, suggesting that fatigue will develop in conditions under-stimulations or of low task demand as well as under conditions of high-stimulations and high task demands.

Previous research offers differing views as to how the mechanisms that underlie the performance decrements in these situations unfold. In his paper, Louw (2013), further stipulates that some researchers attribute the decrement to a resource account (such as attentional resources), while others relate it to an effort account (how much effort is needed to perform the task).

The complexity of a task appears to be an important factor related to monotony, where research from the vigilance field suggests that low task demand contributes to cognitive underload, further resulting in reduced alertness and possibly error prone performance (Grandjean, Baschera, Martin & Weber, 1977). The present study seeks to examine the effect of task demands on performance in varying monotonous contexts and whether increased stimulus variability increases cognitive load sufficient to improve performance.

2.3 REST BREAKS

The effect of rest breaks has been of interest to researchers for many years. The main focus of the studies had been directed to productivity and error rates, where only as recent as the past 15 years, research has further examined the impact of rest breaks on stress and fatigue (Tucker, 2003). Studies centred around driving behaviour and flight simulation (focusing on performance and fatigue) have inferred a relationship between rest breaks and accident/incident risk.

Various studies on long-haul flight crews have shown that 40-minute naps during both day and night flights had positive effects on vigilance performance and physiological measures of sleepiness (Rosekind *et al.*, 1995). In a simulated study of a truck-driving task, Gillber, Kecklund and Akerstedt (1996) reported that 30-minute naps were insufficient to counteract low levels of alertness at night, however in a separate laboratory study, the same researchers found that 30-minute day naps had positive effects on sleepiness and vigilance performance. Napping however could have potential negative effects characterised by a temporary degradation of performance in the immediate result of sleep (sleep inertia).

In a study of transit operators, Greiner, Krause, Ragland and Fisher (1998) reported that accident risk was predicted by the amount of time an operator took rest pauses. On the other hand, Pokorny, Blom, van Leeuwen and van Nooten (1987) found a correlation between total rest duration within the shift and accident risk, looking at bus drivers in the Netherlands. The authors of the latter study suggested that the absence of significant effects of total-rest times might have been masked by other effects such as the effects of particular rests at the particular times or individual differences. According to Tucker (2003), frequent short breaks are beneficial for improving performance and fatigue.

2.3.1 Return to task performance

The placing of attention selectively to the most important location and/or object is essential for an appropriate interaction with our environment, especially under time pressure (Lupianez, 2010). According to Wickens (1998), a central issue to efficient and effective return-to-task from emergency situations is the influence of automation. He further states that, owing to the previously mentioned disadvantages of automation reliance, operators are likely to react more slowly to emergencies if the use of their manual skills is required during the recovery period. Posner *et al.* (1985) proposed the term *Inhibition of return* (IOR), owing to the effects of both endogenous and exogenous cues to return to task performance. Lupianez (2010) suggests that different attentional mechanisms have been developed to accomplish the goal of reorienting ones' attention effectively, either by top-down expectancies (endogenous attention) or by relying on salient characteristics in the environment that automatically capture ones' attention (exogenous attention).

According to Wickens (1998), return to task performance (response time) is greatly controlled by individual differences, characteristics of the team environment, the complexity of the task as well as the familiarity of procedures necessary to cope with a degraded system. Wickens (1998) goes on to state that, in order to effectively predict recovery under a variety of conditions, it is necessary to develop models based on recovery scenarios that are based on human performance data concerning response to low-probability events, under different levels of 'skill degradation' and lowered situational awareness. This being in line with the aims of the current study.

The study acknowledges the complications in replicating such scenarios, as preparation for emergency skills training, according to Wickens (1998), is an open-ended set of circumstances. Linking the two human performance elements of change however (that being in situational awareness and skill degradation), makes it possible to predict the change in 'return to task response time'- that is, the time required to respond appropriately to unexpected failure situations and intervene with manual control skills or automated functionality (Wickens, 1998).

Drory (1985) reported that while the incorporation of a pre-planned 30-minute break taken 3-hours into a 7-hour simulated driving task resulted in improved fatigue levels, performance was generally unaffected. Whilst this suggests that taking sufficient rest breaks may be effective in avoiding fatigue related decrements over time in driving performance; evidence from a number of laboratory studies suggests that the nature of the activity undertaken during the rest breaks (and time period) may be crucial in determining the amount of recovery afforded (Lisper & Eriksson, 1980; Henning *et al.*, 1989; Caldwell *et al.*, 2009).

2.3.2 Performance (behavioural) measures

Over the years, situational awareness has gained considerable attention from the ergonomics community (Kaber *et al.*, 2006; Kirlik & Strauss, 2006; Salmon *et al.*, 2008b), especially when looking into the aviation industry. According to Barker (2016), the 'pilot community' have raised concerns regarding the lack of basic situational awareness caused by the presence of automation in the cockpit. The over-reliance on automatics has thus resulted in a plethora of ergonomic constructs being assessed including situational awareness, mental workload and decision-making, human error as well as many other behavioural measures. In the present study, the former, being situational awareness, is assessed indirectly owing to the debate worthy nature of measurement tools used for this construct (Salmon *et al*., 2008). The constructs that are of focus in this study will be discussed in the following section.

Standard deviation of the lateral position

Much so, like driving, operating an aircraft requires precession, attention and a high level of alertness. Loss in any of the previously mentioned is associated with fatigue and possibly sleep pressure (van Orden, Jung & Makeig, 2000), especially in instances of performing sustained monotonous tasks. These same authors have shown that changes during tracking tasks appear to be consistent with fluctuations in alertness of the participants. Although the task is monotonous, it still requires a certain level of attention from the participant to track appropriately (Ndaki, 2012), involving psychomotor skills and hand-eye coordination (Louw, 2013).

2.3.3 Subjective measures

Subjective measures have been widely used in attempt to obtain the perceived performance measures that participants have on the task. According to Matthews and Desmond (1998), these measures are used according to the context in which they are applied. One of the mostly used tools to measure subjective workload is the NASA task-load index (TLX), which has been shown to be sensitive to cognitive workload, however, due to the nature of the testing protocol of this study, this tool would not have allowed proper assessment of the participants' responses. A limitation of subjective measures is however noted by Recarte *et al*. (2008), stating that they are not able to assess any of the subconscious internal processes of the participants.

Karolinska sleepiness scale

The Karolinska sleepiness scale (KSS) is a nine-graded scale which was developed to constitute a one-dimensional scale of sleepiness (Akerstedt & Gillberg, 1990). This tool has been broadly used in studies for subjective assessment of fatigue, as it is an easy to use and convenient tool. This subjective measure has been validated against alpha and thetha electroencephalogram (EEG) activity as well as electro-oculagraphic measures of slow eye movement (Åkerstedt and Gillberg, 1990).

2.3.4 Psychophysiological measures

Psychophysiological measures, according to Williamson and colleagues (2011), are known to be reflective of various levels of physiological arousal such as drowsiness and sleepiness, sensorimotor function as well as information processing. These measures have the advantage when compared with other methods used to study human performance, particularly workload (e.g. subjective ratings), because they require no overt responses by the operator (Byrne & Parasuraman, 1996, Louw, 2013). They also have the potential to yield 'real-time' estimates of the psychophysiological state of the operator, however, the rationale for having 'real-time' psychophysiological measures in an applied environment is rarely expressed (Hancock & Chignell, 1987; Parasuraman, 1990).

In their study on bus and truck drivers, Harris *et al.* (1972) found that the third three-hourly break did not aid physiological recovery at all, nor did it seize an increasing trend in errors that occurred after nine hours of duty. A decline in psyhophysiological indexes of alertness was also observed, which continued following a rest break. This then resulted in inconclusive results whether increasing the number of rest breaks would be sufficient to counteract the increase in risk associated with the latter stages of a long duty period.

Heart Rate and Heart Rate Variability

Heart rate

Measures of physiological arousal, such as heart rate, can provide converging evidence for the development of fatigue (Williamson, Feyer & Friswell, 1996). Aasman *et al.* (1987) further stipulate that heart rate has typically been found to slow with fatigue and prolonged performance tasks (looking into driving), and that the time between heart beats becomes increasingly variable. The heart rate is derived from the inherent rhythm of the sino-artial (S-A) node; however, the sympathetic and parasympathetic processes have an effect on the inter-beat-interval (IBI) of the heart. This measure has been used as a fatigue indicator (Hartley, Arnold, Smyth &

Hansen 1994; Lal & Craig, 2001), where it increases with task difficulty, consequently decreasing with decreased task difficulty (Jorna, 1992). Although HR has been widely used as a reliable indicator of fatigue, heart rate variability has gained support as an indicator of such, according to Davy, 2010 and Lombard, 2010).

Heart rate variability

Heart rate variability is commonly evaluated using time-based measures or frequency domain measures (Jorna, 1992; Louw, 2013). It illustrates cardiovascular autonomic control exerted by both the parasympathetic and sympathetic nervous system (Mourot *et al.*, 2004). A number of studies have used this parameter to examine both mental workload (Hancock & Verwey, 1997) and fatigue (Horne & Reyner, 1999), whilst a number of authors have suggested that an increase in heart rate variability is a sign of a fall in the level of cerebral activation, which is associated with a diminish alertness (Harris *et al.*, 1972; Louw, 2013).

According to Patel *et al.* (2011), time domain measures are calculated by analysing the standard deviation of the inter-beat intervals (R-R), where an increase of such is indicative of a decrease in workload (Hancock & Verwey, 1997), a decrease in performance and is associated with increased levels of fatigue (Oron-Gilad and Ronen, 2007). Jorna (1992) observed that HRV is limited in terms of its ability to discriminate between subtle changes in workloads, whereas, Mulder (1986) argues that HRV is only able to differentiate between tasks differing considerably in terms of controlled processing.

2.3.5 Oculomotor activity

Eye movements allow for the evaluation of fatigue as they are able to access information that would not be consciously available to the human operator (Chapman *et al.*, 2002). This, according to Louw (2013), somewhat counteracts the limitations of subjective measures. Eye tracking systems are typically non-invasive and capture near continuous eye movements which allow for assessment of moment-to-moment workload into an eventful fatigue state (Marshall, 2000; Ahlstrom & Freidman-Berg, 2006).

Blink duration and Blink frequency

As with pilots, driver fatigue is associated with an increase in both blink duration and blink frequency (Stern et al.,1994; Summala et al.,1999; Sirevaag and Stern, 2000; Van Orden *et al*.,2000; Verwey and Zaidel, 2000; Svensson, 2004; Dinges et al.,2005). Stern *et al*. (1994) further state that an increase in blink frequency is typically indicative of light fatigue, which is the transition from awake to reduced vigilance, having the transition to server sleepiness being accompanied by an increase in blink duration. Hargutt (2003) argues that the inhibition of blinks is rather attention driven, this notice being investigated by the present study.

CHAPTER III

METHODOLOGY

This chapter uses the information summarised in Chapter 2 to design and implement a theoretical simulated study that investigates the effect of rest break tasks and rest break duration on the return-to-task performance of human operators in an automated setting. Data and information on various human information processing aspects reported in the previous chapter have enabled the design of the experiment as well as justification for the selection of variables used during this experiment.

The current chapter highlights and incorporates the background of the study as well as the objectives and methods used and the expected outcomes. This section includes the research design, materials used and the procedure of the experiment.

3.1 RESEARCH CONCEPT

This study uses a simulated human and machine interactive experiment. Whilst the study's paradigm is aviation, not much is known about return to task performance and the human supervisory role in a number of human-automation cases. This study has thus taken a theoretical approach to understanding return to task performance, which will have implications in this particular area of interest, namely, aviation.

The aims of the study lie in investigating the return-to-task performance of the human operator after regaining control from the automated system owing to system failures known as automation surprises (in aeronautics, such situations stem from the fact that the autopilot does not behave as expected by the crew, (Pizziol, Tessier & Dehais, 2013). An example of this in the real world would be the pilot regaining control of the aircraft following a flight system failure which could lead to accidents (Billings, 1997). The experiment aims to evaluate the effects of automation transitions by investigating the effect of a rest break task and rest break duration of being 'out-of-the-loop', at various workload complexities. The dependence of workload and performance during the return-to-task routine is assessed during the transition of operators from passively monitoring a system to actively controlling the system in the case of automation failure. The design of the length of the experimentation correlated with the proposed length of the small African regional airliner (SARA) operational time.

Experimental design

This study used a low-fidelity simulator (Figure 5); considered as more of a continuous tracking task with geometry representative tracking) to mimic a manual-automation interactive task inclusive of a rest break period, to allow for a return-to-task feature (pre- and post-break tracking task). The return-to-task feature required participants to resume manual control of the system, as pilots would in the case of automation surprises.

Table 2: A basic experimental design showing the conditions for: the Activity phase, the Rest break Task and the Rest break Duration, for all four groups.

Activities	**Low** - Motor tracking	Non-repeated
	High - Motor tracking & Cognitive workload	
Recovery activities	**Passive Rest** – in-Seat rest	Non-repeated
	Active – Administrative work & Supervision	
Recovery interval	**Short** -2-minutes	Repeated
	Long - 30-minutes	

The study was a partly repeated design which consisted of six independent conditions, namely Low workload (pure tracking task as a primary task); High workload (tracking task with added secondary cognitive tasks); a Passive rest break (in-Seat rest); an Active rest break (administrative reading with system supervision); a Short rest break (2-minute) and a Long rest break (30-minutes). The reason for the choice of a partially repeated design was to investigate the effects of particular measures under different and varying conditions. The Recovery break duration condition was repeated within the groups but non-repeated between the groups. This was to evaluate the effect of time out-of-the-loop within the groups, having the participants experiencing the same time conditions.

The non-repeated aspect of this condition (Recovery break duration) and the other two conditions (Recovery break task and Activity phase tasks) enabled for the evaluation of the same measures under two different circumstances. Table 2 gives a breakdown of the different conditions that were investigated in the study.

Table 3: Break down of the conditions. The experimental design of the study was partially repeated.

		Testing group 1	Testing group 2	Testing group 3	Testing group 4
Testing session 1	**AP** Phase 1	(Low) Motor	(Low) Motor	(Low) Motor	(Low) Motor
Testing session 1	**RI**	*Pause/sleep* **2minutes**	*Pause/sleep* **30minutes**	*Admin/supervise* **2minutes**	*Admin/supervise* **30minutes**
Testing session 1	**AP** Phase 2	(Low) Motor	(Low) Motor	(Low) Motor	(Low) Motor
Testing session 2	**AP** Phase 1	(High) Cog + motor	(High) Cog + motor	(High) Cog + motor	(High) Cog + motor
Testing session 2	**RI**	*Admin/supervise* **2minutes**	*Admin/supervise* **30minutes**	*Pause/sleep* **2minutes**	*Pause/sleep* **30minutes**
Testing session 2	**AP** Phase 2	(High) Cog + motor	(High) Cog + motor	(High) Cog + motor	(High) Cog + motor

AP= Activity phase; RI= Rest interval; Coloured sections indicative of the engagement of 'automation'. Testing groups n=8 (per group) [Sample group: n=32].

Participants were grouped into four equal groups, where two of the four groups had the same rest break duration and a different two of the four groups had the same rest break task. Table 3 shows how the grouping of the rest tasks and rest durations were permutated. Participants in groups one and three, each attended two 52-minute experimental sessions whereas groups two and four, each attended two 80-minute experimental sessions. Experimentation took place between either 9:00 - 11:30am or 2:00 –5:00pm. These periods have been found to be similar with regard to circadian rhythm, and avoid the periods of greatest change due to circadian effects (Wijesuriya et al., 2007). Testing sessions took place on consecutive days, in the same time slot.

3.2 HYPOTHESES

The experimentation incorporated three group variables, namely physiological responses (Heart rate and heart rate variability as well as blink frequency and duration measures), subjective workload profiles and cognitive and motor performance responses, measured during the tasks performed throughout the test period.

It was expected that the first testing session on the performance (cognitive and motor), subjective and physiological measures would differ from the effect of the second testing session on the performance (cognitive and motor), subjective and physiological measures during all tasks. Furthermore, it was expected that the effect of the short duration recovery interval would produce diverse responses from the long duration recovery interval, in all four testing groups. It was also anticipated that the two recovery activities would elicit differing responses to assist in the rapid transition to return to task.

The statistical hypotheses were as follows:

Hypothesis 1:

The null hypothesis (H_0) proposes that there will be no differences in the responses to all variables during the Activity phase tasks (Low workload and High workload)

Hypothesis 2:

The null hypothesis (H_0) proposes that there will be no difference in responses elicited by the Rest task and/or Rest duration

Hypothesis 3:

The null hypothesis (H_0) proposes that there will be no difference in responses, elicited by the overall and/or immediate before and after condition following the Rest (interval) break

3.3 INDEPENDENT VARIABLES

3.3.1 CONDITIONS

Activity Phase

This condition had two phases, phase 1, a ‘pre-break’, and phase 2, a ‘post-break’. This was to investigate the recovery effect of the break and the transition (return-to-task performance) of the operator back in control after the break (which was looking at performance before and immediately after the break). Two tasks were established to be performed during this phase, varying in complexity. The first task was of ‘Low’ workload complexity, a primary task which entailed a pure tracking performance task (motor), performed in the 1st testing session. This task consisted of psycho-motor (tracking), perceptual motor (system monitoring) and cognitive (target achievement) aspects, attempting to represent the three flight-relevant domains performed by the pilots during a flight (Hancock & Scallen, 1997).

The second task was of ‘High’ workload complexity, with additional secondary tasks which entailed of a combination of the primary tracking performance task and a running memory task as well as an additional rule-based decision making task (cognitive & motor), performed in the 2nd testing session. The secondary tasks were to increase operator workload, as in the cockpit, performing other cognitively challenging tasks concurrently (Baxter, Besnard & Riley, 2007).

Phase 1 of the *activity phase* ran for a fixed 30-minutes. The duration of 30-minutes was considered sufficient control time for the operator as this time period is the handover period between pilots in flight (which occurs every 20 – 40 minutes) (Airbus, 2004). After the set break, the same task of ‘Low’ or ‘High’ complexity (depending on the testing session) resumed again, for 20-minutes. This was to measure the performance effects following each prospective recovery break, where Robinson (2012) found 15-minutes sufficient to allow for comparisons between protocols. This activity phase simulated the active human control aspect in the human-automation interaction, where automation was disengaged.

Rest (interval) break tasks

This was to investigate the type of recovery ‘break’ an operator should adopt in assisting with a quick transition in terms of returning-to-task. Here two types of breaks were observed separately; a passive rest break (*in-Seat rest with no monitoring aspect*) and an active recovery break (*performing an Administrative (reading) task whilst intermittently supervising the system*). As the administrative task did not directly contribute to the expected outcome of the study, it was not measured, but merely contributed as a ‘distraction’ in the supervision of the system. These tasks are explained in detail below.

Rest (interval) break durations

This was looking at the duration of the abovementioned recovery break. Two lengths were investigated; *Short*, which was *2-minutes* and *Long*, which was *30-minutes*. Sauter and Swanson (1992) found that declines in performance during work sessions were disrupted by the distribution of periodic ‘minibreaks’ of 3 minutes, throughout work sessions, where Tucker (2003) also suggests that although short, frequent breaks are beneficial for fatigue recovery, these are disruptive and disturb the workflow. For the purpose of this study, the frequency of rest breaks was not investigated. The length of 2-minutes was chosen in order to see the effects of a slight interruption of a minibreak (2-minutes) on the ‘continuous’ performance of the operator against a rather extended recovery interval of 30-minutes.

The long duration of 30-minutes was chosen as a parameter to mimic long periods of time that an operator is out of control and quite often out-of-the-loop from the automated system (Airbus, 2004). After such a period where the automated system has been running successfully on its own, the possibility exists that in the n^{th}minute or hour, the system might fail and the operator needs to now gain control of the system, navigate through the scenario and find the best possible solution to avoid any incidences or accidents. This recovery interval was intended to diminish as much as possible the fatigue effect of phase 1 in the activity phase.

The experimental concept looked at four different testing groups of homogenous and equally distributed participants, having eight participants (n=8) in each group. Each group had two testing sessions, where they were asked to perform a tracking task in a laboratory where they change from activity (phase 1- 30 minutes) to a break (2 vs. 30 minutes) and back to the activity (phase 2- 20 minutes). The task varied in the complexity of the activity (pure tracking vs. tracking plus running memory task and a rule-based decision making task), the type of break (passive rest vs. actively supervising) and the duration of the break (2 minutes vs. 30 minutes).

3.3.2 TASKS

The ability to react to unpredictable events depreciates when exposed to highly predictable and uneventful monitoring tasks. Such monotonous tasks afford little stimulation and could further lead to incidences or accidents due to inattention (Larue, Rakotonirainy & Pettitt, 2011). Alternatively, an increase in arousal does not necessarily infer better performance because there is a threshold of acceptable arousal after which attention decreases thereafter. Performance in vigilance tasks follows an inverted U-shape function of arousal (Thiffault and Bergeron, 2003b).

Tasks performed during the activity phase

Primary task – Tracking task

This task required the participant to track the middle white line on a 'road scene' with the tip of the arrow as accurately as possible, while the driving speed remained constant at 5 $km.h^{-1}$ throughout the testing (Figure 5). The 'Low' complexity task requires pure motor control, as mentioned above, of the 'tracking simulator' as this uses an under-stimulating, yet attention demanding scenario where the situation tends to favour hypovigilance due to the monotonous nature of the task (Thiffault & Bergeron, 2003; Ndaki, 2012).

Figure 5: A screenshot of the simulator set up for the tracking task (where the participant is required to track the middle white line with the tip of the arrow as close as possible).

Secondary tasks

a) Rule-based decision-making task

The test battery for the cognitive tasks included a rule-based decision making task as well as a running memory task (mentioned below). Both tasks had been derived from the Sternberg memory task (Sternberg, 1975). The rule-based decision-making task looked at the visual spatial sketchpad. There was a visual presentation of various coloured shapes with a number on it (Figure 6). Variations stuck to three colours (red, orange, green), three shapes (circle, triangle, square) and three numbers (60, 80, 100). Presentation of each object lasted for three seconds and thereafter it was removed. This was done in randomized chunks of 5-7, where the participants had to store the information in their Short-term memory (STM) (Sternberg, 1975). After the removal of the last object in the series of each chunk, there was a five second delay where a 'probe' image (positive or negative) was presented to the participant and they had to respond with a "Yes" (positive), the object was in the list or "No" (negative), the object was not in the list. They had three seconds to respond to the 'probe' image. The task routinely ran for 3-minutes in 10-minute blocks every 5-minutes, as to create 'artificial workload' (Parasuraman *et al.*, 1993; Oxford Aviation Academy, 2008, Louw, 2013).

Presented memory set: Probe image "Yes": Probe image "No":

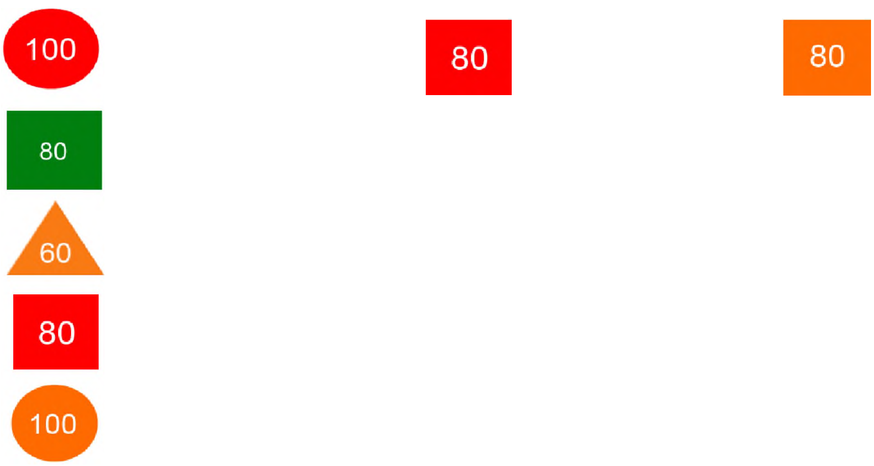

Figure 6: Rule-based decision-making task schematic derived from the Sternberg memory task.

b) Running memory task

The running memory task was an auditory presentation of words ("every day words") with characters ranging between six and ten in each word. The participants were required to mentally analyse the particular word after presentation and respond within certain parameters placed forward in the task. The rules entail presentation of words and within the words; the participants were asked how many of the presented letters there are in that particular word. For example, how many T's are in Fantastic? The participants received the information audibly in a randomized sequence, after the completion of every chunk in the rule-based decision-making task, and had to respond verbally, within 3 seconds.

Tasks undertaken during recovery interval

a) 'In-Seat' rest

During the recovery (interval) break of the experimental procedure, the participants were required to eliminate themselves from the system as to create a breakdown in situational awareness of the operator from the system. This typically occurs when the operator takes a break (commonly sleep) from supervising the automated system as a recovery aid or they handover to a fellow operator where they will have to resume control again, at a later stage. Sleep was not mandatory, however, if participants felt the need to sleep, they had the freedom to do so. In terms of 'sleeping' for the duration of 2-minutes in the abovementioned short duration recovery interval, according to Brooks and Lack (2006), this length was suggested to have negative effects on the return-to-task performance of an operator. This was one of two activities which were performed during the recovery interval.

b) Administrative task with supervision

The second activity which was performed during the recovery (interval) break was an administrative reading task (which was reading a random text document) whilst intermittently supervising the system. This activity is quite common amongst operators monitoring systems with added cognitive tasks to perform concurrently. This activity enabled the operator to some degree, remain in-the-loop and follow the situation as it unfolded.

Physical Set-up

The testing laboratory was a light-controlled room, which ensured that participants were exposed to the same environment regardless of testing time. To prevent glare, the testing station was lit from the behind the seated participant.

The simulator used is shown in Figure 7. It consisted of a custom-built chassis with a non-force feedback steering wheel. The participant was required to sit behind the wheel of the simulator facing the screen onto which the 'road scene' of the simulator was projected onto a white screen using a Liesegang digital projector. The projector was connected to a central computer, which ran the tracking task simulator software. Steering movements were detected by a potentiometer mounted on the steering column. Participants were instructed to control steering movements smoothly.

Simulation Software

The tracking simulator software used in the current study was developed by Goebel et al., (1998). It presented a curved pathway with an arrow at the bottom of the screen representing the tracking tip (Figure 7). The participant was required to track the middle white line with the tip of the arrow as accurately as possible.

The study used this type of simulation as opposed to a flight simulation as in the case of this study, where novice participants were investigated, and the study was interested in the human processing responses, which would entail a simple tracking task, as used in this study. The simulator task requires 100% attention since it is a tracking task. Tracking performance thus directly corresponds to resources allocation and information processing capacity (Bubb, 1993; Louw, 2013).

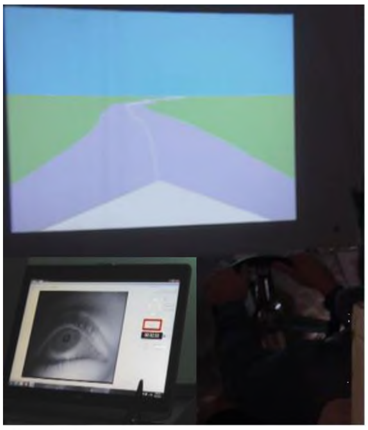

Figure 7: Physical set-up of tracking simulator

3.4 DEPENDENT VARIABLES

The era of ever-increasing automation in industries has led to a change in the overall human-automation interaction. Human performance thus needs to be evaluated in an array of physiological, performance and subjective measures, which were used in this study. The dependent variables for this study were: Performance measures (as explained above) on the cognitive (running memory recall and decision-making in terms of establishing situational awareness), sensory (visual and auditory communication performed concurrently with other performance tasks) and motor tasks (tracking performance task). Psychophysiological parameters included heart rate and heart rate variability. Eye blink frequency and duration (oculomotor activity) are also included in the psychophysiological parameters. Subjective measures taken in this study will be in a form of a questionnaire, using the Karolinska Sleepiness Scale (KSS) questionnaire.

3.4.1 Tracking task performance

Tracking task performance requires precision, attention and a high level of alertness. This task uses an under-stimulating, yet attention demanding scenario involving psychomotor skills and hand-eye coordination (Louw, 2013). The situation furthermore tends to favour hypovigilance due to the monotonous nature of the task (Thiffault & Bergeron, 2003; Ndaki, 2012). Makeig *et al*. (2000) have further shown that changes during tracking tasks appear to be consistent with fluctuations in alertness of the participants. In the current study, this was measured by quantifying the effective response time that the participants took to return to tracking the mid-white line once they deviated away from it.

3.4.2 Rule-based decision-making task and Running memory task

Pilot tasks are complex and very detailed, however, there are many sub-tasks performed by pilots in the cockpit which involve skills necessary to know and have the awareness of the current and future status of the flight as well as decision making (situational awareness), especially in cases of automation surprises (Pizziol, Tessier & Dehais, 2013). The introduction of these tasks addressed the general task loading effect of such sub-tasks on pilot performance. These types of tasks were incorporated in the interaction between the pilot and automated system, using different sensory channels (visual and auditory), according to Bonnel & Hafter, (1998). The authors further state that there typically is a trade-off between resource allocations to two sensory channels, thus the Sternberg memory task was split into two tasks, investigating not only the increase in workload but also the presentation and perception of information. All responses to the cognitive tasks were recorded by the researcher and further analysed into correct and incorrect responses, where the percentage of the correct responses were used as a measure.

3.4.3 Heart rate and Heart rate variability

Heart rate (HR) and heart rate variability (HRV) are non-invasive methods used to assess fatigue states (Patel *et* al., 2011). HR has been considered as an index of arousal, task involvement, anxiety and mental load and effort, where it has been shown to decrease with increased levels of fatigue (Jorna, 1992). Heart rate variability is a measure of variation in heartbeats and is calculated by analysing the time series of inter-beat intervals (i.e. R-R Intervals). It reflects cardiovascular autonomic control exerted by both the parasympathetic and the sympathetic nervous systems, used to examine mental fatigue and effort (Hancock and Verwey, 1997; Woods *et al*., 2002). Harris *et al*. (1972) further suggests that an increase in HRV is a sign of cerebral activity, which is associated with a diminished alertness.

HRV can be evaluated using time-based measures or frequency domain measures (Jorna, 1992). According to Patel *et* al., (2011), time-domain measures are calculated using the standard of R-R (inter-beat) Intervals; where Oron-Gilad and Ronen, (2007) suggest the increase of which is indicative of decreased levels of mental workload, decreased levels of performance and is associated with increased levels of fatigue. Frequency-domain analysis is based on mathematical transformations of the signals from time-domain into separate frequency ranges (Patel *et al*., (2011). The low frequency (LF) power component (0.04 – 0.15 HZ) is typically associated with activity of both the parasympathetic and the sympathetic nervous systems, and more specifically, the changes in the LF/HF ratio reflect a change in sympathetic activity, with focus on the adrenalin aspect required for alertness.

Polar™ T34 heart rate memory belts were used to record the participants' cardiac responses throughout the testing sessions. Located in the electrode of the heart rate belt was a microchip that was responsible for receiving the heart rate data and transmitting it to the DataLog MWX8 receiver.

3.4.4 Oculomotor Activity

Eye blink frequency and duration (oculomotor activity) were included in the psychophysiological parameters of this study as fatigue has been associated with an increase in blink frequency (Stern *et al.*,1994; Summala et al.,1999; Sirevaag and Stern, 2000) and blink duration (Van Orden *et al.*,2000; Verwey andZaidel, 2000; Svensson, 2004; Dinges *et al.*,2005). According to Hargutt (2003), the inhibition of blinks is attention-driven, meaning when blink frequency increases, this will be indicative of fatigue. Similarly, Schleicher *et al.* (2008) links prolonged blink duration with a down-regulation of several other physiological processes.

The head-mounted Dikablis eye-tracking system from Ergoneers GmbH was used to measure both blink frequency and blink duration. The eye camera detects the cornea reflex using an infrared light source and records papillary movements of the left eyes. The field camera is aimed directly in front of the participant and records the participant's field of view. This requires calibration to be performed for both the eye camera (fixing the position of the camera so that the software can have an accurate axis of recording) and the field camera (fixing the gaze of the participant by having them gaze through four defined reference points in the visual field). The head unit transfers the video information via cable to the recording unit, where the information is stored for post-processing with the Dikablis Analysis Software. The weight of the head unit is supported using the nose support, which is kept secure on the participant's head with an elastic retaining band. The head unit is neither obtrusive nor does it interfere with the tracking or the visual process.

Figure 8: The head unit of the Dikablis eye-tracking system

3.4.5 Karolinska Sleepiness Scale (KSS)

Subjective measures taken in this study were in a form of a questionnaire, using the Karolinska Sleepiness Scale (KSS) questionnaire. This is a validated 8-graded scale, with options ranging from very alert to difficulty staying awake. This subjective measure has been validated against alpha and theta electroencephalogram (EEG) activity as well as electro-oculagraphic measures of slow eye movement (Åkerstedt and Gillberg, 1990).

The KSS ranges from 1 being "extremely alert" to 8 being "sleepy, some effort to stay awake" (presented in Appendix B1). This was to assess the quality of the rest break, as well as how the participants felt following the rest break.

3.5 EXPERIMENTAL PROCEDURES

3.5.1 Participant Recruitment

Prior to participant recruitment, permission was requested from the Rhodes University registrar to allow for students of Rhodes University to partake in the study. Participant recruitment took the form of advertisement through posters, e-mail and the social and student networking. A general breakdown of the research was provided, which included exclusion criteria from the study. Eligible participants were asked to contact the researcher as to set up a date when the participants would attend the habituation and two testing sessions. Participants contacted the researcher via e-mail and text messages, with all concerns and queries being dealt answered prior to arranging the first session (habituation), which took place in the Human Kinetics and Ergonomics Department.

All participants indicated having no history of sleeping disorders, had a normal visual field range, were non-smokers and did not suffer from epilepsy nor did they take any stimulant medication. Participants who did not meet this criteria, were not included in the study. 32 participants, 16 males and 16 females (four of each in each group) volunteered for this study, with the age range of 19-26 (mean age = 21 years, SD = 1.7). All participants included in the current study met the previously mentioned criteria.

3.5.2 Habituation

A habituation session was held for each participant to attend individually. This lasted for approximately 45minutes. Upon arrival at this session, the investigator outlined the purpose and aims of the research, risks and potential benefits as well as to familiarize the participants with the equipment, testing procedures and informed them as to what was required of them. During this session, participants were issued with a 'letter to participants' as well as a consent form, which they had to read and sign prior participating in the study. Personal details of the participants were also collected during this session.

They were given time to practice the tasks and get used to the simulator where they performed a 3-minute tracking task, had a 2-minute recovery period where they performed one of the two activities during this recovery period and returned to the tracking task for a minute. After this 'first session', they had a 2-minute rest where they could walk around. Once that time lapsed, they were required to take up their seated position again. They performed the tracking task again for 3-minutes, and had a longer break of 5-minutes where they performed the other activity which they hadn't performed before, then returned to task thereafter for another minute. They were also notified of the Karolinska Sleepiness Scale (KSS) questionnaire (Appendix B1) they had to fill in after the termination of the testing protocol. This was to gain knowledge of the quality of their rest/recovery period.

3.5.3 Experimentation

Participants were tested individually in a quiet room for two testing sessions lasting no more than 1hr 45min. Participants were required to make their way to the Department of Human Kinetics and Ergonomics at the scheduled time. On the testing day, participants were requested to refrain from any strenuous activity or exercise or take in any stimulants (such as caffeine). Participants were not allowed to get out of the seat during the testing protocol; therefore, no hydration was permitted during the testing protocol.

Once participants arrived for each of their sessions, the researcher first enquired as to whether all the requirements prior to testing were upheld. If any of these were not met, the researcher requested that the testing session be rescheduled for a later date. If all requirements were met, the procedure was verbally explained to the participant again to ensure understanding of what was expected during the test session. They then signed a consent form, agreeing to participate in the study on a voluntary base.

Participants were then required to sit in the adjustable seat and were asked to adjust the chair so that they could reach the steering controller comfortably. The participants were requested to stand up again, in order to be fitted with the Polar™ T34 heart rate belt and the head-mounted eye tracker, and were asked to sit again. Conductive gel was placed on the electrodes of the heart rate belt to ensure a strong conduction and reading of the participant's heart rate. After the appropriate fitting of the equipment on the participants, the head-mounted eye tracker was calibrated. This was done by instructing the participants to direct their gaze sequentially at the four corners of the main task display without moving their head until all four corners were calibrated. Once this was done, participants were required to sit in the chair for a period of five minutes, in order to establish their resting heart rate.

Depending on the condition performed, participants began their 52-minute and 80-minute tracking protocol, inclusive of their rest breaks. Participants were instructed by the researcher to transition back into control as quickly as they possibly could. In the first testing session, participants were first required to perform a pure tracking task for 30-minutes after which the simulator was shifted to automatically track itself, this initiated by the researcher with a simple key stroke on the keyboard. This enabled the participants to give up control and take up their relevant rest tasks to be performed during the rest break - depending on whatever condition they were performing (PAUSE or ADMIN) and for whatever duration (2-minutes or 30-minutes). Once the rest break lapsed, the automation effect of the simulator was disengaged, allowing for the resumption of manual control by the participants. This was once again done by a simple key stroke on the key board. The post-break period ran for 20-minutes before it was terminated.

For the second testing session, the same protocol as above was followed with additional secondary cognitive tasks. At every five-minute interval of 10-minute blocks, there was a high workload effect of secondary cognitive tasks performed for three minutes. These were issued and recorded by the researcher, throughout the protocol. Once the protocol was terminated, the participants were required to fill in the KSS questionnaire, giving an indication of how they felt following the rest break that they had for both testing sessions.

3.6 ETHICAL CONSIDERATIONS

3.6.1 Informed Consent

The ethics committee of the Human Kinetics and Ergonomics Department of Rhodes University approved this study before any testing could commence. Full disclosure of procedures and participation requirements was provided to the ethics committee before ethical approval was granted. This was inclusive of the experimental procedure, methodology consideration and participant recruitment. The letter of information and informed consent that the participants would receive during the habituation was also included.

3.6.2 Anonymity

All data and personal information recorded during the study were stored in either electronic or paper format, with each participant's data being assigned a code specific to the condition to which they were assigned. All data were stored on the personal computer of the researcher and removed from any communal research laptops. Only the primary researcher kept the main list of codes and names.

3.7 DATA REDUCTION AND STATISTICAL ANALYSIS

A data reduction tool developed by the department of Human Kinetics and Ergonomics, Rhodes University was used for the analysis of performance and physiological measures. All experimental data were imported into a Statistica Version 13 Software (StatSoft® In.2013) for generating of statistical analyses. A general linear model was applied for the analyses of variance (ANOVA) tests ($p<0.05$) to determine if there were significant differences in performance measures of the experimental conditions. A confidence interval of 95% with a corresponding alpha level of 0.05 (5%) was chosen.

CHAPTER IV

RESULTS

4.1 INTRODUCTION

The prime aim for this investigation was to analyse the return to task performance and the effects of a rest break task and the duration thereof on this very performance, in a pre and post tracking task. This was done from a psychophysiological, behavioural and subjective perspective in order to observe the responses and effects of the rest break, in terms of the length of it and the alertness strategies undertaken during this period. The second aim was to recognize the impact of various workloads on these responses.

Participants were required to perform a tracking task on a low-fidelity tracking simulator, in a pre-break (of 30minutes) and a post-break (of 20minutes) set-up. The rest break entailed two different durations, 2-minutes and 30-minutes, which resulted in two time long protocols; 52-minutes of the 2-minute break and 80-minutes of the 30-minute break. The tracking task required the participants to track a winding white line with the tip of an arrow, in an under-stimulating yet attention demanding scenario. Participants (n=32) were distributed amongst four equal experimental groups (n=8): PAUSE- 2minutes, PAUSE-30minutes, ADMIN-2minutes and ADMIN-30minutes, corresponding to the task done during the rest break and the duration thereof.

Participants were exposed to two different workloads, Low and High, where the former workload involved a primary task which was the pure tracking task and the latter involved a combination of the primary task with secondary tasks, a running memory task and a rule-based decision making task. For the psychophysiological perspective, heart rate and heart rate variability were recorded, with neurophysiological assessments of oculomotor movements such as blink frequency and blink duration. For a subjective assessment, the Karolinska Sleepiness Scale was used to rate the quality of the rest break.

Key considerations for statistical interpretation

In the following chapter, *time on task*, *group, rest task, rest duration* and *before and after* effects will be referred to. These are explained as follows:

- The *time on task* (interval) *effect* refers to changes that occur over the course of the protocol (52-minutes and 80-minutes respectively), analysed in 5-minute intervals.
- The *workload effect* refers to the difference in responses between the two workload complexities; *Low* and *High*.
- The *rest task effect* refers to the differences in performance which have been elicited by the rest task.
- The *rest duration effect* refers to the differences in performance which have been elicited by the rest duration.
- The *before and after effect* refers to the difference in responses before and after the set rest break. A period of 15minutes (3 intervals of 5-minutes) before and 15minutes after was chosen for this analysis with particular focus placed on the last interval before the rest break and the first interval after the rest break.

Due to the extent of the data, only significant results pertinent to the aims of the study are presented in this chapter. Detailed tables are included within each sub-section showing relevant statistical effects. Complete insignificant statistical tables are listed in Appendix B2.

All statistical analyses were performed with a 95% confidence interval ($p<0.05$), denoted by the effort bars in all figures.

4.2 PERFORMANCE PARAMETERS OVERTIME (*TIME ON TASK)*

4.2.1 Performance responses

Tracking Task performance (primary task)

The following section details changes in dependent variables over the two time protocols (52-minutes and 80-minutes) of the tracking task. Effective response time was used to quantify driving performance.

There were no statistically significant effects with regards to tracking task performance in the varying Low and High workload conditions. Subsequently, there were no statistically significant effects on tracking task performance attributed by either *rest task* or *rest duration*. This may be that there was no learning effect nor was there a recovery effect gained over the course of the protocol.

4.2.2 Cardiovascular responses

4.2.2.1 Heart rate frequency

Table 4: Statistical effects for heart rate frequency established during both the Low and High workload condition with time on task, rest task and rest duration as the three factors (*=significant effect, p<0.05).

Heart Rate Frequency	SS	Degr. of Freedom	MS	F	p
REST TASK	1863	1,29	1863	2.920	0.098178
REST DURATION	798	1,29	798	1.251	0.272483
WORKLOAD	728	1,29	728	2.309	0.139436
WORKLOAD*REST TASK	77	1,29	77	0.245	0.624316
WORKLOAD*REST DURATION	165	1,29	165	0.525	0.474500
INTERVAL	2161	7,203	309	16.182	<0.001*
INTERVAL*REST TASK	40	7,203	6	0.297	0.954595
INTERVAL*REST DURATION	121	7,203	17	0.905	0.503794
WORKLOAD*INTERVAL	129	7,203	18	1.193	0.308192
WORKLOAD*INTERVAL*REST TASK	22	7,203	3	0.208	0.983357
WORKLOAD*INTERVAL*REST DURATION	117	7,203	17	1.082	0.376288

Heart rate frequency for low and high workload decreases significantly ($p<0.05$) over time, from 75 $bt.min^{-1}$ in the beginning of the protocol to 70 $bt.min^{-1}$ in the conclusion of the task, suggesting that participants were in a fatigued, sleepy mode at the end of the tracking task. There is no significant *rest task* or *rest duration effect* and no interaction effect between *rest task* and/or *rest duration* and *time on task*.

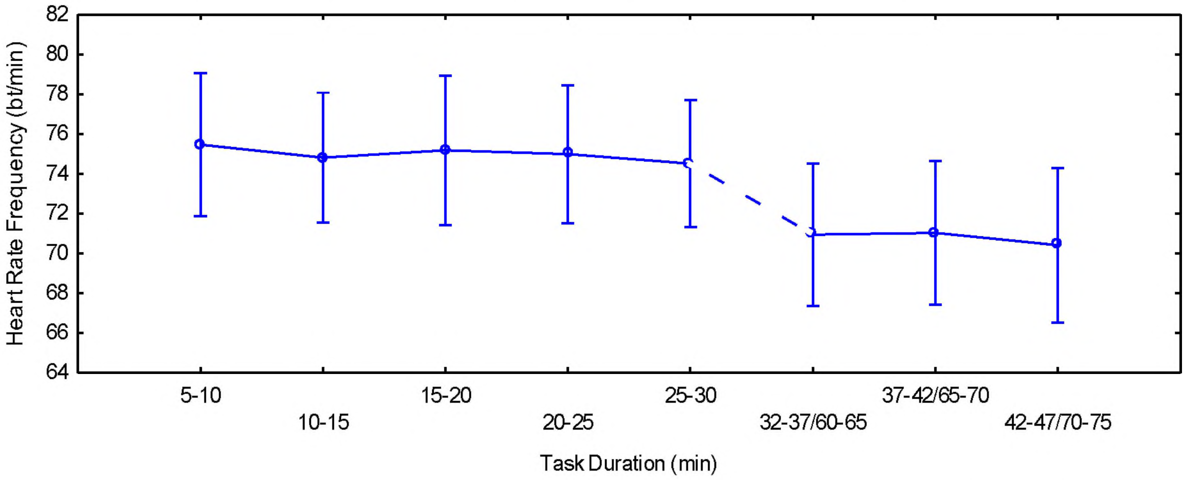

Figure 9: Heart rate frequency (bt.min^{-1}) for both low and high workload decreases significantly over time for all participants. (*=significant effect, $p<0.05$).

4.2.2.2 Heart Rate Variability: Time-Domain Analyses

Table 5: : Statistical effects for heart rate variability established during the Low and High workload condition with time on task, rest task and rest duration effect as the three factors (*=significant effect, $p<0.05$).

HRV (rMSSD)	SS	Degr. of Freedom	MS	F	p
REST TASK	21465	1,29	21465	5.6507	0.024263*
REST DURATION	16398	1,29	16398	4.3166	0.046702*
WORKLOAD	11627	1,29	11627	7.1694	0.012079*
WORKLOAD*REST TASK	45	1,29	45	0.0278	0.868654
WORKLOAD*REST DURATION	1175	1,29	1175	0.7246	0.401602
INTERVAL	5465	7,203	781	5.6173	0.000006*
INTERVAL*REST TASK	625	7,203	89	0.6426	0.720319
INTERVAL*REST DURATION	1696	7,203	242	1.7434	0.100696
WORKLOAD*INTERVAL	2272	7,203	325	3.0644	0.004341*
WORKLOAD*INTERVAL*REST TASK	559	7,203	80	0.7540	0.626517
WORKLOAD*INTERVAL*REST DURATION	799	7,203	114	1.0781	0.378673

There is a significant difference ($p<0.05$) in HRV (rMSSD) between the two *rest tasks* (PAUSE and ADMIN), with the ADMIN task having a low HRV (rMSSD), indicating an increased cognitive workload and thus alertness. There was a significant effect of *rest duration* (SHORT and LONG) as well, where HRV was lower for the *short* rest duration than the *long* rest duration. This suggesting that the longer rest duration elicited effects of low arousal.

The varying workload showed an effect (p<0.05), with the Low workload condition having a higher HRV (rMSSD) than the High workload condition, where the variance of the latter was greater suggesting a dispersed range of responses in this condition.

Task duration (*INTERVAL*) has a significant effect (p<0.05) on HRV (rMSSD), where it increases over time. There is also an interactive effect between *workload* and *time on task (interval)*, suggesting that the varying workloads elicited differing responses on the participants.

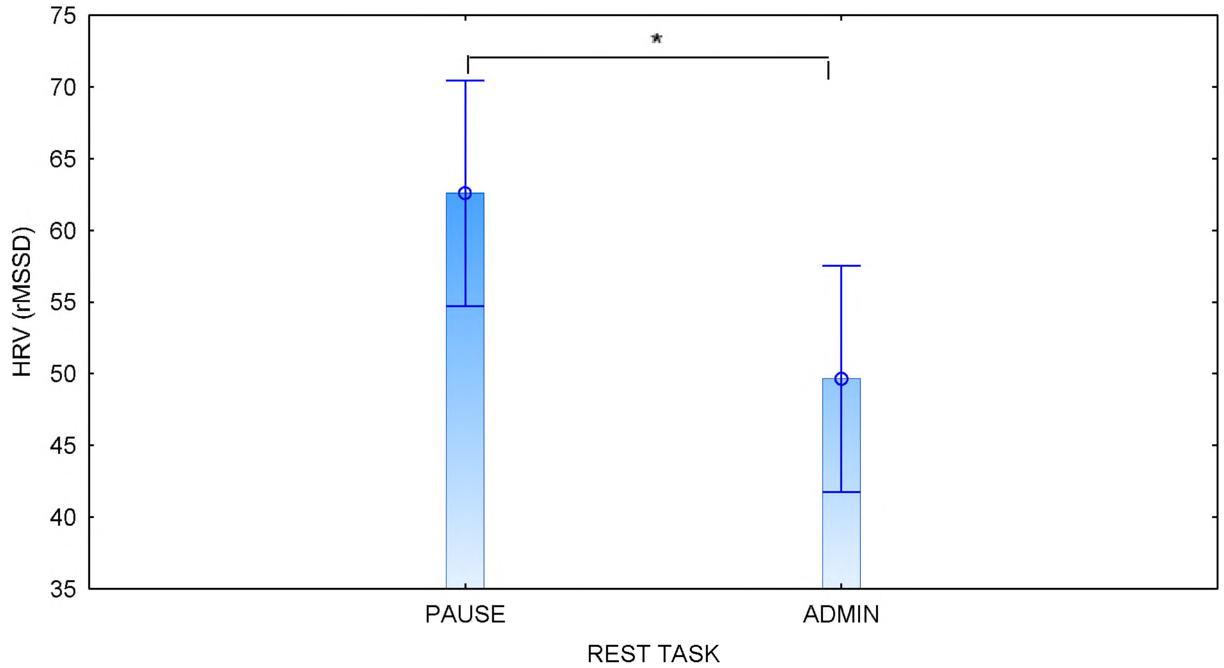

Figure 10: Change in HRV (rMSSD) over time, with the effect of Rest Task for all experimental groups (*=significant effect, p<0.05; Error bars denote 95% confidence interval).

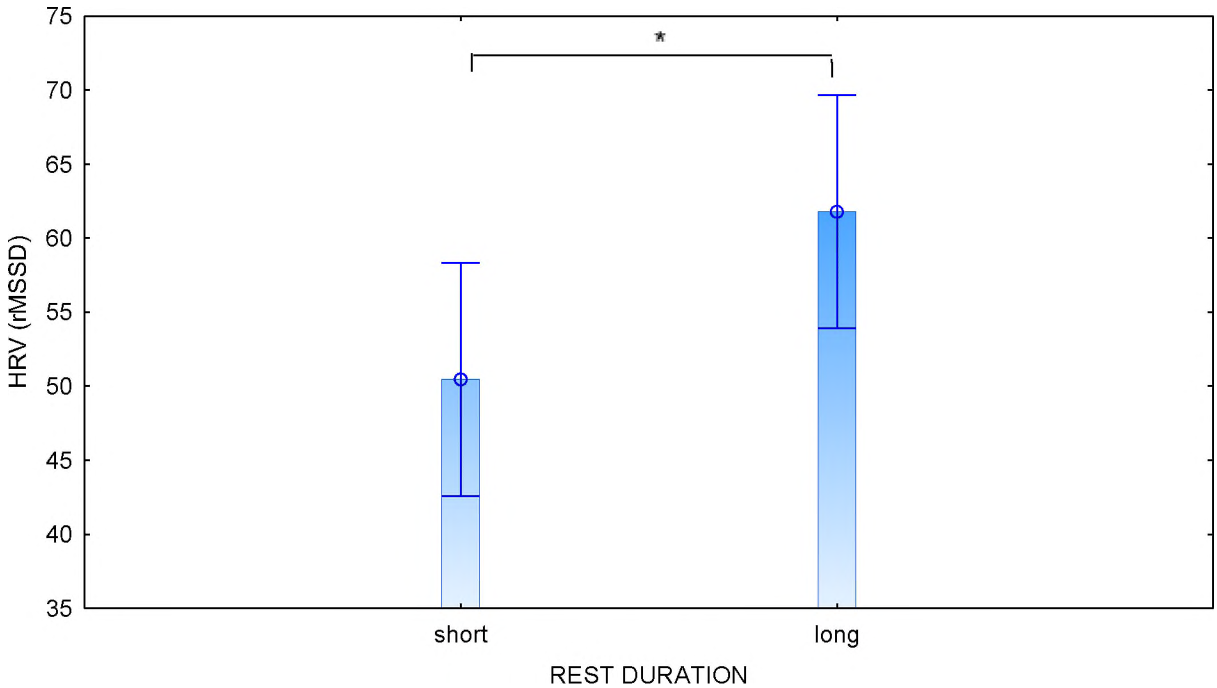

Figure 11: Change in HRV (rMSSD) over time, with the effect of Rest Duration for all experimental groups (*=significant effect, p<0.05; Error bars denote 95% confidence interval).

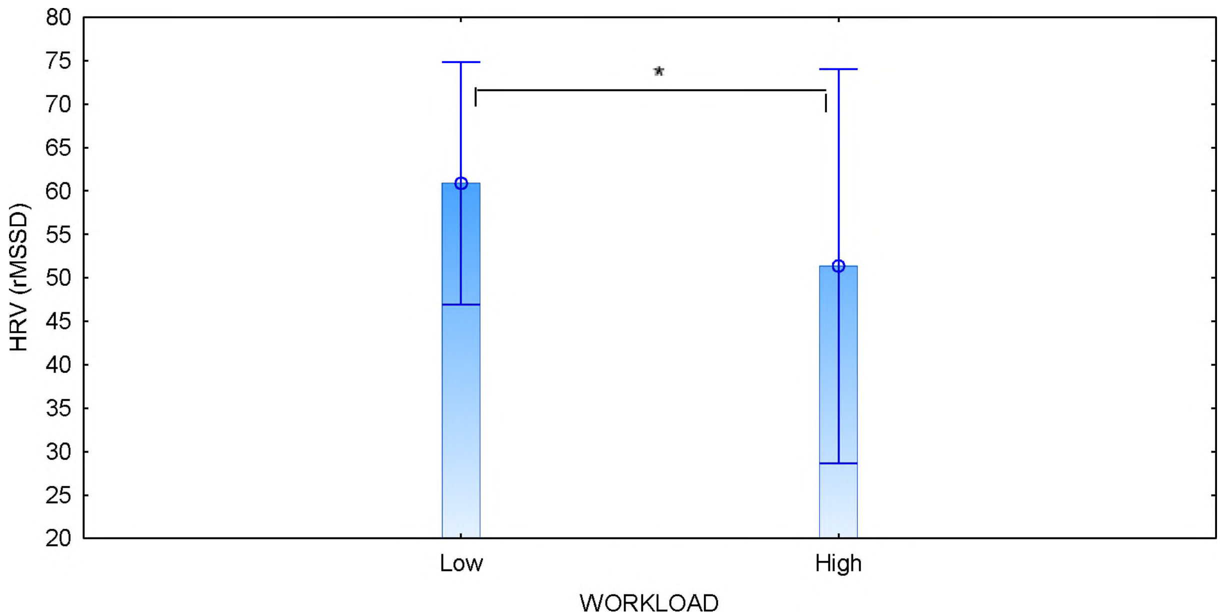

Figure 12: Change in HRV (rMSSD) between the two workloads for all experimental groups (*=significant effect, p<0.05; Error bars denote 95% confidence interval).

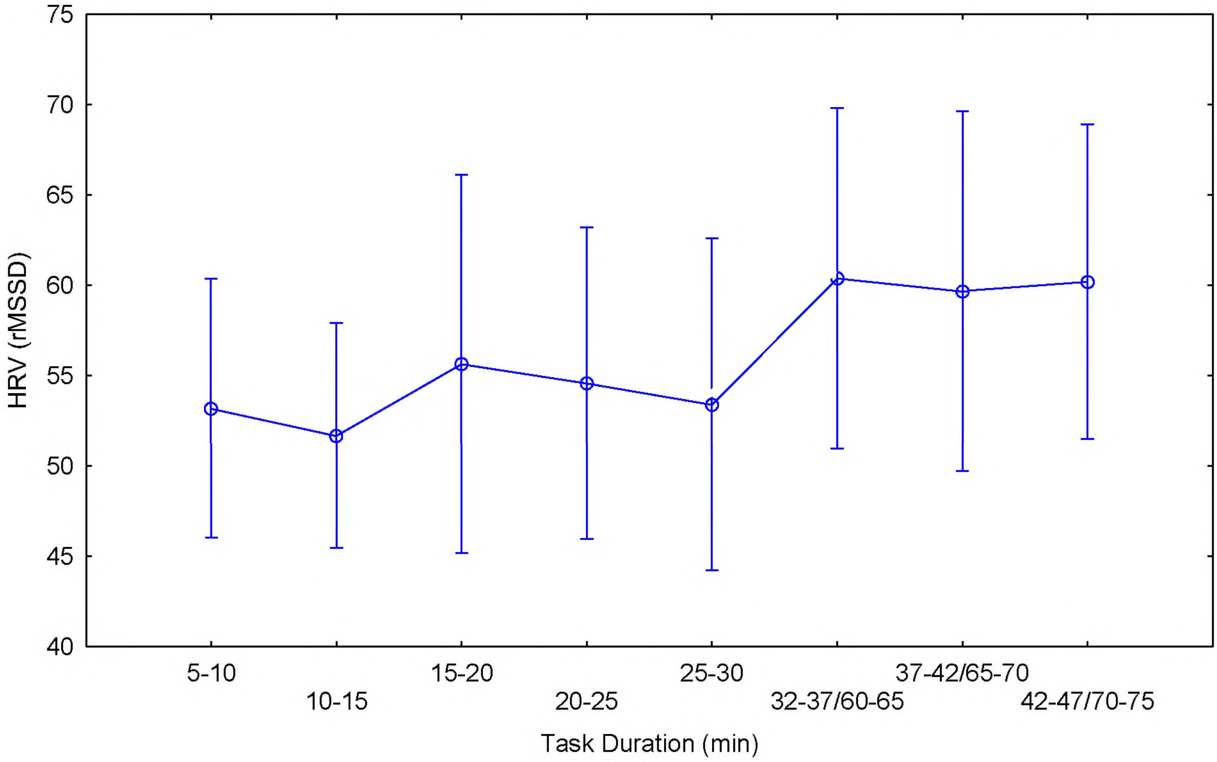

Figure 13: Changes in HRV (rMSSD) for both low and high workload increases significantly over time for all participants. (*=significant effect, $p<0.05$; Error bars denote 95% confidence interval).

4.2.2.3 Heart Rate Variability: Frequency-Domain Analyses

Within the spectral analysis of heart rate variability, HF and LF power commonly indicate the parasympathetic and sympathetic activation of the autonomic nervous system, respectively. It is therefore, expected that states of elevated arousal would be accompanied by increases in LF power responses.

There was a significant interval effect ($p<0.05$), together with an interactive effect between *intervals* (time on task) and the *rest task.* Figure 14 shows fluctuations in LF power relative to (LF + HF) responses prior to the rest break, then starts to decrease.

Table 6: Statistical effects for heart rate variability LF power (LF/HF ratio) established during the Low and High workload condition with time on task, rest task and rest duration effect as the three factors (*=significant effect, p<0.05).

HRV (LF + HF ratio)	SS	Degr. of Freedom	MS	F	p
REST TASK	7019	1,29	7019	4.122	0.051585
REST DURATION	260	1,29	260	0.152	0.699021
WORKLOAD	2488	1,29	2488	2.108	0.157279
WORKLOAD*REST TASK	194	1,29	194	0.165	0.687857
WORKLOAD*REST DURATION	248	1,29	248	0.210	0.650064
INTERVAL	1682	7,203	240	2.147	0.040347*
INTERVAL*REST TASK	3211	7,203	459	4.100	0.000311*
INTERVAL*REST DURATION	385	7,203	55	0.492	0.840019
WORKLOAD*INTERVAL	891	7,203	127	1.144	0.336957
WORKLOAD*INTERVAL*REST TASK	253	7,203	36	0.325	0.942199
WORKLOAD*INTERVAL*REST DURATION	307	7,203	44	0.394	0.905204

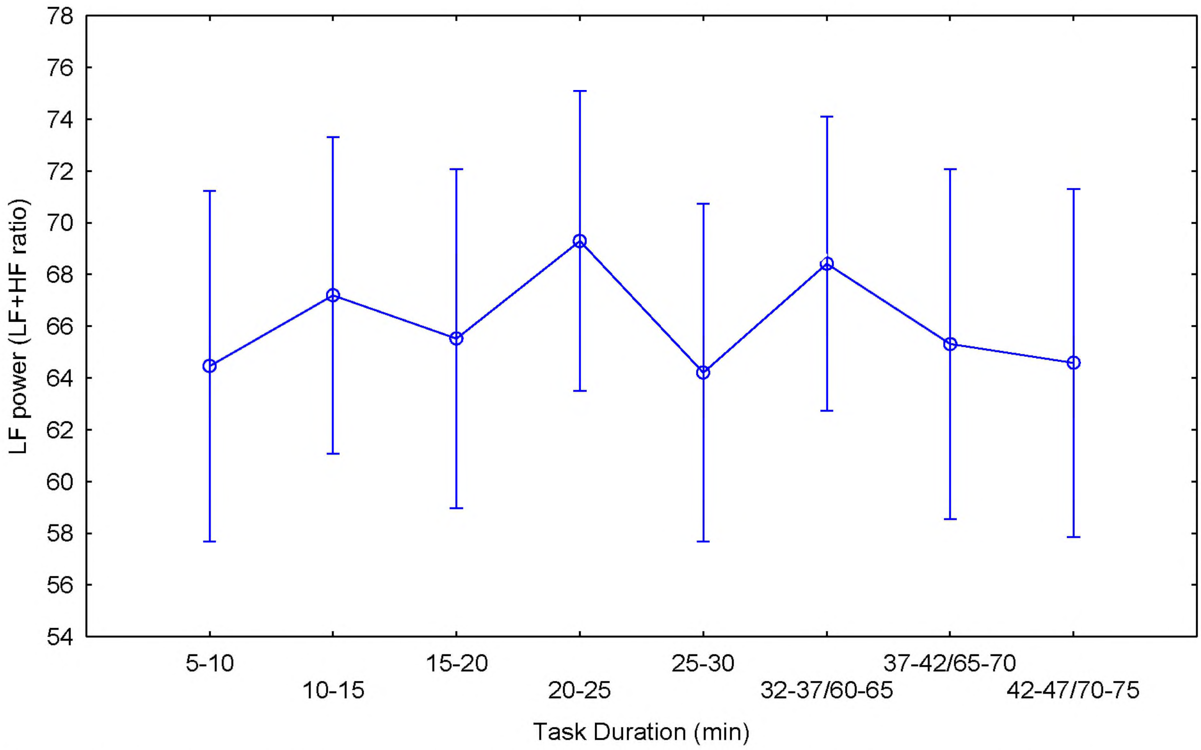

Figure 14: Changes in LF power (LF+HF ratio) with varying workloads over time for all participants. (*=significant effect, p<0.05; Error bars denote 95% confidence interval).

4.2.3 Oculomotor responses

4.2.3.1 Blink Frequency

Table 7: Statistical effects for blink frequency established during the Low and High workload condition with time on task, rest task and rest duration effect as the three factors (*=significant effect, p<0.05).

Bink Frequency	SS	Degr. of Freedom	MS	F	p
REST TASK	206.88	1,29	206.88	2.1381	0.154433
REST DURATION	101.85	1,29	101.85	1.0526	0.313386
WORKLOAD	508.84	1,29	508.84	8.5149	0.006740*
WORKLOAD*REST TASK	14.77	1,29	14.77	0.2472	0.622837
WORKLOAD*REST DURATION	35.52	1,29	35.52	0.5944	0.446954
INTERVAL	281.89	7,203	40.27	2.4039	0.021999*
INTERVAL*REST TASK	98.94	7,203	14.13	0.8438	0.552268
INTERVAL*REST DURATION	137.42	7,203	19.63	1.1719	0.320414
WORKLOAD*INTERVAL	141.40	7,203	20.20	1.4843	0.174476
WORKLOAD*INTERVAL*REST TASK	91.89	7,203	13.13	0.9645	0.458259
WORKLOAD*INTERVAL*REST DURATION	97.90	7,203	13.99	1.0276	0.412873

Blink frequency shows no significant effect for either of the rest break conditions, *rest task* and *rest duration*, however there was a workload effect (p<0.05) and an interval (time on task) effect (p<0.05). Blink frequency was higher in the High workload condition than in the Low workload condition, suggesting an element of fatigue elicited by the condition.

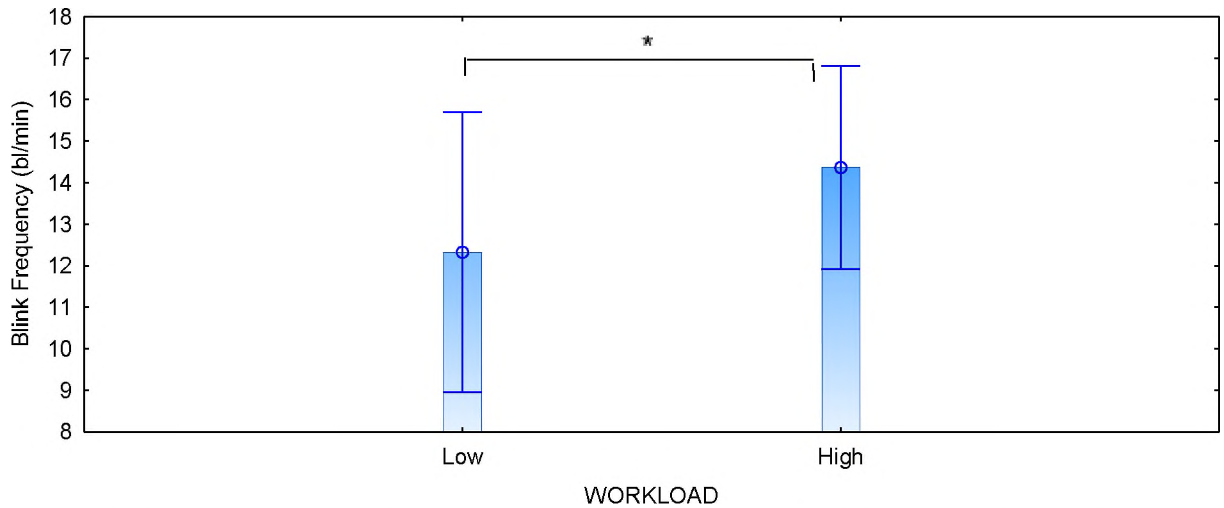

Figure 15: Changes in Blink Frequency (bl.min^{-1}) for Low and High workload conditions for all participants (*=significant effect, p<0.05; Error bars denote 95% confidence interval)

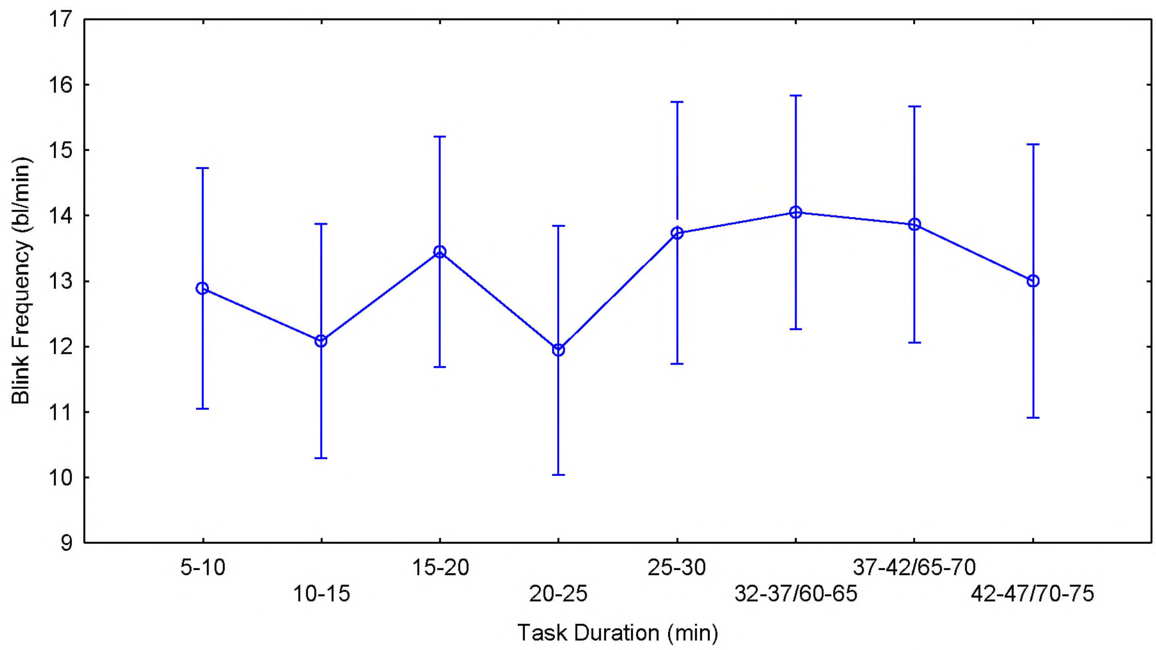

Figure 16: Blink frequency (bl.min^{-1}) for both low and high workload changes significantly over time for all participants. (*=significant effect, $p<0.05$; Error bars denote 95% confidence interval)

4.2.3.2 Blink Duration

Table 8: Statistical effects for blink duration established during the Low and High workload condition with time on task, rest task and rest duration effect as the three factors (*=significant effect, $p<0.05$).

Blink Duration	SS	Degr. of Freedom	MS	F	p
REST TASK	1181	1,29	1181	0.103	0.751014
REST DURATION	13683	1,29	13683	1.189	0.284538
WORKLOAD	22799	1,29	22799	2.824	0.103635
WORKLOAD*REST TASK	244	1,29	244	0.030	0.863301
WORKLOAD*REST DURATION	3547	1,29	3547	0.439	0.512713
INTERVAL	135297	7,203	19328	4.611	0.000083*
INTERVAL*REST TASK	9216	7,203	1317	0.314	0.947089
INTERVAL*REST DURATION	48851	7,203	6979	1.665	0.119416
WORKLOAD*INTERVAL	31466	7,203	4495	1.079	0.377859
WORKLOAD*INTERVAL*REST TASK	16873	7,203	2410	0.579	0.772745
WORKLOAD*INTERVAL*REST DURATION	16281	7,203	2326	0.558	0.788974

There was a significant effect (p<0.05) on time on task (*interval*) for Blink Duration, suggesting a fatiguing effect was present. Blink duration increased prior the rest break, and a decrease was noticed after the rest break, possibly indicating a recovery effect, although non-significant.

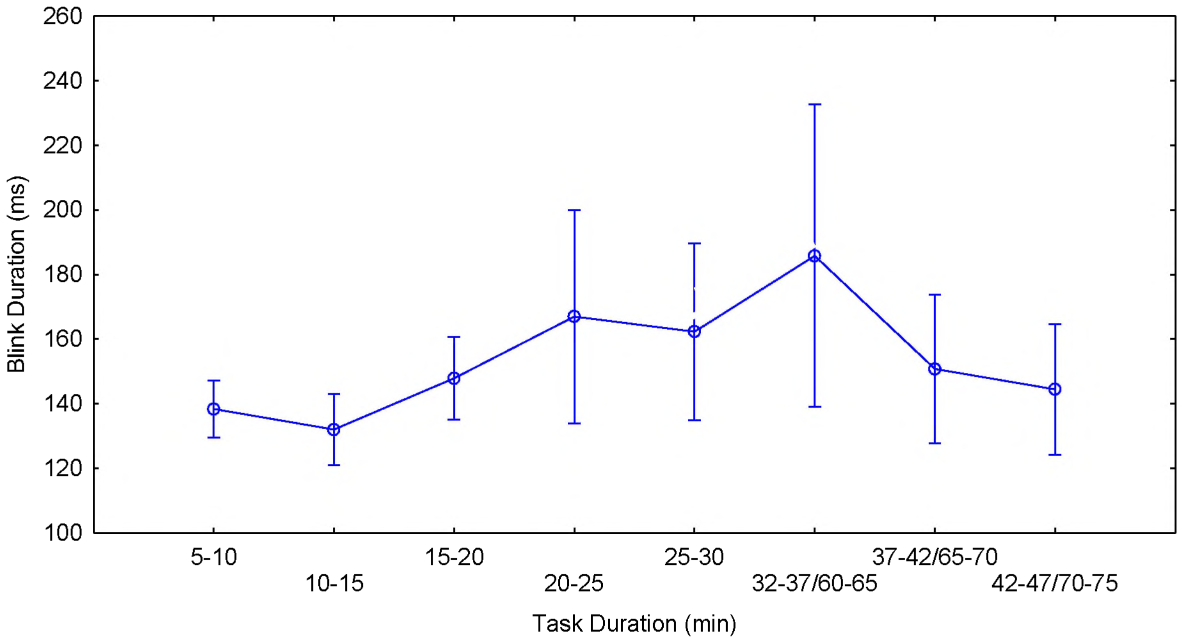

Figure 17: Blink duration for both Low and high workload decreases significantly over time for all participants. (*=significant effect, p<0.05; Error bars denote 95% confidence interval)

4.3 PERFORMANCE PARAMETERS FOR BEFORE AND AFTER REST BREAK

4.3.1 Performance responses

4.3.1.1 Tracking Task Performance

There were no statistically significant effects elicited by the tracking task, before and after the rest break.

4.3.1.2 Rule-Based Decision-Making Task

Short term or working memory was assessed through the application of two cognitive tasks derived from the Sternberg memory task. Participants were presented with a string of images (randomized between 5 and 7 images), after which they were presented with a probe image and had to correctly identify whether the probe image was in the previously presented list or not. The percentage of correct responses was recorded and analysed.

Table 9: Statistical effects for percentage of images correctly identified during the pre- and post- rest break secondary cognitive tasks, with *rest task*, *rest duration* and *before and after* as the factors (*=significant effect, p<0.05).

Rule-Based Decision-Making Task	SS	Degr. of Freedom	MS	F	p
REST TASK	192.5	1,29	192.5	0.693	0.411953
REST DURATION	1415.6	1,29	1415.6	5.096	0.031687*
B-A	37.5	1,29	37.5	0.107	0.745693
B-A*REST TASK	74.4	1,29	74.4	0.213	0.648182
B-A*REST DURATION	178.9	1,29	178.9	0.511	0.480323

*(*B-A* = Before and After)

Image identification was found to be better in the *short* rest break duration groups than in the *long* rest break duration groups, suggesting that the participants who were out-of-the-loop for longer, experienced difficulty in identifying the images correctly, possibly owing to the loss in attention. There was however no statistically significant *before and* after effect.

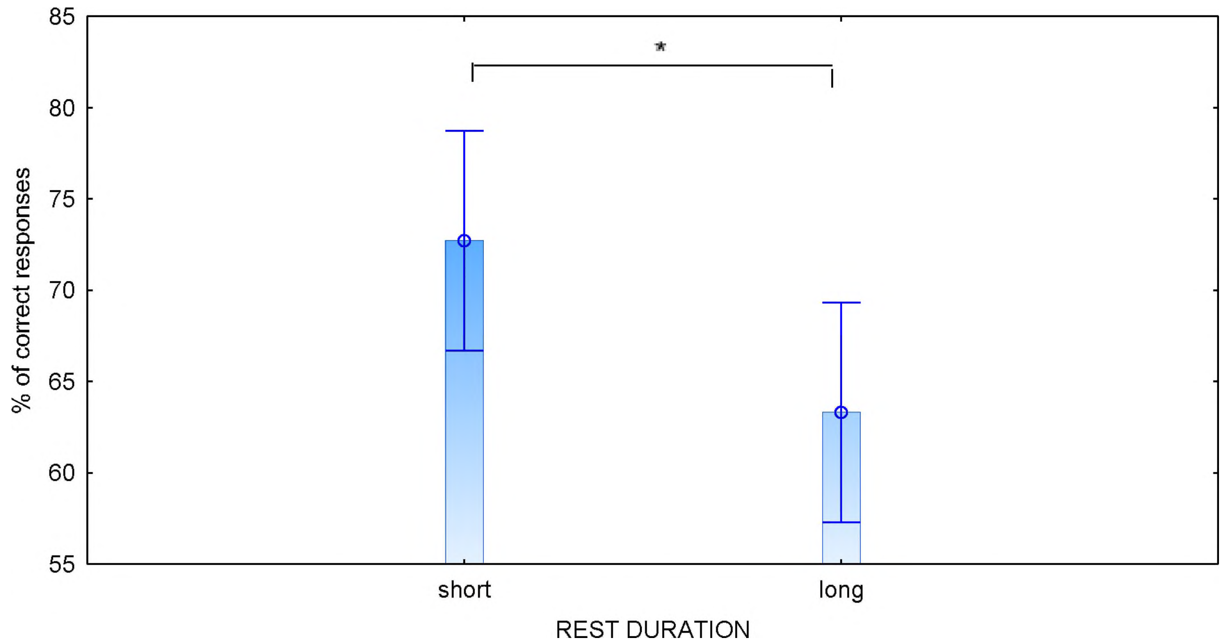

Figure 18: Overall difference in percentage of correctly identified images with the effect of *rest duration*, having the groups with the shorter duration with a higher correct identification percentage (*significant effect, p<0.05; Error bars denote 95% confidence interval).

4.3.1.3 Running Memory Task

There were no statistically significant effects observed in the Running Memory Task. This could be that the task did not elicit any differing responses to the participants and had no impact on the participants as a secondary task to increase workload.

4.3.2 Cardiovascular responses

4.3.2.1 Heart Rate Frequency

Table 10: Analysis of variance for heart rate frequency established during the Low and High workload condition, before and after the rest break, with the rest task and rest duration as factors. (*=significant effect, p<0.05).

Heart Rate Frequency	SS	Degr. of Freedom	MS	F	p
{1}REST TASK	1558	1,29	1558	3.092	0.089225
{2}REST DURATION	493	1,29	493	0.979	0.330523
{3}WORKLOAD	418	1,29	418	1.615	0.213923
WORKLOAD*REST TASK	82	1,29	82	0.315	0.578870
WORKLOAD*REST DURATION	180	1,29	180	0.694	0.411763
{4}B-A	1612	1,29	1612	31.325	0.000005*
B-A*REST TASK	9	1,29	9	0.166	0.686764
B-A*REST DURATION	53	1,29	53	1.032	0.318054
{5}INTERVAL	28	2,58	14	1.497	0.232300
INTERVAL*REST TASK	11	2,58	6	0.589	0.557900
INTERVAL*REST DURATION	3	2,58	2	0.170	0.843994
WORKLOAD*B-A	21	1,29	21	0.481	0.493353
WORKLOAD*B-A*REST TASK	0	1,29	0	0.000	0.989685
WORKLOAD*B-A*REST DURATION	29	1,29	29	0.665	0.421365
WORKLOAD*INTERVAL	1	2,58	1	0.088	0.915979
WORKLOAD*INTERVAL*REST TASK	0	2,58	0	0.012	0.988158
WORKLOAD*INTERVAL*REST DURATION	29	2,58	15	2.170	0.123339
B-A*INTERVAL	1	2,58	1	0.075	0.927962
B-A*INTERVAL*REST TASK	2	2,58	1	0.094	0.910807
B-A*INTERVAL*REST DURATION	22	2,58	11	1.302	0.279726
WORKLOAD*B-A*INTERVAL	37	2,58	18	3.409	0.039828*
3*4*5*1	3	2,58	1	0.261	0.771301
3*4*5*2	31	2,58	16	2.892	0.063486

*(*B-A* = Before and After)

Heart rate frequency decreases significantly between before and after the rest break ($p<0.05$). The intervals chosen for this analysis are 15-minutes before and after the rest break. There was also a significant interactive effect ($p<0.05$) on *workload* in the intervals before and after the rest break, however, there was no significant effect of either the *rest task* or the *rest duration* during the rest break.

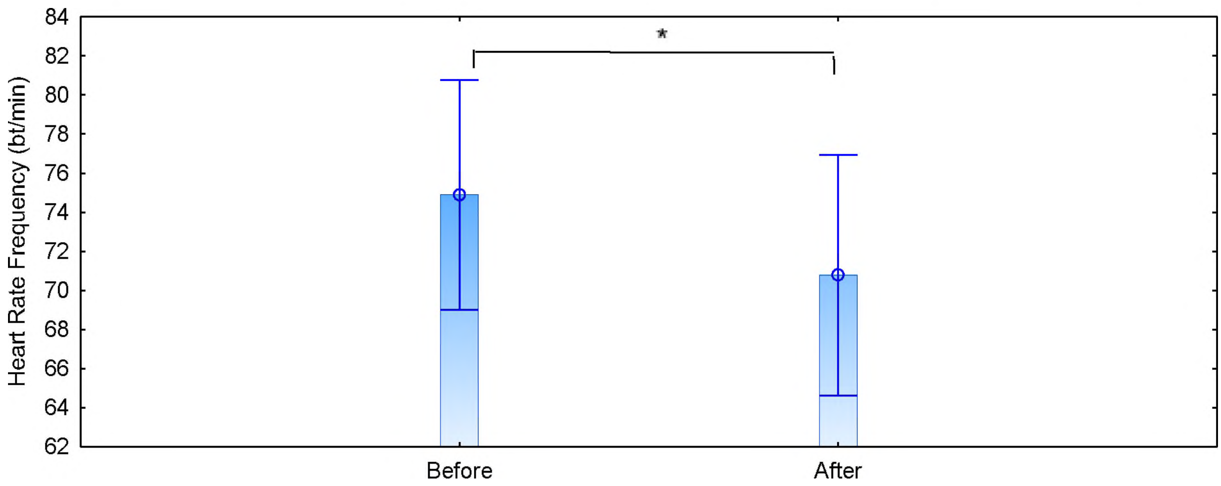

Figure 19: Changes in heart rate frequency (bt/min^{-1}) before and after the rest break. (*=significant effect, $p<0.05$; Error bars denote 95% confidence interval).

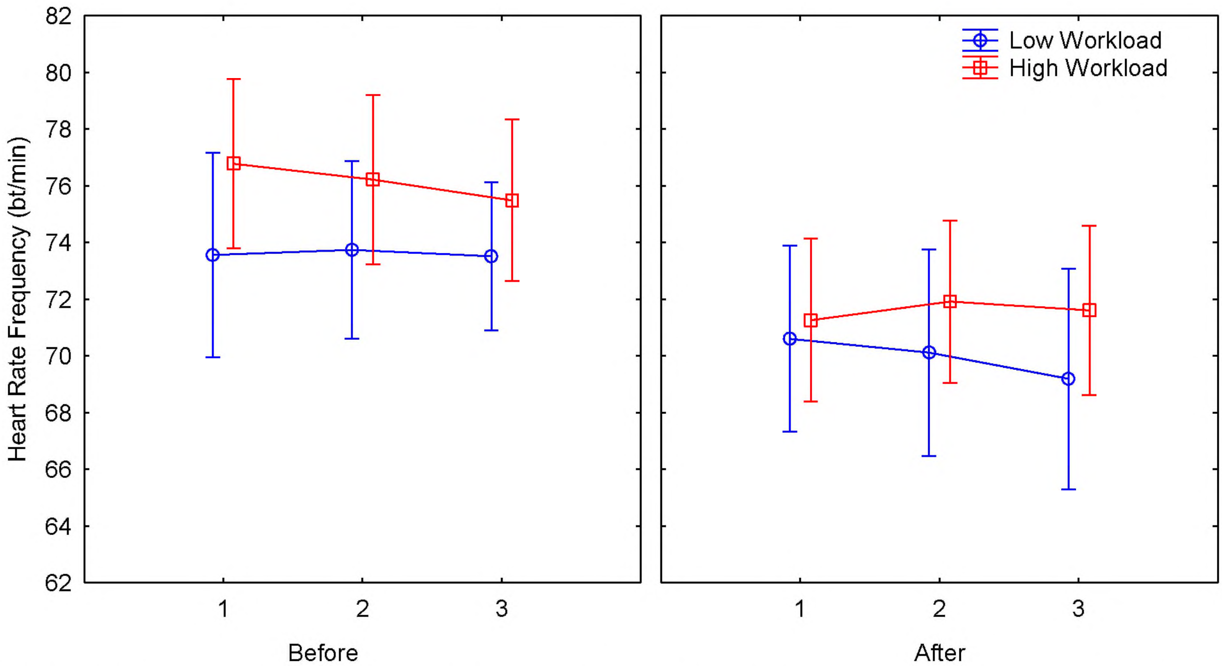

Figure 20: Changes in heart rate frequency (bt/min^{-1}) before and after the rest break, with varying workloads. (*=significant effect, $p<0.05$; Error bars denote 95% confidence interval).

4.3.2.2 Heart Rate Variability: Time-Domain Analyses

Table 11: Analysis of variance for heart rate variability (rMSSD) established during the Low and High workload condition, before and after the rest break, with the rest task and rest duration as factors. (*=significant effect, p<0.05).

HRV (rMSSD)	SS	Degr. of Freedom	MS	F	p
{1}REST TASK	15950	1,29	15950	4.7045	0.038423*
{2}REST DURATION	12277	1,29	12277	3.6213	0.067013
{3}WORKLOAD	7745	1,29	7745	5.9269	0.021299*
WORKLOAD*REST TASK	119	1,29	119	0.0913	0.764668
WORKLOAD*REST DURATION	880	1,29	880	0.6733	0.418595
{4}B-A	2932	1,29	2932	8.5111	0.006751*
B-A*REST TASK	305	1,29	305	0.8867	0.354153
B-A*REST DURATION	84	1,29	84	0.2428	0.625929
{5}INTERVAL	104	2,58	52	0.4619	0.632369
INTERVAL*REST TASK	65	2,58	32	0.2883	0.750617
INTERVAL*REST DURATION	1211	2,58	606	5.3874	0.007145*
WORKLOAD*B-A	1421	1,29	1421	7.0763	0.012592*
WORKLOAD*B-A*REST TASK	302	1,29	302	1.5018	0.230259
WORKLOAD*B-A*REST DURATION	145	1,29	145	0.7201	0.403073
WORKLOAD*INTERVAL	344	2,58	172	2.6743	0.077451
WORKLOAD*INTERVAL*REST TASK	37	2,58	18	0.2866	0.751898
WORKLOAD*INTERVAL*REST DURATION	496	2,58	248	3.8501	0.026914*
B-A*INTERVAL	75	2,58	38	0.6268	0.537867
B-A*INTERVAL*REST TASK	40	2,58	20	0.3330	0.718101
B-A*INTERVAL*REST DURATION	237	2,58	118	1.9732	0.148239
WORKLOAD*B-A*INTERVAL	349	2,58	175	2.9448	0.060528
3*4*5*1	102	2,58	51	0.8581	0.429262
3*4*5*2	50	2,58	25	0.4207	0.658546

*(*B-A* = Before and After)

Heart rate variability (rMSSD) shows a significant *rest task* and *workload effect* (p<0.05), similar to the HRV responses reported above on *time on* task, suggesting that the participants responded differently owing to the varying workload and activity performed during the rest break. This consequently led to a significant *before and after effect* (p<0.05), with a general increase seen after the rest break.

There was an interactive effect between the *intervals* and *rest duration*, as well as between *workload* and *before and after* the rest break, showing an increase after the rest break.

There was no significant effect of *rest duration*; however, there was an interactive effect between *workload*, *intervals* as well as *rest duration.*

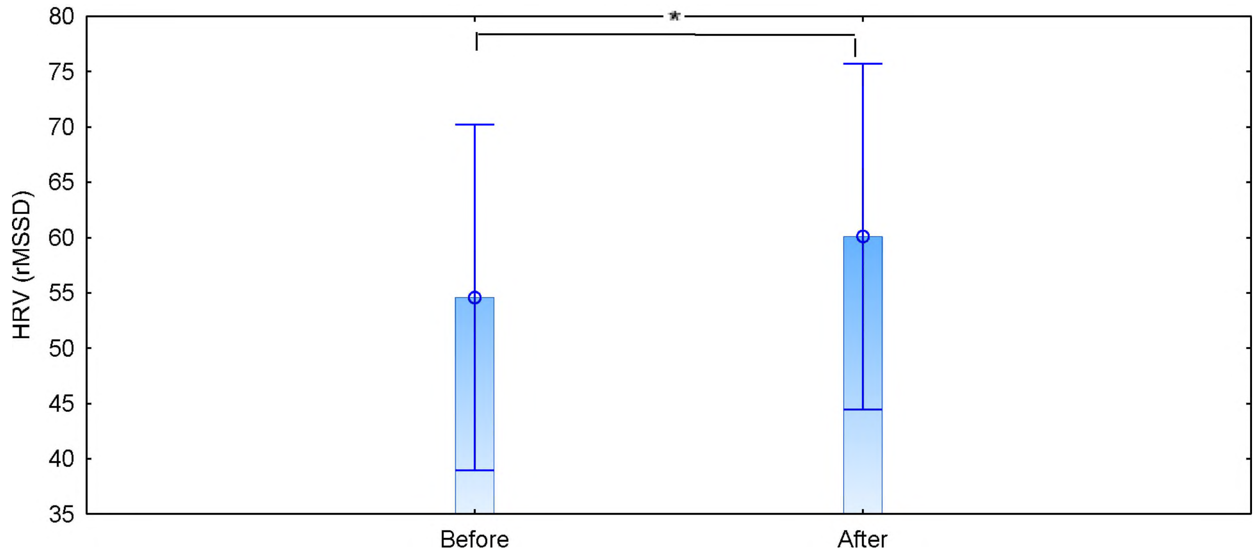

Figure 21: Changes in HRV (rMSSD) before and after the rest break. (*=significant effect, p<0.05; Error bars denote 95% confidence interval).

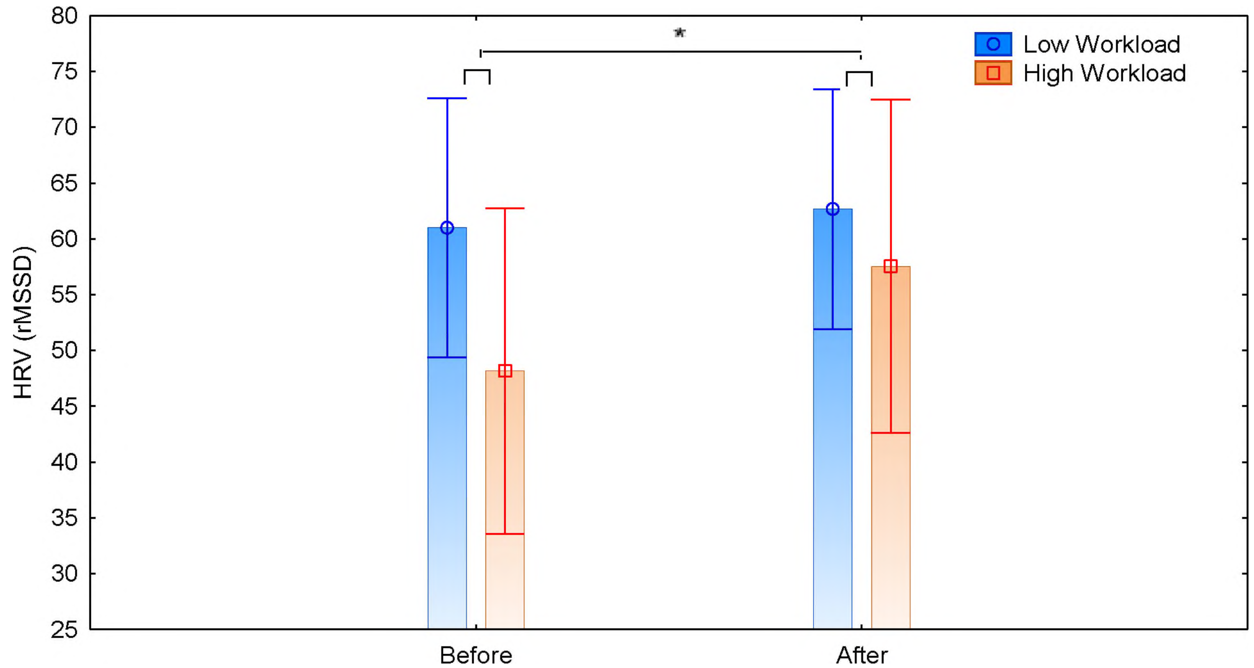

Figure 22: Changes in HRV (rMSSD) before and after the rest break, with the varying workloads. (*=significant effect, p<0.05; Error bars denote 95% confidence interval).

4.3.2.3 Heart Rate Variability: Frequency-Domain Analyses

Table 12: Analysis of variance for LF power (LF + HF ratio) established during the Low and High workload condition, before and after the rest break, with the rest task and rest duration as factors. (*=significant effect, $p<0.05$).

LF power (LF + HF ratio)	SS	Degr. of Freedom	MS	F	p
{1}REST TASK	3447	1,29	3447	2.656	0.113947
{2}REST DURATION	313	1,29	313	0.242	0.626755
{3}WORKLOAD	1573	1,29	1573	1.755	0.195619
WORKLOAD*REST TASK	261	1,29	261	0.291	0.593611
WORKLOAD*REST DURATION	285	1,29	285	0.318	0.577284
{4}B-A	5	1,29	5	0.029	0.865680
B-A*REST TASK	2315	1,29	2315	12.536	0.001370*
B-A*REST DURATION	7	1,29	7	0.038	0.846014
{5}INTERVAL	649	2,58	324	2.938	0.060884
INTERVAL*REST TASK	16	2,58	8	0.071	0.931749
INTERVAL*REST DURATION	288	2,58	144	1.303	0.279529
WORKLOAD*B-A	88	1,29	88	0.278	0.602088
WORKLOAD*B-A*REST TASK	31	1,29	31	0.096	0.758754
WORKLOAD*B-A*REST DURATION	13	1,29	13	0.042	0.838305
WORKLOAD*INTERVAL	677	2,58	338	4.810	0.011677*
WORKLOAD*INTERVAL*REST TASK	61	2,58	31	0.436	0.648932
WORKLOAD*INTERVAL*REST DURATION	180	2,58	90	1.277	0.286473
B-A*INTERVAL	774	2,58	387	5.254	0.007996*
B-A*INTERVAL*REST TASK	95	2,58	48	0.646	0.527826
B-A*INTERVAL*REST DURATION	29	2,58	14	0.194	0.824504
WORKLOAD*B-A*INTERVAL	73	2,58	36	0.772	0.466734
3*4*5*1	20	2,58	10	0.208	0.813010
3*4*5*2	3	2,58	2	0.033	0.967901

There is no significant overall change in LF power (LF + HF ratio) over time (*interval*), suggesting no significant state changes of the sympathetic system. There was however an interactive effect ($p<0.05$) between *before and after* and *rest task* (Table 12, Figure 23), *workload and interval* (where High workload was higher than Low workload) and between *before and after* and *interval*. Figure 23 shows a slight increase in LF power relative to (LF + HF) in the *PAUSE* rest task, after the rest break; whereas, there is a slight, yet elevated, decrease in the *ADMIN* rest task.

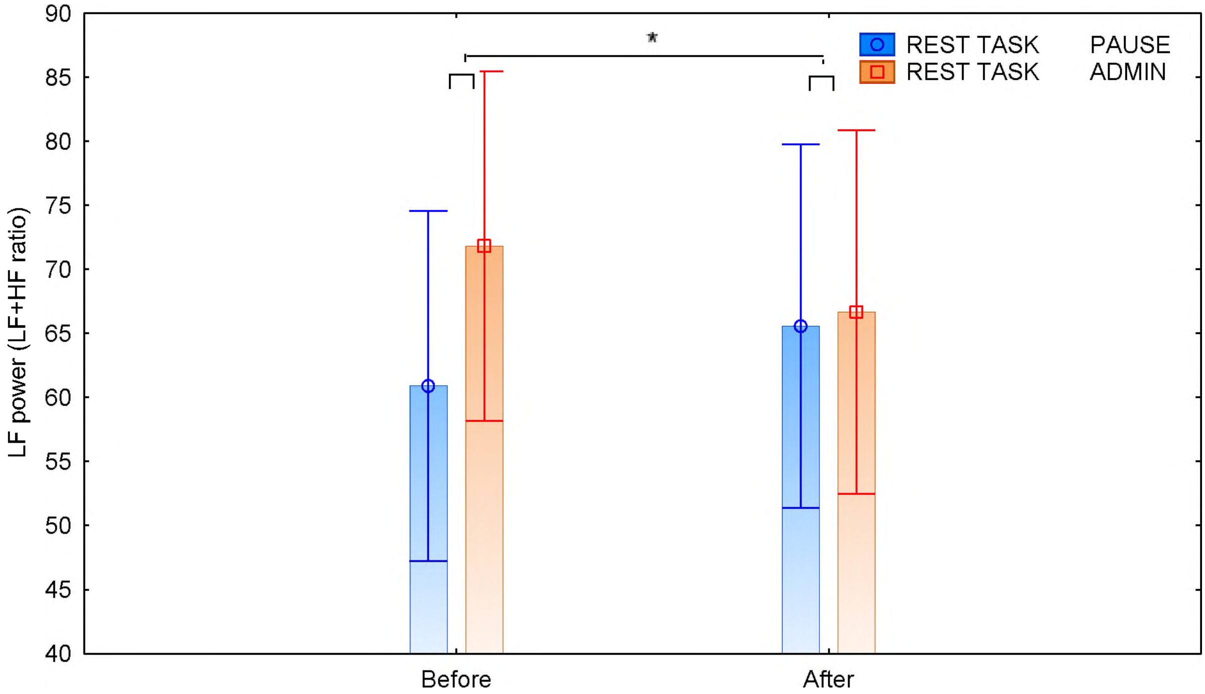

Figure 23: Changes in LF power (LF + HF ratio) before and after the rest break, with the varying workloads. (*=significant effect, p<0.05; Error bars denote 95% confidence interval).

4.3.3 Oculomotor parameters

4.3.3.1 Blink Frequency

Table 13: Analysis of variance for Blink frequency (bl/min^{-1}) established during the Low and High workload condition, before and after the rest break, with the rest task and rest duration as factors. (*=significant effect, p<0.05).

Blink Frequency	SS	Degr. of Freedom	MS	F	p
{1}REST TASK	135.60	1,29	135.60	1.6995	0.202604
{2}REST DURATION	125.21	1,29	125.21	1.5693	0.220323
{3}WORKLOAD	399.57	1,29	399.57	7.5052	0.010413*
WORKLOAD*REST TASK	14.97	1,29	14.97	0.2813	0.599911
WORKLOAD*REST DURATION	7.68	1,29	7.68	0.1442	0.706937
{4}B-A	34.04	1,29	34.04	1.4070	0.245181
B-A*REST TASK	23.64	1,29	23.64	0.9770	0.331120
B-A*REST DURATION	20.67	1,29	20.67	0.8543	0.362953
{5}INTERVAL	45.54	2,58	22.77	1.8953	0.159466
INTERVAL*REST TASK	37.69	2,58	18.85	1.5687	0.217015
INTERVAL*REST DURATION	63.65	2,58	31.82	2.6491	0.079263
WORKLOAD*B-A	27.27	1,29	27.27	1.9559	0.172559
WORKLOAD*B-A*REST TASK	18.93	1,29	18.93	1.3574	0.253474
WORKLOAD*B-A*REST DURATION	0.16	1,29	0.16	0.0113	0.916162
WORKLOAD*INTERVAL	33.56	2,58	16.78	1.3397	0.269909
WORKLOAD*INTERVAL*REST TASK	35.59	2,58	17.79	1.4209	0.249782
WORKLOAD*INTERVAL*REST DURATION	37.06	2,58	18.53	1.4795	0.236229
B-A*INTERVAL	111.85	2,58	55.92	3.1041	0.052394
B-A*INTERVAL*REST TASK	31.97	2,58	15.98	0.8872	0.417330
B-A*INTERVAL*REST DURATION	28.99	2,58	14.49	0.8045	0.452255
WORKLOAD*B-A*INTERVAL	34.12	2,58	17.06	1.3575	0.265346
3*4*5*1	21.27	2,58	10.64	0.8464	0.434175
3*4*5*2	26.18	2,58	13.09	1.0418	0.359333

Blink frequency shows no significant effect for either of the rest break conditions, *rest task* and *rest duration*, or any effect before and after the rest break, however there was a statistically significant *workload effect* ($p<0.05$). The response pattern for workload followed that of the time on task effect reported previously with the High workload condition achieving a higher blink frequency than the Low workload condition.

4.3.3.2 Blink Duration

Table 14: Analysis of variance for Blink duration established during the Low and High workload condition, before and after the rest break, with the rest task and rest duration as factors. (*=significant effect, p<0.05).

Blink Duration	SS	Degr. of Freedom	MS	F	p
{1}REST TASK	1793	1,29	1793	0.1358	0.715180
{2}REST DURATION	14589	1,29	14589	1.1051	0.301841
{3}WORKLOAD	27353	1,29	27353	2.9681	0.095571
WORKLOAD*REST TASK	42	1,29	42	0.0045	0.946764
WORKLOAD*REST DURATION	5517	1,29	5517	0.5986	0.445356
{4}B-A	157	1,29	157	0.0185	0.892619
B-A*REST TASK	244	1,29	244	0.0289	0.866155
B-A*REST DURATION	7074	1,29	7074	0.8372	0.367758
{5}INTERVAL	11767	2,58	5884	1.3654	0.263359
INTERVAL*REST TASK	3250	2,58	1625	0.3771	0.687519
INTERVAL*REST DURATION	18224	2,58	9112	2.1146	0.129885
WORKLOAD*B-A	9863	1,29	9863	1.2467	0.273341
WORKLOAD*B-A*REST TASK	3095	1,29	3095	0.3912	0.536570
WORKLOAD*B-A*REST DURATION	4384	1,29	4384	0.5542	0.462599
WORKLOAD*INTERVAL	9776	2,58	4888	0.9329	0.399252
WORKLOAD*INTERVAL*REST TASK	331	2,58	165	0.0316	0.968944
WORKLOAD*INTERVAL*REST DURATION	7031	2,58	3516	0.6710	0.515133
B-A*INTERVAL	64437	2,58	32219	7.1213	0.001716*
B-A*INTERVAL*REST TASK	5088	2,58	2544	0.5623	0.572991
B-A*INTERVAL*REST DURATION	21477	2,58	10738	2.3735	0.102144
WORKLOAD*B-A*INTERVAL	6306	2,58	3153	0.8270	0.442472
3*4*5*1	11005	2,58	5503	1.4431	0.244550
3*4*5*2	2387	2,58	1193	0.3130	0.732478

There were no statistically significant effects elicited by either rest break conditions, *rest task* or *rest duration*, nor where there any significant effects owing to the varying workload conditions. There was however a significant interactive effect (p<0.05) between *before and after* and *the interval* (Figure 24). Interval 1 after the rest break, which is denoted by the red square in Figure 24, represents the 5-minute interval following the rest break. The large error bar is indicative of the difference in responses of participants following the rest break, however the was no statistically significant effect in the before and after condition.

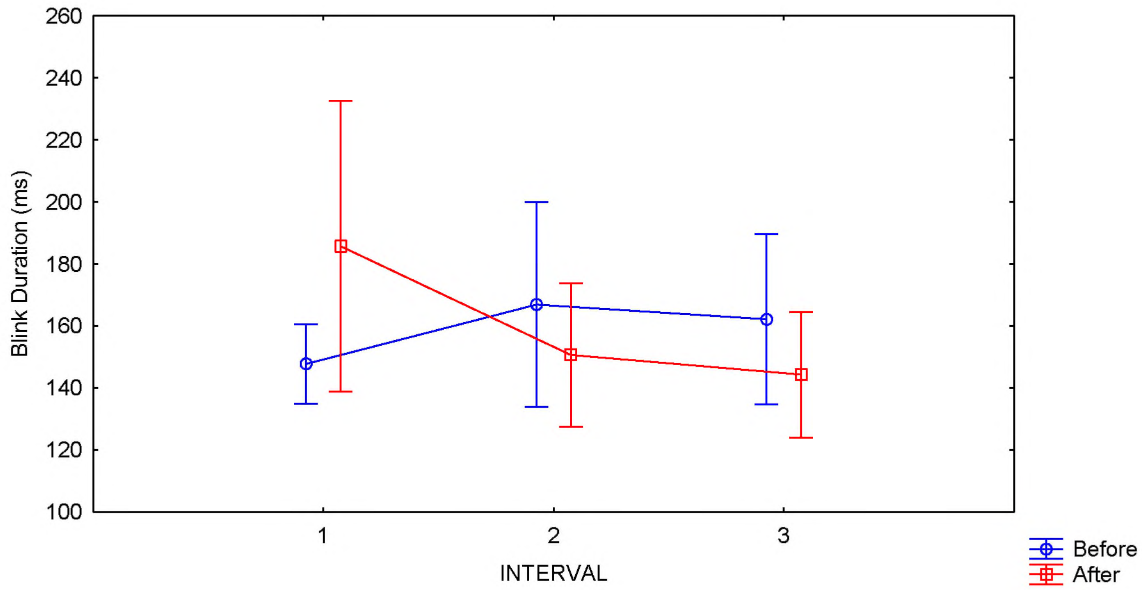

Figure 24: Changes in Blink Duration (ms) before and after the rest breaks, with 15-minutes (5-minute intervals) before and after the rest break (*=significant effect, $p<0.05$; Error bars denote 95% confidence interval).

4.3.4 Subjective responses

Karolinska Sleepiness Scale

There was no statistical significant effect found for the Karolinska Sleepiness Scale in both the Low and High workload conditions. Both the rest task and rest duration were non-significant, suggesting that there was no recovery effect of the rest break.

4.4 PERFORMANCE PARAMETERS FOR IMMEDIATELY BEFORE AND AFTER REST BREAK

The following section details the responses of the 5-minute interval directly before and after the rest break, for each parameter. It places focus on minute interval 25-30 and minute interval 32-37/60-65.

4.4.1 Performance responses

Tracking performance (primary task)

There were no statistically significant responses in tracking task performance. This suggests that the workload did not elicit any effects on tracking performance within the first five minutes before or after the break. This also means that neither the *rest task* nor the *rest duration* had an impact on their return to task performance.

4.4.2 Cardiovascular responses

4.4.2.1 Heart Rate Frequency

Table 15: Analysis of variance for heart rate frequency established during the Low and High workload condition, between the 5-minute intervals directly before and after the rest break, with the rest task and rest duration as factors. (*=significant effect, p<0.05).

Heart Rate Frequency	SS	Degr. of Freedom	MS	F	p
REST TASK	518.7	1,29	518.7	3.125	0.087619
REST DURATION	100.6	1,29	100.6	0.606	0.442457
WORKLOAD	54.9	1,29	54.9	0.718	0.403657
WORKLOAD*REST TASK	31.8	1,29	31.8	0.416	0.524046
WORKLOAD*REST DURATION	10.2	1,29	10.2	0.133	0.717671
INTERVAL	407.2	1,29	407.2	42.891	<0.001*
INTERVAL*REST TASK	20.4	1,29	20.4	2.149	0.153442
INTERVAL*REST DURATION	42.6	1,29	42.6	4.484	0.042901*
WORKLOAD*INTERVAL	13.8	1,29	13.8	1.862	0.182937
WORKLOAD*INTERVAL*REST TASK	0.8	1,29	0.8	0.103	0.751001
WORKLOAD*INTERVAL*REST DURATION	1.8	1,29	1.8	0.242	0.626740

There was a significant interval effect, suggesting that time on task had an effect on the participants' responses overtime. There was also an interactive effect between interval (time on task) and rest duration (Figure 25), where in the shorter rest duration groups, Heart Rate Frequency was higher than in the longer duration groups (as in the above before and after response). Both conditions showed decreased levels after the break, indicative of a recovery effect by the rest break.

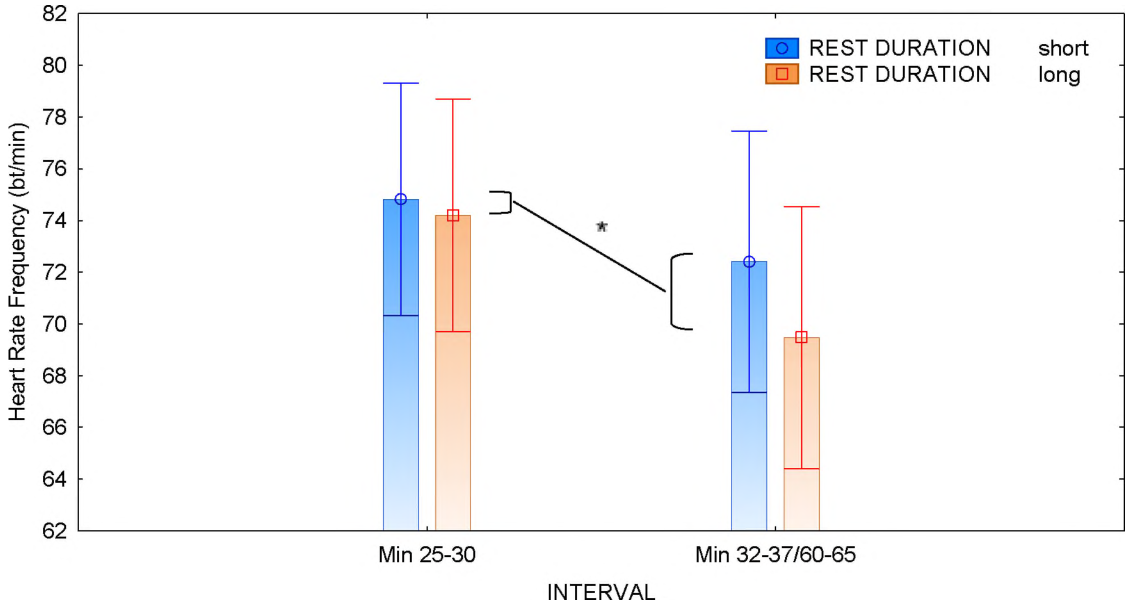

Figure 25: Changes in Heart Rate Frequency (bt/min) between the 5-minute intervals directly before and after the rest break, showing the effect of rest duration. (*=significant effect, p<0.05; Error bars denote 95% confidence interval).

4.4.2.2 Heart Rate Variability: Time-Domain Analyses

Table 16: Analysis of variance for HRV (rMSSD) established during the Low and High workload condition, between the 5-minute intervals directly before and after the rest break, with the rest task and rest duration as factors. (*=significant effect, p<0.05).

HRV (rMSSD)	SS	Degr. of Freedom	MS	F	p
REST TASK	5546.4	1,29	5546.4	4.4889	0.042803*
REST DURATION	2905.7	1,29	2905.7	2.3517	0.135987
WORKLOAD	4011.6	1,29	4011.6	8.0023	0.008389*
WORKLOAD*REST TASK	206.3	1,29	206.3	0.4115	0.526237
WORKLOAD*REST DURATION	509.4	1,29	509.4	1.0161	0.321791
INTERVAL	1559.6	1,29	1559.6	16.8556	0.000300*
INTERVAL*REST TASK	8.5	1,29	8.5	0.0915	0.764434
INTERVAL*REST DURATION	1165.5	1,29	1165.5	12.5960	0.001340*
WORKLOAD*INTERVAL	22.6	1,29	22.6	0.2073	0.652262
WORKLOAD*INTERVAL*REST TASK	62.6	1,29	62.6	0.5749	0.454444
WORKLOAD*INTERVAL*REST DURATION	99.8	1,29	99.8	0.9160	0.346440

There was a statistically significant effect (p<0.05) for *rest task*, *workload* and *interval* (time on task). Both *rest task and workload* followed a similar trend as reported above in the before and after response parameters, where HRV was high in the *PAUSE* condition than in the *ADMIN* condition as well as being higher in the Low workload than in the High workload. For the 5-minute interval directly before and after the rest break, HRV increases significantly after the break, also shown by the interactive effect between *interval* and *rest duration* (Table 16; Figure 26).

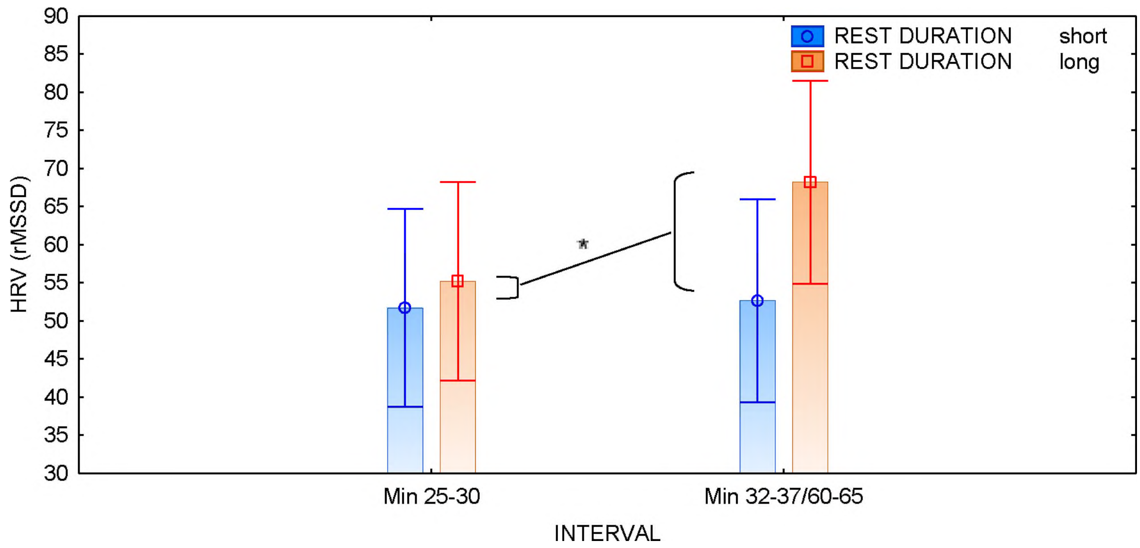

Figure 26: Changes in HRV (rMSSD) between the 5-minute intervals directly before and after the rest break, showing the effect of rest duration. (*=significant effect, p<0.05; Error bars denote 95% confidence interval).

4.4.2.3 Heart Rate Variability: Frequency-Domain Analyses

Table 17: Analysis of variance for LF power (LF + HF ratio) established during the Low and High workload condition, between the 5-minute intervals directly before and after the rest break, with the rest task and rest duration as factors. (*=significant effect, p<0.05).

LF power (LF + HF ratio)	SS	Degr. of Freedom	MS	F	p
REST TASK	874.9	1,29	874.9	1.957	0.172426
REST DURATION	305.0	1,29	305.0	0.682	0.415508
WORKLOAD	179.7	1,29	179.7	0.638	0.431064
WORKLOAD*REST TASK	172.3	1,29	172.3	0.611	0.440625
WORKLOAD*REST DURATION	163.9	1,29	163.9	0.581	0.451920
INTERVAL	566.5	1,29	566.5	4.570	0.041090*
INTERVAL*REST TASK	616.0	1,29	616.0	4.970	0.033705*
INTERVAL*REST DURATION	9.6	1,29	9.6	0.077	0.783088
WORKLOAD*INTERVAL	158.1	1,29	158.1	0.843	0.366077
WORKLOAD*INTERVAL*REST TASK	7.1	1,29	7.1	0.038	0.847310
WORKLOAD*INTERVAL*REST DURATION	28.1	1,29	28.1	0.150	0.701288

There was a significant effect of time on task (*interval*) as well as an interactive effect between *interval* and *rest task*, between the 5-minute intervals directly before and after the rest break. There was an increase in LF power relative to (LF + HF) after the recovery break. In the *ADMIN* condition, it can be noticed that there was not much change in LF power relative to (LF + HF), as there was in the *PAUSE* condition.

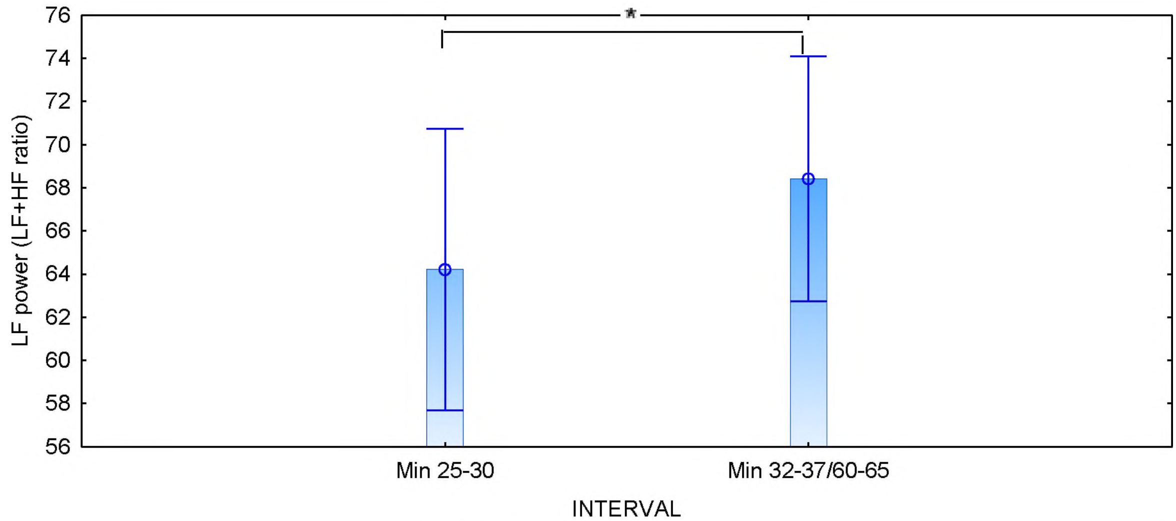

Figure 27: Changes in LF power (LF + HF ratio) between the 5-minute intervals directly before and after the rest break. (*=significant effect, p<0.05; Error bars denote 95% confidence interval).

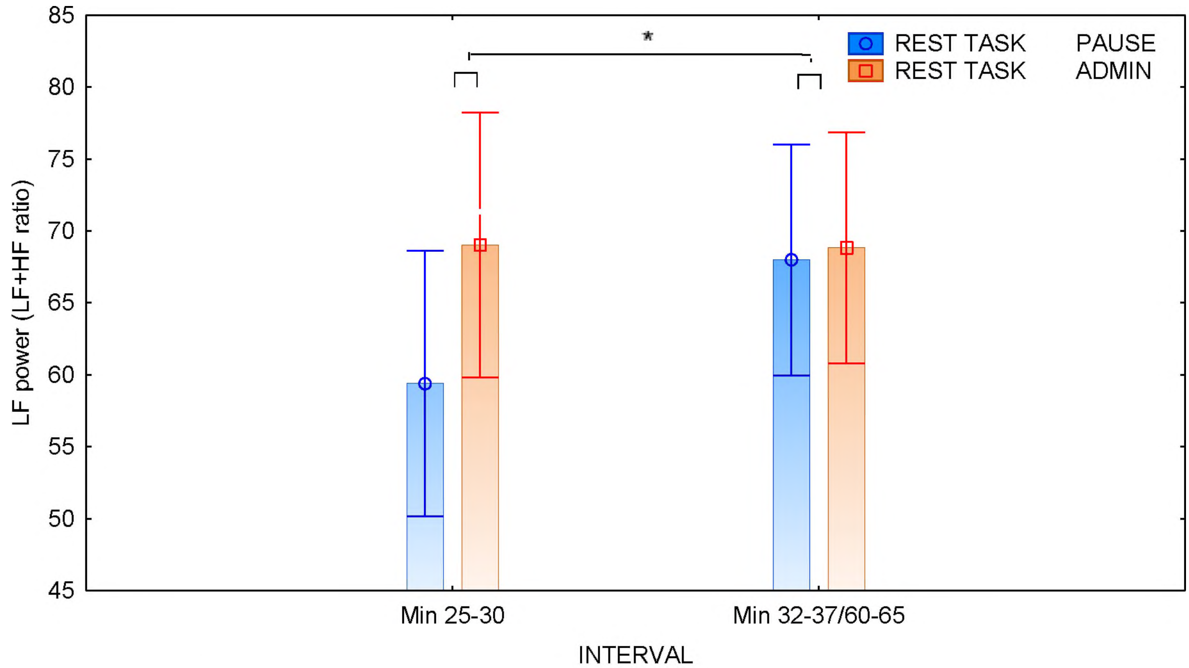

Figure 28: Changes in LF power (LF + HF ratio) between the 5-minute intervals directly before and after the rest break, showing the effect of rest task. (*=significant effect, p<0.05; Error bars denote 95% confidence interval).

4.4.3 Oculomotor responses

4.4.3.1 Blink Frequency

Table 18: Analysis of variance for Blink Frequency (bl/min) established during the Low and High workload condition, between the 5-minute intervals directly before and after the rest break, with the rest task and rest duration as factors. (*=significant effect, p<0.05).

Blink Frequency	SS	Degr. of Freedom	MS	F	p
REST TASK	2.21	1,29	2.21	0.0619	0.805216
REST DURATION	49.30	1,29	49.30	1.3816	0.249397
WORKLOAD	137.82	1,29	137.82	4.4960	0.042651*
WORKLOAD*REST TASK	10.71	1,29	10.71	0.3493	0.559101
WORKLOAD*REST DURATION	2.66	1,29	2.66	0.0867	0.770564
INTERVAL	3.21	1,29	3.21	0.1688	0.684181
INTERVAL*REST TASK	2.05	1,29	2.05	0.1077	0.745166
INTERVAL*REST DURATION	34.74	1,29	34.74	1.8287	0.186733
WORKLOAD*INTERVAL	56.58	1,29	56.58	6.3053	0.017864*
WORKLOAD*INTERVAL*REST TASK	16.95	1,29	16.95	1.8890	0.179839
WORKLOAD*INTERVAL*REST DURATION	10.97	1,29	10.97	1.2230	0.277854

There was a statistically significant *workload effect* as well as an interactive effect between *interval* (time on task) and *workload*. For Low workload, Blink Frequency was lower than in the High workload, indicative of fatiguing effects with the additional cognitive secondary tasks in the High workload condition, however, the Low workload had a large variance between participants. Additionally, it is noticeable in the High workload, there is a decrease in blink frequency, suggesting that there was a recovery effect of the rest break. In the Low workload however, an increase can be seen, indicating the presence of fatigue overtime. The workload response pattern mirrored that of time on task (*interval*) responses.

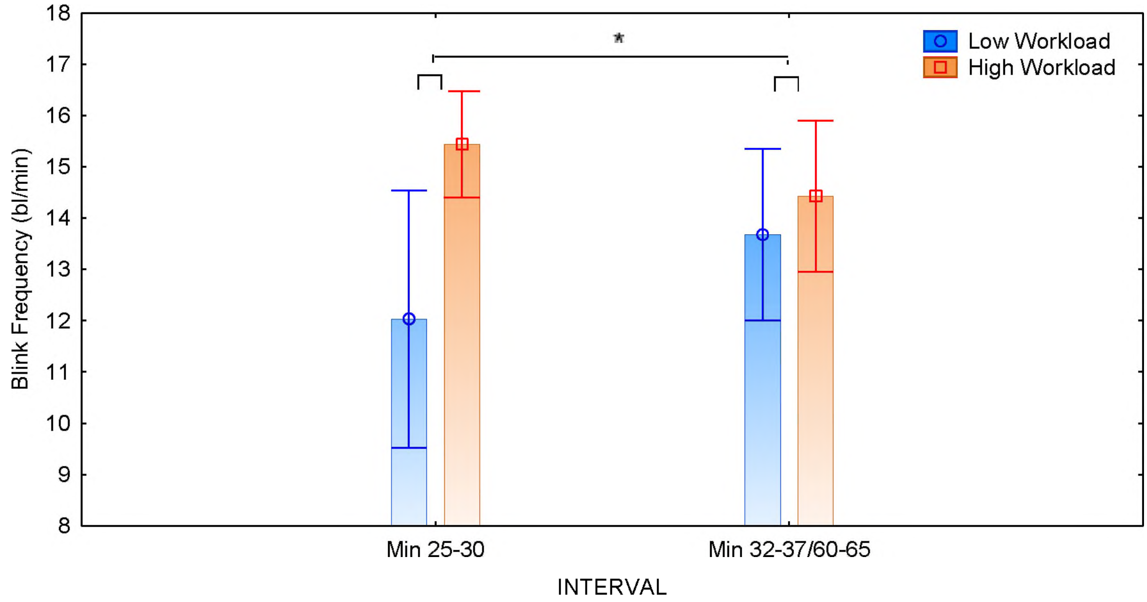

Figure 29: Changes in Blink Frequency (bl/min) between the 5-minute intervals directly before and after the rest break, showing the effect of workload. (*=significant effect, p<0.05; Error bars denote 95% confidence interval).

4.4.3.2 Blink Duration

There was no statistical significant effect for Blink duration observed during the 5-minute intervals directly before and after the rest break.

4.5 SUMMARY OF RESULTS

Performance measures

Tracking task performance, for all variables, showed no significant effect. This is indicative of the absence of a learning effect during the tracking task protocol of 52-minutes and 80-minutes, respectively. With regards to the secondary cognitive tasks, the Running memory task showed no significance in all of the variables. The Rule-based decision making task however did elicit significant differences which were brought about by the rest duration, suggesting that the longer one is out of the control loop, the more their cognitive performance is compromised.

Cardiovascular measures

Cardiovascular responses revealed a decreased state of arousal overtime, displaying a significant before and after effect, following the rest break. The overall change in responses indicate that participants were more aroused and alert in the shorter, administrative tasks which entailed a higher level of workload.

Oculomotor measures

The overall changes in oculomotor responses suggest a recovery effect caused by the rest break, however the parameters were not sensitive to the differences in behavioural responses between the groups.

Subjective measures

The Karolinska Sleepiness Scale was, with regards to this study, not found to be significant or be sensitive to the responses of the participants.

4.6 RESPONSE TO HYPOTHESES

Hypothesis 1:

<u>The null hypothesis (H_0) proposes</u> that there will be no differences in the responses to all variables during the Activity phase tasks (Low workload and High workload)

<u>Response</u>: Significant differences were established between the two workload conditions performed during the Activity phase for heart rate, heart rate variability

(time-domain and frequency-domain) and blink frequency, therefore the null hypothesis was rejected for these measures. Alternately, the study fails to reject the null hypothesis with regards to tracking-related performance, blink duration and subjective KSS responses.

Hypothesis 2:

The null hypothesis (H_0) proposes that there will be no difference in responses elicited by the Rest task and/or Rest duration

Response: There were significant differences established in the secondary cognitive task (rule-based decision making task), heart rate and heart rate variability (time-domain and frequency domain) which were elicited by either Rest task and/or Rest duration, therefore for these measures, the null hypothesis was rejected. Alternately, the study fails to reject the null hypothesis with regards to tracking (and running memory task) performance, blink frequency, blink duration and subjective KSS responses.

Hypothesis 3:

The null hypothesis (H_0) proposes that there will be no difference in responses, elicited by the overall and/or immediate before and after condition following the Rest (interval) break

Response: Significant differences were established for heart rate, heart rate variability, blink frequency and blink duration, therefore the null hypothesis was rejected for these variables. Alternately, the study fails to reject the null hypothesis for tracking-related performance and subjective KSS responses.

CHAPTER V

DISCUSSION

The present study was designed to investigate the effects of rest breaks on the return-to-task performance of human operators back in the control loop, in a semi-automated setting. These rest breaks entailed two types of rest tasks and rest durations, assessing the impact of the type of rest break prescribed on return to task performance, by comparing performance before and after the rest break as well as performance in two varying workloads (Low and High). The effect of recovery was quantified using changes in performance, physiological as well subjective sleepiness levels experienced during the tracking task.

Initially it was predicted that the two levels of workload, being Low and High, would stimulate differing responses in terms of performance (cognitive and motor), subjective and physiological measures during all tasks. Furthermore, it was predicted that the short duration recovery interval would produce differing responses from the long duration recovery interval in all testing groups. Lastly, it was anticipated that the two recovery activities (PAUSE and ADMIN) would elicit different responses to assist in the rapid transition to return to task.

The outcome of the results to be discussed in this section therefore represent further support for the general case in return-to-task performance of human operators in terms of human responses. There are, however, limitations to interpretations placed on the present results. Firstly, the sample of participants of the study were not habitual human-automation operators and had no vast experience in simulator operations. In general, pilots with extensive experience of differing automation configurations are difficult to solicit for voluntary participation, as suggested by Hancock *et al*. (2013) and the present pattern of responses must be considered with this level of automation familiarity in mind. Since ‘automation surprises’ and the high pressure of the real-world could not be replicable in a laboratory setting, the influence of adrenalin-like responses experienced upon rapid return to control and detrimental influence of certain vigilance-related effects may not have been seen in this study because of the target frequency employed.

5.1 PERFORMANCE MEASURES

When performing a pure tracking task, attention must be maintained for an extended period of time against the cost of effort. If motivation to invest effort is low, performance may deteriorate. In terms of tracking performance in this study, effective response time to tracking was recorded and thus analysed to quantify tracking performance, before and after the prescribed rest break. Effective response time showed no statistical significance, in comparing both Low and High workload conditions. When looking solely at the Low workload condition, there was a time on task effect ($p<0.05$, appendix B2), which can be expected, suggesting an impact of fatigue-related processes, however this was non-significant when comparing it to High workload.

As the High workload complexity required cognitive interruptions in the form of secondary cognitive tasks every 5-minutes for 3-minute durations in 10-minute blocks, the continual administration of these tasks introduced intermittent multitasking deficits in the participants' performance. With the need to perform the motor tracking task accurately, locate and analyse the visual stimuli in the Rule-based decision-making task and the auditory stimuli in the Running memory task, this resulted in a trade-off in general task performance, owing to a number of reasons, individual differences being one of them (Motowidlo, Borman & Schmit, 1997).

According to Wickens' (1998), return to task performance is greatly ordered by individual differences, the complexity of the tasks (as discussed above) as well as by the familiarity of procedures necessary to cope with a degraded system. As the participants of the current study were novice operators of a human-automation interactive setting and the fact that they did not necessarily have the experience of resuming control from an automated system, the latter idea from Wickens' (1998) serves difficult to prove in the study's setting, and will therefore not be discussed further.

The lack of significant findings between the workload levels could also be explained by highly fatigue-resistant factors which, according to Holding (1983), occur due to tasks that offer high levels of challenge and intrinsic interest. These factors are in line with the nature of the tasks carried out in the present study, where, although under-stimulating in the Low workload condition, the tracking task, being the primary task together with the secondary cognitive tasks still necessitate attention throughout the testing protocol.

The influence of the rest breaks in this study also showed insignificant results with regards to tracking performance, comparing to those of Lipser and Erikson (1980), looking at the reaction time in car driving of a similar sample group to the current study. Their findings were inconclusive in determining the most appropriate duration of rest breaks for better recovery. There was, however, upon returning to task, a huge spike in response time, in both workloads. This was indicative of poor return to task performance. As Lupianez (2010) has suggested, orienting attention in space takes time, thus returning into the control loop, after having been out-of-the-loop, steered to such poor performance. This is in agreement with Klein's (2000) claim of when the event of the rest break is not task-related and attention has had time to disengage from it (the breakdown in situational awareness and being out-of-the-loop from the primary task), an 'inhibitory after-effect' can be measured in postponed responses to stimuli, as in the example of *Inhibitory of return* (IOR) by Posner *et al.* (1985).

In terms of the cognitive rule-based decision-making secondary task, which entailed image identification by a probe picture, the results showed significant differences presenting an effect cause by rest duration. This significant rest duration effect on performance is in agreement with Lombardi *et al*. (2014), who looked at the effects of break durations in a Chinese working population. Their findings suggest that rest breaks of any duration have a significant effect on delaying performance decrements, which could possibly decrease the occurrence of incidences and/or accidents. The present study however found that the shorter rest duration had more favourable effects on performance than the longer rest duration.

The *short* rest duration experimental groups achieved a higher percentage of correct responses in the cognitive task, after the rest break, which is indicative of higher alertness achieved possibly owing to the short-lived period of being out-of-the-loop from the relevant task, as expected. This was, however, without a significant before and after effect, resulting in inconclusive findings in terms of before and after performance comparison. In contrast to the recovery effect in the current study, Henning *et al.* (1989) reported, from their laboratory study involving a self-paced data entry task, that the degree of recovery was proportionate to the length of the rest break taken, meaning with regards to the current study, the longer rest duration would have advantageous benefits over the shorter rest duration. This was in terms of motor and cognitive performance as well as heart rate. Whist this is the case in the findings by Henning *et al*. (1989), according to the above mentioned results of the current study in terms of cognitive performance, relatively shorter, and frequent, rest breaks are considered beneficial for performance, in accord with Tucker (2003).

Performance decrements presented in the *long* rest duration depicts effects of diminished attention possibly caused by a reduction in vigilance. According to a number of authors, vigilance has been expressed as a physiological state of activation and alertness and as a cognitive process pertaining to one's ability to maintain sustained attention when required to identify signals during a prolonged period of time (Davis & Parasuraman, 1982; Thiffualt *et al*., 2003). Dinges (1995) suggests vigilance decrement is the most robust effect of fatigue and sleepiness, thus reflecting a decreased capability to perform as demonstrated in the long duration condition. A number of endogenous factors, such as circadian variations and time on task, have been associated with variations of alertness (Thiffault *et al*., 2003). However, according to the authors, vigilance research has also explored the impact of exogenous or task-induced factors that may cause variations in arousal. The current study unfortunately did not find any significant effects caused by the rest break task performed during the rest break as an exogenous factor. The time on task, or rather time out-of-the-loop however showed significant effects. The second cognitive task being the running memory task was, however, not significant.

These types of cognitive tasks require the engagement of the short-term memory, which is stored in the brain's prefrontal cortex. Several researchers have suggested the frontal cortex to be the site, or at least an important part of an executive system (Kusak, 2000; Klein, 2000). In their study, looking at a running memory task based on recognition, Smith and Jonides (1997) discussed the outcome of a series of experiments, which showed that apart from a separation of neural structures of storage and rehearsal processes, a neural basis for executive processes can be found in regions of the dorsolateral prefrontal cortex, an area where if negatively affected could lead to short-term deficits and negatively impact the functioning of the prefrontal cortex which is involved the inhibition of the activation of the sympathetic nervous system (SNS).

5.2 CARDIOVASCULAR RESPONSES

5.2.1 *Time on task*

In this study, heart rate decreased significantly overtime by nearly 5 beats/min^{-1} (Figure 9). This was indicative of a fatigued state, which subsequently suggests a state of low arousal/activation levels of the participants. In the current study, heart rate was used to make inferences to activity levels or effort investment by the participants. According to Reimersma and colleagues (1977), investigating an eight-hour night drive, they too found a decrease in heart rate overtime. However, their argument was against the notion of relating heart rate and fatigue, suggesting that a steady decline heart rate is usually in response to participants adapting to the experimental situation and should not be seen as an indication of fatigue. The main point of their argument was that if a decline in heart rate were due to a build-up in fatigue, then it would be expected later rather than earlier. The decline in heart rate, however, is also synonymous with the activation of the parasympathetic nervous system (PNS) represented by HRV, which is dominant during periods of down regulation of the body.

Heart rate variability is a sensitive psychophysiological indicator of mental effort (Lal and Craig, 2001), in that the analysis of changes within it can provide insights into the functional state of the body's autonomic systems (Pagani *et al.*, 1997). The activation of parasympathetic nervous system indicated by an increase in HRV in the current study, suggests that the rest break prompted a recovery effect, of which there was a significant effect of both rest break task and rest break duration on HRV. This is reflective of a decrease effort and increased levels of fatigue, in agreement with Oran-Gilad and Ronen, (2007). Various authors, such as Harris *et al.* (1972) tend to interpret an increase in HRV as a sign of a decline in the level of cerebral activation, which is associated with a diminished alertness, which was expected as there was a breakdown in the interaction with the system (situational awareness) and participants were out of the control loop (some participants longer than others, respective of their experimental groups).

As expected in terms of the type of rest break task, HRV was higher in the *PAUSE* condition, where participants had to close their eyes and rest (and could sleep if they chose to do so) and lower in the *ADMIN* condition, where they were given a reading task and requested to supervise the 'automated system' intermittently. The results of the lower HRV in the *ADMIN* rest break task suggested that participants were more alert in this condition than in the *PAUSE* condition. According to Caldwell *et al.*, (2009) and several studies, even if there is no associated increase in physical activity (such as standing up or any postural change), an improvement in alertness and performance is associated with a cognitive break from continuous tasks. In contrast, the result of the *PAUSE* condition was indicative of the residual effects of the type of rest break task performed, which created a complete breakdown in situational awareness from monitoring the relevant task. The findings by Smith *et al.* (2012), in their study investigating the effects of rest breaks in driver fatigue, conflicted those of the present study. In looking at active rest breaks against passive (napping) rest breaks, they found a greater benefit for passive (napping) rest breaks over active rest breaks, however this was looking into the effects on physiological sleepiness.

In terms of rest break duration, HRV was lower in the *short* rest break condition than in the *long* rest break condition, showing that the *short* duration elicited favourable responses with regards to alertness/arousal achieved, in agreement with Tucker (2003) proposing short breaks as being beneficial for performance and fatigue. This result is coupled with that of the cognitive task represented earlier which favours the *short* duration over the long duration in terms of alertness.

Workload conditions also stimulated differing responses with regards to HRV, where the High workload condition presented a lower HRV than the Low workload condition. This also showed an interactive effect with time on task, suggesting that the different workloads posed differing responses from start to finish, however following a similar trend before the rest break. A lower HRV was achieved in the High workload, indicating a more alert state being achieved during this condition than in the Low workload. According to Roscoe (1992), it has been shown that HRV is suppressed when a person is subjected to an increased mental load, thus the activation of the sympathetic nervous system in the case of the High workload condition, maintaining the state of alertness/arousal. Although High workload achieved favourable responses, there was a vast dispersion of responses indicated by the large standard deviation in responses (Figure 12). This could be owing to individual differences, causing differing effects being experienced by the participants.

Even though High workload achieved a lower HRV, the pattern in responses following the rest break show an increase in HRV, which could be detrimental to performance and alertness after an extended period of time, whereas in the Low workload conditions, the opposite was the case. The increase in parasympathetic nervous system activation (HRV) following the rest break suggests negative effects of fatigue setting in; where possibly the optimal level of arousal in the High workload condition has been depleted and performance may possibly deteriorate thereafter. In contrast, the decrease in HRV of the Low workload condition, following the rest break, indicates a recovery effect of the rest break, which could be beneficial for performance in the end. Overall, time on task had a significant effect on HRV, where a slight increase is observable, signifying an effect of fatigue.

Although there was a time on task effect on LF power (LF+HF), where a relatively steady state was observed throughout the protocol prior to the rest break, and a slight decrease following the rest break; the frequency-domain results did not agree with the time-domain (rMSSD) responses. These results compare to those of Luft *et al.* (2009), where they too observed that although their time and frequency-domain measures were highly correlated, they did not reflect exactly the same physiological substrate. The results of the current study however show that in the 30-minutes prior to the rest break, there was an interchange between the sympathetic and the parasympathetic branches of the autonomic nervous system (ANS). This could be explained by the influences of the discontinuous arousal peaks owing to the introduction of the cognitive workload bouts in the High workload condition, although workload effects were insignificant in this case.

Following the rest break however, there was a noticeable decline in LF power (LF+HF), implying a weakening in the sympathetic and strengthening of the parasympathetic branches of the autonomic nervous system. This is commonly associated with an increased level of fatigue and the down regulation of the circadian system (Ndaki, 2012). There was also an interactive effect between time on task (*interval*) and rest task. This was an unexpected result, especially in terms of the pattern response. In the first 30-minutes prior to the break, it was expected that rest break effects, either caused by the rest task or duration, would not have an effect, however the opposite was observed. Although the responses followed a similar trend over the first 30-minutes, achieving the fluctuations as mentioned above, the *ADMIN* rest task achieved a higher LF power (LF+HF) than the *PAUSE* condition. This could be explained by an effect caused by pacing strategies (Frewen *et al.*, 2013), as participants were aware of the type of rest break they were prescribed prior commencing the experimental protocol. Performance after the rest break, however, declined in the first 5-minute interval following the rest break of the *ADMIN* condition, but there was an indication of a slight increase thereafter, whereas the *PAUSE* condition showed a continuous decline, suggesting a decline in arousal.

5.2.2 *Effects before and after Rest Break*

The current study found that heart rate showed a *before and after* effect, where heart rate was higher prior to the rest break. This suggests that the rest break had a relaxing effect on the physiological response further implying a decrease in alertness/arousal after the rest break. This was coupled with responses from the last 5-minute interval directly before the break compared against the first 5-minute interval directly after the rest break (Figure 25). Heart rate also showed an interactive effect between workload, before and after as well as the 15-minute intervals taken before and after the rest break. Mirroring the results of time on task, the High workload condition achieved a higher heart rate than the Low workload condition, however, a similar response pattern was followed before the rest break. More so, after the rest break, High workload showed a slight but noticeable incline in response whereas the Low workload condition showed a decline in response. This suggests an increase in fatiguing and lower arousal levels in the Low workload condition. In looking at the 5-minute intervals directly before and after the rest break, an interactive effect was observed between the intervals and rest duration, where the short duration achieved a higher heart rate than the long duration. This again, is indicative of heightened arousal levels associated with the shorter rest duration.

HRV responses for before and after state emulated those of time on task responses with effects of rest task and workload achieving similar results (a lower HRV for the *ADMIN* and High workload conditions and consequently a higher HRV for the *PAUSE* and Low workload condition, respectively). In terms of the before and after effect, HRV was significantly higher after the rest break, suggesting decreased levels of alertness/arousal and again, a relaxing effect caused by the rest break. Here, it can be seen that the return-to-task performance is supposedly negatively affected by being out-of-the-loop (regardless of the duration as rest duration did not have an effect in this regard), suggesting poor alertness upon returning to task, with HRV being high. According to Klein (2000) who reports on the inhibition of return in performance and earlier stated that when attention has been disengaged from the task, being out-of-the-loop, there is a delay in response to stimuli, which further hinder the speedy transition in return to task, but could be beneficial for the accuracy aspect of responding appropriately to the task, as the increase in parasympathetic nervous system will allow for appropriate decision making. This could possibly be evidence of the speed and accuracy trade-off upon return-to-task. Moreover, Thayer *et al.* (2009) found that in performing executive-function tasks (tasks which involve the activation of the prefrontal cortex of the brain), a high HRV showed better performance on reaction time and accuracy parameters, somewhat conflicting with the results of the current study, however, the study was looking at participants with low and high resting HRV.

For the 5-minute intervals directly before and after the rest break (Figure 26), responses for HRV (for both time and frequency-domain) were parallel to those reported above in the before and after rest break condition. Rest task as well as Workload too mirrored the effects of the time on task condition. In this case, rest duration also showed a significant effect, where HRV in the long duration increased after the break as opposed to before the break, whereas in the short duration, HRV responses remained relatively steady. Although rest duration did not have an overall impact on the before and after state response, the 5-minute intervals immediately prior to and post the break suggest otherwise. The increase in HRV suggests that the long rest duration brought about a fall in the level of cerebral activation, which is yet again associated with diminished levels of alertness (Harrist *et al.*, 1972). Although HR showed a decrease in both rest duration of the same condition, HRV presented a steady state in the short rest duration condition suggests that return to task performance remained unchanged following the rest break. LF power (LF+HF) showed comparable responses to the abovementioned, however in this case, with rest break task, where in the 5-minute intervals prior to and post the rest break, HRV increased after the rest break in the *PAUSE* condition (implying similar argumentation as above) and remained unchanged in the *ADMIN* condition.

5.3 OCULOMOTOR RESPONSES

5.3.1 *Time on task*

An increase in blink frequency is revealing of light fatigue and a changeover from awake to reduced vigilance and increased drowsiness, whereas the increase in blink duration is commonly seen in the transition to sever sleepiness (Lal and Craig, 2001). As expected, time on task and workload had an effect on blink frequency, where the High workload condition revealed a higher blink frequency than the Low workload condition. According to Ponder and Kennedy (1927) and further suggested by a number of authors that followed, their early conclusions around theories on blink frequency advocate that blink frequency is closely related to 'mental tension' of the participant at the time. Such a response implies effects of the mental workload imposed in this condition.

In their study, Fogarty and Stern (1989) have documented and thus propose another possible explanation for the increase in blink frequency, the likelihood of blinks being in association with saccade. These authors requested participants to determine if a peripheral presented letter was different from one presented centrally and found that blinks were most likely to occur as gaze shifted from the peripheral back to the central display, this being in anticipation for the next trial of stimulus presentation. Similarly, participants in the current study had to adjust their eye movements accordingly to locate the images from the image identification task which was located on a different, yet, adjacent screen. Stern *et al*. (1994) contend this notion by stating that such blinks are not obligatory, but rather likely to occur when information acquisition and processing demands are minimal, which opposes what the study found.

Stern *et al*. (1994), further stipulate that blinks are inhibited as gaze shifts to the peripheral location and that this is done as an active process that is said to be impacted by fatigue processes. Thus, the presence of higher blink frequency typically associated with impaired performance may be a function of the reduction of such inhibitory processes. Veltman *et al*. (1996) propose that eye blinks are sensitive to visual load rather than cognitive load, where in their study looking at flight simulator operators, when operators had to process a lot of visual information, they tended to blink less frequently and for shorter durations, otherwise information may be missed. A number of authors, according to Stern *et al*. (1994) have demonstrated a reduction in blinking associated with visual and, to a lesser extent, auditory task performance. On the contrary, the results of the current study suggest otherwise, where in the High workload condition, which incorporated a secondary visual and auditory task, blink frequency was in fact higher than in the Low workload condition. The results of this study are supported by those of Stern *et al*. (1994) and Frolov (1990), where they observed an increase in blink flurries during sustained attention tasks, which may also serve as some form of self-alerting mechanism. Blink flurries are said to be after effects that are the result of relatively long periods of inhibition, in accord with Capenter (1948) who also reported bursts of blinks appearing after periods of blink inhibition.

The fluctuations in blink frequency prior the rest break suggest this very theory, where the secondary cognitive tasks were administered every 5-minutes in 3-minute bouts of 10-minute blocks (the intervals which achieved a peak in blink frequency, Figure 16). The decrease in blink frequency after the rest break suggests a relaxation effect caused by the rest break.

Blink duration had a time on task effect, where it increased over the 30-minutes prior to the rest break. An increase in blink duration during sustained attention tasks is typically correlated with decreased performance (Oken *et al.*, 2006), as seen being supported by other physiological responses. Although insignificant, there is a noticeable decrease in blink duration post rest break, suggesting a relaxation effect on the rest break.

5.3.2 *Effects before and after Rest Break*

Blink frequency showed an effect of workload overtime, which followed a similar response pattern to that of the workload effect on time on task. There were no explicit effects on the general before and after condition; however, there was an interactive effect between workload and the 5-minute intervals immediately before and after the rest break. Although blink frequency was high in the High workload condition than in the Low workload condition, the before and after effects within the 5-minute intervals show a decrease in blink frequency after the rest break in the High workload condition and an increase after the rest break in the Low workload condition (Figure 29). The response in the High workload condition suggest a decrease in blink flurries, however, the pattern of responses from before and after the break suggest the notion being advocated for by Stern *et al.* (1994), that a reduction in blinking could be linked to the visual and auditory task performance. The increase in blink frequency after the rest break in the Low workload condition thus indicates the onset of fatigue.

In terms of blink duration, no significant effects were observed in the 5-minute intervals immediately before and after the rest break. The same was found for the subjective responses concerning the Karolinska Sleepiness Scale, suggesting that the protocol did not elicit strong enough responses to determine the effectiveness of subjective responses.

It has been well established, through a body of research, that rest breaks help maintain performance and further, avoid the accumulation of fatigue over the period of work (Tucker, 2003, Blanche *et al.*, 2017). According to Blanche *et al.* (2017), performance is better maintained by frequent, short rest breaks as opposed to longer breaks or no breaks at all, this being in accord with the findings of the current study.

These types of rest breaks are commonly used to enhance employees' and operator work experiences, particularly in cases of monotonous monitoring regimes. Skilled individuals generally learn when they can withdraw their attention from a given task and for how long without compromising their concentration (Tucker, 2003). Given the sample of the current study, the novice operator cannot rely on such heuristics and thus has to remain in-the-loop at all times if possible. This could also be the reason for the active administrative rest breaks gaining favour over the passive pause rest break. With the former type of rest break, the operator can follow the situation of the task as it unfolds, so to know and understand how the system acts and possibly predict its future status (maintaining situational awareness), in order to achieve the required transition back into control.

Taken together, these results indicate that passive tasks that are carried out for a prolonged period being out of the control loop are detrimental to return-to-task performance and alertness, especially in low levels of arousal. Unfortunately, no deliberation could be inferred from tracking performance as no statistical significance was found with all the variables in question. In terms of the secondary cognitive tasks, the rule-based decision-making task displayed a significance in the percentage of correct responses from participants, linked with an effect of the rest break duration. This was supported by cardiovascular responses, where they too portrayed the short rest duration as being more favourable than the longer rest duration, suggesting that the shortness of being out-of-the-loop allowed the participants to maintain a degree of alertness and awareness. These responses also suggested that the active rest task (which entailed administrative reading and intermittent supervision) was advantageous in terms of achieving alertness over the passive rest task (which allowed participants to either just close their eyes to rest of take naps for a period of 2-30 minutes, depending on the condition of the experimentation group). Oculomotor responses largely showed workload effects, where the high workload elicited more favourable responses, similar to those responses of cardiovascular measures. Subjective responses from the KSS questionnaire suggest that the scale was not sensitive enough to the type of tasks being carried out in this study, thus showing no significance.

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

The research study sought to investigate the effects of rest breaks (with regards to task and duration) on return-to-task performance in semi-automated tasks of varying complexities. This chapter brings together the work presented in previous chapters. It highlights the results of this research in light of the original aims of this thesis and discusses issues that have arisen. It further suggests directions for the application and future work around the topic

6.1 SUMMARY

In Chapter 1, the issue of human-automation interaction, particularly in cockpits, was introduced. The costs that have accompanied the interaction into glass cockpits has been due to a number of issues such as overreliance on automated systems and degradation in operator awareness and performance owing to being out-of-the-loop. These issues have an influence on the return-to-task performance of the operators back into control should manual intervention be required, in the case of automation surprises. Chapter 2 further elaborates on the factors of influence on return-to-task performance, shedding light on the different levels of automation available to the operator, human performance capabilities and limitations as well as by looking at examples of incidences and accidents that have been attributed to such an interaction in flight control. The methodology section in the third chapter outlines the experimental concept adopted by the research study in attempt to investigate the basic human information responses to automation control breakdowns and return-to-task performance. Various behavioural, psychophysiological and subjective assessments were used to assess human alertness/arousal upon returning to the task following a rest break, entailing two different types of tasks and durations. These were collected, analysed and presented in chapter 4 and further discussed in chapter 5. The equipment that was used in this study included a low-fidelity tracking simulator, a Polar^{TM} T34 heart rate belt and receiver, from which were captured on the Biometrics DataLOG MWX8 and the eye-tracking device used was the Dikablis Gaze Analytic System. All psychophysiological data were synchronized and analysed using the Data Reduction and Analysis Tool.

6.2 CONCLUSIONS

The commonly accepted 72% of accidents attributed to 'human error' urged engineers to introduce automation technology to improve pilot handling and judgement inadequacies (Barker, 2016). This introduction of automation in aviation has thus gained considerable appreciation as it has increased the safety aspect of commercial flying aircrafts by reducing human error. Along with the benefits however, it also reduces pilot control which could induce pilot complacency, further leading to decreased alertness, arousal and situational awareness. The consequence of this is that in certain situations, pilots are expected to loop back into control of the aircraft. This requires rapid and efficient transitioning back into control by the operators. In examining failures associated with such a transition, it becomes apparent that monitoring, task partitioning between the two agents (the human and the automated system) as well as maintaining alertness in order to respond promptly and efficiently to failures is far from perfect (Sumwalt, Thomas and Dismukes, 2002; Hancock *et al*., 2013).

The aims of the current research were to investigate the effects of rest break tasks and durations on the return-to-task performance of operators in the face of 'automation surprises', looking at different workload levels of arousal. With regards to the most appropriate rest break tasks, the study concluded that active, administrative tasks, which allowed the operator to maintain some form of situational awareness by monitoring the automated system, achieved favourable effects of being more alert than the passive rest break of being disengaged from the system. In terms of the most appropriate rest break durations, the shorter duration of being out-of-the-loop from controlling the system proved to be more advantageous than the longer out-of-the-loop duration. In looking at the workload levels of arousal, the results suggest that the higher workload level is better at maintaining the alertness of operators.

Wickens' (1998) puts it forward that in order to successfully predict recovery under a variety of conditions, human performance needs to be investigated in response to low-probability events, under different levels of 'skill degradation' and lowered situational awareness, however, in light of the results, replicating such scenarios can prove to be difficult. This study functions as a foundational framework for future investigations around the topic of human-automation interaction, looking specifically at return-to-task performance.

6.3 APPLICATIONS BEYOND AVIATION

Initially, it might seem as though the present study is very much constrained to aviation, however this is not the case. According to Hancock *et al.* (2013), there is an ample range of potential applications for principles of human interaction with automated systems that have the capacity to change in their sub-tasking profile. Human beings remain intimately involved in most automated systems, especially in their conception, design, fabrication and maintenance phases, leaning towards more human-partially-in-the-loop automated and semi-automated systems.

6.4 RECOMMENDATIONS

Further investigation into the effects of rest break (tasks and durations) on return-to-task performance by operators in semi-automated tasks, of varying complexities, should consider the following recommendations:

1. As the current study acts as a foundational study for return-to-task performance of operators in semi-automated tasks, experienced human operators (pilots) could be solicited for voluntary participation into a study of a similar nature to that of the current one.

2. It should be noted that the tracking task used in the current study was adopted from a low-fidelity driving simulator which included an under-stimulating, yet attention demanding scenario where the situation tends to favour hypovigilance due to the monotonous nature of the task. For future work, a flight simulator could be considered in order to place the context of the investigation into perspective.

3. Different designs of the rest break tasks (in order to achieve a complete replication of pilot tasks, for instance) could be considered, in order to achieve a much better representation of the actual task contents that pilots undertake during their time disengaged from manually controlling the aircraft system. Another design to be considered is the difference in workload levels (tasks),

looking at the two extremes of the arousal theory, paying close attention to the pressures that are synonymous to those in the cockpit.

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Appendix A: General Information

1. Letter to the participant
2. Informed consent
3. Ethical clearance

APPENDIX A1: LETTER OF INFORMATION TO THE PARTICIPANT

Dear participant

Thank you for agreeing to participate in this Master's research study. This study is titled: ***"The effects of the type of rest breaks on return-to-task performance in semi-automated tasks with varying complexities"***. This letter serves to inform you of the aim of the study, the protocol, the equipment as well as any benefits and/or risks that you may be exposed to. Also attached to this document is a consent form that you have to sign prior to commencing with the testing. Please ensure that you read everything carefully before signing. Should you be uncertain about anything or want further explanation, please do not hesitate to contact the researcher, who will attempt to timeously address any queries.

Purpose of study

The purpose of this study is to investigate the shift in control between the human and the automation in technologically driven industries, such as the aviation industry. These two agents commonly share control in operation of the system at different stages. Due to the nature of automation (being able to run on its own), the operator typically undertakes the role of monitoring the system, shifting from actively being in control to passively monitoring the system (this being the engagement of 'autopilot'). Because humans are not good at passively monitoring monotonous systems over a long period of time, the study is to investigate which strategies could improve this matter. This study thus aims to measure the effects of varied workload on the performance of the human operator whilst in control, the passive versus active monitoring strategies during the engagement of automation control (operator taking a break from the system) as well as the duration thereof, on the return-to-task performance of the human operator. The findings of this study will assist in determining more efficient monitoring strategies in human and automation interactions.

Procedure

You will be required to attend three laboratory sessions, one of which will be a habituation session, at the Human Kinetics and Ergonomics Department. In the habituation session (lasting no longer than 45minutes) you will be introduced to the equipment (tracking simulator, heart rate monitor and eye tracking device) and procedures. You will be allowed to practice the tracking task for an allocated time. Any questions or concerns you have about the testing protocol are welcome. The two testing sessions will entail you performing a tracking task in a laboratory where you will change from the tracking activity (30 minutes) to a break (2 vs. 30 minutes) and back to the activity (20 minutes). The tracking task varies in the complexity of the activity (pure tracking in the first testing session vs. tracking plus memory plus rule-based decision making in the second testing session), the type of break (passive rest, in the first testing session vs. actively supervising with a reading task, in the second testing session) and the duration of the break (2 minutes vs. 30 minutes). Depending on your testing group (2 minutes or 30 minutes) the duration will be repeated for both testing sessions.

The heart rate monitor and eye tracker will be attached and worn throughout the procedure. A Karolinska Sleepiness Scale (KSS) questionnaire will be issued to you at the end of testing to fill out. I am not able to give you any form of contact time feedback during the testing procedure as to eliminate any pacing strategies that you might develop during the testing procedure. However, testing for each session will not take longer than 1hr 15min or 1hr 45minutes (depending on which testing session you perform in). Hydration is prohibited during the duration of testing.

Risks and benefits

It is unlikely that you will experience any injuries during this study, as the procedures are not considered harmful in any way. However, some minor risks accompany this particular study. These include a risk of embarrassment as you will have to expose your trunk so that the researcher may be able to fit the heart rate monitor correctly around your chest cavity. As testing will be done in a room where only you and the researcher will be in, no-one else will be permitted in the testing venue for the purpose of privacy.

Another risk might be of being uncomfortable as the researcher will again fit you with a head mounted eye-tracking device for the purpose of recording your eye movements. In terms of the eye-tracking device, this might cause you to feel slightly claustrophobic due to the nature of the device being placed and sitting on the bridge of your nose. Due to the lack of haptic feedback from the simulator, you might feel nauseous (simulator sickness). This feeling is transient, and should dissipate once you have stopped the task. If you feel uncomfortable and unable to complete the protocol, please note that you may request to stop the test at any point. The session will unfortunately be cancelled, however if you wish to continue, another session will be made available to you.

Benefits derived from this study include exposure to the equipment and technology that many otherwise be difficult to encounter. You will be able to determine appropriate workload management whilst performing tasks simultaneously as well as strategic recovery breaks and activities to partake in, in order to achieve an improvement in performance overtime. By participating in this study, you will also contribute to the body of knowledge impacting the greater society in terms of determining appropriate monitoring strategies when dealing with automated systems.

Confidentiality

All data collected will be coded and thus you will remain anonymous with regards to your data and results. If at any stage you wish to withdraw from the study, you may do so without any adverse consequences to you. If there are any queries involving the testing procedures or any other concerns you may have, the researcher's details are provided at the end of this letter.

In the interests of limiting the effects of extraneous variables, you are asked to please refrain from the following before coming for your data collection:

- Consuming alcohol 24hours before testing
- Strenuous exercise/activities 24 hours before testing
- Consuming caffeine 8 hours prior to testing
- Eating one hour before testing
- Medication such as stimulants or performance enhances (Ritalin, Concerta)

If you do any of the above, please inform the researcher. By the time of testing, ethical approval will be obtained from the ethics committee of the Department of Human Kinetics and Ergonomics.

Thank you for your time and co-operations.

Yours sincerely,

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APPENDIX A2: SIGNED CONSENT

I, …………………………………………… have been fully informed of the research project entitled; *"The effects of the type of rest breaks on return-to-task performance in semi-automated tasks with varying complexities*".

I have read the information sheet and understand the testing procedure that will take place. All testing procedures, associated risks and the benefits from partaking in this study have been verbally explained to me as well as in writing [*letter of information appended to this document*]. I have had ample opportunity to ask questions and to clarify any concerns or misunderstandings. I am satisfied that these have been answered satisfactorily. I understand that all data collected for publication purposes will be kept anonymous and all information gained in this regard will be treated confidentially. Furthermore, I consent to photographs, knowing that these will be altered to ensure my anonymity. I understand that I am able to withdraw from the study at any point, irrespective of external influences placed on me by the researcher.

In agreeing to participate in this research study I waive any legal recourse against the researchers from the Department of Human Kinetics and Ergonomics (HKE), Rhodes University, from claims resulting from personal injuries sustained whilst participating in the above mentioned research. I am aware and fully understand that the Department of Human Kinetics and Ergonomics is not responsible for any injuries due to my personal negligence and non-compliance with instructions. This waiver shall be binding upon my heirs and personal representatives. I am further aware that my anonymity will be protected at all times, and agree that all the information collected may be used and published for statistical or scientific purpose. I also agree to the reuse of my data, which will be used strictly for research purposes by researchers from the Department of Human Kinetics and Ergonomics. I give my consent to recordings of the session by the researcher which will be used only for the purpose of this study.
I have read and understood the above information, as well as the information provided in the letter accompanying this form. I therefore consent to voluntarily participate in this research project.

PARTICIPANT PROVIDING CONSENT:

____________________	__________________	________________
(Print Name)	(Signed)	(Date)

WITNESS:

____________________	__________________	________________
(Print Name)	(Signed)	(Date)

PRINCIPAL RESEARCHER:

____________________	__________________	________________
(Print Name)	(Signed)	(Date)

APPENDIX A3: ETHICAL CLEARANCE

Human Kinetics and Ergonomics Ethics Committee Report

RHODES UNIVERSITY
Where leaders learn

Student Name: Zandile Hoyi	
Project Title: The effects of the type of rest breaks on return-to-task performance in semi-automated tasks with varying complexities.	
Supervisor: Dr S Zschernack	**Type of Research**: MSc study
Application received: 10 June 2016	**Code:** HKE-2016-05
Final Report compiled: 20 July 2016	

Dear Zandile

The adjustments to your ethics application have been approved and you may proceed with your study. Any subsequent changes made to your protocol must be communicated to the HKE Ethics Committee prior to testing.

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

On behalf of the HKE Ethics Committee I wish you all the best with your study.

Signed

Miriam Mattison.

MC Mattison

Chair: Human Kinetics and Ergonomics Ethics Committee

Confidential HKE Ethical Committee Review Form

APPENDIX B: Data collection & statistical tables

1. Karolinska Sleepiness Scale (KSS)
2. Statistical tables

APPENDIX B1: Karolinska Sleepiness Scale

1 Extremely alert

2 Very alert

3 Alert

4 Rather

5 Neither alert nor sleepy

6 Some signs of sleepiness

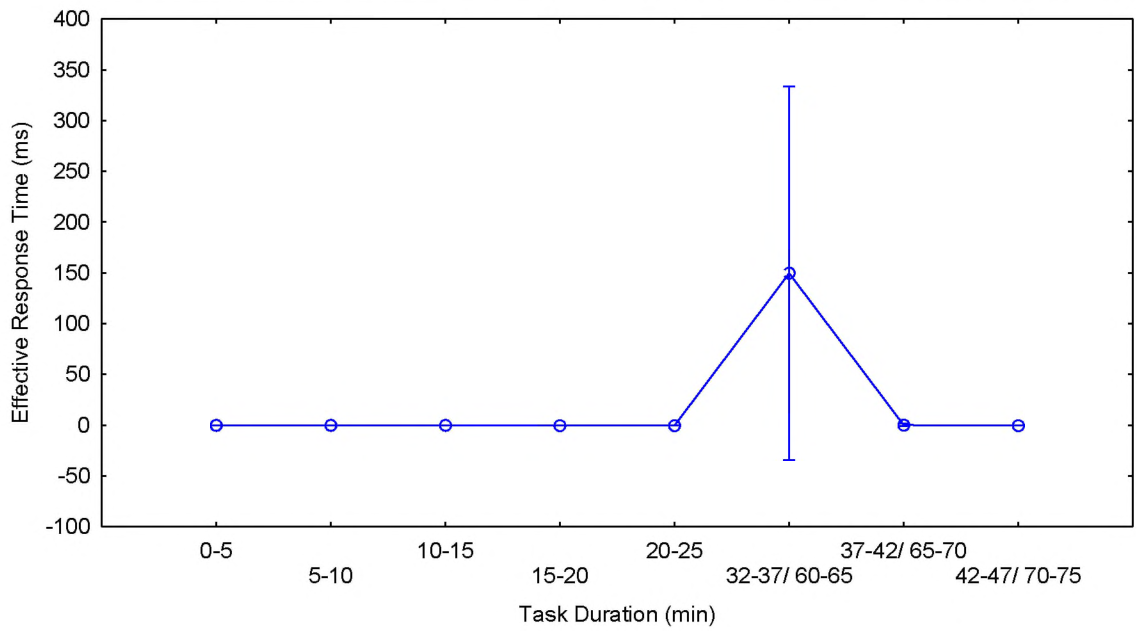
7 Sleepy, no effort to stay awake

8 Sleepy, some effort to stay awake

APPENDIX B2: Statistical tables

Analysis of variance for tracking task performance established during the Low workload condition, with rest task, rest duration, workload and time on task (interval) as factors

Effective response time (Low workload)	SS	Degr. of Freedom	MS	F	p
REST TASK	7	1,29	7.14	0.000218	0.988330
REST DURATION	4	1,29	4.23	0.000129	0.991014
TIME	628009	7,203	89715.55	2.792139	0.008547
TIME*REST TASK	33	7,203	4.68	0.000146	1.000000
TIME*REST DURATION	99	7,203	14.10	0.000439	1.000000



Analysis of variance for tracking task performance established during the Low and High workload conditions, with rest task, rest duration, workload and time on task (interval) as factors

Effective response time	SS	Degr. of Freedom	MS	F	p
REST TASK	667570	1,29	667570	0.516701	0.478005
REST DURATION	604511	1,29	604511	0.467893	0.499388
WORKLOAD	1610308	1,29	1610308	1.205356	0.281286
WORKLOAD*REST TASK	661410	1,29	661410	0.495082	0.487281
WORKLOAD*REST DURATION	599996	1,29	599996	0.449112	0.508059
INTERVAL	11997786	7,203	1713969	1.430648	0.194613
INTERVAL*REST TASK	9534136	7,203	1362019	1.136876	0.341353
INTERVAL*REST DURATION	9912417	7,203	1416060	1.181983	0.314535
WORKLOAD*INTERVAL	5565291	7,203	795042	0.646303	0.717193
WORKLOAD*INTERVAL*REST TASK	9498736	7,203	1356962	1.103098	0.362483
WORKLOAD*INTERVAL*REST DURATION	9828790	7,203	1404113	1.141427	0.338574

Analysis of variance for the Karolinska Sleepiness Scale, during the Low and High workload conditions, with rest task, rest duration, workload and time on task (interval) as factors

Karolinska Sleepiness Scale	SS	Degr. of Freedom	MS	F	p
REST TASK	1.932	1,29	1.932	0.4055	0.529421
REST DURATION	3.259	1,29	3.259	0.6841	0.415187
LOW-HIGH	1.552	1,29	1.552	0.6027	0.444049
LOW-HIGH*REST TASK	0.225	1,29	0.225	0.0875	0.769600
LOW-HIGH*REST DURATION	0.052	1,29	0.052	0.0203	0.887631

Analysis of variance for Blink Duration (ms) established during the Low and High workload condition, between the 5-minute intervals directly before and after the rest break, with the rest task and rest duration as factors. (*=significant effect, $p<0.05$).

Blink Duration (ms)	SS	Degr. of Freedom	MS	F	p
REST TASK	1291	1,29	1291	0.1036	0.749889
REST DURATION	1938	1,29	1938	0.1555	0.696207
WORKLOAD	8	1,29	8	0.0009	0.975769
WORKLOAD*REST TASK	5947	1,29	5947	0.7022	0.408915
WORKLOAD*REST DURATION	1539	1,29	1539	0.1817	0.673023
INTERVAL	17684	1,29	17684	1.7603	0.194936
INTERVAL*REST TASK	22	1,29	22	0.0021	0.963390
INTERVAL*REST DURATION	6437	1,29	6437	0.6408	0.429945
WORKLOAD*INTERVAL	6420	1,29	6420	0.6554	0.424793
WORKLOAD*INTERVAL*REST TASK	3265	1,29	3265	0.3333	0.568155
WORKLOAD*INTERVAL*REST DURATION	4206	1,29	4206	0.4293	0.517485