AN ANALYSIS OF REGULATORY MECHANISMS DURING SUSTAINED TASK EXECUTION IN COGNITIVE, MOTOR AND SENSORY TASKS

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Submitted in fulfilment of the requirements for the Degree Master of Science

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Rhodes University, 2013

Grahamstown, South Africa

ABSTRACT

Fatigue is a state that, although researched for many years, is still not completely understood. Alongside this lack of a general understanding of fatigue is a lack of knowledge on the processes involved in the regulation of fatigue. The existing theories relating to regulation are focussed on mental effort regulation, suggesting that performance outcomes are co-ordinated by effort regulation that functions by making alterations to physiological processes and strategic adjustments at a cognitive level in response to cognitive demands and goals. Since fatigue is a multi-dimensional construct with psychological, physiological, and behavioural effects that respond to endogenous and exogenous variables, it follows then that fatigue assessment techniques ought to include multi-dimensional measures to acquire a holistic depiction of the fatigue symptom.

This study aimed to assess whether or not a mechanism that regulated fatigue during sustained task execution could be identified and whether this mechanism resulted in regulation patterns that were distinct to a specific task. An additional aim of the study was on assessing whether the manner in which performance, psychophysical and subjective variables were modified over time followed a similar regulation pattern. The research design was aimed at inducing task-related fatigue twice on two different occasions in the same participants and evaluating the resultant changes in fatigue manifestation. This was done to assess the ability of participants to cope with fatigue as a result of previous experience. The research protocol included three tasks executed for an hour aimed at targeting and taxing the sensory, cognitive, motor resources, each task performed twice. 60 participants were recruited to participate in the current study, with 20 participants – 10 males and 10 females – randomly assigned to each of the three tasks. The cognitive resource task consisted of a memory recall task relying on working memory intended to evaluate the extent of reductions in memory and attention. The sensory resource task consisted of a reading task measuring visual scanning and perception designed to evaluate the extent of reduced vigilance. The motor resource task consisted of a modified Fitts' stimulus response task targeted at monitoring the extent of movement timing disruption. Performance measures comprised of: response delay and the number of correctly identified digits during the cognitive resource task, the amount of correctly identified errors and reading speed during the sensory resource task, response time during the motor resource task, and responses to simple auditory reaction time tests (RTT) initiated at intervals during the task and then again at the end of each task. Physiological measures included ear temperature, eye blink frequency and duration, heart rate (HR), and heart rate variability (HRV). Subjective measures included the use of the Ratings of Perceived Exertion Category Ratio 10 scale (RPE CR 10) to measure cognitive exertion and the NASA-Task Load Index (NASA-TLX) to index mental workload.

Eye blink frequency and duration, HR and HRV were sensitive to the type of task executed, showing differing response patterns both over the different tasks and over the two test sessions. The subjective measures indicated increasing RPE ratings over time in all tasks while the NASA-TLX indicated that each task elicited different workloads. Differing task performance responses were measured between the 1st test session and the 2nd test session during all tasks; while performance was found to improve during the 2nd test session for the motor and sensory tasks, it declined during the cognitive task.

The findings of this research indicate that there was a regulatory mechanism for fatigue that altered the manner in which performance, psychophysical and subjective variables were modified over time, initiating a unique fatigue regulation pattern for each variable and each task. This regulation mechanism is understood to be a proactive and protective mechanism that functions through reducing a person's ability to be vigilant, attentive, to exercise discernment, and to direct their level of responsiveness, essentially impacting how the body adapts to and copes with fatigue. The noted overall findings have industry implications; industries should consider accounting for the effects of this regulatory mechanism in their fatigue management interventions, specifically when designing job rotation and work/rest schedules because each cognitive task, having elicited a unique fatigue regulation pattern, ought to also have a different management program.

ACKNOWLEDGEMENTS

The following people deserve my gratitude:

To my Father, thank you for giving me your love, your insight, your creativity and your encouragement. May this work bring you glory.

To Professor Matthias Göbel, thank you for being willing to help me and for sacrificing your time to do this. You went over and above what was required of you every time. Thank you also for your guidance and for sharing your knowledge; you have taught me how to think outside the box and how to work smart.

To Dr Swantje Zschernack, thank you for the many meetings during the conceptualization phase; this project would have not succeeded if it were not for your efforts during that crucial stage.

To Sma Ngcamu, I appreciate you so much; you are such a gem. I feel so blessed to have had an opportunity to work with and learn from you. I will remember your brilliance, kindness, encouragement, generosity and belief in me always.

To Tyrone Douglas, thank you for putting up with our requests for new devices and equipment and for getting it done. I really appreciate all the effort you put into ensuring that we had everything we asked for.

To the participants, you are all rockstars! I will always be grateful to the 60 people who were willing to go through two tough and very annoying 2 hour sessions for the sake of being helpful. Thank you all so much.

To June McDougall, Collen Ngqoyiya and Joyce Nontyi, seeing you always reminded me of my parents. Thank you for always being gentle with me.

To Dema, thank you for being so supportive; you have always made sure that I had everything I needed to succeed. You’re the best D.

To my family and friends, I love you guys so much. Some of you pushed, fed, and distracted me when I needed it. Thank you for being my support system and for always reminding me that a little hard work was good for the soul.

May God abundantly bless you all.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

Fatigue is a phenomenon that has been experienced by everyone sometime in their work or leisure time (Williamson *et al.*, 2011). Fatigue is a state that, although researched for many years, is still not completely understood as there is still no universally accepted definition of fatigue (Hartley *et al.*, 2003; Craig *et al.*, 2006; Noy *et al.*, 2011). Furthermore, the shift in the nature of performance requirements on activities, from requiring physical effort to requiring cognitive effort, has resulted in more emphasis being placed on sustained effort, selective attention, and complex decision making, with only an occasional exercise of perceptual-motor control skills (Brown, 1982). The types of tasks performed in industry have thus become more cognitive in their nature (Wei and Salvendy, 2006), for instance most automated tasks resemble vigilance tasks as they require, typically, prolonged monitoring with infrequent responses (Nilsson *et al.*, 1997).

Research that has been done on fatigue (inclusive of cognitive fatigue) has described a number of characteristics and symptoms of fatigue. These include the perception of fatigue as a cumulative and progressive subjectively experienced state resulting in disruptions of function and impairment of will (Noy *et al.*, 2011; Brown, 1982; Lal and Craig, 2001; Bultmann *et al.*, 2002; Thiffault and Bergeron, 2003b). These disruptions of function include failures in attention and memory, reduced vigilance, disrupted movement timing and response slowing (Noy *et al.*, 2011; Brown, 1982). This view of fatigue accounts for why fatigue affects performance and attention (Lal and Craig, 2001). This view also accounts for why implications of fatigue in the workplace include an increase in the number of errors leading to accidents and an increased risk for injury (Di Milia *et al.*, 2011; Nilsson *et al.*, 1997). This is because fatigue impacts the various bodily systems (from the cognition and sensory processing systems to the physiological and performance related mechanisms), especially if a task is done for a prolonged period of time, causing failures in attention and suppressing inappropriate strategies or behaviours (Di Milia *et al.*, 2011; Nilsson *et al.*, 1997). It is the affected bodily systems (for instance the physiological and psychological processes) that lead to a diminished capacity to perform (Thiffault and Bergeron, 2003b).

Since fatigue is a multi-dimensional construct with psychological, physiological and behavioural processes (with complex effects on task execution and on performance), fatigue measures must include measurements of these processes accordingly (Thiffault and Bergeron, 2003b; Noy *et al.*, 2011). While general fatigue states can be assessed through the use of self-reports or subjective measures (Matthews and Desmond, 2002), this method of measuring fatigue has received criticism. The criticism has been centred on the suggestion that fatigue has an ability to impair an individual's capacity for introspection and change the propensity to report symptoms, making subjective measures highly subject to inaccuracies (Brown, 1982).

Although subjective measures have received criticism, they are, nonetheless, reported to elicit clearer and more consistent results in comparison to physiological measures (Nilsson *et al.*, 1997). Researchers believe that cognitive fatigue can be objectively measured through analyzing changes in physiological variables such as heart rate, electroencephalographic and blood pressure and performance measures.

Performance measures are often in the form of vigilance tests and simulated tasks (Williamson *et al.*, 2011). Performance changes are also used to measure cognitive fatigue as performance tests are understood as providing a direct evidence link of fatigue effects (Dinges and Kribbs, 1991).

Even though fatigue studies have a history that spans as far back as a hundred years (Noy *et al.*, 2011), there is yet no universally accepted definition of it or clear understanding about how cognitive fatigue is adjusted and managed within the body available. As a consequence, there is no commonly accepted set of criteria available that can be used to validate or measure fatigue (Lewis and Wessely, 1992; Noy *et al.*, 2011).

As a theory that describes how resource allocation and use, within the information processing system, affects task completion (with resources being understood as the very energy sources driving task execution), the resource theory is one that has attempted to describe how fatigue manifests in the body. Hockey’s compensatory control theory describes the regulation of actions and goals, in response to environmental demands, through an effort monitor functioning through the occurrence of dynamic resource allocation (Hockey, 1997); this theory has also attempted to describe how fatigue manifests. However, certain questions remain as there is still no clear understanding of how fatigue is modulated within the body.

With the consideration of the remaining questions regarding how fatigue is modulated and manifested in the body, the focus of this study was on identifying factors that caused decrements in performance during task execution. Although an array of factors exist, the focal point was on fatigue and fatigue regulation. This study thus attempted to identify and understand the manner in which fatigue was regulated as a possible means of understanding the fatigue phenomenon, including how and why fatigue developed in the manner that it did. As such, the aim of this study was to outline the dynamic changes in regulatory mechanisms (or regulatory behaviour/activity) configured by the body during fatiguing tasks by studying and measuring variables (incorporating the multi-dimensional states of fatigue) that have been shown to reflect changes in effort and performance protection. It was believed that outlining the dynamic changes in regulatory mechanisms would deliver quantitative accounts of fatigue regulation, allowing for a clear understanding of how fatigue was modulated within the body. It was therefore reasoned that fatigue regulation could be identified by observing the fatigue pattern (as depicted by the measured variables) during any fatiguing task. However, in an attempt to clearly identify the regulatory behaviour, an investigation on how and if fatigue regulation occurred when individuals performed the same task twice was conducted. This was done to verify whether the observed regulatory behaviour during the first task was similar or different to the second task. Therefore, participants were asked to conduct two identical fatiguing tasks where the differences in responses to the identical tasks would be observed and interpreted as indicators of regulatory activity. In this way the study aimed at assessing if performance improved or worsened as a result of previous experience gained with a task.

This study intended to assess the effects of cognitive fatigue associated with sustained cognitive task performance during three resource specific tasks. These resource specific tasks were based on the broad information processing categories (sensory, cognitive, and motor). Thus, three tasks were designed; each task was aimed at selectively taxing the sensory, cognitive and sensory-motor processes. The results of this research could provide information, however small, that could aid in creating more appropriate fatigue risk management parameters on both an organizational and operational level, allowing better planned and controlled work environments that minimize, as far as possible, the adverse effects of fatigue on workforce (Gander *et al.*, 2011)

STATEMENT OF THE PROBLEM

Fatigue is a phenomenon that is known and yet not well understood; the problem with fatigue is not the under reporting but the lack of understanding regarding how it functions, its characteristics, as well as how factors interact to cause decrements in performance. One of the ways of gaining a better understanding of fatigue is to comprehend how the body copes with fatigue during sustained task execution, in particular how fatigue regulation and the mechanisms that control it function. Thus, the premise of the study was based on viewing fatigue as a negative effect that the regulatory mechanism would act to control and minimize. The mechanism was supposed to operate through anticipating the negative effects of fatigue and adapting to cope with said effects. Therefore, regulation was viewed as a proactive and protective mechanism. In order to measure this, it was hypothesized that people having experienced a fatiguing task would anticipate fatigue (as a function of previous experience) and their regulatory mechanism would alter their responses or behaviour in an attempt to minimize or avoid the negative effects of fatigue. Thus, a way of assessing this (as a direct measurement of how individuals cope or anticipate fatigue is difficult) was to have individuals execute one task twice and then compare the task performance and responses from the first task to those from the second identical task. In this way, the learning, coping or anticipatory function in response to fatigue, would be tested as a way of indexing the regulatory mechanism. If this mechanism could not be identified, then the performance and responses during the first task would be similar to those during the second identical task.

The three specific tasks selected to tax the specific resources were structured around research findings; as it is understood that the symptoms usually attributed to fatigue include disruptions of function (Noy *et al.*, 2011; Brown, 1982), each of the resource tasks was targeted at inducing a specific cognitive symptom of fatigue. The resultant disruption of function that emerged was then studied. As such, there existed a cognitive resource task, a motor resource task, as well as a sensory resource task, making a total of three tasks. The tasks consisted of a reading task measuring visual scanning and perception (the sensory resource task), a memory recall task that relied on working memory (the cognitive resource task), and a modified Fitts' stimulus response task (the motor resource task). In line with the study design, each task was performed twice (test session one and test session two) then a comparison was made between the two test sessions.

RESEARCH HYPOTHESIS

Two identical test sessions, during which a task had to be sustainably performed for an hour, were performed with a delay period of at least 48hours between test days. It was expected that a difference would be found during the first test session relative to the second test session (in all tasks) in the form of an effect on the performance, subjective and physiological measures. It was further expected that fatigue regulation would not only evoke effects specific and unique to the task being conducted but would also induce different patterns over time as indicated by the performance, subjective and physiological measures.

STATISTICAL HYPOTHESES

The three tasks measured incorporated variables such as subjective responses in the form of the Ratings of Perceived Exertion category ratio 10 scale and a NASA-Task Load Index recordings, physiological responses in the form of heart rate and heart rate variability, skin and tympanic temperature, eye blink frequency and duration measures, and performance responses measured during the tasks performed throughout the test period.

The following was expected for this study:

- The effect of the first test session on the performance, subjective and physiological measures would differ from the effect of the second test session on the performance, subjective and physiological measures during all tasks.
- The fatigue regulation mechanism would evoke different effects during the first test session in comparison to the second test session during all tasks comparable to the level of fatigue induced as indicated by the performance and response measures.
- All three tasks would elicit differing response patterns as recorded by the performance, subjective and physiological measures.

The statistical hypotheses were as follows:

Hypothesis 1:

The null hypothesis (H_o) proposes that there will be no differences in the responses to all variables during the fatiguing task between the first test and the second test sessions:

$\mu\ 1^{st}$ Test fatiguing task $_{sensory} = \mu\ 2^{nd}$ Test fatiguing task $_{sensory}$
$\mu\ 1^{st}$ Test fatiguing task $_{cognitive} = \mu\ 2^{nd}$ Test fatiguing task $_{cognitive}$
$\mu\ 1^{st}$ Test fatiguing task $_{motor} = \mu\ 2^{nd}$ Test fatiguing task $_{motor}$

The alternative hypothesis (H_A) proposes that there will be differences in the responses to all variables during the fatiguing task between the first test and the second test sessions:

$\mu\ 1^{st}$ Test fatiguing task $_{sensory} \neq \mu\ 2^{nd}$ Test fatiguing task $_{sensory}$
$\mu\ 1^{st}$ Test fatiguing task $_{cognitive} \neq \mu\ 2^{nd}$ Test fatiguing task $_{cognitive}$
$\mu\ 1^{st}$ Test fatiguing task $_{motor} \neq \mu\ 2^{nd}$ Test fatiguing task $_{motor}$

Hypothesis 2:

The null hypothesis (H_o) proposes that there will neither be any differences in the responses to all variables when comparing the responses during the first test session of all the three tasks nor any differences in the responses to all variables when comparing the responses during the second test session of all the three tasks:

$\mu\ 1^{st}\ \text{Test fatiguing task}_{sensory} = \mu\ 1^{st}\ \text{Test 1 fatiguing task}_{cognitive} = \mu\ 1^{st}\ \text{Test fatiguing task}_{motor}$
$\mu\ 2^{nd}\ \text{Test fatiguing task}_{sensory} = \mu\ 2^{nd}\ \text{Test fatiguing task}_{cognitive} = \mu\ 2^{nd}\ \text{Test fatiguing task}_{motor}$

The alternative hypothesis (HA) proposes that there will be differences in the responses to all variables when comparing the responses during the first test session of all the three tasks and differences in the responses to all variables when comparing the responses the second test session of all the three tasks:

$\mu\ 1^{st}\ \text{Test fatiguing task}_{sensory} \neq \mu\ 1^{st}\ \text{Test 1 fatiguing task}_{cognitive} \neq \mu\ 1^{st}\ \text{Test fatiguing task}_{motor}$
$\mu\ 2^{nd}\ \text{Test fatiguing task}_{sensory} \neq \mu\ 2^{nd}\ \text{Test fatiguing task}_{cognitive} \neq \mu\ 2^{nd}\ \text{Test fatiguing task}_{motor}$

Hypothesis 3:

The null hypothesis (H_o) proposes that there will be no differences in the responses to all variables when comparing responses from each of the three tasks during the first test and the second test sessions:

$\mu\ 1^{st}\ \text{Test fatiguing task}_{sensory} = \mu\ 2^{nd}\ \text{Test fatiguing task}_{sensory} = \mu\ 1^{st}\ \text{Test fatiguing task}_{cognitive} = \mu\ 2^{nd}\ \text{Test fatiguing task}_{cognitive} = \mu\ 1^{st}\ \text{Test fatiguing task}_{motor} = \mu\ 2^{nd}\ \text{Test fatiguing task}_{motor}$

The alternative hypothesis (HA) proposes that there will be differences in the responses to all variables when comparing responses from each of the three tasks during the first test and the second test sessions:

$\mu\ 1^{st}\ \text{Test fatiguing task}_{sensory} \neq \mu\ 2^{nd}\ \text{Test fatiguing task}_{sensory} \neq \mu\ 1^{st}\ \text{Test fatiguing task}_{cognitive} \neq \mu\ 2^{nd}\ \text{Test fatiguing task}_{cognitive} \neq \mu\ 1^{st}\ \text{Test fatiguing task}_{motor} \neq \mu\ 2^{nd}\ \text{Test fatiguing task}_{motor}$

Where:

- **1st Test** means the first test session
- **2nd Test** means the second test session
- **Cognitive** means the cognitive resource task
- **Motor** means the motor resource task
- **Sensory** means the sensory resource task

DELIMITATIONS

As the aim of the study was to examine fatigue regulation as it presented during a fatiguing task. The scope of the examination was restricted to quantifying whether differences in responses to two identical tasks could serve as indicators of a regulatory mechanism.

This study did not focus on finding ways of reducing or preventing fatigue regulation but focussed on attempting to measure, understand and observe how and when instances of fatigue regulation occur. The primary aim of the study was on understanding how individuals cope with task-related fatigue by analysing their responses during one test to those during a second identical test. Therefore, other regulatory systems/patterns were not studied within this scope of research. In this way, circadian rhythm related down-regulation and self-regulation (relating to participants consciously and intentionally reducing or improving their performance) were not assessed in detail and, but were controlled for as much as possible.

The present research also did not focus on the effect of motivational changes (participants given no incentive, just asked to perform maximally) or the environment (as the environment was kept constant). This study did not aim to distinguish the roles of workload and task duration on fatigue or fatigue regulation.

Sixty participants (30 males and 30 females) between the ages 18 to 30 were recruited as test participants for this study. Three independent sample groups were then formed from the 60 participants for each of the three tasks. All participants were randomly assigned to one of the three tasks; 20 participants for visual scanning and perception (the sensory resource) task, 20 participants for the memory recall (the cognitive resource) task, and 20 participants for the modified Fitts' stimulus response (motor resource) task. The participants were assigned to each task in a way that ensured that there were an equal number of males and females for each task.

Both the first test session and the second test session were conducted in exactly the same way, except that the first test session included an introduction to the tasks at the beginning. Each testing task was 110 minutes.

The testing was set-up in a closed and controlled laboratory with few distractions and noise. The use of a controlled setting was selected to allow the researcher to ensure that the lighting, room temperature and testing procedure was identical for each test session. All participants were exposed to the same order of testing every time they came for testing.

Several physiological measures were recorded throughout all the testing sessions; heart rate and heart rate variability, skin and tympanic temperature, eye blink frequency and duration were recorded continuously. Subjective performance was assessed through a range of performance indicators measured during the tasks performed throughout the test period; response time was assessed during the motor resource task, the percentage of correctly identified errors and response time were assessed during the cognitive resource task and the percentage of correctly identified errors and reading speed were assessed during the sensory resource task. Performance on a simple auditory reaction time test was also assessed. Subjective measures that were used included the Ratings of Perceived Exertion category ratio 10 (RPE CR) scale and a NASA-Task load Index (TLX).

LIMITATIONS

While each participant was asked to adhere to a number of guidelines in the interests of limiting the effects of extraneous variables, it was impossible to access the level of adherence to the guidelines provided. Therefore actions such as alcohol consumption or stimulant ingestion might have influenced participant responses.

As the sample group of the study was drawn from the student population, the researcher expected to have no direct control over the activities of each participant before and after each test session, however, participants were asked to refrain from

engaging in strenuous physical and cognitive activities, drinking alcohol or taking stimulants such as coffee and performance enhancers.
It was understood that the decision to use a population sample purely comprised of students would potentially limit the utility of the findings and place constraints on how generalisable the information that was collected from this study was. However, it was believed that other populations would likely show the same characteristics, making the decision to use the student population reasonable.

This study occurred in a controlled laboratory context (where participants were required to perform at a constant maximal level for 110 minutes) with tasks and work demands not representative of tasks and stressors that workers may encounter in an actual work place; the tasks were more monotonous and rigid in the required execution procedure and time commitment. This may not be the case in an actual work environment as workers are often allowed to select their own pace (even if they work according to a tact time system), take breaks and work for longer durations.

CHAPTER II

REVIEW OF RELEVANT LITERATURE

INTRODUCTION

Fatigue in the context of work life is a common worldwide experience that has utmost important implications for the performance and the wellbeing of workers (Sluiter *et al.*, 2003; Di Milia *et al.*, 20011). Occupationally induced fatigue, specifically, has been found to affect most of the working population (Bultmann *et al.*, 2002; Di Milia *et al.*, 2011; Lewis and Wessely, 1992). Fatigue has been identified as a contributing factor for accidents, injuries and even fatal incidents in different settings (including occupational settings such as law enforcement, hospitals, community and primary care, emergency operations and in transport sectors such as aviation, rail, and road) as it reduces attention and performance during task execution, causing an increase in reaction time, errors, and tiredness; tired individuals are less vigilant and produce performance that is less safe (Williamson *et al.*, 2011; Abbiss and Laursen, 2007; Bultmann *et al.*, 2002). Fatigue is therefore viewed as a state that needs to be managed as it not only places the worker at risk for injury, but threatens companies since it causes accidents as well as reductions in productivity and efficiency (Dawson *et al.*, 2011; Boksem *et al.*, 2006). Fatigue therefore needs to be managed so that these negative outcomes are reduced. However, before fatigue can be managed, it has to be well understood; the existence of numerous definitions of fatigue and various fatigue theories, the lack of a criteria against which fatigue can be validated, the absence of a universally agreed upon method of quantifying fatigue, and a lack of consensus on how the fatigue inducing factors interact, all indicate that we lack a lot of knowledge about fatigue due to the complexity and nature of research on fatigue (Di Milia *et al.*, 20011; Lewis and Wessely, 1992; Abbiss and Laursen, 2007).

Furthermore, this problem has been enhanced by the change in the nature of the worker's task that has occurred over the years from being primarily comprised of physical and motor activities towards more cognitive activities (Wei and Salvendy, 2006). As the world has become more advanced through increased automation, workers are now expected to engage in decision making and problem solving activities on a day to day basis (Wei and Salvendy, 2006). In addition, tasks now require more and more sustained attention such as those in monitoring, inspection, quality control and surveillance (Williamson *et al.*, 2011). This shift poses new challenges now as tasks place a heavier cognitive fatigue burden on workers. The impact of cognitive fatigue thus needs to be understood because people may not be as able to detect the signs (often subtle) of mental fatigue as well as they can those of physical fatigue. This, consequently, poses a greater risk of accidents and injuries as they may in turn fail to realize the impact that these subtle changes have on their performance. Moreover, an understanding of the impact of cognitive task demands on a worker must be achieved before task demands can be fitted to the worker's capacities and knowledge (Wei and Salvendy, 2006).

This review will first attempt to define fatigue and mental fatigue (using the terms 'mental' and 'cognitive' interchangeably), highlighting task-related fatigue and briefly discussing the existing fatigue theories relating possibly to fatigue regulation. The review will then address the background for the difficulties in defining fatigue and discuss the existing fatigue-inducing factors. A final section will review current techniques of measuring fatigue focussing on objective, physiological and subjective methods of indexing fatigue.

THE FATIGUE PHENOMENON

Fatigue is a phenomenon that has been experienced by everyone sometime in their work or leisure time (Williamson *et al.*, 2011). Craig *et al.* (2006) noted that fatigue was initially thought of as a general feeling of tiredness. This definition was one of the first of the numerous and varying definitions of fatigue that began to emerge; most definitions were greatly unspecific and entirely too general to permit any kind of understanding of what fatigue truly was, while others were so particular that all other tasks not expressed as fatigue were defined as not fatigue (Craig *et al.*, 2006). These particular definitions were misleading as they excluded some important characteristics of fatigue. As a result, there exists no universally agreed upon definition of fatigue and researchers tend to choose a definition of fatigue that is most appropriate for their research purpose (Hartley *et al.*, 2003; Craig *et al.*, 2006; Noy *et al.*, 2011; Di Milia *et al.*, 2011; Matthews and Desmond, 2002).

However, even though there is no universal definition of fatigue, there has been a general consensus about some characteristics of fatigue: a) fatigue is a cumulative or progressive subjectively experienced state, usually emerging during sustained activity (in this way, it could be offset by adequate rest), that is accompanied by reduced alertness, efficiency and attention (Lal and Craig, 2001; Bultmann *et al.*, 2002; Brown, 1982); b) fatigue includes the feeling of tiredness and an impaired ability or willingness (relating to motivational aspects) to perform a task (Hartley *et al.*, 2003; Haworth, 1998; Thiffault and Bergeron, 2003b; Thiffault and Bergeron, 2003a) and c) the symptom severity and appearance form of fatigue are individual dependent and result in a change and deterioration (leading ultimately to failure) in performance of a task over time (Hartley *et al.*, 2003; Haworth, 1998; Matthews and Desmond, 2002). Fatigue effects are believed to exist on a continuum that ranges from mild to severe performance disruptive and injury (disabling) intensive manifestations (Dawson *et al.*, 2011). Fatigue is cumulative, researchers understand that it will increase in severity with increasing time-on-task until it is counteracted by rest (Lal and Craig, 2001).

Fundamentally, fatigue as a multi-dimensional construct including physiological, emotional, cognitive and behavioural components that can present in physical and/or mental states (Abbiss and Laursen, 2007; Lewis and Wessely, 1992; Jansen *et al.*, 2003). Mental fatigue and physical fatigue (which includes subjective, physiological, and objective fatigue) are the main categories or states of fatigue. The onset of fatigue, in both categories, results in symptoms such as performance breakdown, disruption of function (such as failures in attention and memory, reduced vigilance, and disrupted movement timing), complete exhaustion and impairment of will (Noy *et al.*, 2011; Brown, 1982). It is these very symptoms that increase the risk of injury to workers when they work while fatigued (Di Milia *et al.*, 2011). Physical fatigue (muscle fatigue) refers to a state of diminished performance of a muscle in response to stress or repetitive work, resulting in reduced movement, muscle activation and muscular power (Lal and Craig, 2001; Dawson *et al.*, 2011). Conversely, mental fatigue relates to the psychological and cognitive facets (Lal and Craig, 2001). It refers to a progressive process resulting in feelings of weariness, inhibition, disinclination for effort, reductions in alertness and efficiency, and impaired mental performance in response to mental or intellectual work (Dawson *et al.*, 2011). While physical fatigue is primarily thought to be due to a reduced capacity to perform physical work in response to a reduced function of preceding physical effort, mental fatigue is thought to emerge as a central state deduced from performance reductions on tasks requiring mental manipulation and alertness (Staal, 2004).

The experience of fatigue is considered a highly undesirable one as it is associated with an inability to function at the required or desired level and high levels of discomfort. Additionally, fatigue effects will be enhanced if a worker has only had partial recovery from prior work demands and other activities. This is because fatigue symptoms are more severe when there has not been sufficient rest and recovery time resulting in a reduced capacity to perform optimally (Gander *et al.*, 2011).

More recently, researchers have taken on a broader understanding of fatigue by appreciating, firstly, the role that the perception of fatigue plays in its development and secondly, the ability of fatigue to take different forms: the definition of fatigue by Williamson *et al.* (2011) as a recuperative drive for rest addresses this point by recognising the possibility for fatigue to take multiple mental and physical forms (allowing for the converse assumption that a fatigue remedy will depend on the fatigue form). Hartley *et al.* (2003) and Brown (1982) described fatigue as a subjectively experienced state with task performance implications because the effects of fatigue could be traced by evaluating task performance. This view of fatigue also accounts for individual variability in the experience of fatigue and makes the consideration of fatigue more complex.

AN OVERVIEW OF THE BASIC CONCEPTS AND THEORIES RELATING TO THE REGULATION OF FATIGUE

Fatigue is thought of in relation to energetical concepts such as effort, resources and activation, thus energetic constructs are often used to explain how fatigue affects performance (Kahneman, 1973). Usually, this is attributed to constructs such as a loss of arousal, effort or resources (Matthews and Desmond, 2002).

The Resource Concept

The resource theory is based on an information processing concept asserting that any information processing device has within it programs which allow for the optimal functioning of its mechanisms (Norman and Borrow, 1975). Resources are seen then as the energy that the input data requires for the execution of the program (Norman and Borrow, 1975). Specifically, they are energy sources that power human information processing existing in pools with an ability to perform basic operations across an array of tasks (Hockey, 1997; Matthews and Desmond, 2002). Thus, the resource theory posits that there exists a general reservoir of mental resources elicited to assist in task completion (Staal, 2004; Kahneman, 1973). These resources can exist in the form of memory capacity, processing effort and communication channels (Norman and Borrow, 1975). According to the resource theory, the information processing system has a fixed amount of resources available for task execution (Norman and Borrow, 1975). This limited capacity assumption is based on the idea of scarcity (Hockey, 1997). Resources are thought to be distributed or availed according to tasks demands, with more demanding tasks and multiple component tasks requiring more of the limited commodity (Matthews and Desmond, 2002; Williamson *et al.*, 2011). The tasks that demand more resources are understood as being more prone to fatigue as the depletion rate is increased (Matthews and Desmond, 2002; Williamson *et al.*, 2011). As such, a decline in performance will occur if too many processes compete for the same resources because said processes will reduce the resources (Norman and Borrow, 1975; Kahneman, 1973). Therefore, resource depletion will occur if the rate at which the resources are used supersedes the rate at which they are replenished (Norman and Borrow, 1975; Kahneman, 1973; Wei and Salvendy, 2006; Hockey, 1997).

Multiple Resource Theory

Formally, the multiple resource theory, as outlined by Wickens (1980) and Wickens (2002), describes the connection between the concepts ‘resource’ (still defining resources as limited capacity energy sources that power human information processing that are availed according to task demands) and ‘multiple’ (denoting parallel or relatively independent processing) during multiple task (time sharing) performance. This theory specifically addresses the apparent ability of task performance to be maintained during multiple resource requiring tasks or in the ‘overload’ situation, where performance is required on two or more tasks simultaneously (Wickens, 2002) without resulting in immediate performance decline and the premature onset of fatigue (as expected under the perspective of the resource theory). This theory has practical and theoretical implications: on a theoretical level, the theory can account for variability in task interference not easily explained by simpler models of human information processing (Broadbent, 1958 and Welford, 1967 in Wickens, 2002) and make predictions regarding the level of dual task interference between concurrently performed tasks based on the neurophysiological mechanisms underlying task performance (Wickens, 2002). On a practical level, the theory takes into consideration the practical implications of task performance by looking at the operator’s ability to perform in high workload multi-task environments (Wickens, 2002). A multiple resource model was thus proposed that assessed changes in the operator or the task design that could be analysed and coded to predict ‘operationally meaningful differences in performance in multi-task environments’ (Wickens, 2002; Wickens, 1980). The multiple resource model outlines four dimensions namely, processing stages, perceptual modalities, visual channels, and processing codes (Wickens, 1980). As outlined in Wickens (1980), the theory posits that a greater interference between two tasks will occur to the extent that theses tasks share processing stages (perceptual/cognitive versus response), codes (spatial versus visual), sensory modalities (auditory versus visual), and channels of visual information (focal versus ambient). In this way, a greater performance interference will be observed during the performance of two tasks that both demand one level of a given dimension (e.g. two tasks demanding visual perception) than the performance of two tasks that demand separate levels on the dimension (e.g. one visual, one auditory task) (Wickens, 2002). To date, the most essential applications of this model are in predicting the level of performance disruption/interference of two or more time shared tasks and guiding dichotomous categorical task design decisions (Wickens, 2002).

The Concepts of Attention, Arousal/Alertness and Activation

The amount of resources available is believed to vary according to the individual's level of attention and arousal/alertness (Staal, 2004). This is because attention is understood as being the resource that allows individuals to shift between stimuli to focus on relevant stimuli (Kahneman, 1973). Attention is seen in two ways; as a commodity that is divisible (in its capacity and thus having a selective/controllable capacity) and limited from moment to moment depending on the demands of the current activity (Kahneman, 1973; Wei and Salvendy, 2006). Therefore, if attention is understood as a limited commodity, tasks that require sustained attention will induce fatigue sooner as they will deplete the attention resource.

Attention is understood as being related to the arousal/alertness (terms used interchangeably) of the task because the amount of attention demanded can often be measured in terms of arousal (Schmidt, 1982). This is because tasks that evoke much attention are those that are arousing (Schmidt, 1982). Arousal refers to the energetic state of a subject or extent to which a subject is activated or excited (VaezMousavi *et al.*, 2007; Barry *et al.*, 2005; Schmidt, 1982). Arousal is essentially a function of stimulation from a task that influences the amount of selective attention control an individual has (Brown, 1982; Van Dongen and Dinges, 2003). A decrease in arousal has been associated with a decrease in vigilance and cognitive attention, situation discernment, and slowed motor responses/reactions (Craig *et al.*, 2006). This is because, as noted by VaezMousavi *et al.* (2007), physiological responses to stimuli in a task depend on the arousal level at the time of the presentation of the stimuli. Therefore, the level of arousal is understood as being able to affect the amount of attention resources and the manner in which the attention resource is allocated, influencing performance- which is heavily reliant on attention (Wei and Salvendy, 2006). Moderate increases in arousal have been noted to result in performance peaks; this increase in arousal must not be too low as excessively low levels of arousal are correlated to performance drops perhaps due to a repetitive and unchanging environment/task (Brown, 1982). In essence, low arousal tasks will require more attention to execute (Schmidt, 1982). Conversely, increases in arousal must not be too high since high arousal tasks (associated with extreme excitement) may also require more attention to execute as the environment may be changing too rapidly to allow for proper task execution, preparation and adaptation (Schmidt, 1982; Brown, 1982).

Activation has been referred to as the task related mobilization of arousal (Barry *et al.*, 2005). As activation is understood as affecting behaviour/performance, performance measures such as those of reaction time and number of errors have been found to reflect activation levels (VaezMousavi *et al.*, 2007; Barry *et al.*, 2005). More specifically, mean reaction time and number of errors were noted by Barry *et al.* (2005), to improve with increasing activation but not with arousal. This finding emphasises the fact that arousal and activation are not interchangeable; while activation determines the task-related behavioural responses, arousal determines physiological responses (VaezMousavi *et al.*, 2007; Barry *et al.*, 2005).

Effort Theory

Effort theory asserts that effort is the modulator of sustained performance (Hockey, 1997; Kahneman, 1973). This modulation is carried out through energy mobilization dependent on the task and load demands (Kahneman, 1973). It has been suggested that effort may also be described as a way in which the information processing and behaviour during high workload tasks is controlled (Matthews and Desmond, 2002). This view of effort implies that the level of effort will not be determined prior to the action but will vary continuously according to the task demands and the load inflicted by the action. The activities (their level of difficulty, nature and intrinsic complexities), therefore, serve as the main determinants of the amount of effort necessary to be exerted (Kahneman, 1973). This assertion essentially means that the performance of a task will have an associate amount of effort allocated to it to ensure optimal performance (Kahneman, 1973).

Mental effort in particular, was characterised by Hockey (1997) as a mode of information processing restricted by working memory capacity and altered to improve efficiency of performance. Mental effort will be increased or decreased in response to the temporal and complexity demands as well as the other existing determinants of cognitive demand (Fairclough *et al.*, 2005). Basically, the investment pattern of mental effort is a coordinated, energy mobilisation response to cognitive goals, able to result in catabolic alterations at a physiological level and strategic adjustments at a cognitive level (Hockey, 1997; Fairclough *et al.*, 2005; Fairclough and Houston, 2004). These changes respond to learning; while the initial learning stages may be characterised by slow, inaccurate and intentional responses as well as high mental effort, repeated practice has been shown to lead to a strategy formulation supported by effective performance as mediated by the atomization and reinforcement of the cognitive processes responsible (Fairclough *et al.*, 2005).

The finding that fatigued individuals generate less effort implies that fatigue is a state that ultimately generates a change in functioning; it is assumed that the fatigue state is accompanied by a disinclination to apply effort due to the difficulty experienced in recruiting adequate effort necessary to maintain performance (Matthews and Desmond, 2002). Therefore, fatigue's influence may be a result of the individual's inability to maintain task-directed effort, resulting in poor performance due to a failure to match task demands to the level of effort (Matthews and Desmond, 2002). This difficulty is thought to be compensated for or managed (by a supervisory executive system) by altering task goals (either changing performance standards or choosing low effort strategies) to allow the required effort to be lowered; thus this difficulty is managed through effort regulation or a dynamic adaptation to changing demands to maintain the desired level of performance and achieve effective effort use (Matthews and Desmond, 2002; Kahneman, 1973).

Compensatory Control Theory

Hockey, in his 1997 paper, built on Kahneman's 1973 model and asserted that actions and goals were regulated through compensatory control. This compensatory control refers to a mechanism that functions through an effort monitor allowing for dynamic resource allocation to occur (Hockey, 1997). Hockey's theory provides a mechanism for the dynamic regulatory activity supporting the adaptive response to environmental demands (Hockey, 1997). It also postulates that a supervisory controller is responsible for implementing various forms of performance-cost trade-off (Hockey, 1997). The model is essentially a regulation model of compensatory control that is based on the supposition that, although primary task performance remains stable under high demands, this performance (under high demands) results in high subjective strain and physiological activation levels (Hockey, 1997). Herein, the primary performance protection often observed during high stress tasks is not only as a result of further resource recruitment, but at the expense of enhanced behavioural, physiological, emotional and subjective costs (Hockey, 1997). These costs could be experienced and interpreted as mental effort or involving the straining and expenditure of mental resources (Hockey, 1997). This theory argues that the maintenance of performance is an active process under the individual’s control as a result of being managed by cognitive resources functioning through mental effort mobilisation (Hockey, 1997). This effort management is proposed to occur (in order to control task behaviour effectiveness) regardless of changing demands, energetic resource levels, or competing coexisting goals (Hockey, 1997). As such, the compensatory control model speaks of a process that adopts a strategy aimed at protecting primary goal performance (Hockey, 1997).

Hockey’s theory proposes that the cost of performance maintenance may be indirectly observed through secondary activities and/or a change in performance strategies including the use of less efficient strategies (Hockey, 1997). Hockey (1997) asserts that system stability during task output can be achieved by reducing performance goals.

The focus of the compensatory control theory is on the function of energetical resources (such as effort, activation, arousal, fatigue, stress and resources) as resources can both be subject to resource-management decisions and allocated as required (Hockey, 1997). The theory is centralised around a supposition that the biological/motivational context of behaviour has a separate effect on performance besides that of energising force (Hockey, 1997). The theory posits that motivation is actively involved in the maintenance, initiation and regulation of action (Hockey, 1997). Although Hockey’s theory is an extension on the work of Broadbent (1971) and Kahneman (1973) in that it features energetical processes and their role in performance, it differs from the earlier works as it highlights the role that motivation plays in controlling behaviour and action (Hockey, 1997).

The model is primarily a negative feedback system that allows a comparison between target output values (subject to modification should changes in perceived benefits and costs of alternative actions and states occur) and current activity (functioning as an action monitor) to be made (Hockey, 1997). As with all negative feedback models, changes in output are made in order to remove, reduce or maintain the discrepancy level within acceptable limits (limits set around a permissible error tolerance range) according to ‘cost-benefit decisions’ (Hockey, 1997).

The model distinguishes between two levels of control: one functioning on a lower ‘routine regulation’ level associated with 1) automatic control of well-learned skills that operate under the supervision of fixed performance goals, 2) no effort or active regulation beyond the normal effort needed to meet task demands, and 3) actions that do not require high effort expenditure because the system is not taxed above set functional limits (Hockey, 1997). The second level functions on an upper ‘effort-based regulation’ level associated with 1) the controlled processing of highly-skilled behaviour by a supervisory controller to manage additional and unpredictable modifications of the demands-resources balance, 2) organisation of effort which is sensitive to motivation and individual differences in how the value of task goals are perceived, and 3) regulation towards the target range when the discrepancy is too great for low-level corrections (Hockey, 1997).

Hockey pointed out that serious primary task output disruptions could be minimised under some circumstances by adopting a different way of performing the task (Hockey, 1997). This could be done perhaps to reduce the effort required to maintain task performance at a desired level, possibly allowing the worker to reduce the control requirements needed (Hockey, 1997). The compensatory control model predicts that increased activation of physiological systems ‘emergency’ reactions will surface as a result of the body mobilising further resources during tasks requiring high effort to maintain performance (Hockey, 1997). Lastly, the theory predicts that, fatigued individuals are more likely to choose or shift to low effort strategies (less use of high level control actions), even though they may be accompanied by increased risk (Hockey, 1997).

Challenges encountered when defining Task-induced Fatigue

The main concern with understanding task related fatigue has been centred on a lack of a way of quantifying and measuring it. It is perhaps because of this that there is no criterion, for instance, stating the percentage of performance decrement that must be evident before fatigue can be said to have occurred; a criterion that would mark the onset of fatigue during task execution. As it is difficult (if not impossible) to define fatigue holistically on an operational level, researchers have opted to measure it indirectly by considering its effect on performance (Spurgeon *et al.*, 1997). This means that effort is exerted on identifying symptoms and factors associated with fatigue and relating them to decrements in performance once they have already occurred.

An additional challenge in the pursuit for a better grasp of fatigue is the lack of a reliable fatigue indicator, as the currently suggested indicators have produced contradictory results (Lal and Craig, 2001). These contradictory findings may be largely due to sample sizes that fail to produce sufficient statistical evidence and poor experimental designs than to the failing of the technology used (Lal and Craig, 2001). Further, most views of fatigue rely on an inference being made about the existence of fatigue once it has already been presented as there is an absence of an a priori indicator of fatigue (Di Milia *et al.*, 2011).

Additionally, as studies have failed to determine causal relationships between variables that influence fatigue, there is still much that is unknown about the nature, effects, and ultimate causes of fatigue (Di Milia *et al.*, 2011; Abbiss and Laursen, 2007). Furthermore, its tendency to be altered by individual differences (depending on the individual’s susceptibility and adaptation to fatigue ability) heightens the difficulty in understanding the causal relationships between variables that influence fatigue (Noy *et al.*, 2011).

Fatigue Inducing Factors

A number of factors have been identified as being able to induce fatigue. However, a majority of the factors only alter the fatigue state and do not heavily influence or directly affect it like factors such as time-on-task and the intensity of task demands or workload (Gander *et al.*, 2011). The impact of the fatigue-inducing factors will depend on the intensity of each of the fatigue-inducing factors and the manner in which it interacts with the other factors; however, as it is unclear how much of a role on actual fatigue development each factor has, the impact of any individual fatigue-inducing factor is difficult to determine. Nonetheless, certain factors (all of which are inter-related) are generally believed to induce fatigue more rapidly than others, these include (but are not limited to): time-on-task, motivation, attention requirements and the level of monotony of the task.

Fatigue inducing factors have been divided into two basic categories: endogenous factors and exogenous factors (Di Milia *et al.*, 2011; Thiffault and Bergeron, 2003a). These two broad factors are believed to influence and contribute to the presentation of physiological states (Di Milia *et al.*, 2011). It is normally not possible to consider these factors individually as they occur collectively (Di Milia *et al.*, 2011).

Endogenous factors emanate from within the individual, affecting the individual's basic preparation state, relating to tonic phases of physiological activation and long term fluctuations of alertness, circadian variations (associated with time of day), and performance as a result of the task (Thiffault and Bergeron, 2003a). Exogenous factors are generated as a result of the individual's interaction with the environment and are therefore related to task-induced factors (Thiffault and Bergeron, 2003a).

Age, sex, physical and mental health, genetic makeup, race, circadian attributes, nutritional status and personality traits are among the endogenous factors that have been linked to fatigue (Di Milia *et al.*, 2011; Hartley *et al.*, 2003; Thiffault and Bergeron, 2003b; Smolensky *et al.*, 2011). The exogenous factors on the other hand, include: motivation, education, social class, time-on-task, work schedules and time of day effects, partner/marital status, workload, work recovery time and environmental tasks (Di Milia *et al.*, 2011; Hartley *et al.*, 2003). Neither the endogenous factors nor the exogenous factors happen independently as they interact and affect each other (Hartley *et al.*, 2003). Fatigue-inducing factors such as stimulation, boredom, monotony, sleep homeostasis, task-related and work related factors (related to the nature of work tasks such as time-on-task) have been identified as being able to induce mental fatigue (Williamson *et al.*, 2011; Smolensky *et al.*, 2011).

Time-on-Task

Research has indicated that tasks that require effort ultimately result in fatigue (Schmidt, 1982). It seems that time induces fatigue simply because any activity carried out for a long enough period will result in an increased difficulty maintaining the activity (Lal and Craig, 2001). This is why performance decreases as a function of time-on-task. It has been suggested that fatigue will result due to an imbalance between the intensity and duration and timing of work with recovery time (Dawson *et al.*, 2011). This imbalance emerges as a result of working for prolonged periods of time and an inability to sustain performance at the required level (Dawson *et al.*, 2011).

Motivation

Motivation seems to play a vital role in the initiation, maintenance and regulation of an action (Hockey, 1997). High ratings in alertness and motivation have been found to correlate with high performance scores (Hull *et al.*, 2003). In order to execute a task, the worker must first direct their behaviour towards meeting certain externally imposed target goals over a specified time period (Hockey, 1997). The success of the task will be determined by their ability to be co-operative with and to internalise the goals (Hockey, 1997; Matthews and Desmond, 2002; Hull *et al.*, 2003). In order for this to happen, they must assign a sufficient priority to the goals, resulting in them being co-operative and motivated (attending to the tasks, avoiding distractions from competing goals, focussing their attention on the goals etcetera) so that they can maintain performance at the required target output (Hockey, 1997). In this way, motivation will be swayed by the individual's view of the benefits, abilities/skills, and the job attributes in relation to themselves (Wei and Salvendy, 2006). If workers are not motivated to actively pursue the required level of performance and to maintain it, they will experience a disinclination to apply effort necessary to maintain performance (Matthews and Desmond, 2002). This disinclination to apply effort necessary to maintain performance can be understood as fatigue (in as far as an association exists between fatigue and a disinclination to apply effort); that is, the understanding of fatigue as including a reduced willingness to perform a task, points directly to fatigue emerging, to a degree, as a result of lack of motivation. Therefore, because fatigue usually emerges during sustained activity and motivation is involved in the maintenance of an action, the relationship between fatigue and motivation is such that an absence of motivation or low levels of motivation will increase the impact of fatigue. This accounts for why fatigue is often associated with a lack of motivation (Saxby *et al.*, 2007).

Monotony

Monotony is a complex and multidimensional phenomenon which affects physical, cognitive and affective sensations (Brandt *et al.*, 2004). Monotony is often defined according to sensory stimulation present in any situation; it is understood as presenting when stimulation is unvarying and highly repetitive (Brandt *et al.*, 2004; Thiffault and Bergeron. 2003a; Larue *et al.*, 2010). It often emerges whenever the stimuli remains unchanged or changes in a predictable manner resulting in a perception of the situation as being dull or uninteresting and boring due to the low arousal nature of the situation (Thiffault and Bergeron, 2003a; Brandt *et al.*, 2004). As a result, operators tend to develop a disinterest in performing the task any longer (Thiffault and Bergeron. 2003a; Lal and Craig, 2001; Larue *et al.*, 2010). By this definition, a situation will be perceived as monotonous depending on the nature, variation, frequency or quantity of the stimulation (Thiffault and Bergeron. 2003b). Monotony is understood as being a phenomenon that through the low stimulus situation, which it often occurs with, creates tasks that ‘unmask’ underlying latent sleepiness (Williamson *et al.*, 2011). The relation and distinction between monotony and boredom must be acknowledged; boredom is a subjectively experienced state or feeling that often emerges as a result of exposure to a monotonous task, resulting in reduced brain activation levels or alertness (Lal and Craig, 2001; Saxby *et al.*, 2007). In this way, monotony can instigate and worsen boredom.

Time-on-task, monotony and motivation are inter-related as an individual will perform better at tasks that are interesting (with an adequate level of arousal) because their interest in the task both motivates them to exert effort on the task and to pay attention to the task (Hull *et al.*, 2003).

Hull *et al.* (2003) noted that alertness and motivation needed to be taken into account when considering results from human performance tests as performance could be improved by countermeasures that increase alertness and motivation. It seems that fatigue induced by the aforementioned factors appears to result in what Desmond and Hancock (2001) referred to as ‘passive fatigue’: this is a fatigue state elicited by monotony resulting in a heavy reliance on a supervisory role including monitoring a task with infrequent responses, which reduces active control and produces passive fatigue (Matthews and Desmond, 2002). Understanding this type of fatigue means that individuals may fail to maintain task-directed effort not because the task is difficult, but because the task is not motivating or exciting (Matthews and Desmond, 2002). Active fatigue, however, refers to a type of fatigue induced by prolonged workload (Matthews and Desmond, 2002); tasks carried out for a long duration requiring sustained attention may induce both passive and active fatigue states.

FATIGUE ASSESSMENT TECHNIQUES

Since individuals affected by fatigue often exhibit (among other characteristics) slower reactions and an impaired visual scanning ability, fatigue measurements try to evaluate these particular reductions (Haworth, 1998). Thus the specific fatigue assessment techniques that may be selected to assess, for instance, the slower reactions and impaired visual scanning ability (associated with fatigue), may be those that are able to quantify alertness. This may perhaps be achieved through indexing the brain activity through monitoring blinking while other measures may index visual demand through monitoring eye closures and saccades (Lal and Craig, 2001). This is because the fatigue assessment techniques that are often selected are those that have been found to best index the particular fatigue attributes (characteristics associated with fatigue) or fatigue-induced reductions being assessed. If a change in alertness is the attribute under observation, then measures such as electroencephalography (EEG) may be used. And since many measures have been developed, each assessing a different aspect of fatigue, the ones deemed more ideal are those that have been found to be more predictive, valid and reliable (Lal and Craig, 2001). Researchers often select fatigue assessment techniques not only according how reliable, valid and predictive they are but also according to their accessibility, practicality (including the extent to which said devices are problematic) and affordability (Lal and Craig, 2001). As such, certain devices are favoured over others. The most preferred devices are small, portable, non-intrusive, easy to use, easily applicable to a number of environments and able to provide an objective and continuous index of fatigue (Lal and Craig, 2001). The preferred devices allow participants to execute the task without confounding the measures being recorded and are able to sense fatigue symptoms and present appropriate signals (Lal and Craig, 2001; Brown, 1982). For instance, EEG measures are preferable as the signal derived is often the most reliable and predictive owing to the measure's sensitivity to vigilance and ability to predict performance degradation during sustained cognitive work (Lal and Craig, 2001).

Most fatigue measures, however, function through assessing the consequences of fatigue or the impact of fatigue on performance and not necessarily the perception of fatigue. As this has a potential to elicit only a partial understanding of fatigue, reliable and valid subjective measures are necessary not only to gauge the perceived severity of fatigue, but also to assess changes in fatigue (as perceived by individuals) over time (Lee and Nino-Murcia, 1990). In this way, multi-dimensional measures of fatigue are used to allow researchers to infer any possible changes in strategies and workload in response to altering system demands (Rowe and Irwin, 1998). While performance measures target fatigue-induced task performance decrements, physiological tests serve as correlates of these performance decrements (Morris and Miller, 1996). Subjective measures of fatigue are necessary as performance measures tend to overlook the impact of individual differences in response to fatigue and the possibility that the observed change may be due to other factors (Di Milia *et al.*, 2011).

Therefore, fatigue assessment techniques need to take into account psychological, physiological, and behavioural measurements (Di Milia *et al.*, 2011; Thiffault and

Bergeron, 2003b). This is because fatigue is a complex phenomenon requiring that a multi-parametric approach, with regards to fatigue monitoring, be used as no single measure alone may be sensitive and reliable enough to quantify it (Heitmann *et al.*, 2001). Fatigue effects can thus be assessed by noting alterations in behaviour, subjective experience in addition to bodily and brain function (Gander *et al.*, 2011).

According to Heitmann *et al.* (2001), Lal and Craig (2001), Morris and Miller (1996) and Oken *et al.* (2006) electrooculographic measures (ideal for assessing arousal through looking at eye movement), EEG measures (ideal for indexing alertness through observing eye movements), heart rate responses (ideal for indexing workload), psychomotor tests (which have been used to assess perception, motor reactions and cognitive interpretation of fatigue), questionnaires (measuring the subjective component of fatigue such as when fatigue appeared consciously to the participant as well as the factors contributing to fatigue), and video imaging data (focussing on facial characteristics associated with fatigue such as slow eyelid closure, yawning, nodding and facial tone) have been used to monitor fatigue attributes. Although a large number of techniques exist, the fatigue assessment techniques discussed in this paper (though only a small portion of the methods available) are those that were deemed more appropriate to for the study.

Performance Measures

Dinges and Kribbs (1991) put forward a notion that performance changes were ideal fatigue indicators as performance (being a critical probe of the central nervous system ability) provided a direct evidence link of fatigue effects. This view suggests that changes in performance occur as functional consequences of the physiological effects of fatigue (Williamson *et al.*, 2011). This is because task-induced fatigue appears to impair performance, reduce the level of control an individual has over an activity and diminish task-directed effort (Matthews and Desmond, 2002). Effectively, one of the main effects that fatigue has is performance degradation (Staal, 2004). Research on fatigue effects on performance has indicated that performance also decreases as a function of time-on-task (Hartley *et al.*, 2003). Performance measures target fatigue-induced task performance decrements often in the form of speed, accuracy, reaction time and vigilance tests as well as simulated tasks (Morris and Miller, 1996; Haworth, 1998; Di Milia *et al.*, 2011). More specifically, these measures often target frequency and accuracy of detections or reaction times of responses to stimuli (Hartley *et al.*, 2003; Van Dongen and Dinges, 2003).

Although it is understood that any activity requiring effort carried out for a long enough period will result in an increased difficulty maintaining the activity (Lal and Craig, 2001; Schmidt, 1983), Williamson *et al.* (2011) note that predictable performance and vigilance decrements will result from tasks that require individuals to sustain performance and attention, as such tasks are fatigue-prone. Tasks that have also been found to be fatigue-prone are those that are monotonous (Matthews and Desmond, 2002; Williamson *et al.*, 2011); it has been noted that the more monotonous the task, the more likely a rapid performance decline will occur (Thiffault and Bergeron, 2003b).

Cognitive fatigue research has indicated that activities involving vigilance and complex cognitive performance are more sensitive to fatigue than simple, well-learned tasks (Staal, 2004). Research on the ability to react to changes in stimuli, sustain attention, and maintain vigilance over time, has shown that extreme performance declines occur after only a short time after the commencement of monitoring/vigilance tasks (Schoenfeld and Scerbo, 1999). Since vigilance is described as a form of arousal or alertness whose activity is affected by the frequency and variation of stimulation, noise, ambient temperature and vibration, performance in vigilance tasks is affected by the signal type (the source of the signal, the frequency of the signal and its intensity) and the motivation of the observer (Wei and Salvendy, 2006). Usually, performance will decline rapidly in vigilance tasks with a lower signal frequency and intensity.

Performance tests usually aim at assessing cognitive functions objectively; most tests assess cognitive function ranges- some assess simple psychomotor functioning (such as reaction time) while others assess working memory (Van Dongen and Dinges, 2003). They typically focus on indirect measurements of performance, such as speed and accuracy, in tasks designed to be approximations of work (Spurgeon *et* *al.*, 1997). Essentially, performance measures capture how well the user is performing a given task (Palinko *et al.*, 2010). With regards to measuring speed and accuracy specifically, although individuals tend to exhibit a speed/accuracy trade-off on cognitive measures in response to fatigue, performance speed tends to decrease slightly while accuracy suffers a moderate decrease over time on a fatiguing task (Fitts, 1966 in Staal, 2004). Since fatigue affects attention and performance, tests designed to evaluate vigilance are often used as it overlaps with attention and performance (Lal and Craig, 2001).

Redondo and Valle-Inclan (1992) acknowledged that performance tests had to be conducted alongside physiological, subjective and behavioural measures in order to properly evaluate human performance. According to Hockey (1997) this is because, individuals tended to cope actively with changes in task demands and protect performance. Consequently, the true effects of fatigue may be masked if no other supplementary measures are used (Hockey, 1997). In addition, while effects of fatigue on tasks can be observed in vigilance tasks, not all performance functions are sensitive to fatigue. Matthews and Desmond (2002) thus argued that researchers needed to evaluate performance across a broad range of performance indicators to determine the effects on performance functions, because variations have been found in the effects of fatigue on task performance (Williamson *et al.*, 2011). Additionally, Drowatzky (1981) found that an individual’s performance usually showed erratic and irregular variation implying that the progression from not fatigued to fatigued was not a linear and simple one but one that was subject to other feedback mechanisms. Ideally, performance factors must be considered critically as each performance measurement will elicit different results as it depends on the task and motivational context of the experiment (Nilsson *et al.*, 1997).

Simple Reaction Time Tests

Reaction time at its core is a matter of timing as it measures the time that has elapsed from the moment a stimulus is presented until the beginning/appearance of the response (Drowatzky, 1981; Schmidt, 1982). This means that reaction time tests are able to indicate the speed at which an organism can perceive and respond to a stimulus (Kell, 2007; Drowatzky, 1981). Since reaction time is informed largely by the central nervous system (CNS) and its processes (Kell, 2007; Drowatzky, 1981), it is dependent on the processes of the CNS. In this way, how quickly an organism responds will depend on speed of the CNS process relating to: the excitation and arousal of the sense organs by the stimulus, the conversion of the sense organ excitation into a nerve impulse, the arrival of the nerve impulse at the brain, the interpretation of set impulse, the sending of a second impulse to the appropriate muscles and the contraction of the muscles (Drowatzky, 1981). As reaction time remains the same regardless of motivation, it is used to gauge the true response ability of the mental processes and the CNS (Schmidt, 1982). Reaction time tests have been used to assess fatigue (more especially mental fatigue) as fatigue increases the time it takes to respond to a stimulus (Kosinski, 2010). Reaction time tests have also been used to index alertness/arousal and attention (Van Dongen and Dinges, 2003). Reaction time has been found to increase as time-on-task increases (Hartley *et al.*, 2003). Average simple reaction time values are dependent on the stimulated sense organ and stimulus intensity; for instance, human beings respond faster to sound than to light (Drowatzky, 1981). Typically, instead of worsening, response time on simple tasks is often enhanced as mastery on the task is developed (Staal, 2004).

Physiological Measures of Fatigue

Psychophysiological measures are thought to have the advantage of event concurrency as they index effort and load naturally because any task requires physiological activity by definition (Rokicki, 1995; Brookhuis and De Waard, 2010). Rowe and Irwin (1998) suggested that physiological measures were beneficial as they could be recorded continuously, allowing for the identification of phasic shifts in mental effort and workload as they occur. Furthermore, as many of the physiological measures are unobtrusive, operators are often able to perform their tasks with little interference (Rowe and Irwin, 1998). Other advantages of physiological measures are that they do not always require overt performance and the multi-dimensional physiological measures provide different perspectives of mental effort and workload

(Rowe and Irwin, 1998). Physiological measures depend on many factors, such as the worker's physical activity, other aspects that contribute to the worker's cognitive state (such as stress and arousal), and environmental variables (Palinko *et al.*, 2010). Usually, tasks requiring a higher cognitive load and effort place a higher demand on the worker's cognitive resources (Palinko *et al.*, 2010). These tasks will, if performed continuously, result in error (Palinko *et al.*, 2010). Fairclough *et al.*, (2005) reported that measurements of psychophysiological variables were regularly used to index the level of cognitive demand related to a task. The changes in cognitive demand related to a task have been found to elicit responses which occur in a predictable fashion (Fairclough *et al.*, 2005). Furthermore, these changes are reported to be associated with energy mobilisation and an investment of mental effort (Fairclough *et al.*, 2005). According to Fairclough and Houston (2004), any measure of mental effort ought to be responsive to both the computational demands and the presence of biological/environmental stressors.

Eye motion Analysis

Research has indicated that physiological measures that assess heart rate activity and variability, eye movement activity and changes in facial muscle activity are able to adequately indicate fatigue (Craig *et al.*, 2006). Oculomotoric parameters are used in modern day to assess fatigue effects (Schleicher *et al.*, 2008). Eye measures are used to assess oculomotor related symptoms, which are thought to build over time (the longer they are demanded) until their responsiveness is diminished, resulting in a decline in performance (Sullivan, 2008). Sullivan (2008) reported that such symptoms (inclusive of changes in eyeblink responses) could be assessed objectively. These symptoms have been used to indicate visual fatigue and general fatigue. While visual fatigue may be depicted by an increase in visual discomfort and/or a reduction in visual performance, general fatigue (often indicative of mental workload) has been associated with a decline in arousal (leading to performance reductions) with no actual visual discomfort present (Sullivan, 2008). Eye motion analyses have also been extensively used in monitoring alertness and the onset of drowsiness/sleepiness during task requiring sustained attention (Schleicher *et al.*, 2008; Van Orden *et al.*, 2000; Oken *et al.*, 2006).

The commonly used eye motion parameters include pupil diameter, saccades, fixations, blink frequency and blink duration. Pupil diameter, thought to change in response to the activity of the sympathetic and peripheral nervous systems, has been found to reduce with decreased performance in tasks requiring sustained attention and during drowsiness (Oken *et al.*, 2006; De Waard, 1996). Although the usefulness of using pupil diameter as a measure of fatigue during visually-oriented tasks is still to be established (Van Orden *et al.*, 2000), pupil diameter has been found to indicate mental workload (Recarte *et al.*, 2008; Kahneman, 1973; Van Orden *et al.*, 2000). Saccades have been found to relate to workload, performance and time-on-task, with declines in saccades observed as a function of time-on-task (Morris and Miller, 1996; Van Orden *et al.*, 2000; Stern *et al.*, 1994). Saccadic speed has been proved to be a fatigue indicator (Schleicher *et al.*, 2008). Fixations, found to correlate with vigilance during visual task performance (Oken *et al.*, 2006), are sensitive to time-on-task effects during task execution (Van Orden *et al.*, 2000). A clear relationship with fatigue is however, yet to be determined (Schleicher *et al.*, 2008).

Though the above-mentioned eye motion parameters have been used to assess fatigue effects, only blink frequency and duration are discussed in detail. As the aim was to assess fatigue on a multi-dimensional level, these two eye motion parameters, and validated fatigue indicators, (in addition to the other physiological assessment techniques employed) were deemed able to sufficiently indicate fatigue. It was also decided that using only these two parameters would avoid duplicating the measurement of fatigue attributes already being assessed by other measurements.

Blink frequency and duration

Blink frequency and duration, in particular, are frequently used oculomotoric indicators for alertness and an ability to react to environmental stimuli (Schleicher *et al.*, 2008). Eye movement activity measurements are used as the data elicited from eye measurements is indicative of the functioning of the CNS (Stern *et al.*, 1984; Morris and Miller, 1996). Eye blink movements in particular react to the response and attentional demands of the task. This is because the mechanics involved in the eye blink (including the frequency of its occurrence) are influenced by higher nervous processes (Stern *et al.*, 1984). These higher order processes seem to produce blinks at predictable points during task execution, occurring at points in time when they are least likely to hinder information intake or performance. These higher order processes tend to alter blinking in response variables such as arousal, alertness, situational demands, fatigue, higher cognitive processes and anxiety (Stern *et al.*, 1984; Schleicher *et al.*, 2008; Recarte *et al.*, 2008; Bentivoglio *et al.*, 1997).

Research on the effects of fatigue on eye parameters has, however, elicited contradictory results. For instance, Haworth (1998) indicated that reduced eye blinks were an indication of fatigue. Conversely, Schleicher *et al.* (2008) and Nilsson *et al.* (1997) observed that increases in blink frequency and duration were associated with fatigue; this is in line with Stern *et al.* (1994) who contended that increased blink frequencies were indications of fatigue. Craig *et al* (2006) reported that persons experiencing fatigue displayed changes in their eye movement activity; these changes were in the form of their eye blink and duration (Craig *et al.*, 2006). Blink duration, defined as the sum total duration of lid closure, is considered the idlest variable to indicate subjective fatigue (Schleicher *et al.*, 2008). Blink frequency changes have been found to be sensitive to even light fatigue as an increase in blink frequency has been found to emerge to indicate when a person has transitioned from being awake to having reduced vigilance- a fatigue symptom (Schleicher *et al.*, 2008). Blink duration changes are more sensitive for transitions into severe sleepiness (Schleicher *et al.*, 2008). Craig *et al.* (2006) further reported that closure times of eye blinks tended to increase from approximately 200ms to 300ms during fatigue. It was reported that an eye blink closure range from 100 to 300 ms was indicative of normal blinks while that between 200 to 450 ms was indicative of definite fatigue onset (Craig *et al.*, 2006). Bentivoglio *et al.* (1997) reported that although blinks occurred at a rate of 12 – 15 blinks a minute, this rate increased with fatigue. De Waard (1996) reported mixed results with regards to the sensitivity of eye blink rate and duration to workload; conversely prolonged blink durations have been reported to correlate with an increase in task demands.

Schleicher *et al.* (2008) understood increased eye blink durations as reflecting a deactivation or slowing down process of a number of physiological processes as a result of decreased neuronal firing rates. This would account for fatigue, as fatigue is essentially a form of decreased activation (Recarte *et al.*, 2008). Eye blink frequency reductions are thought to be related to the level of visual demand of a task (Stern *et al.*, 1994). Since eye functions have been deemed useful for evaluating visual demands (De Waard, 1996), tasks involving reading could be used to index the proposed reduction in blink inhibition as a result of both the visual demand on the processes and time-on-task function (Stern *et al.*, 1994).

Stern *et al.* (1994) and Schleicher *et al.* (2008) suggest that increases in blink rate, as a result of fatigue influences, could be understood as occurring as a result of decreased attentional demands or visual load, leading to a reduced blink inhibition. This way of interpreting increases in blinking over time assigns the increased blink rate to a reduced ability to maintain inhibitory control over extended periods of time (Stern *et al.*, 1994).

The endogenous eye blink is unique as it refers to blinks that occur with an absence of an identifiable external eliciting stimulus (Stern *et al.*, 1994). While increases in the endogenous eye blinks can occur in response to the complexity and nature of a task, exogenous blinks are categorised by voluntary and reflex blinks either in response to an identifiable stimulus or as a protective response (Stern *et al.*, 1994). For instance, difficult cognitive tasks such as arithmetic tasks elicit an increase in blink rate (Stern *et al.*, 1984; Stern *et al.*, 1994). The endogenous eye blink duration has been reported to increase with time-on-task (Morris and Miller, 1996; Stern *et al.*, 1994). Bentivoglio *et al.* (1997) and Recarte *et al.* (2008) reported that tasks that only required visual fixation such as reading and detecting targets elicited reduced blink rates as they were not as cognitively demanding as they were visually demanding. Tasks such as mental arithmetic have tended to produce the highest number of blinks while others like reading have been found to produce the fewest blinks (Stern *et al.*, 1984; Stern *et al.*, 1994).

The endogenous eye blink also responds to whether or not tasks being performed require vocalisation; Stern *et al.* (1984) reported that tasks performed silently elicited significant blink rate decreases while those that required verbal input elicited increased blink rates. It seems then that tasks involving memory or speech increase blink rate (Bentivoglio *et al.*, 1997). Furthermore, a decrease in arousal has been found to be associated with a reduced blink rate (Stern *et al.*, 1984). The nature of a task has also been found to contribute to blink rate; increases in blink rate have been found to occur in highly repetitive tasks that have been performed for a long period (Stern *et al.*, 1984; Stern *et al.*, 1994; Van Orden *et al.*, 2000). This has been reported during tasks that lead to fatigue and boredom (Stern *et al.*, 1984). Previous research on eye movement and pupil measures has shown that sustained attention to a monotonous task can result in performance fluctuations (Van Orden *et al.*, 2000).

Body Temperature Measures

Temperature has been recorded to monitor and measure several processes occurring within the body (Moran *et al.*, 2007). Although temperature measurements are traditionally used to monitor vital signs for medical purposes (Moran *et al.*, 2007), they have also been used to monitor fatigue (Lal and Craig, 2001). Body temperature is primarily regulated by the hypothalamus as the hypothalamus is responsive to temperature increases or decreases (Brinnel and Cabanac, 1989; Hammel *et al.*, 1963; Levy *et al.*, 2006). The hypothalamus is a part of the nervous system which controls thermoregulation (Stolwijk and Hardy, 1966). It has been established that the regulation of the human body temperature is possible through the combination of skin temperature and brain temperature in the brain stem (Hammel *et al.*, 1963). Skin temperature responds to external environmental changes as the skin exchanges heat with the environment (Hammel *et al.*, 1963; Stolwijk and Hardy, 1966). Often, the hypothalamus uses feedback from the skin to know when and how to alter body temperature, increasing or decreasing heat production accordingly (Hammel *et al.*, 1963). It is because of this fact that skin temperature is perceived as an unreliable temperature indicator (Stolwijk and Hardy, 1966). Core temperature recordings are preferred as they are not influenced by external factors (Moran *et al.*, 2007). Tympanic temperature measurements have been identified as accurate core temperature recording sites (Moran *et al.*, 2007; Chamberlin *et al.*, 1995). The accuracy of tympanic temperature measurements has however been criticised as the auditory canal has been established to be affected by ambient air during exposure to cold environments (Brinnel and Cabanac, 1989). Furthermore, the presence of skin within the auditory canal is thought to contaminate any measurements in the same way that skin temperature measurements are contaminated (Brinnel and Cabanac, 1989).

Temperature is believed to be positively correlated with neurobehavioural performance (Kleitman *et al.*,1963); with high and low temperature values being found to correlate with good and poor performance (Kleitman *et al.*,1963; Van Dongen and Dinges, 2003; Wright *et al.*, 2002). Kleitman *et al.* (1963) also suggested that temperature served as a mechanism underlying performance regulation. Reilly and Waterhouse (2009) supported Kleitman *et al.* (1963)'s suggestion as they noted that a rhythm of human performance (mental and physical) existed that followed a rhythm of core temperature over time. Based on literature reports that stated that body temperature influenced human performance, the extent of the relation between performance and temperature was researched (Wright *et al.*, 2002). It was found that body temperature modulated neurobehavioral function in humans as performance was better when body temperature was high and worse when body temperature was low (Wright *et al.*, 2002). Increases in core temperature have been reported to be associated with fatigue (Lal and Craig, 2001).

Further, Wright *et al.* (2002) reported that a positive relationship existed between alertness and daily rhythms of body temperature. As a result, cognitive function was reported to increase with an increase in body temperature and reduce with a reduction in body temperature (Wright *et al.*, 2002; Kleitman *et al.*,1963; Van Dongen and Dinges, 2003). Processes controlling performance on reaction time tests, memory tests, attention maintenance tasks, and subjective alertness were reported by Wright *et al.* (2002) to have improved with increases in temperature; specifically, fewer attention lapses, higher subjective alertness reports, faster reaction times and better memory recall were associated with higher body temperature (Wright *et al.*, 2002).

Heart Rate

Heart rate (HR) has been used historically to index arousal level, mental effort and load, anxiety and task involvement (Jorna, 1992; De Waard, 1996). HR refers to the number of heart beats within a fixed period of time (Brookhuis and De Waard, 2010). Generally, previous studies assessing HR responses to task demand have found that HR increases with an increase in demand (Fairclough *et al.*, 2005).

Fundamentally, HR is understood as an index of activation levels in response to the autonomic nervous system (ANS, Choi and Gutierrez-Osuna, 2009). As the ANS is responsible for maintaining the body at a steady state (homeostasis) through the responses of the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS, the two main branches of the ANS), HR may be used to approximate the activation level of the two branches (Choi and Gutierrez-Osuna, 2009; Brookhuis and De Waard, 2010). In this way, HR is innervated both by the PNS and the SNS and irregularities in heart rate will emerge as a result of the continuous feedback between the ANS and peripheral autonomic receptors (De Waard, 1996). However, as inferring changes in the activation of the SNS versus the PNS is difficult since they are indistinguishable, changes in HR cannot be solely relied on (Choi and Gutierrez-Osuna, 2009). Instead, the difference in effects of the branches on HR must be assessed. This analysis is usually done through calculating heart rate variability (Choi and Gutierrez-Osuna, 2009).

Heart Rate Variability

Heart rate variability (HRV) is used as an indicator of the autonomic regulation activity of HR, specifically sympathetic and parasympathetic activity as it essentially is a measure of autonomic activity that describes variations in the HR (Tran *et al.*, 2009). HRV is an analysis of the beat-to-beat fluctuations periods of the heart rhythm (Choi and Gutierrez-Osuna, 2009; Jorna, 1992; Boyle *et al.*, 2007). Essentially, HRV is a spectral analysis of inter-beat intervals (Jorna, 1992). HRV refers to heartbeats comprised of variable time durations with different oscillation patterns that lead to time series with source-characteristic patterns and frequency contents (Brookhuis and De Waard, 2010).

HRV has been identified to be sensitive to changing levels of effort, fatigue and stress (Rowe and Irwin, 1998; Boyle *et al.*, 2007). Assessing the changes in HRV associated with fatigue was suggested by Tran *et al.* (2009) as a potential way of understanding processes involved with fatigue. Traditionally, the standard deviation of the normal to normal heart rate intervals (SDNN) is analyzed when studying HRV (Tran *et al.*, 2009). The many studies that have evaluated the relationship between fatigue and HRV suggest that fatigue tends to cause a reduction in HRV (Tran *et al.*, 2009). This association of HRV to fatigue can also be expressed as an increased low frequency (LF) component or an increased sympathetic activity (Tran *et al.*, 2009). Also pertaining to fatigue studies, HRV measures have been used to outline the point/time during task execution when fatigue becomes problematic (Boyle *et al.*, 2007).

An increase in HRV on average serves as an indication of reduced stress, fatigue, vigilance or mental workload associated with a task (Boyle *et al.*, 2007). HRV measures are popular as they are non-intrusive measures that allow for continuous recordings responsive to task changes (Rowe and Irwin, 1998). HRV measures are also widely used as HRV is able to respond to rapid shifts in mental effort, strategies and workload (Rowe and Irwin, 1998; Redondo and Valle-Inclan, 1992). During task performance when participants have to spend mental effort, increases in HR and decreases HRV are typically clear (Brookhuis and De Waard, 2010). The extent of the response patterns will however, dependent on amount and type of effort required by the task (Brookhuis and De Waard, 2010). Furthermore, research has indicated that mental effort expended by the operator is not automatically determined by the task load but more by internal goals and criteria they decided to adopt (Rowe and Irwin, 1998). For instance, Tran *et al.* (2009) reported that studies assessing HRV responses under different tasks found increased HRV during vigilance tasks compared to proofreading tasks. Furthermore, tasks thought to be too mentally challenging are believed to lead to performance decrements and increases in HRV as a result of participants giving up and disengaging in the task, indicative of the investment of less effort (Rowe and Irwin, 1998).

Time-based measures and spectral (frequency-based) analyses are used to evaluate HRV (Boyle *et al.*, 2007).

Time-domain Analysis

The time domain analysis is more commonly used as it can be assessed through the use of a simple calculation of the standard deviation of R-R (inter-beat) intervals (Boyle *et al.*, 2007; Jorna, 1992). Time domain examinations are also valuable as they can assess immediate HRV changes (Boyle *et al.*, 2007). The disadvantage of time-domain analysis however, is that it provides very little insight into the sources of variance influencing HRV (Jorna, 1992).

Spectral Analysis

The spectral analysis of HRV is a non-invasive tool used to detect the ANS regulation of the heart (Zengyong *et al.*, 2005). In essence, the spectral analysis produces details about separate rhythms and mechanisms that control heart rate fluctuations (Jorna, 1992). Spectral analyses are the preferred method as they reveal the total frequency content of analog signals (Jorna, 1992). This same analysis has also been implicated as potentially contributing to the identification factors involved in the reductions and improvements of mental efficiency (Jorna, 1992). A power spectral analysis is also conducted when measuring HRV as an indicator of the autonomic modulation of heart rate (Tran *et al.*, 2009). Studies have further inferred parasympathetic influences on cardiovascular control by assessing power spectral analysis (Fairclough and Houston, 2004). Spectral components for short-term HRV changes are normally split into three frequency ranges (Rowe and Irwin, 1998; Jorna, 1992): the very low frequency or VLF range (0-0.04 Hz); low frequency or LF range (0.04-0.15 Hz) mediated by (and thus reflecting) both PNS and SNS; and high frequency or HF range (0.15-0.4 Hz) mediated by PNS activation and influenced by respiratory-related fluctuations (Rowe and Irwin, 1998; Choi and Gutierrez-Osuna, 2009; De Waard, 1996; Tran *et al.*, 2009).

This allows for a divide of the components of HRV into LF power versus HF power analyses intervals and an ability to distinguish between sympathetic (LF) and parasympathetic (HF) activity with LF/HF being the sympathovagal balance (Boyle *et al.*, 2007; Zengyong *et al.*, 2005).

The LF or 0.1 Hz component is usually evaluated as an indicator of cognitive workload (Rowe and Irwin, 1998; Choi and Gutierrez-Osuna, 2009); a peak in this component indicates reduced cognitive workload and effort while a flattening of the 0.1 component reflects increased mental workload (Rowe and Irwin, 1998; Fairclough *et al.*, 2005). A decrease in power in both the 0.1 Hz component and HF band has been revealed to be related to mental effort and task demands (De Waard, 1996). Since the 0.1 Hz component of HRV is sensitive to a range of sources of mental effort, it will be affected by tasks involving complex decision-making, time-pressure and an increased time-sharing in working memory component (Fairclough and Houston, 2004). Specific tasks inclusive of a high cognitive demand that the 0.1 Hz mid-frequency component has shown sensitivity to include tasks made up of increased working memory load and problem solving factors (Fairclough *et al.*, 2005; Fairclough and Houston, 2004). Furthermore, sources of the effort state such as noise, sleep deprivation and time-on-task have been shown to affect the 0.1 Hz component (Fairclough and Houston, 2004). Despite the above stated about the sensitivity of the 0.1 Hz component, critical arguments against the component have stated that it is suspect and limited in its sensitivity as it tends to be discriminative of only gross changes in task demands (Fairclough and Houston, 2004; Jorna, 1992).

As a result of the impact of the ANS branches on HR, the ratio of LF to HF power is occasionally used as an index of automatic balance (Choi and Gutierrez-Osuna, 2009). The HF component of HRV has been reported to respond to tasks requiring multitasking and a high working memory load and to decrease when task demand is high (Fairclough *et al.*, 2005).

Subjective Measures of Fatigue

Subjective ratings and measures are the most commonly used methods of conducting workload assessments (Hart and Staveland, 1988). Matthews and Desmond (2002) asserted that fatigue states could be assessed by self-reports. Subjective measures have been used to validate and explain physiological measures and are understood as being necessary for attaining the operator’s perspective about how much they are exerting and their level of discomfort (Recarte *et al.*, 2008; Rokicki, 1995; Borg, 1990). Subjective ratings are able to function as a criterion against which other measures are compared (Hart and Staveland, 1988). Furthermore, it is proposed by Hart and Staveland, (1988) and Sheridan (cited in Wickens, 1984) that subjective measures may be the best measures as they can tap into the core of mental workload and offer a valid and sensitive indicator. Additionally, subjective ratings are ideal measures as they are able to combine the effects of numerous workload contributors as well as serve as the sole source of information about the subjective impact of a task on operators (Hart and Staveland, 1988; De Waard, 1996). Subjective measures are valued as their subjectivity allows for a description of the operator’s awareness of increasing effort, even before any performance degradation occurs (De Waard, 1996). Most self-report measures include workload dimensions such as effort and performance in addition to the operator’s attitude and state (De Waard, 1996). As the focus of subjective measures is not solely on performance, a measure of the cost behind performance (whether this cost be perceptual or physiological) is taken into account (Borg, 1990). This measure of the cost behind performance is based on a necessity to integrate the three different effort variable kinds including physiological measurements, perceptual responses and performance (Borg, 1990). Subjective data must, however, take individual differences into account and also permit a comparison with the objective data (Nilsson *et al.*, 1997).

Even though subjective measures have many advantages, the identified disadvantages and criticisms reveal that they cannot be the sole or dominant data collection method (Rokicki, 1995). Subjective ratings and self-report measures have been criticised for not being accurate measures as it is difficult to introspectively diagnose (within a dimensional framework) the source of resource demand as some internal processes may not yet be accessible to consciousness (De Waard, 1996; Recarte *et al.*, 2008). Additionally, fatigue has an ability to impair an individual’s capacity for introspection (Brown, 1982). An additional criticism is based on the fact that it is difficult to discriminate between the task demands (De Waard, 1996; Recarte *et al.*, 2008). Additional limitations for subjective measures include the tendency for the successful completion of a task to reduce the impact of the task in the operator's mind shortly after the event thus changing the operator's propensity to report symptoms (Rokicki, 1995; Brown, 1982). This will, in turn, bring the accuracy and validity of the data to question (Rokicki, 1995). Moreover, subjective measures collected in real-time tend to increase the workload of the operator and may thus hinder primary task execution or impose invalid results (Rokicki, 1995).

Conversely, in spite of the above stated criticisms, several authors assert that subjective data tends to elicit clearer and more consistent results in comparison to physiological measures (Nilsson *et al.*, 1997). Nilsson *et al.* (1997) believed that this was the case as the brain was unable to adequately monitor all the physiological processes by objective means as cognitive factors (including information from the external environment), motivational states and memory to calculate fatigue are often already in use in conjunction with physiological processes.

The NASA-Task Load Index

The NASA-Task Load Index (NASA-TLX) is among the more frequently used subjective rating scales (De Waard, 1996). It is a subjective workload assessment tool, which provides a method to identify specific sources of workload related to a given task (Hart and Staveland, 1988; Hart, 2006). The NASA-TLX has been found to be sensitive and has functioned effectively in a broad range of tasks (Recarte *et al.*, 2008). As it is a subjective rating scale, it derives a score based on the workload imposed on the operator (Hart, 2006). Essentially, the NASA-TLX is a multidimensional rating technique designed to obtain an overall workload estimate from operators while they are performing a task or immediately afterwards (Hart and Staveland, 1988; Hart, 2006; De Waard, 1996). The information that can be attained from the NASA-TLX includes specifics about the predictive validity of performance in different tasks as well as the sources of mental workload (Recarte *et al.*, 2008). The rating scale is based on weighted average ratings on six subscales (Hart and Staveland, 1988; Hart, 2006). These subscales include mental demand, physical demand, temporal demand, own performance, effort and frustration (Hart, 2006; Reacrte *et al.*, 2008). Each subscale represents an independent variable cluster and dimension assumed to contribute to workload experienced while performing a task (Hart, 2006).

Ratings of Perceived Exertion Category Ratio Scale

Ratings of perceived exertion (RPEs) complement physiological measurements by providing descriptions of how subjective intensity varies with physical intensity (Borg, 1990). Perceived exertion has been defined by Robertson and Noble (1997) as the subjective intensity of strain, discomfort, effort, and/or fatigue experienced during physical exercise. RPEs are highly informative perceptions of exertion as they are able to indicate the degree of physical strain (Borg, 1990; Faulkner and Eston, 2008). RPEs function by combining information from the CNS, peripheral muscles and joints, and the cardiovascular and respiratory systems to give an indication of the impact of the task on the person (Borg, 1990; Eston, 2012). In this way, RPEs are able to specify the conscious awareness of the sensation of fatigue. As perception of exertion seems to increase positively with an increase in physical workload, increases in perceived exertion can often be predicted from increases in heart rate (Faulkner and Eston, 2008; Borg, 1990). This is because high correlations have been found between perceived exertion and physiological variables such as heart rate, blood lactate concentrations, and many others ‘both in reference to peripheral and central cues’ (Borg, 1990; Eston, 2012). The terms ‘effort’ and ‘exertion’ are used interchangeably. The RPE category ratio (CR) 10 scale, particularly, is a more informative method that allows for determinations of psychophysical intensification functions and direct level estimations to be obtained (Borg, 1990). This new method is particularly useful when conducting ergonomic work tasks evaluations to obtain estimations of the level of physical strain, fatigue and discomfort (Borg, 1990). Even though the RPE CR 10 scale does not give a valid intensity level for differential use, it provides an informative category ratio scaling useful for measuring the direct intensity level of the degree of perceived exertion (Borg, 1990; Eston, 2012).

CHAPTER III

METHODOLOGY

AIM

The current research project intended to deliver accounts of fatigue regulation by studying fatigue at a resource level and detailing how fatigue develops in an attempt to understand the roles that down and up regulation play in the regulation of fatigue. In this way, this study aimed to detail the possible identification of regulatory mechanisms for cognitive fatigue by investigating how fatigue was regulated. A second aim of the study was to establish whether or not the manner in which performance, psychophysical and subjective variables were modified over time followed a similar regulation pattern. The study also aimed to assess if and when instances of down and up regulation occurred during a fatiguing task as well as whether instances of down and up regulation observed occurred before the onset of fatigue exclusively or if the regulation pattern was an ongoing cyclic process that occurred until the end of task execution.

Furthermore, this study intended to research the extent to which the fatigue regulation pattern changed or remained the same when different resources were fatigued. In an attempt to achieve this, an investigation was carried out that aimed to give a description of fatigue development and regulation in specific resources, detailing: (1) the impact that regulation had on the duration of time it took for each resource to fatigue, (2) whether or not the regulation pattern evidenced in the performance, psychophysical and subjective variables differed for each resource as well as (3) whether examining the short-term recovery profile of fatigued resources could be used to indicate whether performance reduction was caused by fatigue regulation or fatigue as well as to give insight into the possible purpose of fatigue regulation.

RESEARCH CONCEPT

Conceptual Considerations

Schmidt (1983) postulated that any task requiring the exertion of effort would ultimately result in fatigue. Additionally, the identification of fast fatigue-inducing circumstances and factors meant that researchers desiring to observe fatigue simply had to ensure that individuals performed a task with the fatigue inducing circumstances and factors for a long enough duration. The discovery about how to induce fatigue meant, for the author, that the body had a seemingly automatic fatigue response to certain tasks. The identification of this seemingly automatic fatigue response may thus also be systematic, in that, the body must have a way of trying to prevent the occurrence of fatigue or a way of managing fatigue. The fact that fatigue is a multi-dimensional construct with psychological, physiological, emotional and behavioural effects (Di Milia *et al.*, 2011; Abbiss and Laursen, 2007, Lewis and Wessely, 1992; Jansen *et al.*, 2003) means that fatigue has a large enough and an important enough impact on the body's functioning to elicit responses from as many of the body's systems as possible. In light of this, such a phenomenon must be one that is regulated and monitored.

Drowatzky (1981) found that an individual's performance usually showed erratic and irregular variation, meaning that the progression from 'not fatigued', to 'fatigued' was not a linear and simple one but one that was subject to feedback mechanisms and regulation. In addition to noting that erratic and irregular variations were observed during task performance, Drowatzky (1981) noted that usually, the variations (understood as slight improvements) became less erratic over time. This suggests a regulation pattern of sorts responding to time-on-task and experience.

The First Pilot Session

Several pilot studies, that included fatigue-inducing test batteries and tests, were conducted by the researcher. These tests were based on simple cognitive tasks that individuals had had previous experience with in their lives (e.g. reading, memory recall) that required sustained attention and were highly monotonous. In line with

Drowatzky (1981)'s finding, several erratic and irregular performance variations over time were observed. All variations were inclusive of up and down regulation. These instances of up and down regulation are referred to here as 'the regulation pattern'.

Initially, the focus of the project was on differentiating regulatory mechanisms from fatigue mechanisms. This was done because research had indicated the existence of an 'end spurt' (or sudden improvement in performance) response towards the end of a task in fatigued individuals and an ability for the level of motivation and interest in the task to improve task performance (Brown, 1982). This finding led the author to presuppose that the sudden improvement in performance noted in such instances could have occurred because the individuals were not actually fatigued but were experiencing a decline in performance due to a regulatory mechanism. Such a regulatory mechanism, it was supposed, could serve or served as a proactive protective mechanism that reduced activation levels (thus displaying identical fatigue characteristics) in an attempt to spare depleting resources before the onset of fatigue. As such, the initial aim of the first pilot test was to induce a sudden 'fatigue breaker' intervention (to initiate an immediate arousal and activation increase without providing a micro-rest break) to fatigued individuals then have them continue with the task. It was assumed that a sustained performance increase after the 'fatigue breaker' intervention would indicate that the initial decrease in performance was not due to fatigue but to a regulatory mechanism (because, it was assumed, a truly fatigued individual would not be able to improve and maintain performance suddenly, without a rest break as their resources would have been depleted); conversely, a continued decrease in performance would have indicated that the initial decrease in performance was in fact due to fatigue.

Seven participants were recruited for this first pilot session. The tests that were used for this research had already been developed; the initial test required participants to read a text set at a low resolution and to identify spelling errors (errors such as 'boyy'). All the participants conducted the tests for 40 minutes each. The 'fatigue breaker' intervention was initiated at 10 minute intervals for a period of 5 - 10 seconds. Three different types of 'fatigue breaker' interventions were used: one included placing an ice pack on the back of the participants' neck, another included asking the participants to do a 15 meter sprint and the last one required participants to respond to a simple auditory reaction time test.

The results indicated that fatigue effects were present after 20 minutes on the task. A temporary performance increase after the introduction of the ‘fatigue breaker’ was noted only in two of the participants while the effects of the ‘fatigue breaker’ were inconclusive in the results of the other five participants. Additionally, participants seemed to adapt quickly to the effect of the ‘fatigue breaker’. The results indicated that the ‘fatigue breaker’ did not elicit a clear arousal or increased activation effect and it was later established that, instead of increasing arousal, the ‘fatigue breakers’ were in fact causing a stress response (thus the responses that could have been observed would have merely been stress responses and not necessarily ‘fatigue breakers’); as a result, this method was abandoned and the aim of the research revised.

The Second Pilot Session

A further two participants were recruited to assess the exact time needed to induce fatigue. These participants were asked to conduct the memory recall (numbers were called out by a computer and the participants had to type them back in immediately) task. The participants were asked to perform the task continuously with no interruptions for an hour. Participants were also asked to wear a heart rate belt so that heart rate parameters could be recorded. Fatigue characteristics were noted from as early as 10 minutes into the task with heart rate increasing continuously and heart rate variability responses decreasing slightly. The same two participants were asked to perform the test for a second time; the results indicated that the performance characteristics and fatigue experienced the first time a participant performed the tasks were different when compared to the second time the same task was executed. It was hypothesised that the experience carried over from the first task was instrumental in determining the manner in which the individual regulated their performance and could thus potentially assist in meeting one of the aims of the research; the aim that related to investigating how fatigue was regulated was then addressed by comparing the regulation patterns exhibited during the first task to those of the second task. As such, participants were required to attend two separate identical testing sessions.

Factors that needed to be accounted for

Drowatzky (1981) indicated that a learning effect could account for performance changes as learning and practice were able to reduce the amount of time required for decision making, and consequently, decrease reaction time and improve performance. Levy *et al.* (2006) described learning as a process through which behaviour was modified (for the better) based on past experience. Additionally, Van Dongen and Dinges (2003) reported that task performance reliability was limited by the practice effect which tended to result in cognitive performance improvement the more a task was repeated. However, this was not the case with the results of the second pilot study as instead of getting better, the participants performed poorly during the second test. As such, the difference between the first task and the second task was not attributed entirely to a learning effect. Additionally, to account for a possible learning effect, the tasks were kept simple (involving simple movements and processes) to allow them to be easy to learn thus requiring less practice to perfect and not being open to observable performance improvements with further practice (Levy *et al.*, 2006).

It was evident from the results of the pilot tests that any study on the manner in which fatigue was regulated had to compare the participants' responses from the first time they execute a task to the second time. The results also indicated that responses had to be monitored for their change in patterns over at least one hour. Additionally, the performance patterns of the first pilot study differed considerably from those of the second pilot study when compared as the two pilots taxed two different resources. It was decided that it was important that the effect of fatigue regulation on the different resources be assessed. As the aim was to explore cognitive fatigue regulation, a fatigue inducing task set was designed then the manner of fatigue modification was observed.

Additionally, it was decided that the participants within the study would not be given any extrinsic incentive to improve their performance during the protocol.

EXPERIMENTAL DESIGN

Experimental Conditions and Design

In order to measure fatigue development, recovery and the mechanisms of regulation during these processes, it was necessary to induce fatigue by requesting that participants perform tasks designed to target specific resources for a long enough period to bring about fatigue. This was based on the work of Williamson *et al.* (2011), Thiffault and Bergeron (2003b), Craig *et al*, (2006) and Schoenfeld and Scerbo (1999) which purported that performance declines due to fatigue presented more rapidly during highly monotonous-monitoring tasks (complex and simple tasks alike) that required that participants engage in sustained attention (as in the case of vigilance tasks) for extended periods of time in a stimulus, temperature and noise controlled environment. This was found to be the case as such tasks require effort (Schoenfeld and Scerbo, 1999; Schmidt, 1982).

In this regard, three tasks representing the three broad information processing categories (sensory, cognitive and motor) were designed. The tasks consisted of a reading task measuring visual scanning and perception, a memory recall task that relied on working memory, and a modified Fitts' stimulus response task (Figure 1). These three different fatiguing tasks were performed for one hour (a time established from the pilot studies to be sufficient to induce fatigue).

In the interest of designing a smooth testing practice, all the tasks were placed on a single round table. Wheels were inserted at the base of the round table to allow it to rotate. As such, the participant sat at the table and then the table was rotated to the required task. A foot stool was placed under the table to increase the comfort of the participants.

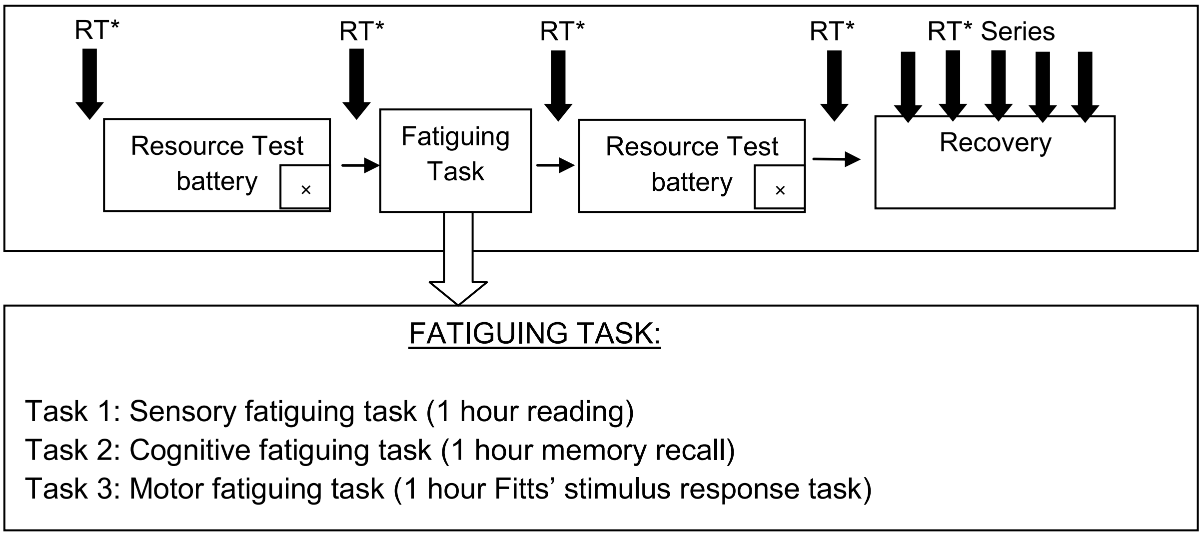

Figure 1: Basic research concept and study design showing the three fatiguing tasks (RT* = Simple auditory reaction time test; × = not part of this study).

In order to establish the extent to which specific resources were fatigued by the fatiguing tasks, a battery of tests comprised of resource specific tests were conducted pre and post [1] the fatiguing task (Figure 1). As the role of regulation within the fatigue process was unknown, an investigation was undertaken into the behaviour of the resources; behaviour that was of particular interest was one that initiated a decrease in performance, activity levels and alertness.

Simple auditory reaction time tests were performed at 10 minute intervals during the fatiguing tasks (not depicted in the figure), before and after both the fatiguing task and the pre and post battery of resource tests, as well as during recovery (Figure 1). These tests were interpreted in two ways: (1) the reaction time tests conducted during the fatiguing task were used as an indicator of arousal and activation levels and thus attention; and (2) to differentiate between resource specific fatigue effects and fatigue regulation (be it monotony related) performance effects.

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[1] The pre and post resource tests or 'Resource Test Battery' were part of another study conducted alongside this current one. The researcher from that study conducted the Resource Test Battery before and after the Fatiguing Tasks in an attempt to measure the state of the resources before and after the Fatiguing Task. The test batteries were identical to the three Fatiguing Tasks but were only conducted for 35 minutes in total (17.5 minutes before the Fatiguing Task and 17.5 minutes after the Fatiguing task).

Participants were required to perform a series of simple reaction time tests at 30 second intervals (for 15 minutes) with short rest breaks in between immediately after the post battery of resource tests. Reaction time test performance was used to monitor short-term resource recovery which was used to give an indication of whether or not, depending on the speed of recovery, recovery profiles from fatiguing tasks were subject to regulatory patterns.

FATIGUING TASKS CONCEPT

Tasks representative of modern work that could be performed by most people were selected and altered. The protocol made use of resource specific tasks that selectively taxed sensory, cognitive and sensory-motor processes. The tasks selected to tax the specific resources were structured around research findings; as it is understood that the symptoms usually attributed to fatigue include disruption of function such as failures in attention and memory, disrupted movement timing, reduced vigilance and heightened emotional responding, complete exhaustion and impairment of will (Noy *et al.*, 2011; Brown, 1982), each resource task was targeted at inducing a specific cognitive symptom of fatigue. The sensory resource task was targeted at monitoring the extent of reduced vigilance; the motor resource task was targeted at monitoring the extent of movement timing disruption; and the cognitive resource task was targeted at monitoring the extent of failures in attention and memory. The reaction time tests (later explained) were used to monitor the extent of failures in attention.

As stated previously, the fatiguing tasks were performed for a period of 60 minutes to induce fatigue responses. The task within each protocol was one that attempted to make use of that resource for a high percentage of time; this was expected to induce fatigue more rapidly than when the resource was used for a short percentage of time.

SUBJECT CHARACTERISTICS

60 student volunteers (30 males and 30 females) between ages 18-30 years, with a mean age of 21.8 (± 2.1) years, were recruited from Rhodes University to participate in this study. The age restriction was selected not only because an association existed between an increased age and altered perceptions of fatigue and task difficulty (Czaja and Sharit, 1993; Mallo *et al.*, 2007), but also because a large percentage of the South African working population fall within this age range. University students were also recruited as the inclusion of the reading/scanning task necessitated literacy on behalf of the participants; since a matric level qualification is the minimum education entry level of University students, they met the literacy requirement.

The participants were distributed randomly through the tasks at a distribution proportion of 20 participants per task (10 males and 10 females per task). The mean ages of participants assigned to the cognitive resource task, the motor resource task and the sensory resource task were 22.3 (± 2.7), 21.5 (± 2), and 21.7 (± 1.6) years respectively.

In the interests of limiting the effects of extraneous variables, all participants had to meet the following additional criteria:

- No alcohol consumption
- Healthy eyesight
- No strenuous physical and cognitive exercise/activities: Participants were asked not to engage in these kinds of activities at least 2 hours before testing
- No mental/cognitive diseases
- No medication such as stimulants or performance enhancers: Participants were asked to refrain from these at least 6 hours before testing.
- No sleeping disorders
- Not suffer from chronic fatigue

INDEPENDENT VARIABLES

As mentioned above, the fatiguing task used the reading, memory recall, and Fitt's stimulus response tasks. In an attempt to induce fatigue rapidly, the three selected fatiguing tasks were moderately challenging and highly monotonous (Williamson *et al.*, 2011; Craig *et al.*, 2006). The next section describes these tasks in more detail.

The Sensory Task: visual scanning and perception with a reading task

A visually demanding reading task was developed which required participants to read and scan a text to identify errors in the form of double characters (e.g. bookk) in a hard copy text set at a resolution of 75 dpi (a resolution found, during pilot tests, to be moderately challenging). The error rate for the fatiguing task was set at one double letter every 50 words. Within this task, participants were required to call out and circle the words with the typing error when spotted then continue reading. The time when each error was identified was noted. Furthermore, at 5 minute-intervals, participants were asked to indicate how far they had read by making a mark in the text with a pen. Participants were informed to perform the task without prioritizing reading accuracy over reading speed (or vice versa).

The position of the text in front of the participant was set relative to each participant's preferred positioning and in relation to the upright seated posture in which participants were required to perform the task. The text resolution was altered using Microsoft Word (where the double letters were typed in) then the document was converted to a PDF file using Adobe Acrobat Pro®. Once this was done, the PDF file was saved as a JPEG image then set at 75 pixels/inches (dpi).

The Cognitive Task: short term memory recall task

A short term working memory task where participants had to recall specific digits was developed. The tests were administered by means of an auditory signal using the Psychology Experiment Building Language (PEBL) Software. The computer based program (PEBL dspan test) called out the six numbers of each one digit at one number per second. The software was programmed to have a rehearsal time of 8 seconds (after having called out the digits) before allowing the user to type back in the digits. This means that participants had to wait 8 seconds before typing back in the digits correctly and in the same sequence. An auditory signal (in the form of a beep) was sounded to inform the participants to type in the digits. The 8 second wait was set in order to force participants to use working memory instead of relying heavily on the phonological loop and rhythm to recall the digits. The next set was immediately initiated once the participants had completed one set. Participants were informed to perform as quickly as possible without compromising accuracy during task performance. As Miller (1956 in Schmidt, 1982) noted that individuals could remember ‘only seven (plus or minus two) items at any one time’, the six chunks set was selected as a way of ensuring that the fatiguing task was at a central difficulty point.

Motor Task: Fitts’ task

A modified version of the Fitts task (using an LG ^{TM} Flatron LS1730SF touch screen as the input interface) was used to analyse motor response. The participants were required to tap with a finger onto randomly appearing target dots (accompanied by an acoustic signal) on the screen as quickly as they could. Participants were not required to hit the centre of the dot, but only within the area of the dot. The work field used measured a horizontal length of 300 mm and a vertical length of 280mm. The background of the screen was black while the dots appearing were green. Exclusionary criteria for this test included double tapping incidences and a response time greater than 2.5 seconds. The variation that was included in the protocol for the fatiguing task was one where targets interchanged between appearing at a random position on the bottom half of screen or the top half of screen exclusively. This means that the target alternated between appearing at random places either within the top half of the screen or within the bottom half of the screen. The targets were set at a minimum size of 7 mm. The program was set to alternate successively at a 750-1000 ms presentation delay so that the targets appeared within specified field (either the bottom half or the top half of the screen) in an uninterrupted manner for a duration of 3600 seconds.

DEPENDENT VARIABLES

As fatigue is a multi-dimensional construct with psychological, physiological, and behavioural effects (Di Milia *et al.*, 2011), an array of physiological, performance and subjective measures were applied in this study in an attempt to capture as many of the effects of the different experimental tasks on the participants as possible. The dependent variables for this study were: performance on the cognitive (short-term memory recall including a percentage of correctly identified numbers and response duration), sensory (visual scanning and perception in reading including reading speed and error identification rate) and motor (including response time) tasks, simple auditory reaction time, heart rate and heart rate variability, tympanic and forehead skin temperature, eye blink frequency and duration, in addition to subjective effort on the Ratings of Perceived Exertion Category Ratio and NASA-Task Load Index scales. Such a range of dependent variables was observed or measured to account for and indicate as many of the possible ways in which fatigue regulation mechanisms can/may manifest. It was hypothesized that these different variables would provide a more holistic insight into fatigue regulation, increasing the potential for acquiring additional information about how fatigue was regulated.

Performance measures

Dinges and Kribbs (1991) put forward a notion that performance changes were able to serve as ideal fatigue indicators as performance provided a direct evidence link of fatigue effects. Performance tests were thus used within this study to assess cognitive fatigue objectively as suggested by Van Dongen and Dinges (2000).

Performance on the Short Term Memory Recall Task

Performance was prescribed for the memory recall task; participants' performance was measured by the number of correctly identified digits (in sequence) over time as well as the response duration (this was the time it took to punch the numbers back once the 8 second waiting time was up). The participants' performance on these tasks was used as a possible indicator of cognitive slowing and a reduced attention capacity associated with fatigue.

Performance on the Visual Scanning and Perception with a Reading Task

Performance was also prescribed for the visual scanning and perception task; performance was measured by counting the number of correctly identified errors (reading accuracy) and the number of words read over time (reading speed). Instances of correctly spelled words with double letters (for example 'shovelling') being identified by participants as being spelling errors were also used as an indication of performance; an analysis was conducted on the frequency of the appearance of such errors over time.

Performance on the Fitts' Task

The performance requirement for the motor task was speed; performance was measured by noting the time taken to select targets (speed of movement).

Simple Auditory Reaction Time Tests

Performance tends to deteriorate with increasing time-on-task (Williamson *et al.*, 2011; Brown, 1982). Although it is commonly attributed to fatigue, the cause of this decrement is not yet clear, as fatigue regulation may also limit the extent to which optimal performance can be executed. In this way the series of reaction time tests served as indicators of whether or not decrements seen in performance were due to fatigue or fatigue regulation. It was expected that, should reaction time return to the pre fatiguing task value within a few seconds during the recovery period, then the previously perceived performance decrement was due to fatigue regulation mechanisms and not fatigue. This meant that the reaction time test series (after post battery of resource tests) was used to identify regulation during recovery.

A concern with continuous performance of a task was the onset of boredom and monotony which can be indicated by a reduction in arousal and activation levels and subsequently, performance (Van Dongen and Dinges, 2000). Since this effect could become a confounding factor, three short reaction time tests were performed in a row prior to and after the battery of resource tests and the fatiguing task, as well as at 10 minute intervals during the fatiguing task (Figure 1). These tests were conducted to serve as a measure of the level of arousal and attention in view of the fact that a decrease in arousal has been associated with a decrease in vigilance and cognitive attention, situation discernment, and slowed motor responses (Van Dongen and Dinges, 2000; Schmidt, 1982; Drowatzky, 1981). As VaezMousavi *et al.* (2007) stated that performance on the task is also dependent on the task-related activation (measurable also through reaction time), these tests were used to determine if the arousal and activation levels were comparable between the fatiguing tasks. These tests were thus, designed to measure the effects of fatigue on arousal, activation and thus attention during task execution.

Given that the proposed understanding of down regulation stated it as being a phenomenon that results in a decrease in activation levels (with activation levels therefore being a possible indicator of its activity), these reaction time tests were used for their potential to identify and track down regulation. Therefore, the measured level of arousal, activation and attention were interpreted as fatigue regulation indicators.

The HKE Stimulus Response Test v2.3a software was used to measure simple auditory reaction time. The software was a computer-based reaction time test where the participant was required to respond as quickly as possible to an audio signal by clicking a button that the participant was asked to hold (in their non-dominant hand) for the duration of each test session. Each participant was asked to click on the button as soon as the audio signal (in the form of a beep) was heard. The presentation of the signal was three times at a 500 and 2000 ms delay to prevent anticipatory effects.

As the reaction time test was used to indicate attention levels, and since attention, as reported by Schmidt (1982), has been perceived as limited (in that there is a limit to the number of things that can be attended to at any one time), the first reaction time trial was used to reflect the change in attention (the rapid switch from one primary task to a second one) as people have difficulties dealing with two sources of information or tasks at the same time. The second and third reaction time trials were used to reflect ‘true’ reaction time. Therefore, the first, second and third trials were analysed individually providing three reaction time values for each interval.

As these reaction time tests took roughly 5 seconds to complete, they did not interfere with the main fatiguing task

A series of single reaction time tests were also administered repeatedly at 30 second intervals after the battery of resource tests performed after the fatiguing task to track the potential recovery function of the fatigued resources. In order to measure simple auditory reaction time during the ‘one signal every 30 seconds’ period, the signal presented every 30 000 to 31 000 ms for 15 minutes. The variation of the signal appearance was included to prevent participants from anticipating when the next signal would present. The simple reaction time test was quick and did not cause a stress response which could have influenced performance and individual responses. The arousal response noted as a result of the reaction time test was perceived to have been too small, brief and inconsistent to considerably influence the data.

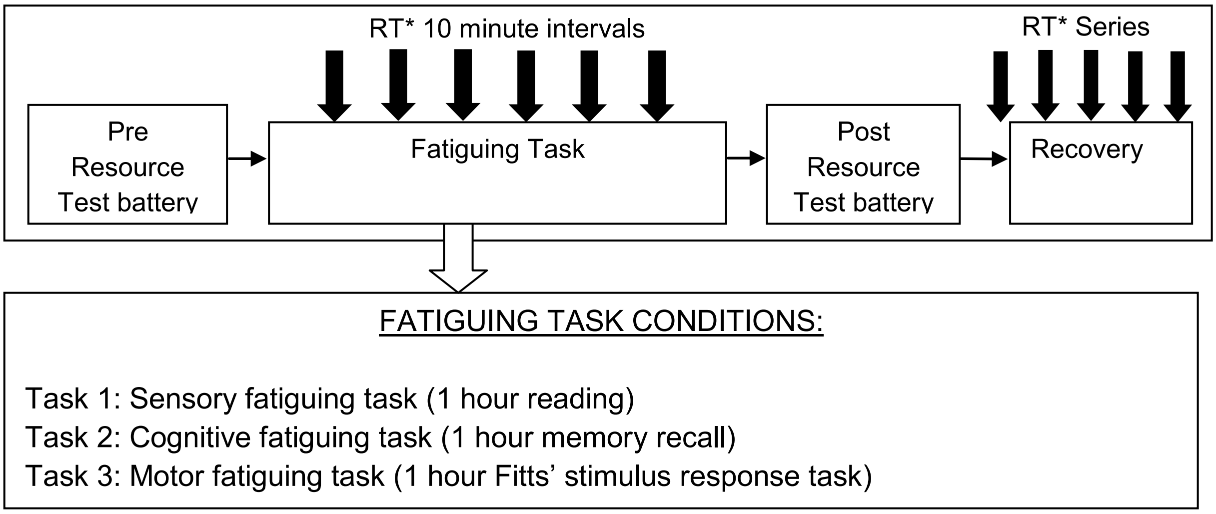

Figure 2: Reaction time test distribution for the Fatiguing task and the Recovery period (RT* = Simple reaction time test and RPE rating).

Physiological measures

Researchers believe that fatigue can be objectively measured through analyzing changes in physiological variables such as heart rate, blood pressure and performance measures. Objective indicators of fatigue rely on using biochemical, performance, perceptual and electrophysiological measurements, to name a few (Nilsson *et al.*, 1997).

Blink Frequency and Duration

The Dikablis Eye tracker was used to aid in the assessment of blink frequency and duration as indicators of alertness as well as fatigue (Schleichera *et al.*, 2008). The eye tracker is a unit that uses two different cameras (one field camera and one eye camera) to assist in the measurement of saccade performance, accurately monitoring pupil movement and blink frequency rate. The field camera was programmed to detect the cornea reflex to allow it to monitor the direction of the participant's gaze, subsequently recording changes in the field of view. The eye camera monitored the pupil direction and size. Only images from the left eye were captured and transferred to the eye tracker recording unit. The eye tracker was fitted onto the head of the participant and secured with an elastic retaining band that was placed around the participant's head. The weight of the entire unit was supported by the nose support to allow for the eye camera to align to the eye (Robertson, 2009).

The eye blink data was processed through the Human Kinetics Ergonomics (HKE) Data Analysis Tool; the tool was set to filter out eye blink durations over 500 ms and less than 50 ms as well as eye blink frequencies over 20 blinks per minute. Blink frequency and duration were calculated as the number of blinks and the duration of blinks per 5 minute interval respectively. When analysing eye blink data, the blinks were grouped into long blinks (blinks above 300 ms), short blinks (blinks between 50 and 100 ms) and normal blinks (blinks between 100 and 300 ms).

Heart Rate and Heart Rate Variability

The Polar® T31 memory belts were used to measure heart rate (HR) and heart rate variability (HRV). The HR belts were attached by fastening the HR strap around the participant's chest prior to the start of the test session. HR was recorded for the entire duration of the test session as an objective measure of mental effort; the information was recorded using a Biometrics Data Log V4.0 Ltd and analysed. The data was processed by assessing the inter-beat-intervals in time domain in addition to the Low Frequency (LF) band and High Frequency (HF) band (0.04- 0.15 Hz and 0.15-0.4 Hz, respectively) to acquire HRV.

The HR data was processed through the HKE Data Analysis Tool; the tool considered HR as pulses in time row. The tool was set to filter extra beats and missing beats and accept a minimum HR of 50bpm and a maximum HR of 180bpm. The maximum variation among beats was set at 33%. HRV indices were considered with an interval length of 180 seconds for time-domain analyses and frequency-domain analyses inclusive of the HF band and the LF band. The data elicited from the HR measurements was divided into time-domain analyses and frequency-domain analyses; SDNN, RMSSD, PNN30 and PNN50 were analysed as part of time-domain analyses while low frequency component of the (LF+HF) power, HF and LF (including frequency power and centre frequency values) were analysed as part of frequency-domain analyses.

Body Temperature

Tympanic or ear temperature was used as it had been identified by Chamberlin *et al.* (1995) as being a practical measure of body temperature. Forehead skin temperature was also recorded to serve as a secondary temperature indication source. The sensor was attached to an ear plug (to measure tympanic temperature) and a circular flat conductor (to measure skin temperature). The two means of measuring temperature were connected to a Biometrics Data Log V4.0 Ltd to allow for continuous temperature measurements. All temperature data was processed through the HKE Data Analysis Tool. The tool was set to consider the average value for ear and skin temperature data. Temperature was expected to decrease with time-on-task as performance deteriorated since high and low temperature values have been found to correlate with good and poor performance (Van Dongen and Dinges, 2000).

Subjective measures

All subjective measures used took individual differences into account, permitting a comparison with the objective data. The subjective data was used to provide assistance with the interpretation of and insight into the objective data. Participants were introduced to and taught how to use the subjective measures during the habituation session.

NASA-Task Load Index (TLX)

Since the NASA-TLX calculates the effect of the interaction between the individual and task (analysing the mental, physical and temporal demands on the individual as well as the effort, frustration and performance requirements), it was used to measure subjective mental workload of the tasks (Hart, 2006; Schoenfeld and Scerbo, 1999). This questionnaire was completed at the end of each test session. The main reason for the use of the NASA-TLX in the study was to assess the extent to which the subjective mental workload correlated to (or differed with) the recorded physiological and performance workload responses and whether or not the perceived subjective workload changed between the two test sessions. This method was designed to assess workload on a six point scale with increments of high, medium and low estimates for each point resulting in 21 gradations on the scale (Hart, 2006). The participants were first asked to evaluate the scales to indicate the contribution of each to the total evaluation of workload (so that a comparison of the six scales to each other could be done) then to indicate which of the two dimensions contributed the most to the feeling of workload (De Waard, 1996). An electronic version of this tool was used that produced an Excel sheet containing the scores of each of the dimension values (expressed in percentage) and weighting (expressed in rating).

<u>Ratings of Perceived Exertion</u> <u>(RPE) Category Ratio (CR) Scale</u>

Each participant was required to give an RPE CR10 rating at 10 minute intervals while conducting the task; they were allowed to either give the number or the description. The scale, which ranged from 0 (nothing at all) to 10 (very very hard or maximal), was used to assess and describe the cognitive effort required during task execution. Since the verbal expressions such as ‘noting at all’ were anchored to the coinciding positions on the ratio scale, participants were aware that the number 10 implied an exceptionally strong perceptual intensity (Borg, 1990). The measure was used as it allowed the participants to express any changes in perceived mental exertion as workload increased.

EXPERIMENTAL PROCEDURES

The protocol was set up as a mixed repeated design study where each participant was asked to perform only one of the 3 tasks for the 1st and 2nd testing sessions. The duration of each task was 110 minutes including 17.5 minute battery test + 60 minute fatiguing task +17.5 minute battery test + 15 minute recovery (RT series). Both the 1st test session and the 2nd test session were conducted in exactly the same way, except that the 1st test session included a 30 minute habituation session. Thus, the duration of the 1st test session was 140 minutes.
Therefore, the total time commitment for each participant was four and a half hours split over two non-consecutive days.

Both sessions were carried out at the same time of day throughout the day as detailed below. The times chosen for testing coincide with normal working hours for industrial operators working morning and early evening shifts thus considering the time of day effects on the resources specific tasks. The testing times during the day for all test sessions were: 8:00 – 10:30, 10:30 – 13:00, 13:30 – 16:00 and 16:00 – 18:30.

The concern with testing throughout the day was that participants’ performance and thus fatigue responses would be susceptible to circadian rhythm related effects.

Therefore, in an attempt to circumvent circadian rhythm effects, participants were allocated randomly and evenly to the varying test times (so that, where appropriate, time of day effects could also be established) and each participant was tested at the same time for both sessions (so that the circadian effects on the individual were comparable on both days) with at least a day between the sessions.

Ethical Considerations

The researcher had received ethical clearance from the Human Kinetics and Ergonomics Ethics Committee.

All participants were made aware of the time commitment, the procedures, requirements, as well as the potential risks and benefits of the study verbally and in written form. The researcher ensured that the involvement of the participants was completely voluntary and that each participant signed a consent form only once they both understood entirely what the study required of them and agreed with the requirements stipulated therein. Participants were also made aware that they were free to withdraw from the research study at any time with no penalty.

All participants who participated in this study were given codes to make it impossible to trace back collected data to specific individuals. Access to raw data during and after data collection and personal information recorded during the study was restricted to only the researcher and supervisor and was stored in the personal computers of the researchers involved, and removed off any communal research laptops.

Participants were notified via email of the findings of the study as a whole and specific to the task in which they participated in.

Habituation to Tests, Tasks and Equipment

A habituation session was held before the start of the 1st test session to familiarise all participants with the experimental protocol, procedures and equipment to be used. Participants were reminded of the controlled parameters that they had to adhere to prior to and during the course of testing (participants were briefed on the parameters during the recruitment process and via email before they were asked to come for testing).

Once this process was complete, each participant was shown how to correctly conduct the reading/scanning, the memory recall and Fitts tasks in addition to the reaction time tests before they were asked to sit at the workstation and execute these tasks (for 1.5 minute per task) themselves. The equipment that was used (heart rate belt, tympanic and skin temperature sensors and the eye tracker) was then attached and the participants were asked to sit down.

Test Battery and Tasks organisation

All the tasks were designated to sections on a round table. All the tasks were performed while the participants were seated. The sections were as follows:

- Section one included all cognitive tasks equipment; the section included a laptop with the PEBL program.
- Section two included the motor task equipment; this equipment was inclusive of another laptop with the modified Fitts task which was connected to a touch screen that was placed next to the laptop.
- Section three included all sensory tasks equipment; this equipment included a paper-holder, a clip board, reading material, a piece of press stick, a paper clip, a pencil and a reading lamp. The reading material was placed on the clip board and secured there using a paper clip. The clip board (with the reading material attached) was then placed on the paper-holder.

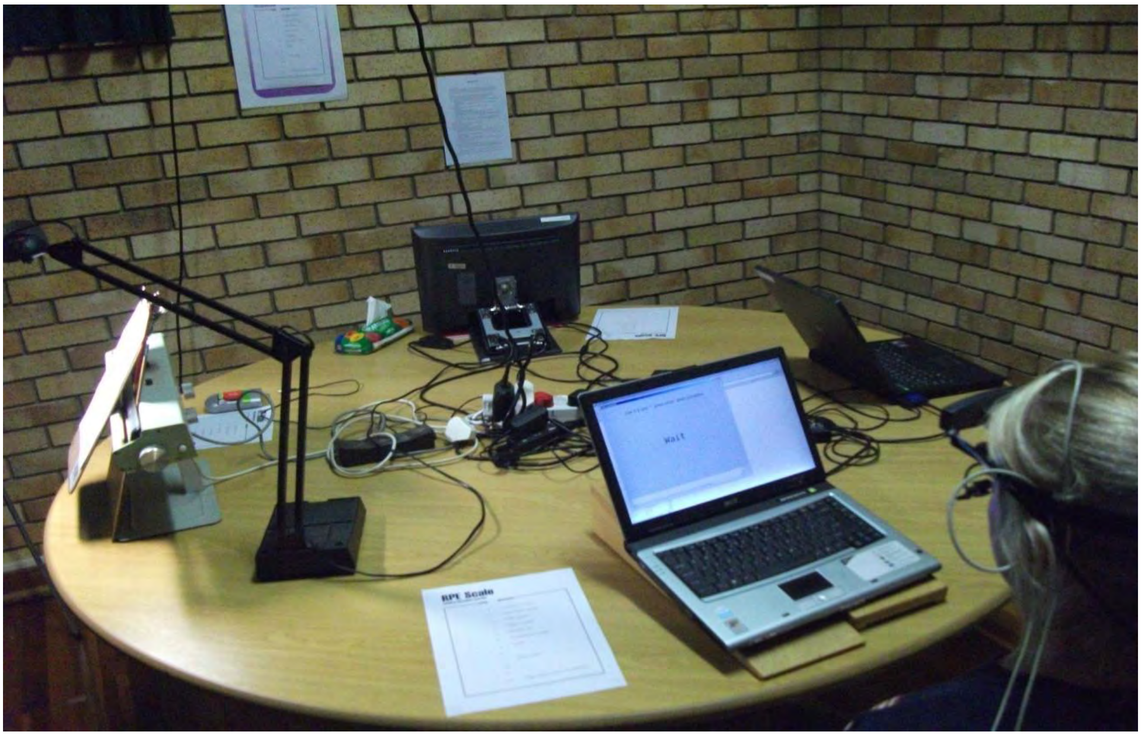

Figure 3: The organisation of tasks around the round rotatable table.

Additional Measures Organisation

Three copies of the RPE CR scale were printed; a single copy was placed with press stick on the left side of sections one, two and three on the round table (Figure 3). The participants were fitted with the necessary equipment including the heart rate belt, tympanic and skin temperature sensors and the eye tracker (which was fitted onto each participant's head once the heart rate belt had been attached) and given the button (for the reaction time tests) to hold in their non-dominant hand. Participants were then asked to sit down and conduct the first reaction time tests to record their reference reaction time. This was followed immediately by the pre resource test battery.

Procedures

The testing occurred in private a room within a laboratory.

Testing began as soon as all the equipment had been attached and the participants were satisfied and comfortable. The first step was (as stated previously) to conduct a reaction time test and to ask for an RPE rating (to confirm that they were not exerting themselves in any way at the start of the test session) before the first test within the test battery. Participants always conducted the reaction time test then followed by an RPE rating. They were reminded that they were to perform maximally throughout each test session in an attempt to account for pro-active self-regulation. The pre resource test battery was always followed by the fatiguing task which was then followed by the post resource test battery and finally, by the recovery session. If the participant was assigned to task 1 (for example) they would, after the reaction time test and RPE rating, be asked to read a text set at a resolution of 75dpi for an hour, conducting reaction time tests at 10 minute intervals; the last reaction time test and RPE rating would mark the end of the hour task and the beginning of the post test battery.

Figure 4: A participant holding the reaction time test button and conducting the Fitts task fitted with the eye tracker and temperature sensors.

Participants were asked to complete the NASA-TLX during the 15 minute recovery and reaction time test period. The end of the recovery session marked the end of the complete test session. All attached equipment was then removed and the participant was sent home once the researcher had spoken to them and ensured that they were feeling well.

Statistical Analysis

All results were analysed using Statistica software package Version 10 (Statistica©, Statsoft Inc). Descriptive statistics were run on all data to obtain mean and standard deviation of all responses for all tasks as well as to test for normality. A comparison was made between the responses to the 1st test session and the 2nd test session (referred to here as the effect of the test session) over the course of the three resource tasks during all primary statistical evaluations. In addition, two and three way factorial ANOVAs were conducted to determine the general effects of the independent variables for all the variables and the tasks: three-way ANOVAs were performed to assess the effect of the test sessions on the three resource tasks, allowing for an assessment to be conducted on the differences between the tasks; two-way ANOVAs were calculated to assess the effect of the test sessions on the individual tasks separately. All statistical responses were set at an error probability of $p \leq 0.05$ to indicate a significant effect.

CHAPTER IV

RESULTS

INTRODUCTION

The current study evaluated the regulation of fatigue by assessing participants' ability to cope with fatigue as a result of previous experience. Each participant was asked to perform a 1st test session then a 2nd identical test session of 60 minutes. The two test sessions comprised of three separate resource-specific tasks; these tasks represented the three broad information processing categories: the sensory resource (consisting of a reading task measuring visual scanning and perception), the cognitive resource (consisting of a memory recall task that relied on working memory) and the motor resource (consisting of a modified Fitts' stimulus response task). Participants had to complete only one of the three resource-specific tasks for both sessions. Reaction time, subjective ratings, and physiological measures (such as blink frequency and duration, forehead skin and ear temperature in addition to heart rate and heart rate variability) were measured as dependent variables.

Data was analysed by assessing the effects of the tasks on the dependent variables over 5 or 10 minute intervals, depending on the variable. Three-way factorial ANOVAs were conducted to determine the effect of the experience of having performed a similar session before, the effect of time-on-task over the 60 minutes, and the effect of the different tasks (focussing on the cognitive, motor and sensory resource specifically).

As such, the following factors were assigned:

- TEST SESSION:
    - Outlines the experience of having conducted a similar session before.
    - Technically processed by considering the difference between the '1st test' session and the '2nd test' session.
- TIME:
    - Outlines the change over the 60 minutes task duration.

    - Technically processed by 12 intervals of an average value of 5 minutes each or by 6 intervals of an average value of 10 minutes respectively.
- TASK TYPE:
    - Outlines the effects of the three different tasks with a focus on cognitive, motor and sensory resources. These were labelled as follows:
        - ‘sensory task - the reading task measuring visual scanning and perception
        - ‘cognitive task’- memory recall task that relied on working memory
        - ‘motor task - a modified Fitts’ stimulus response task

Additionally, ‘Post Hoc’ tests were calculated in the form of two-way ANOVAs in cases when the tasks showed a significant effect. Post hoc analyses were conducted for each of the tasks to assess whether or not the results depended on the task and to allow for an analysis of which way the effects were different for the different tasks. In this way, the post hoc tests were a separate analysis conducted to assess the effect of the test sessions and the general effects of time on the individual tasks separately (with factors TIME and TEST SESSION).

All statistical responses were set at an error probability of $p \leq 0.05$ to indicate a significant effect. Although the processed data elicited statistical values inclusive of measures of variance, nominator and denominator degrees of freedom and the probability value, only the probability value is depicted within this section; the remaining values have been placed in the Appendix section. The use of three-way ANOVAs to analyse the general effects was processed for all variables except for the performance data as each task included a different performance criteria. As such, the nature of the performance data from the different tasks did not allow for a direct comparison. Three two-way ANOVAs were analysed (with factors TIME and TEST SESSION) for these parameters. The significant effects are considered in detail while the non-significant effects are only briefly mentioned.

Gender was analysed as a covariate throughout all conducted statistical analyses. Although gender effects were noted during certain variables, those that did relate to the hypothesis of the study were minor and considered as side-effects. These effects are discussed in a separate section at the end of this chapter.

RESPONSES

Performance Responses

The following responses are of the dependent variables over a period of 1 hour of undertaking a sustained attention task. 12 intervals, each an average value of 5 minutes, were processed for this section. Performance responses (and all other responses) have been grouped into three broad resource categories. Effects will be considered according to a particular task: the ‘cognitive task’, the ‘motor task’ and the ‘sensory task’. Two-way ANOVAs were analysed (with factors TIME and TEST SESSION) for these parameters.

Task Performance

As stated previously, the measured variables for the cognitive task (memory recall task), namely: correctly identified digits over time as well as the response duration, were used as possible indicators of cognitive slowing and a reduced attention capacity associated with fatigue. The measured variable for the motor task (Fitts task), namely: the time taken to select targets, was used an indicator of possible fatigue-related reductions in speed of movement. The measured variables for the sensory task (visual scanning and perception task), namely: the number of correctly identified errors and the number of words read over time, were used as possible indicators of fatigue-related disruptions in reading accuracy and reading speed.

Task Responses for Cognitive Tasks

a) Correctly identified digits

A statistical effect ($p < 0.05$) was elicited for the TIME by TEST SESSION factor as analysed by the two-way ANOVA. Both test sessions show performance decreases during the first 15 minutes followed by more steady performance fluctuations. No significant results were elicited for the TEST SESSION factor and the TIME factor; p= 0.76 and p= 0.17 respectively.

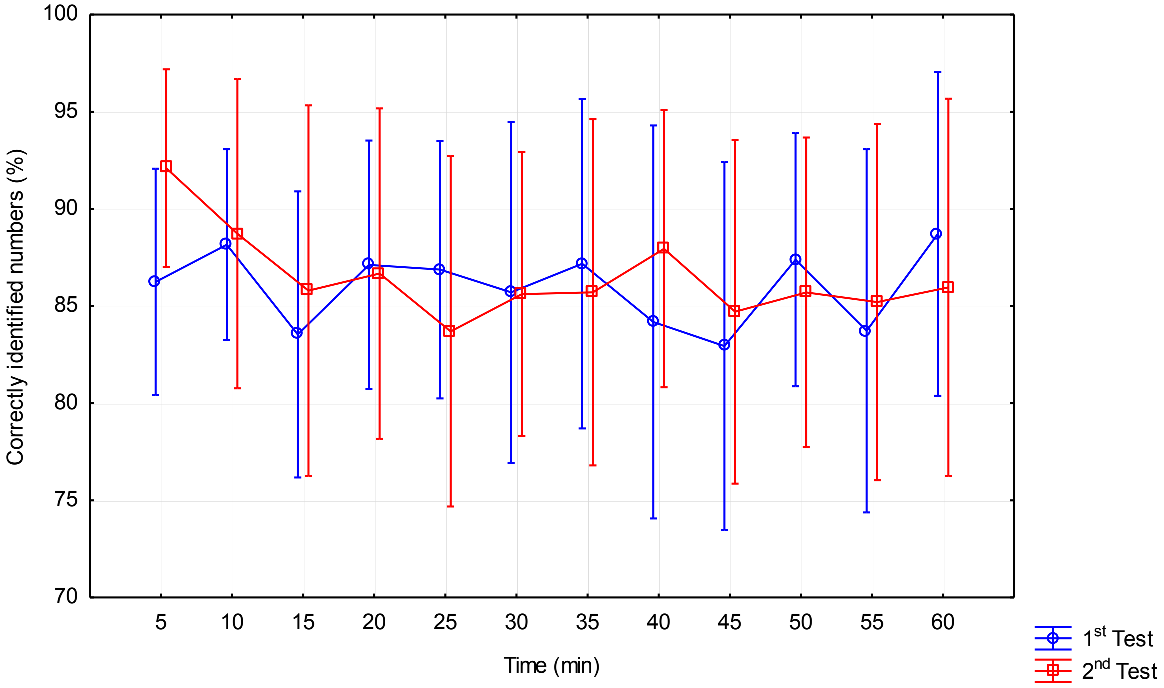

Figure 5: Percentage of correct digits response as function of time-on-task for the cognitive resource during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

b) Response Delay

A significant TIME effect was measured ($p < 0.01$) with both test sessions showing a steady increase in response delay over time. A calculation by the two-way ANOVA showed statistically significant differing trends ($p < 0.05$) for the TEST SESSION factor with the 2nd test eliciting higher response delay values on average. No significant response effect was measured for the TEST SESSION by TIME effect (p= 0.35).

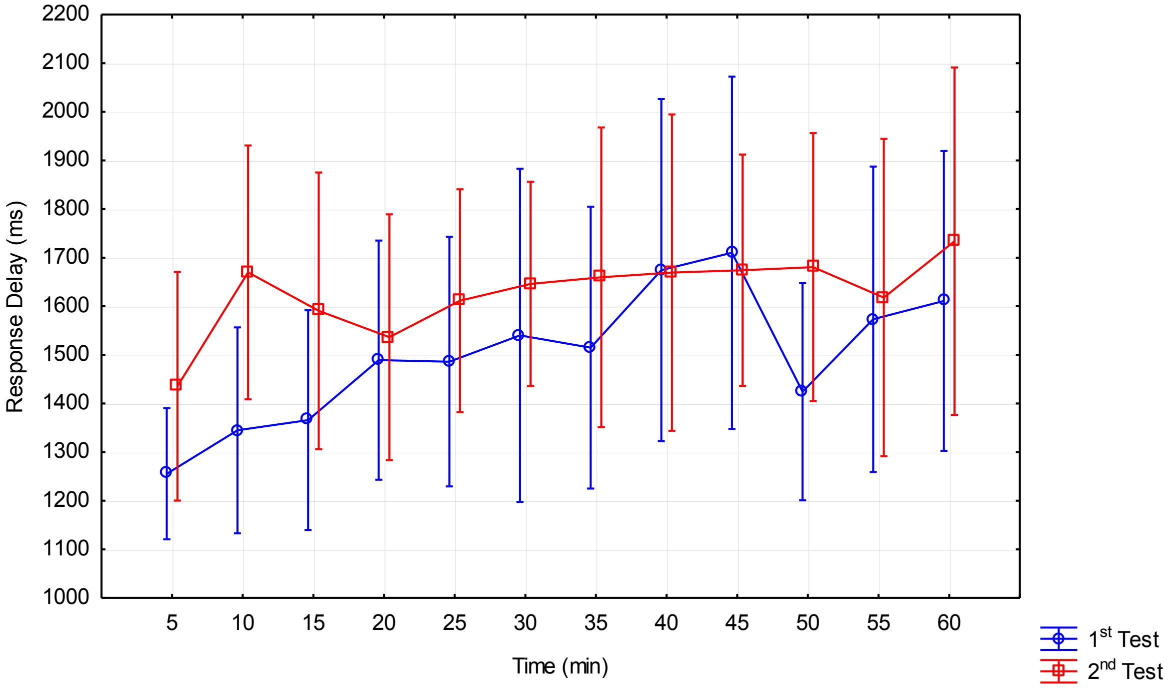

Figure 6: Response delay responses as function of time-on-task for the cognitive task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

Task Responses for Motor Tasks

As the Fitts task protocol included responding to targets appearing at the top and bottom of the screen, target response results elicited directionality results for up (top of the screen) and down (bottom of the screen). The change in the directionality of targets was selected in an attempt to make the motor task moderately fatiguing; no difference in speed of movement when responding to targets appearing at the top and bottom of the screen was expected. As such, a three-way ANOVA was processed (factor 1 being the differences in the direction of target appearance, factor 2 being the TEST SESSION function and factor 3 being the TIME function). No significant response effect was attributed to responding to targets appearing up and down (that is, there was no up and down effect): p= 0.06. However, the up and down effect was close to significance; perhaps an increased sample size could permit for an increase in significance. The TEST SESSION effect, elicited from the two-way ANOVA, showed a statistically significant result ($p < 0.01$); responses during the 2nd test were faster than those in the 1st test. There was no significant TIME effect (p= 0.98). The TIME by TEST SESSION effect did not elicit any significant results either (p= 0.24).

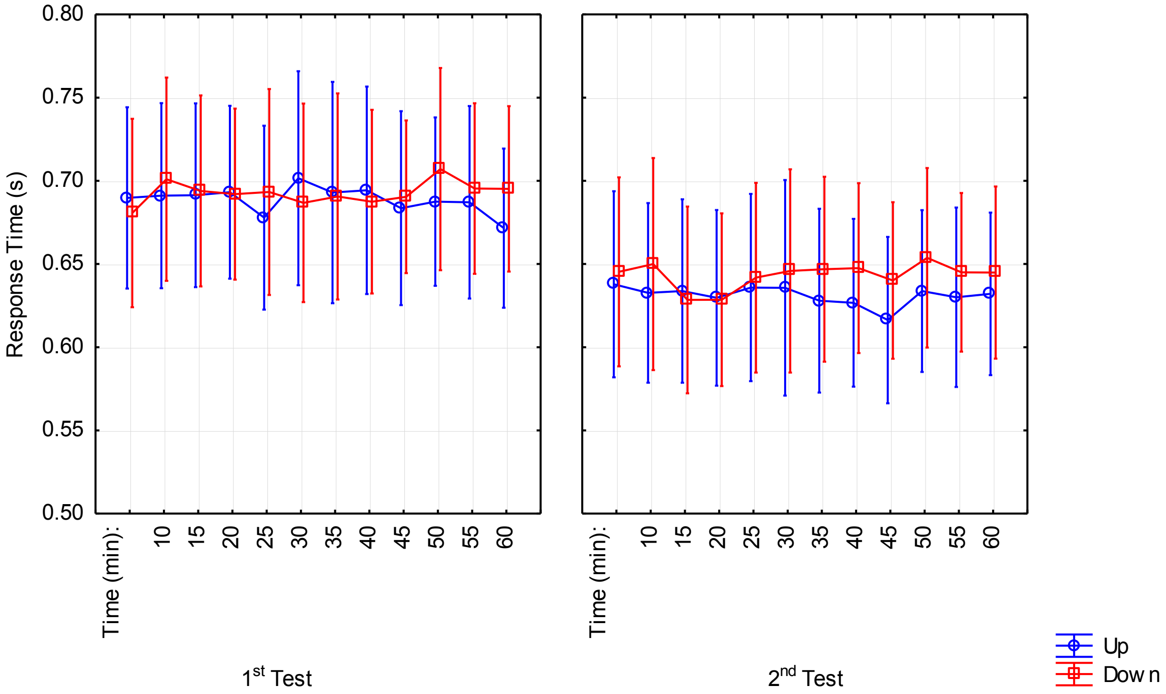

Figure 7: Response time responses for up and down target direction as a function of time-on-task for the motor task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

Task Responses for Sensory tasks

a) Correctly identified errors

The difference in the error identification rate during the ‘1st test’ versus the ‘2nd test’ sessions elicited no statistically significant effect (p= 0.28). No significant TIME effect (p= 0.48) was measured. The TIME by TEST SESSION factor, elicited from the two-way ANOVA, also showed no significant results (p= 0.81).

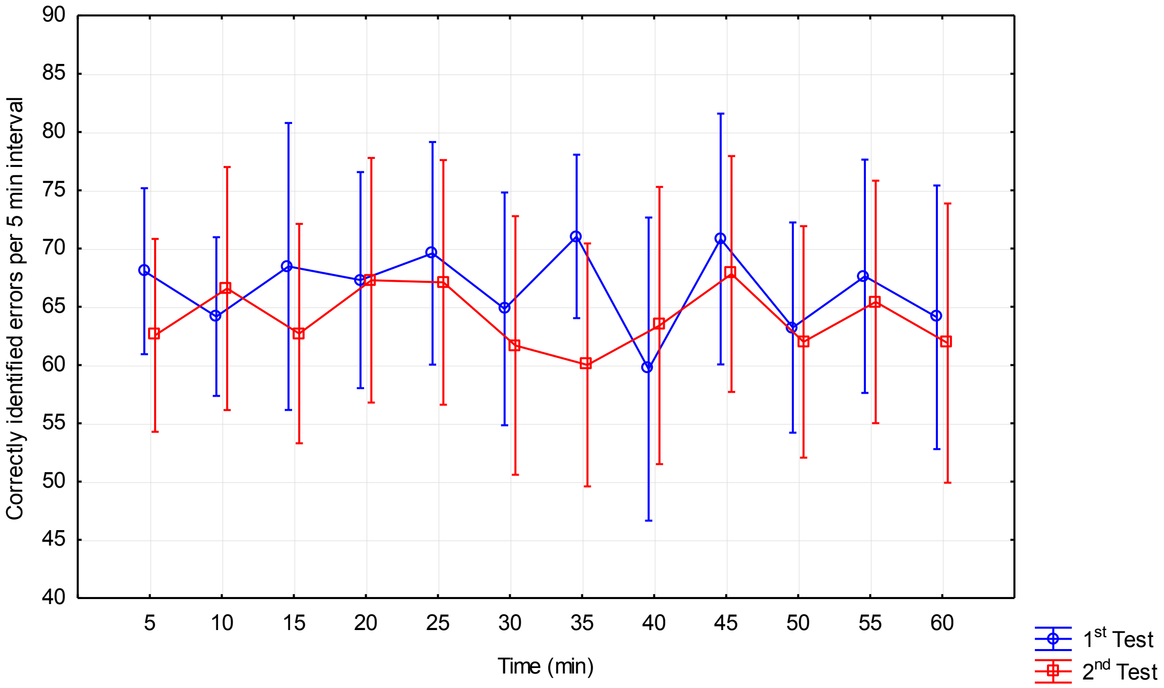

Figure 8: Correctly identified error responses as function of time-on-task for the sensory task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

b) Word count/reading speed

The TEST SESSION effect, elicited from the two-way ANOVA, showed a significant effect ($p < 0.05$); reading speed increased significantly during the 2nd session. A statistically significant TIME effect was measured ($p < 0.01$). There was no statistically significant difference measured as calculated by the two-way ANOVA for the TEST SESSION by TIME effect ($p= 0.19$).

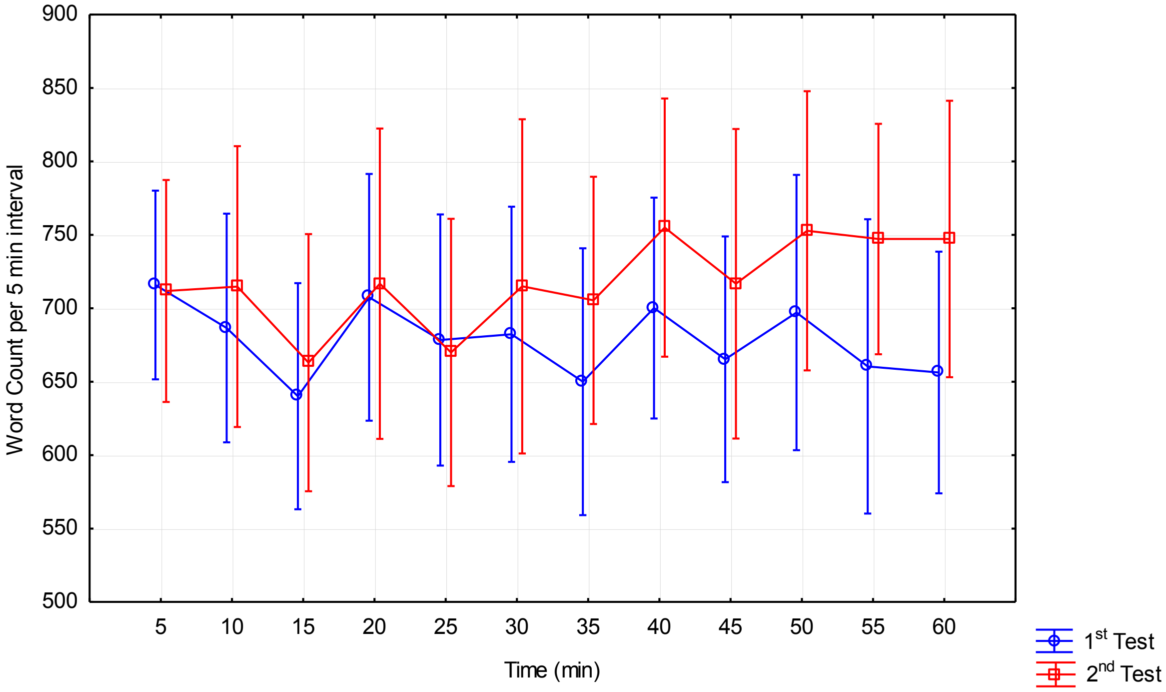

Figure 9: Reading speed (word count) responses as function of time-on-task for the sensory task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

Task Effects on Simple Reaction Time

Simple reaction time tests (RTT) were conducted every 10 minutes during the 1 hour task as an indication of arousal, activation and attention levels. Each RTT had 3 repetitions that the participants had to respond to. First, a four-way factorial ANOVA was analysed to determine the general effects of the tasks and to incorporate the 3 repetitions. That is, the following factor variables were analysed: factor 1 considered the differences in responses of the three reaction time repetitions (called the REPETITION effect), while factors 2, 3 and 4 considered similar variables to previous tests (that is, TASK TYPE effect, TEST SESSION effect and TIME effect respectively). Then post hoc analyses were conducted were significance was recorded to identify effects of each task separately to assess to which extent the tasks produced similar effects. Post hoc analyses were calculated using either two-way factorial ANOVAs (with factors TIME and TEST SESSION) or three-way factorial ANOVAs (with factors TASK TYPE, TIME and TEST SESSION).

General Effects results from the Simple Reaction Time Test

There was a significant REPETITION effect ($p < 0.01$) indicating a statistically significant response time between repetition 1 and repetitions 2 and 3 ($p < 0.01$). This was an indication of statistically significant slower responses during RTT repetition 1 as the second and third RTT repetitions elicited similar response values. There was no measured statistically significant values for the REPETITION by TEST SESSION by TIME effect (p= 0.33), the TIME by TEST SESSION factor (p= 0.13), the TEST SESSION factor (p= 0.21), the TEST SESSION by TASK TYPE factor (p= 0.58), or the TIME factor (p= 0.71). The differences in response time during the 1st test and 2nd test were not statistically significant (p= 0.29). In terms of the inter-task comparison calculation, a significant REPETITION by TASK TYPE effect was found ($p < 0.01$). This indicates that the reaction speed differed depending on the task being performed; the cognitive task elicited slower reaction times on average during all three repetitions.

Post Hoc Analyses Results during the 1st Simple Reaction Time Repetition

Statistical calculations (with factors TIME and TEST SESSION) showed no significant results for the TIME by TEST SESSION factor, the TEST SESSION factor and the TIME factor during the cognitive task; p= 0.24, p= 0.37 and p= 0.99 respectively. The statistical calculations performed for the motor task responses also did not elicit any significant results; the TEST SESSION factor, TIME factor and the TIME effect by TEST SESSION factor showed values of p= 0.47, p= 0.37 and p= 0.19 respectively. The sensory task also elicited no significant results as the TEST SESSION factor (0.41), TIME factor (p= 0.39) and the TIME effect by TEST SESSION factor (p= 0.13) all showed p-values that were greater than 0.05.

Although *Figure 10* illustrates a difference in patterns of response to the RTT during repetition 1, no significance was found (with factors TIME, TASK TYPE and TEST SESSION) for: the TEST SESSION factor (p= 0.16), TIME factor (p= 0.52), TEST SESSION by TASK TYPE effect (p= 0.93) and the TIME by TEST SESSION factor (p= 0.22). The differences in responses for the three task tests elicited a statistically significant value at p= 0.05. The cognitive task showed numerous fluctuations with different trends over time during both test sessions with the 2nd test eliciting faster reaction time results. The motor task showed similar increases in reaction time over time during both test sessions. The sensory task showed that RTT responses during repetition 1 measurements during the 2nd test showed fewer fluctuations while the results from 1st test showed more fluctuations.

Post Hoc Analyses Results during the 2nd and 3rd Simple Reaction Time Repetition

Statistical calculations for responses during the second reaction time repetition set (with factors TIME and TEST SESSION) showed no significant results for the TIME by TEST SESSION factor, the TEST SESSION factor and the TIME factor during the cognitive task; p= 0.52, p= 0.66 and p= 0.17 respectively. The statistical calculations performed for the motor task responses also did not elicit any significant results; the TEST SESSION factor, the TIME factor and the TIME by TEST SESSION factor showed values of p= 0.45, p= 018 and p= 0.82 respectively. The sensory task also elicited no significant results as calculations by the ANOVA for the TEST SESSION factor (0.25), TIME by TEST SESSION factor (p= 0.5) and TIME factor (p= 0.67) all showed p-values that were greater than 0.05 (illustrated in *Figure 11)*.

Statistical calculations during the third reaction time repetition set (with factors TIME and TEST SESSION) showed no significant results for the TIME by TEST SESSION factor, the TEST SESSION factor and the TIME factor during the cognitive task; p= 0.95, p= 0.64 and p= 0.54 respectively. The statistical calculations performed for the motor task responses also did not elicit any significant results: the TEST SESSION factor, TIME factor and the TIME by TEST SESSION factor showed values of p= 0.92, p= 0.6 and p= 0.84 respectively. The ANOVA calculations for the sensory tasks also elicited no significant results as the TEST SESSION factor (p= 0.43) and TIME factor (p= 0.23) all showed p-values that were greater than 0.05. The TIME by TEST SESSION factor for the sensory task showed a significant result ($p < 0.05$) indicating that the RTT patterns during the 1st and 2nd test sessions differed over time (illustrated in *Figure 12)*.

Since no statistically significant differences were recorded between repetitions 2 and 3 over the three tasks (p= 0.72), repetitions 2 and 3 were analysed together (with factors TIME, TASK TYPE and TEST SESSION). No significance was found for the TEST SESSION factor (p= 0.49), the TEST SESSION by TASK TYPE factor (p=

0.24), the TIME by TEST SESSION factor (p= 0.23), the TIME by TEST SESSION by TASK TYPE factor (p= 0.76) nor the TIME factor (p= 0.9). However, a statistically significant result was found for the TASK TYPE factor ($p < 0.05$); figures 11 and 12 illustrate the response patterns during the different tasks.

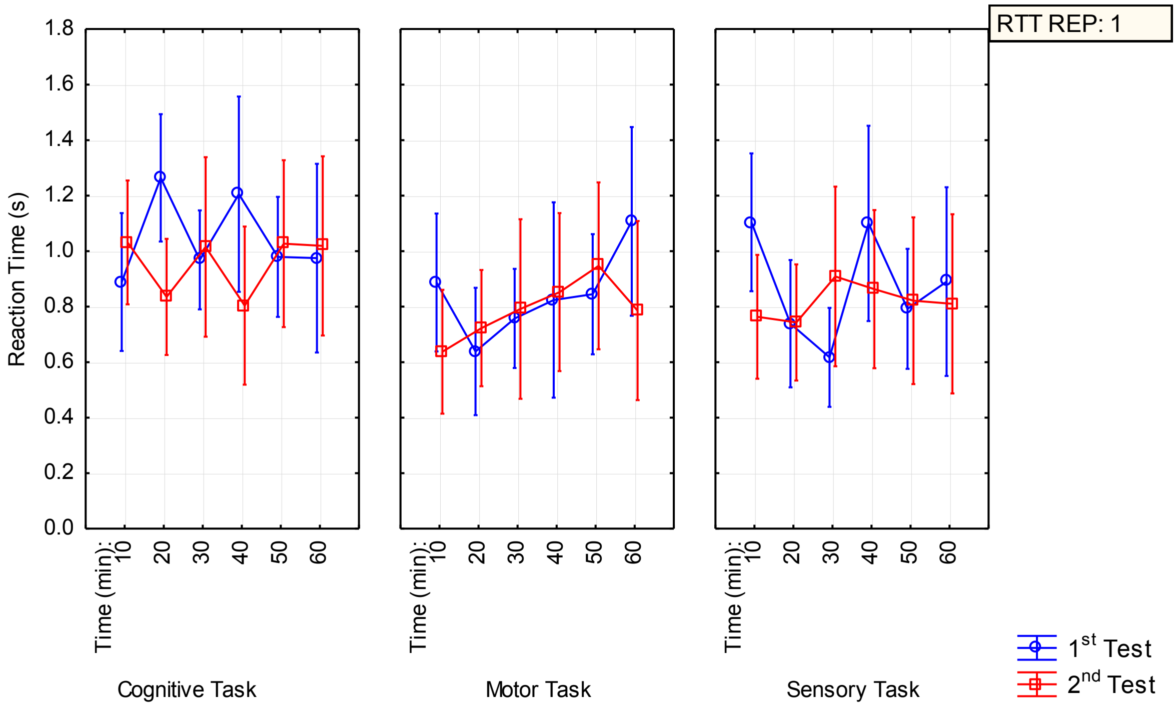

Figure 10: First reaction time repetition responses as function of time-on-task for the cognitive, motor and sensory tasks during the 1st test and the 2nd test. Error bars depict a 95% confidence interval. RTT REP 1: the first repetition of the simple reaction time test.

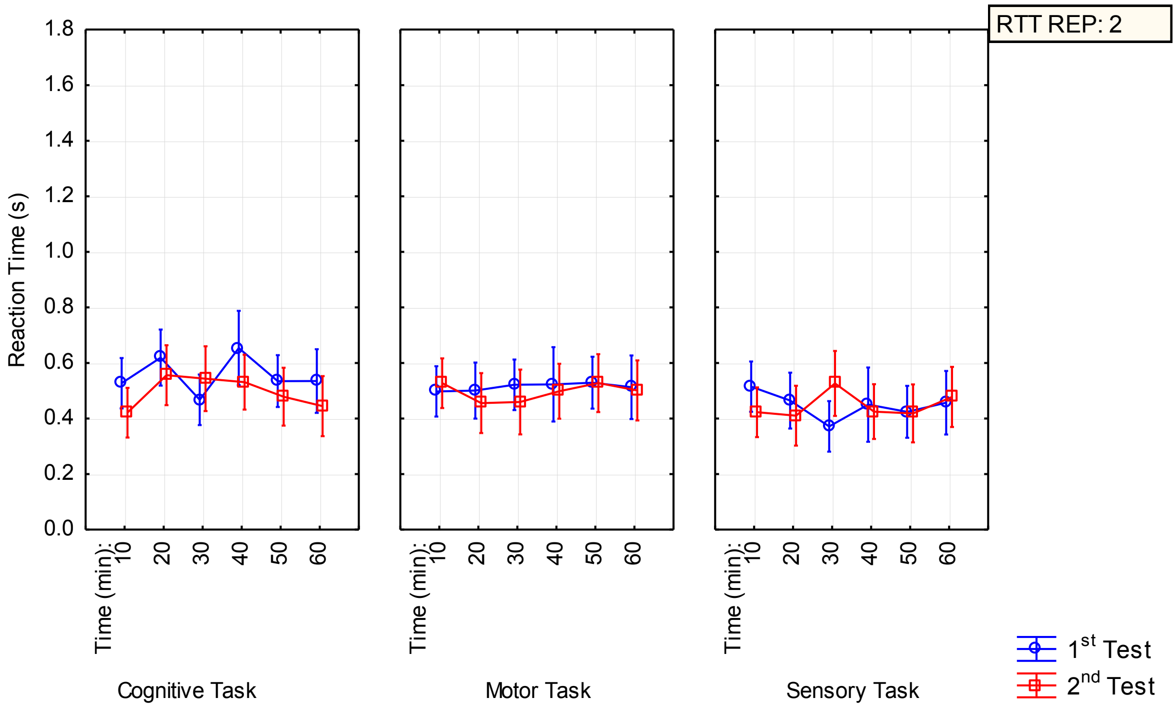

Figure 11: Second reaction time repetition responses as function of time-on-task for the cognitive, motor and sensory tasks during the 1st test and the 2nd test. Error bars depict a 95% confidence interval. RTT REP 2: the second repetition of the simple reaction time test.

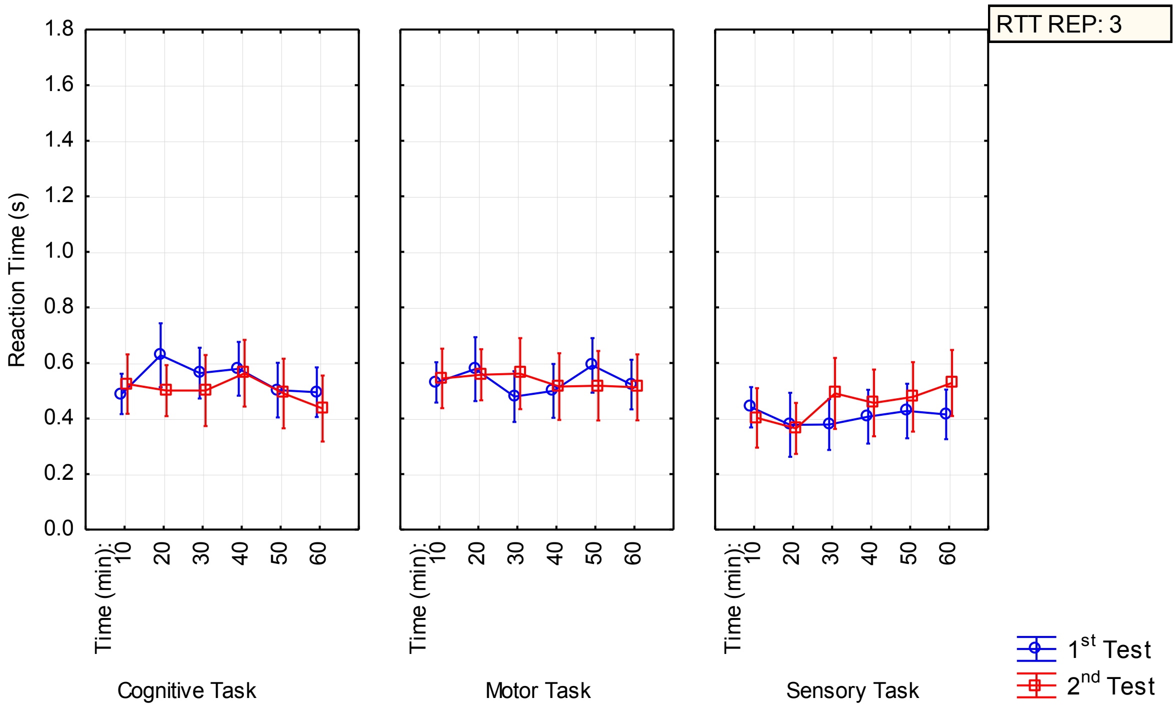

Figure 12: Third reaction time repetition responses as function of time-on-task for the cognitive, motor and sensory tasks during the 1st test and the 2nd test. Error bars depict a 95% confidence interval. RTT REP 3: the third repetition of the simple reaction time test.

Reaction Time Test Responses during the Recovery Period

Participants were asked to conduct RTT where a single stimulus appeared every 30 seconds for a period of 15 minutes after each test session. This was done to track their recovery profile. A comparison was made between the responses during the 1st test and 2nd test sessions across the three tasks. Three-way factorial ANOVAs were calculated to determine the general task effects (with factors TIME, TASK TYPE and TEST SESSION). A post hoc analysis was also conducted through a two-way factorial ANOVA (with factors TIME and TEST SESSION).

The general responses to the Reaction Time Tests during the Recovery Period

All three tasks had a significant decrease in reaction time over the 15 minute recovery period ($p < 0.01$). However, the TEST SESSION effect and the TEST SESSION by TIME effect (as calculated by the ANOVA) did not show any significant results; p= 0.14 and p= 0.76 respectively. There was a significant result when a calculation was made by the ANOVA for the TEST SESSION by TIME by TASK TYPE factor ($p < 0.05$). Reaction time was faster only during the 2nd test session for both the cognitive and motor task whereas the sensory task elicited faster reaction time responses during the 1st test session. A statistical analysis showed a significant result for the TIME by TASK TYPE factor ($p < 0.05$) in a way that the recovery profile elicited was different for the tasks: The sensory task initially elicited slower reaction time values but then elicited a rapid increase in reaction time after approximately 4 minutes into the recovery period during both test sessions. Reaction time results during the motor and cognitive task recovery period showed a slow and relatively constant decrease in reaction time over time.

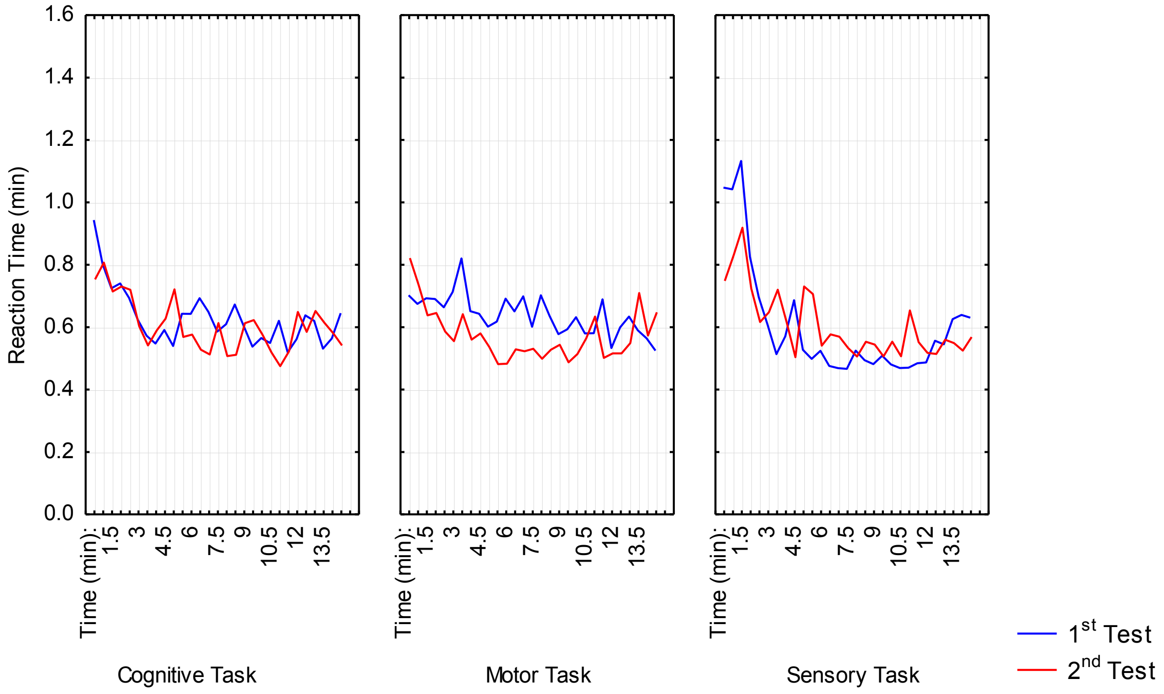

Figure 13: Reaction time responses as function of time-on-task over the 15 minute recovery profile of for the cognitive, motor and sensory tasks during the 1st test and the 2nd test. Error bars depict a 95% confidence interval. Note: Standard deviation values and markers removed to make trend clearer.

Post Hoc recovery responses during the Cognitive Tasks

The differences in response time during the 1st test and 2nd test were not statistically significant ($p = 0.55$). The results from the recovery protocol show a statistically significant TIME effect ($p < 0.01$) that depicts a gradual decrease in reaction time. There was no statistically significant TEST SESSION by TIME effect ($p = 0.83$) recorded.

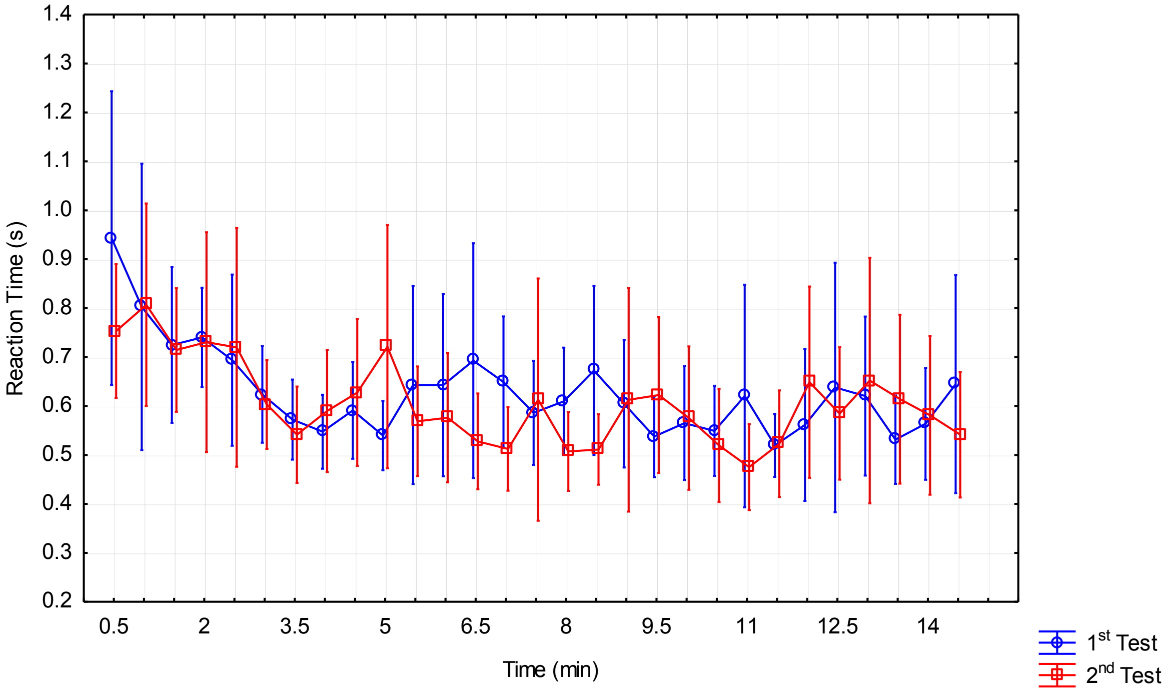

Figure 14: Reaction time responses as function of time-on-task over the 15 minute recovery profile of the cognitive task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

Post Hoc recovery responses during the Motor Tasks

Although the differences in response time during the 1st test and 2nd test were not statistically significant ($p = 0.07$), they were close to significance. The results from the recovery protocol show a statistically significant TIME effect ($p < 0.01$) that depicts a gradual decrease in reaction time during both test sessions. There was no statistically significant TEST SESSION by TIME effect ($p = 0.13$).

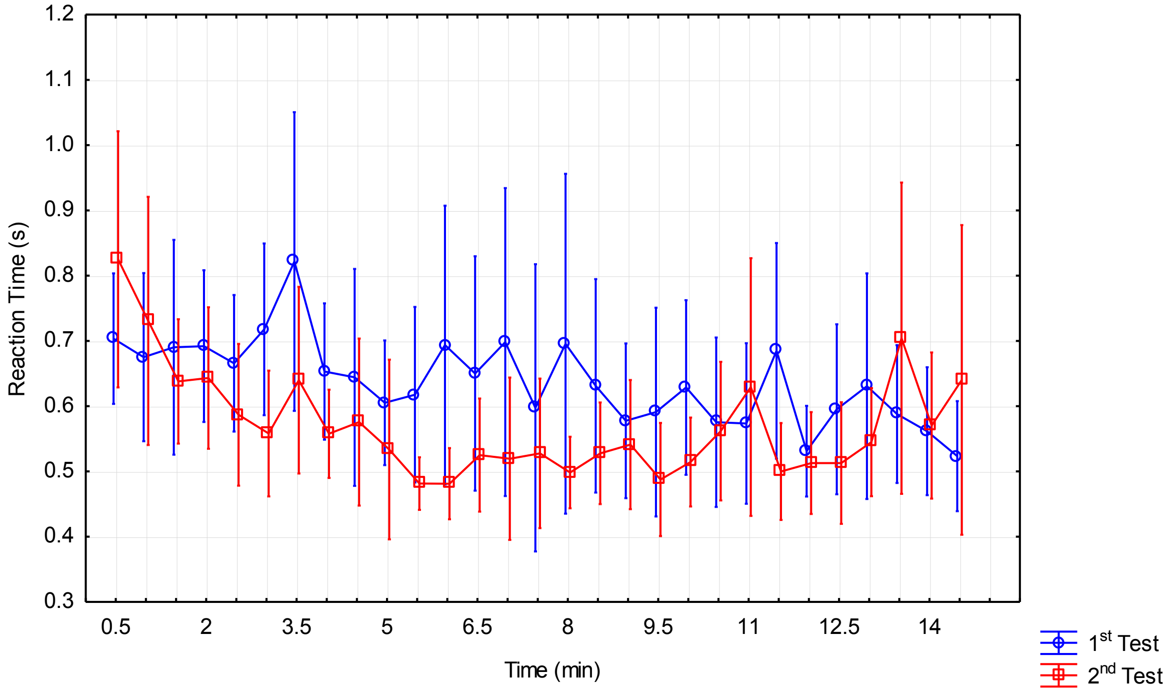

Figure 15: Reaction time responses as function of time-on-task over the 15 minute recovery profile of the motor task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

Post Hoc recovery responses during the Sensory Tasks

The differences in response time during the 1st test and 2nd test were not statistically significant (p= 0.9). The recovery protocol results display a statistically significant TIME effect (p < 0.01) that depicts a gradual decrease in reaction time over the recovery period. A statistically significant TEST SESSION by TIME effect (p < 0.05) was measured. Although both test sessions followed a similar trend and elicited decreases in reaction time from minute 2, the 1st test showed more oscillations. This observed response during the first 2 minutes may have been caused by a measurement problem (resulting in the presence of outliers) since the recorded standard deviation/confidence intervals for those values were very large.

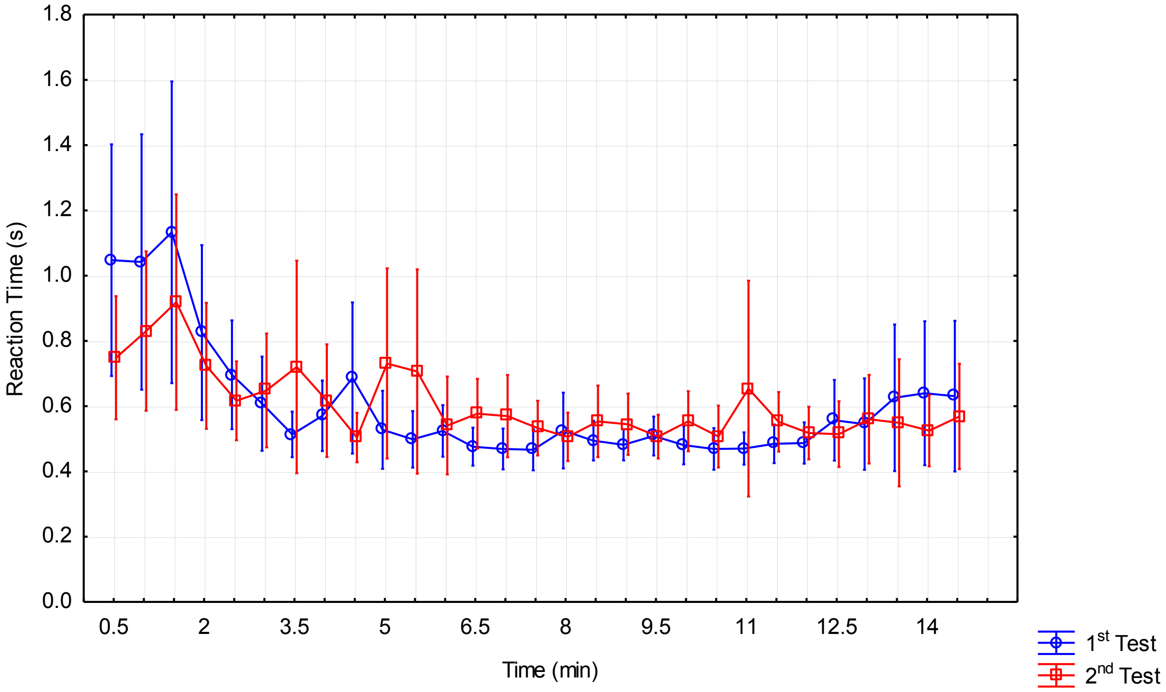

Figure 16: Reaction time responses as function of time-on-task over the 15 minute recovery profile of the sensory task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

Table I: Summary of significant task performance effects and simple reaction time test results; where TEST SESSION EFFECT = the differences between the '1st test' session and the '2nd test' session; TIME EFECT = the time-on-task effects; TEST SESSION BY TIME EFFECT = the differences between the 1st test session and the 2nd test session over time on the task; TASK TYPE EFFECT = the effects of the three different tasks with a focus on cognitive, motor and sensory tasks; TASK TYPE BY TIME EFFECT = the differences during the tasks over time; TASK TYPE BY TEST SESSION BY TIME EFFECT = the differences during the three tasks between the 1st test session and the 2nd test session over time (↓ denotes a decrease; ↑ denotes an increase, ^{1} denotes the '1st test'; ^{2} denotes the '2nd test'; **c** denotes the cognitive task; **m** denotes the motor task and **s** denotes the sensory task).

PARAMETERS	TEST SESSION EFFECT	TIME EFECT	TEST SESSION BY TIME EFFECT	TASK TYPE EFFECT	TASK TYPE BY TIME EFFECT	TASK TYPE BY TEST SESSION BY TIME EFFECT
PERFORMANCE: **Cognitive Task:**						
a) Correctly identified digits			$\downarrow^{1}$; $\downarrow^{2}$			
b) Response delay	↑	↑				
Motor Task:	↓					
Sensory Task:						
a) Correctly identified errors						
b) Word count	↑	↓				
REACTION TIME TESTS:						
Repetition 1						**c**: $\downarrow^{1}$;$\uparrow^{2}$; **m**: $\uparrow^{1}$;$\uparrow^{2}$; **s**: $\downarrow^{1}$;$\uparrow^{2}$
Repetition 2 & 3			**s**: $\uparrow^{1}$;$\uparrow^{2}$	**c**, **m**, **s**		
REACTION TIME DURING RECOVERY:		↓	**s**: $\downarrow^{1}$;$\downarrow^{2}$		**c**, **m**, **s**: ↓	**c**: $\downarrow^{1}$;$\downarrow^{2}$; **m**: $\downarrow^{1}$;$\downarrow^{2}$; **s**: $\downarrow^{1}$;$\downarrow^{2}$

Physiological Responses

As with the performance responses, the following responses are of the dependent variables over a period of 1 hour. 12 intervals, each an average value of 5 minutes, were processed for this section. The measured physiological responses included blink frequency and duration, skin and ear temperature as well as heart rate and heart rate variability. These parameters were measured continuously during task execution. These responses have been grouped into three broad resource categories; effects will be considered according to a particular task. Three-way factorial ANOVAs were calculated to determine the general task effects (with factors TIME, TASK TYPE and TEST SESSION). A post hoc analysis was also conducted through a two-way factorial ANOVA (with factors TIME and TEST SESSION).

Ear Temperature Responses

Only ear temperature results were considered as the skin temperature recordings elicited huge standard deviation variations with substantial inter-individual variance and results that did not coincide with normal skin temperature recordings. An additional reason was that the skin temperature probe would move during testing; as a result, this data was rendered unreliable.

The General Effects of Ear Temperature Results

The TIME by TEST SESSION factor (as calculated by the three-way ANOVA) showed a significant result ($p < 0.05$). *Figure 17* shows that each task elicited a unique ear temperature trend: the cognitive task elicited lower temperature values during the 2nd test but showed a general increase in temperature over time in contrast to the 1st test session (which first elicited a steady decrease in temperature during the first 30 minutes of the task then an increase after that time); the motor task data indicated that the 2nd test session elicited higher temperature values, showing an initial decrease in temperature then an increase followed by a decrease; and the sensory task elicited relatively linear and higher temperature values in comparison to the lower and constantly increasing temperature values during the 2nd test session. The TEST SESSION factor, the TASK TYPE factor, the TIME factor and the TEST SESSION by TIME by TASK TYPE factor did not show any significant effects; p= 0.48, p= 0.85, p= 0.19 and p= 0.71 respectively.

Post Hoc Analyses of Ear Temperature Results

Two-way ANOVA calculations did not elicit any significant results for the TEST SESSION factor: p= 0.3 during the cognitive task, p= 0.47 during the motor task and p= 0.4 during the sensory task. The TIME factor did not show any significant results either, with p= 0.1 during the cognitive task, p= 0.99 during the motor task and p=

0.17 during the sensory task. The TEST SESSION by TIME factor also did not show significant results: p = 0.08 during the cognitive task, p= 0.06 during the motor task and p= 0.97 during the sensory task.

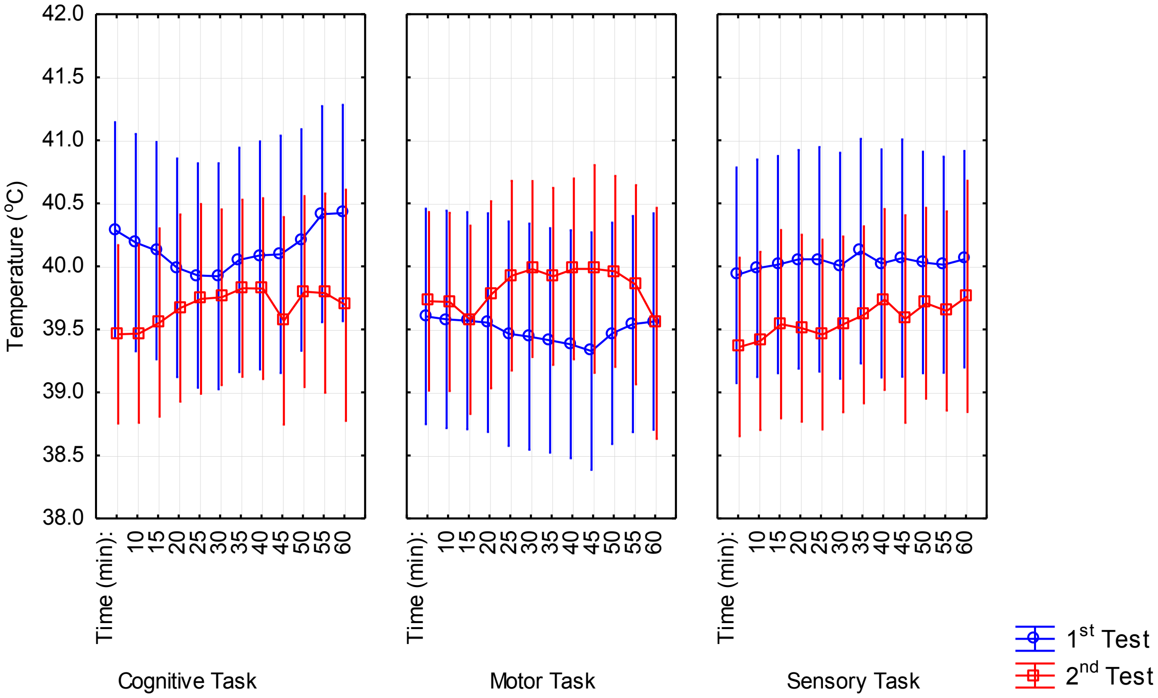

Figure 17: Ear temperature responses as function of time-on-task for the cognitive, motor and sensory tasks during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

Eye Blink Responses

Eye Blink Frequency Responses

a) General Effects of Eye Blink Frequency Results

The TASK TYPE by TIME by TEST SESSION factor showed a statistically significant result ($p < 0.05$) as calculated by the ANOVA. The results indicate that the sensory tasks elicited lower blinks consistently, with marked differences in responses during both test sessions and an increase in blinks over time. The cognitive and motor tasks elicited a similar blink frequency response over time. The figure shows that the 2nd test resulted in a lower number of blinks in all tasks. TIME was found to have no significant effect on the tasks (p = 0.21). The TEST SESSION factor, the TASK

TYPE factor, the TIME factor and the TEST SESSION by TIME factor did not show any significant results; p= 0.11, p= 0.15, p= 0.21 and p= 0.29 respectively.

b) Post Hoc Analyses of Eye Blink Frequency Results

No significant results were shown from the TEST SESSION factor, with p= 0.54 during the cognitive task, p= 0.61 during the motor task and p= 0.14 during the sensory task. The TEST SESSION by TIME factor also did not show significant results during the cognitive task (p= 0.9) and the sensory task (p= 0.59). The TIME factor did not depict any significant results during the cognitive task (p= 0.35) or the motor task (p= 0.84). There was a significant TIME effect recorded for the two test sessions ($p < 0.05$) during the sensory tasks. *Figure 18* illustrates an increase in the blinks over time during the 1st and the 2nd test sessions during the sensory tasks. The TEST SESSION by TIME factor showed a significant result during the motor task ($p < 0.05$). *Figure 18* illustrates that the 2nd test session elicited more blinks on average; the blinks increased for the first 20 minutes of the task then decreased and reached a relatively steady state for 15 minutes, increasing slightly then finally decreasing again. The 1st test elicited fewer blinks on average; the blinks during this test session increased over time.

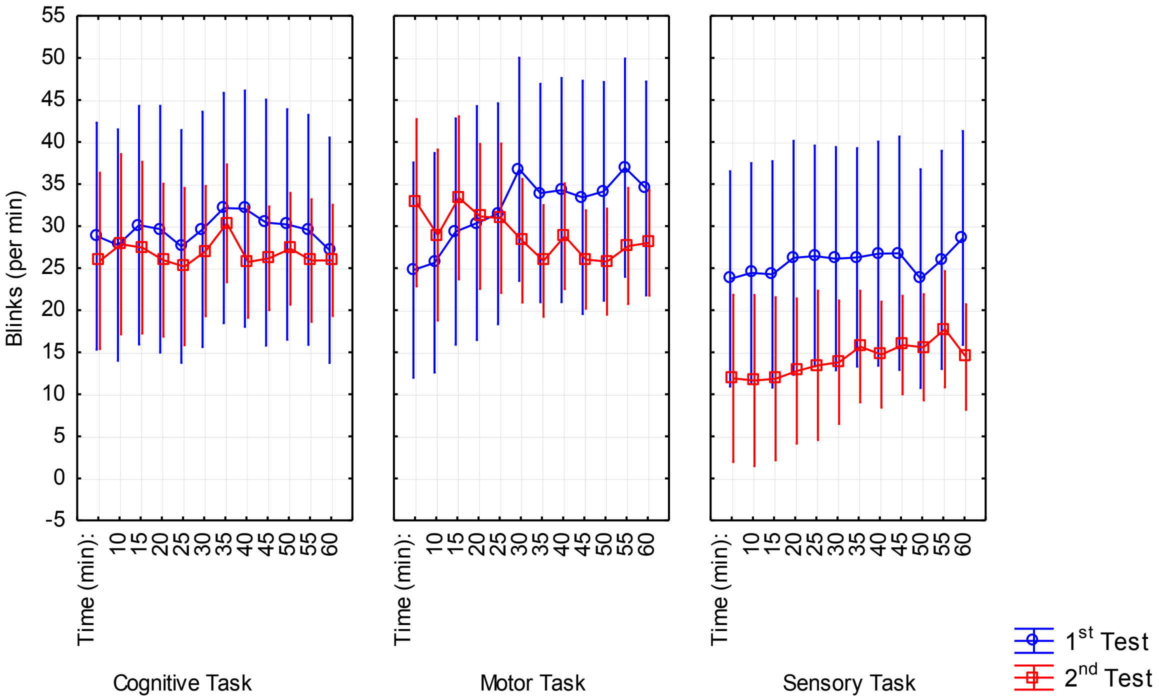

Figure 18: Eye blink frequency responses as function of time-on-task for the cognitive, motor and sensory tasks during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

Eye Blink Duration Responses

a) General Effects of Eye Blink Duration Results

A statistically significant TASK TYPE response effect was found ($p < 0.05$). An evaluation of the effect of TIME on the tasks during the 1st test and 2nd test elicited a statistically significant result ($p < 0.05$). TIME was found to have a significant effect on the tasks ($p < 0.01$). The results indicate that there was an increase in blink duration over time during all three tasks. The sensory tasks elicited lower blinks consistently, with similar responses during the 1st and 2nd test and an increase in blinks over time. The cognitive and motor tasks elicited marked differences in responses during the 1st and 2nd test and higher blink durations over time.

b) Post Hoc Analyses of Eye Blink Duration Results

The TEST SESSION factor did not elicit any significant results, with p= 0.36 during the cognitive task, p= 0.18 during the motor task and p= 0.61 during the sensory task. The TEST SESSION by TIME factor also did not show significant results during the cognitive task (p= 0.65) and the sensory task (p= 0.96). The TIME factor did not reveal any significant results during the sensory task (p= 0.53) either. There was a significant TIME effect recorded for the two test sessions during both the cognitive ($p < 0.01$) and motor ($p< 0.05$) tasks. A significant effect for the TEST SESSION by TIME factor during the motor tasks was recorded ($p < 0.01$). The figure shows different fluctuation patterns over time during the 1st test and the 2nd test sessions when participants were completing the motor tasks.

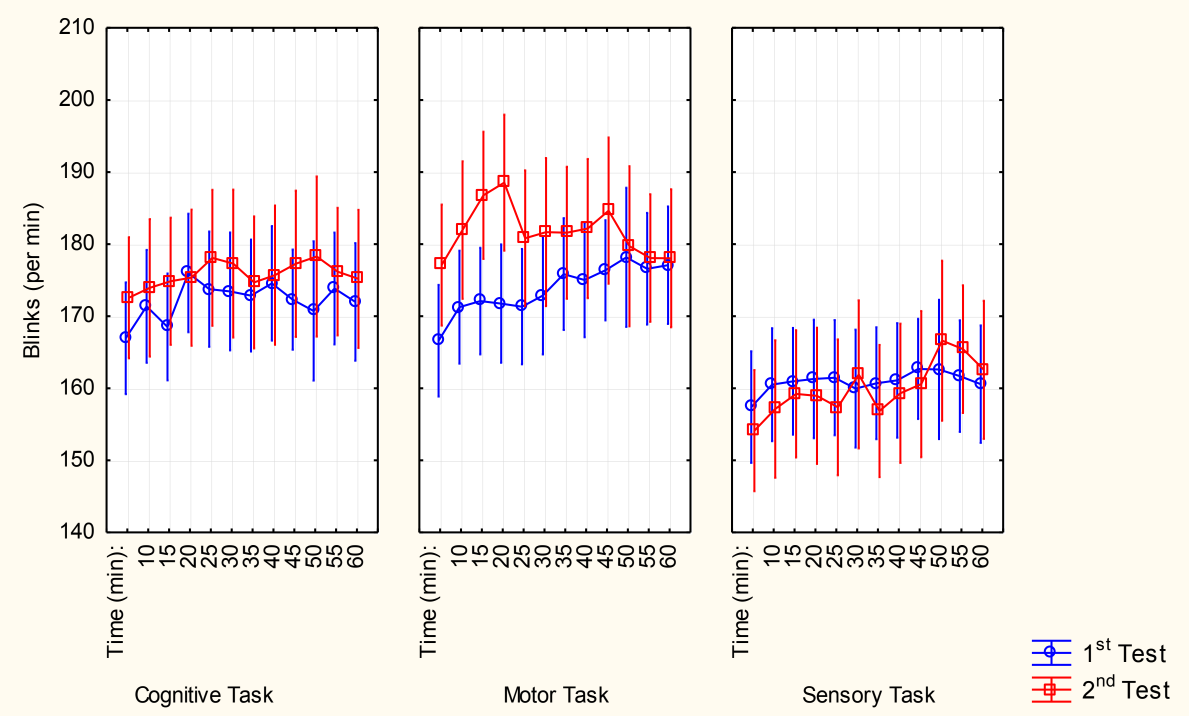

Figure 19: Eye blink duration responses as function of time-on-task for the cognitive, motor and sensory tasks during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

Heart Rate and Heart Rate Variability Responses

Heart Rate Responses

a) General Effects of Heart Rate Results

A statistically significant TASK TYPE effect was recorded ($p < 0.01$) for all tasks; as illustrated by the figure, the different tasks produced different patterns. A comparison of the effect of TIME by the TEST SESSION by the TASK TYPE effect showed a statistically significant result ($p < 0.05$). The effect of TIME on the tasks during the 1st and 2nd test sessions was also found to be statistically significant ($p < 0.05$); the figure depicts reductions in heart rate with increasing time-on-task and over the different test sessions. The TEST SESSION factor and the TEST SESSION by TIME factor did not show any significant results; $p= 0.16$ and $p= 0.82$ respectively.

b) Post Hoc Analyses of Heart Rate Results

The results indicate that there was a significant TIME effect recorded for the two test sessions ($p < 0.05$) during the cognitive and sensory tasks separately. As illustrated by *Figure 20*, the heart rate responses during the cognitive and sensory resource tasks show a gradual decrease over the duration of both test sessions. There was no significant TIME effect recorded during the motor task ($p= 0.93$). Statistical calculations show that no significant results were shown for the TEST SESSION factor and the TEST SESSION by TIME factor during all three tasks: $p= 0.84$ and $p= 0.09$ (respectively) during the cognitive task, $p= 0.98$ and $p= 0.66$ (respectively) during the motor task and $p= 0.88$ and $p= 0.7$ (respectively) during the sensory task.

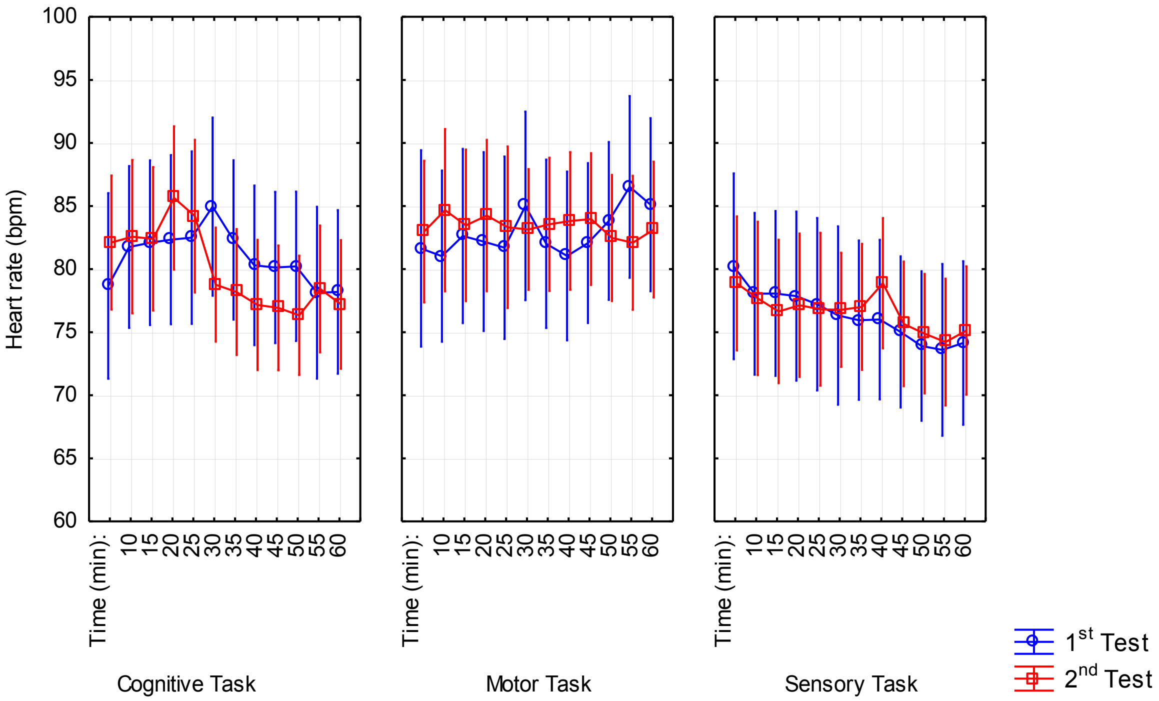

Figure 20: Heart rate frequency responses as function of time-on-task for the cognitive, motor and sensory tasks during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

Heart Rate Variability Responses

The frequency domain analyses of HRV evaluated the high and low frequency spectra. Although the power of the bands (LF power; HF power), the centre frequencies (LFcf; HFcf) and the low frequency component of the combined (LF+HF) power spectrum were assessed, the only significant effects that emerged for centre frequencies (LFcf and HFcf) and the low frequency component of the combined (LF+HF) power spectrum were gender effects. As a result, these effects (in as much as they relate to the hypothesis of this study) will be discussed within the ‘Gender Effects’ section. Therefore, only the results of the power of the bands are discussed within this section.

Frequency-domain Analyses

- HF Power

a) General Effects of HF Power results

TIME was found to have a significant effect on the tasks ($p < 0.01$); there was a slight increase in high frequency responses over time in all tasks. No significant results were recorded for the TEST SESSION factor, the TASK TYPE factor, the TEST SESSION by TIME factor or the TEST SESSION by TIME by TASK TYPE factor; p= 0.73, p= 0.85, p= 0.73 and p= 0.37 respectively.

b) Post Hoc Analyses of HF Power Results

No significant results were shown for the TEST SESSION factor, with p= 0.19 during the cognitive task, p= 0.85 during the motor task and p= 0.55 during the sensory task. The TIME factor also showed no significant results, with p= 0.19 during the cognitive task, p= 0.53 during the motor task and p= 0.1 during the sensory task. The TEST SESSION by TIME factor also did not show significant results; p= 0.28 during the cognitive task, p= 0.66 during the motor task and p= 0.68 during the sensory task.

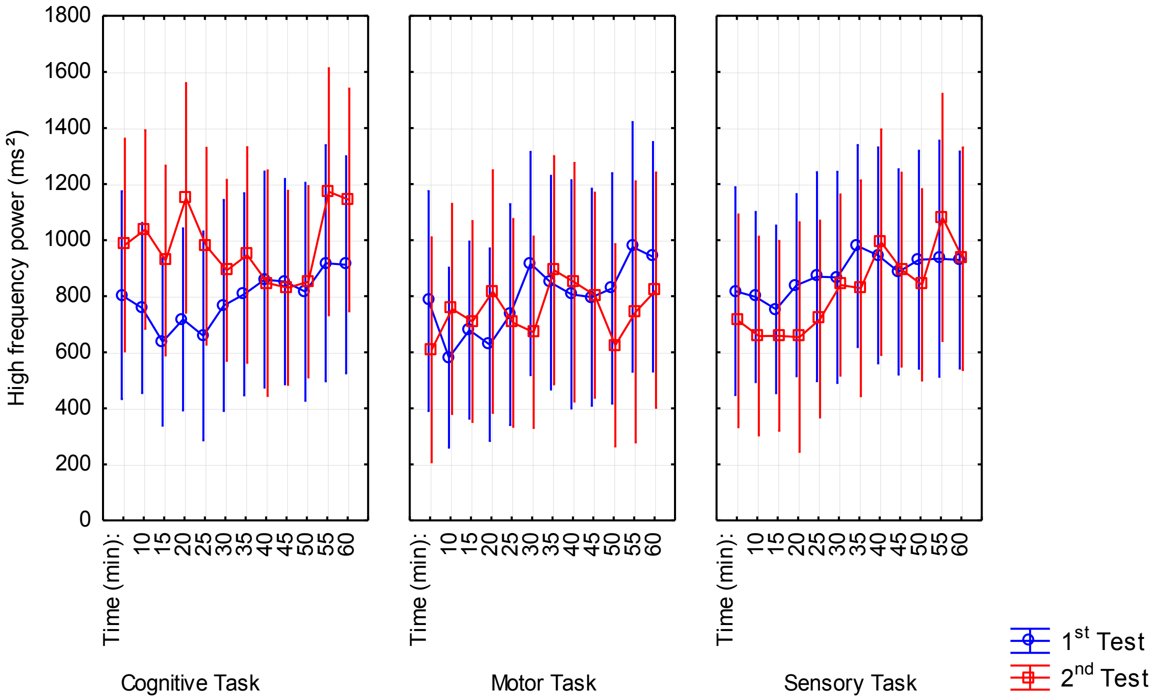

Figure 21: High frequency power responses as function of time-on-task for the cognitive, motor and sensory tasks during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

- *LF Power*

a) General Effects of LF Power results

TIME was found to have a significant effect on the tasks ($p < 0.05$); the tasks elicited results that remained at a steady state throughout testing. The TEST SESSION factor, the TASK TYPE factor, the TEST SESSION by TIME factor and the TEST SESSION by TIME by TASK TYPE factor did not show any significant results; p= 0.22, p= 0.63, p= 0.73 and p= 0.73 respectively.

b) Post Hoc Analyses of LF Power results

The TEST SESSION factor did not show any significant results, with p= 0.52 during the cognitive task, p= 0.31 during the motor task and p= 0.44 during the sensory task. The TIME factor did not show any significant results either; with p= 0.48 during the cognitive task, and p= 0.98 during the sensory task. A significant TIME effect was recorded for the two test sessions ($p < 0.05$) during the motor task. The TEST SESSION by TIME factor showed no significant results; $p = 0.94$ during the cognitive task, $p= 0.44$ during the motor task and $p= 0.96$ during the sensory task.

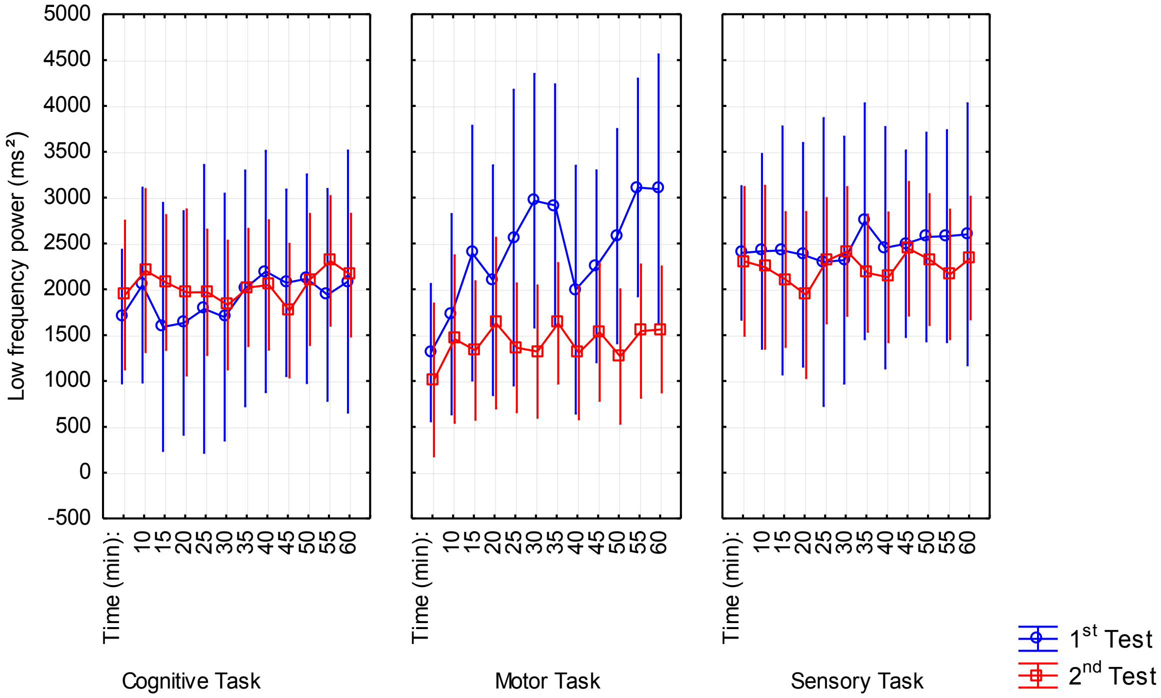

Figure 22: Low frequency power responses as function of time-on-task for the cognitive, motor and sensory tasks during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

Time-domain Responses

The time-domain analyses considered included SDNN, RMSSD, PNN50 and PNN30. Only RMSSD is discussed within this section as both the SDNN and RMSSD were calculated according to the same principle. The PNN50 value was excluded from the results section as some intervals yielded a value of zero. The PNN30 measure was used as it performs a similar factor with a lower variance allowance (with intervals differing by 30ms being considered instead of 50ms).

- *PNN 30*

a) General Effects of PNN30 results

TIME was found to have a significant effect on the tasks ($p < 0.01$); there was an increase in the PNN 30 values over time in all tasks. The TEST SESSION factor, the TASK TYPE factor, the TEST SESSION by TIME factor and the TEST SESSION by TIME by TASK TYPE factor did not show significant results; p= 0.4, p= 0.51, p= 0.13 and p= 0.98 respectively.

b) Post Hoc Analyses of PNN30 results

ANOVA calculations showed no significant results for the TEST SESSION factor; with p= 0.9 during the cognitive task, p= 0.57 during the motor task and p= 0.42 during the sensory task. The TEST SESSION by TIME factor also did not show significant results; with p= 0.56 during the cognitive task, p= 0.68 during the motor task and p= 0.76 during the sensory task. The TIME factor did not show any significant result during the motor task (p= 0.35) but showed significant effects during both the cognitive and sensory tasks ($p < 0.01$). *Figure 23* illustrates an increase in the PNN 30 values over time during the 1st and the 2nd test sessions.

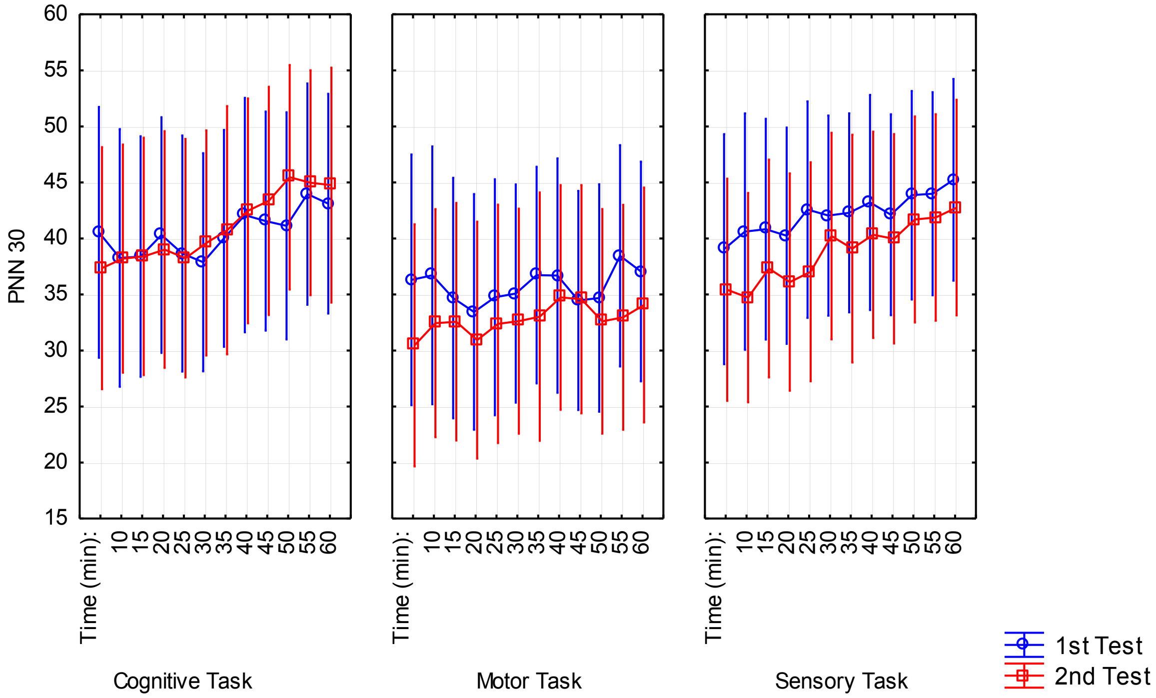

Figure 23: PNN 30 responses as function of time-on-task for the cognitive, motor and sensory tasks during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

— *SDNN*

a) General Effects of SDNN results

TIME was found to have a significant effect on the tasks ($p < 0.01$); there was a slight strong increase in the SDNN values over time in all tasks. The TEST SESSION factor and the TEST SESSION by TIME factor did not show significant results; p= 0.69 and p= 0.7 respectively. Statistical calculations performed showed a significant TASK TYPE factor ($p < 0.05$). The results indicate that the motor task elicited the lowest SDNN, followed by the sensory task then lastly the cognitive task (in ascending order). A significant TIME by TASK TYPE factor ($p < 0.01$) was measured. The patterns of SDNN that emerged in response to the 1st and 2nd test sessions followed very different and somewhat opposing trends.

b) Post Hoc Analyses of SDNN results

No significant results were shown for the TEST SESSION factor; with p= 0.22 during the cognitive task, p= 0.67 during the motor task and p= 0.69 during the sensory task. The TEST SESSION by TIME factor also did not show significant results during the motor and the sensory tasks; with p= 0.06 and p= 0.4 respectively. The cognitive task elicited a significant TEST SESSION by TIME result ($p < 0.05$). The figure below shows that the 1st test produced responses with very few fluctuations in contrast to the 2nd test which followed a different trend. There was a significant TIME effect recorded for the two test sessions ($p < 0.01$) in all tasks. Both responses during the 1st and 2nd test sessions were seen to increase gradually over the duration of the test in all the tasks.

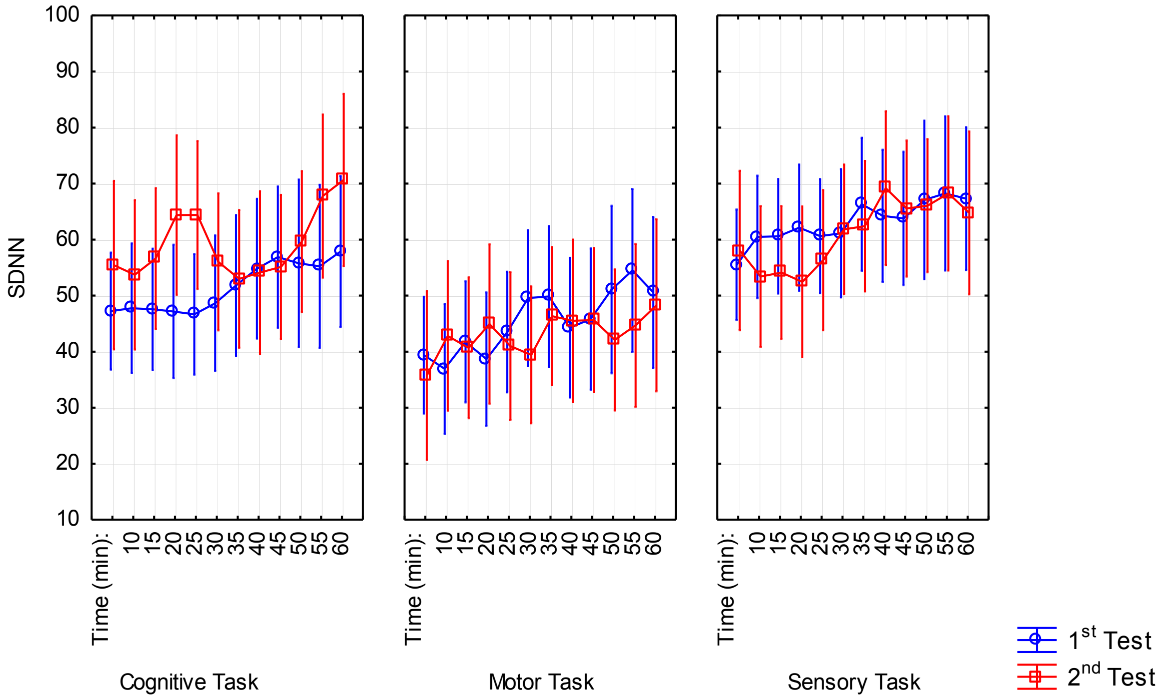

Figure 24: SDNN responses as function of time-on-task for the cognitive, motor and sensory tasks during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

Table II: Summary of significant physiological responses; where TEST SESSION EFFECT = the differences between the ‘1st test’ session and the ‘2nd test’ session; TIME EFECT = the time-on-task effects; TEST SESSION BY TIME EFFECT = the differences between the 1st test session and the 2nd test session over time on the task; TASK TYPE EFFECT = the effects of the three different tasks with a focus on cognitive, motor and sensory tasks; TASK TYPE BY TIME EFFECT = the differences during the tasks over time; TASK TYPE BY TEST SESSION BY TIME EFFECT = the differences during the three tasks between the 1st test session and the 2nd test session over time (↓ denotes a decrease; ↑ denotes an increase; ⟶ denotes no change; ^{1} denotes the ‘1st test’; ^{2} denotes the ‘2nd test’; **c** denotes the cognitive task; **m** denotes the motor task and **s** denotes the sensory task).

PARAMETERS	TEST SESSION EFFECT	TIME EFECT	TEST SESSION BY TIME EFFECT	TASK TYPE EFFECT	TASK TYPE BY TIME EFFECT	TASK TYPE BY TEST SESSION BY TIME EFFECT
PHYSIOLOGICAL:						
Ear Temperature			$\uparrow^1;\uparrow^2$			
Eye Blink:						
a) Blink Frequency		**s**: ↑	**m**: $\uparrow^1;\downarrow^2$			**c**: $\uparrow^1;\rightarrow^2$; **m**: $\uparrow^1;\downarrow^2$; **s**: $\uparrow^1;\uparrow^2$
b) Blink Duration		↑	**m**: $\uparrow^1;\downarrow^2$	**c**, **m**, **s**		**c**: $\uparrow^1;\uparrow^2$; **m**: $\uparrow^1;\downarrow^2$; **s**: $\uparrow^1;\uparrow^2$
Heart Rate & Heart Rate Variability:						
a) Heart Rate		↓		**c**, **m**, **s**	**c**: ↓; **m**: ⟶ **s**: ↓	**c**: $\downarrow^1;\downarrow^2$; **m**: $\uparrow^1;\downarrow^2$; **s**: $\downarrow^1;\downarrow^2$
b) High Frequency Power		↑				
c) Low Frequency Power		↑				
d) PNN30		↑				
e) SDNN		↑	**c**: $\uparrow^1;\uparrow^2$	**c**, **m**, **s**		**c**: $\uparrow^1;\uparrow^2$; **m**: $\uparrow^1;\uparrow^2$; **s**: $\uparrow^1;\uparrow^2$

Subjective Responses

Subjective responses were recorded during task execution at 10 minute intervals for the Ratings of Perceived Exertion (RPE) measure. The NASA-Task Load Index (TLX) rating scale was completed by the participants after each test session. The two types of subjective responses were analysed differently. For instance, a three-way factorial ANOVAs (with factors TASK TYPE, TIME and TEST SESSION) was analysed for the RPE results. Then post hoc analyses were conducted where significance was recorded to identify the different characteristics that might have appeared exclusively for each task. Post hoc analyses were calculated using a two-way factorial ANOVAs (with factors TIME and TEST SESSION).

The NASA-TLX was analysed through a two-way ANOVA (with factors TEST SESSION and the difference between the ratings, called RATING effect) to allow for a measure of the general task effects for each task. In addition, a one-way ANOVA (with TEST SESSION as a factor and the TASK TYPE as a covariate) was analysed to allow for the differences and similarities in task ratings to be observed.

Ratings of Perceived Exertion Category Ratio Scale Responses

General Effects of the Ratings of Perceived Exertion Category Ratio Scale Responses

The TEST SESSION factor, the TEST SESSION by TASK TYPE factor, the TIME by TASK TYPE factor and the TEST SESSION by TIME factor showed no significant results, with $p= 0.06$, $p= 0.9$, $p= 0.64$ and $p= 0.16$ respectively. The TEST SESSION by TIME by TASK TYPE factor, as calculated by the three-way ANOVA, also did not show any significant results ($p= 0.28$). The TIME factor showed significant results ($p < 0.01$) as the TASK TYPE tasks show an increase in RPE ratings over time.

Post Hoc Analyses Results on the Ratings of Perceived Exertion Category Ratio Scale Responses

The differences between the 1st and 2nd test sessions during the cognitive task, the motor and sensory task did not elicit a statistically significant result at $p= 0.26$, $p= 0.51$ and $p= 0.06$ respectively. A TEST SESSION by TIME factor, as calculated from the three-way ANOVA, during the cognitive task and the motor task did not elicit a significant result ($p= 0.41$ and $p= 0.89$ respectively). The TEST SESSION by TIME result for the sensory task showed a significant result ($p < 0.05$). As illustrated by *Figure 25*, the test sessions followed similar patterns until minute 40 after which point responses during the 2nd test sessions decreased for 10 minutes before increasing again. Furthermore, the ratings during the 2nd test session were lower than during the 1st test session. The measurements indicated that time had a significant effect on the two test sessions ($p < 0.01$) during all three separate tasks as shown by the constant increase in rating over time.

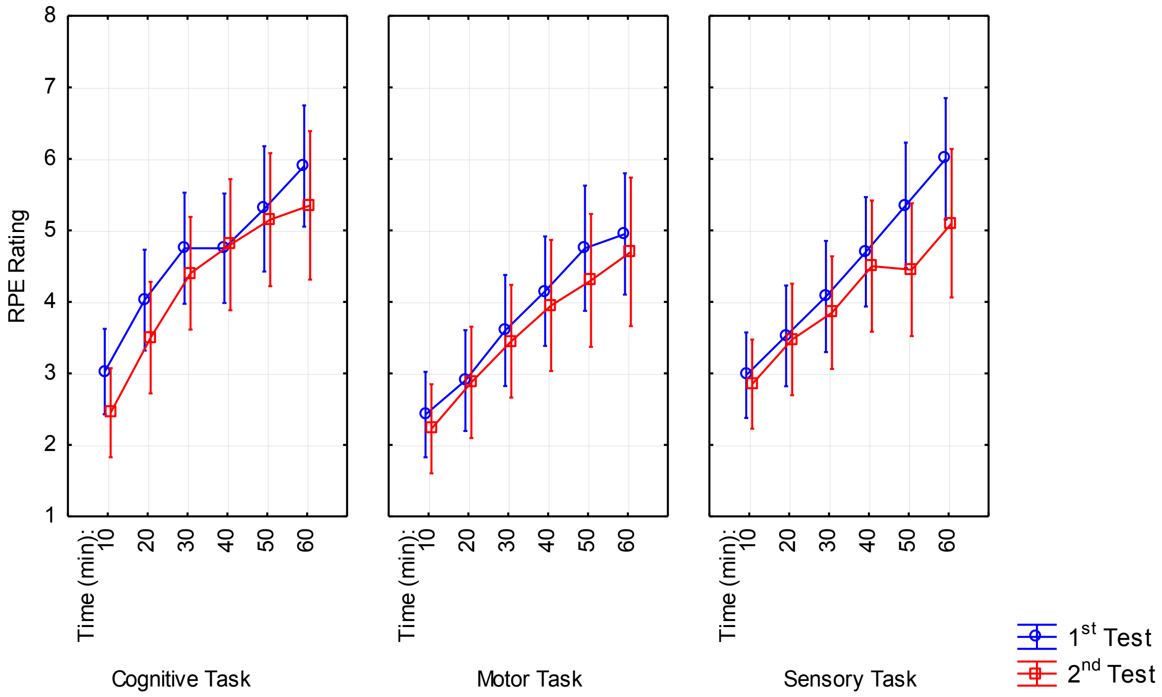

Figure 25: RPE responses as function of time-on-task for the cognitive, motor and sensory tasks during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

The NASA-Task Load Index Responses

The NASA-TLX was used to calculate the effect of the interaction between the individual and task. It elicited 7 ratings, namely: mental, physical and temporal demands, effort, frustration, total workload and performance. All ratings will be represented in one graph for each task.

NASA-TLX responses after the Cognitive Task

The difference between the ratings of the subscales elicited a significant result ($p < 0.01$); the highest rated subscales were mental demand and effort at approximately 78% (1st test) and 80% (2nd test) and 80% (1st test) and 76% (2nd test) respectively. There was no significant difference between the ratings during the 1st and 2nd test sessions ($p = 0.87$) or the TEST SESSION by RATING factor ($p = 0.92$).

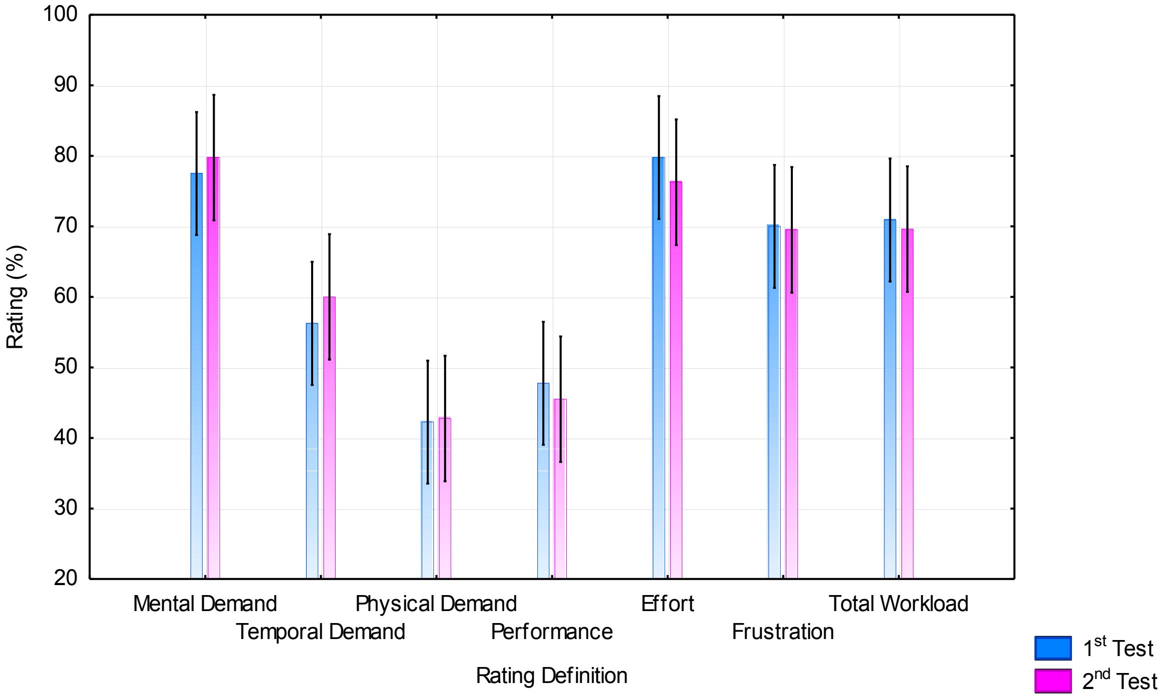

Figure 26: NASA-TLX ratings for the cognitive task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

NASA-TLX responses after the Motor Task

The difference between the ratings of the subscales did not elicit a significant result ($p = 0.15$). There was no significant difference between the ratings during the 1st and 2nd test sessions ($p = 0.61$) or the TEST SESSION by RATING factor ($p = 0.61$).

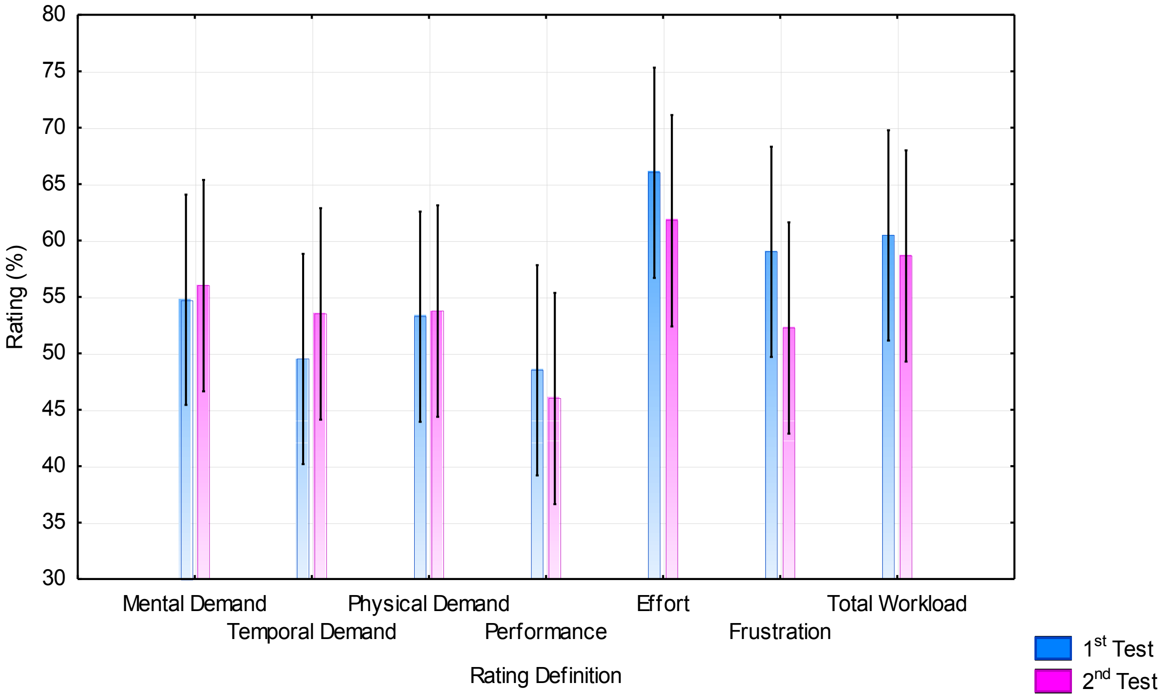

Figure 27: NASA-TLX ratings for the motor task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

NASA-TLX responses after the Sensory Task

The difference between the ratings of the subscales given during the 1st and 2nd test session elicited a significant result ($p < 0.01$). In addition, a calculation using the two-way ANOVA elicited a significant TEST SESSION by RATING effect and RATING factor; $p < 0.01$ for both. As illustrated by *Figure 28*, the highest rated subscales were mental demand, effort and frustration at approximately 72% (1st test) and 75% (2nd test), 69% (1st test) and 73% (2nd test) and 70% (1st test) and 66% (2nd test) respectively. The 2nd test session received higher ratings than the 1st test session.

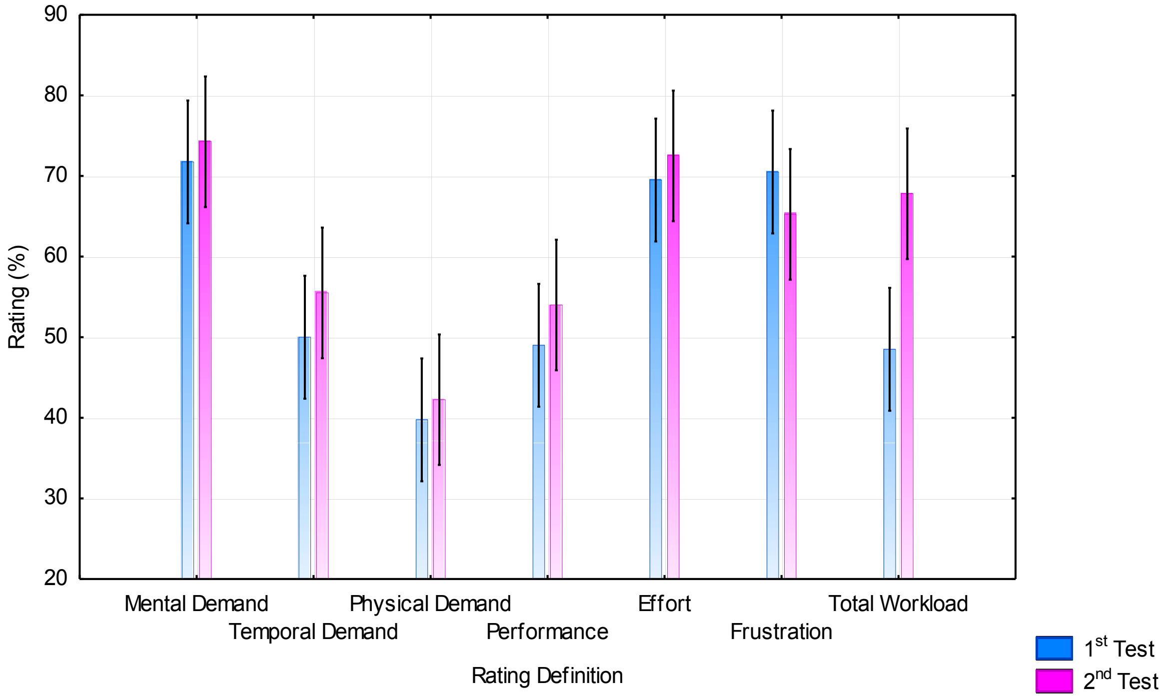

Figure 28: NASA-TLX ratings for the sensory task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

NASA-TLX Ratings after the three separate Tasks

Physical Demand

There were no significant NASA rating results for the TASK TYPE factor (p= 0.15), the TEST SESSION factor (p= 0.6) or the TEST SESSION by TASK TYPE factor (p= 0.91) across all three tasks.

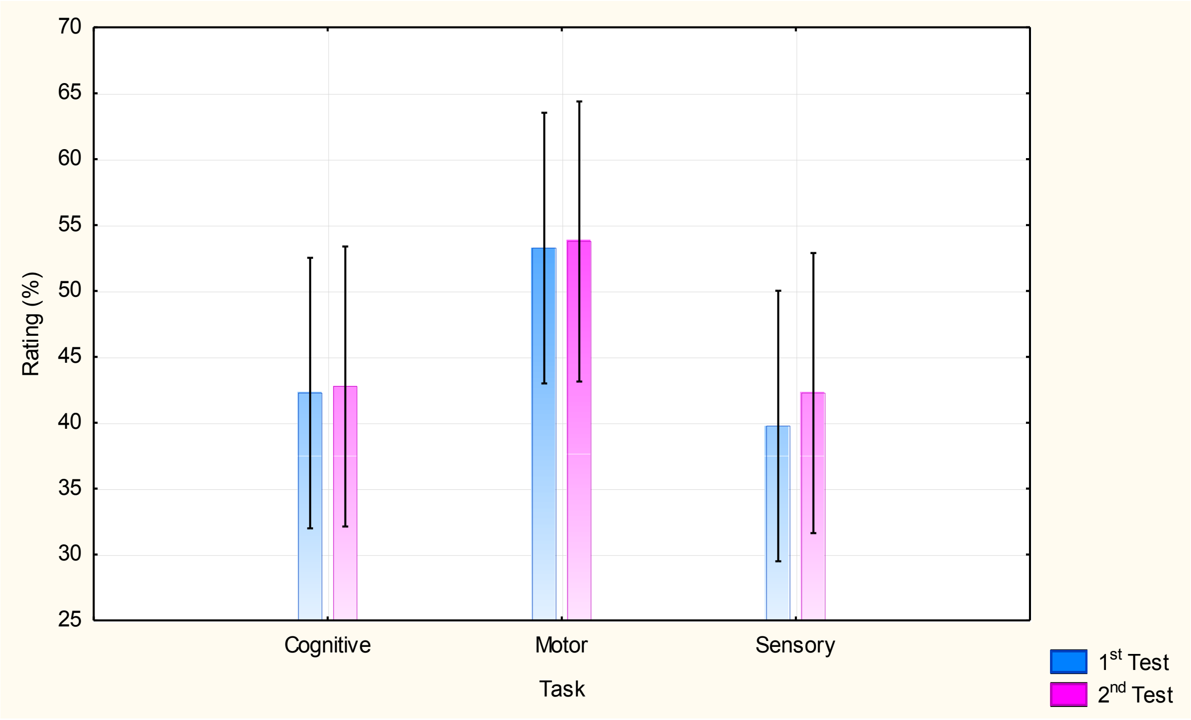

Figure 29: Comparison of NASA-TLX ratings over all tasks for physical demand. Error bars depict a 95% confidence interval.

Performance

The two-way ANOVA calculation performed on the performance variable elicited similar non significant results. For instance, the TASK TYPE factor (p= 0.64), the TEST SESSION factor (p= 0.97) and the TEST SESSION by TASK TYPE factor (p= 0.36), across all three tasks, did not show significance.

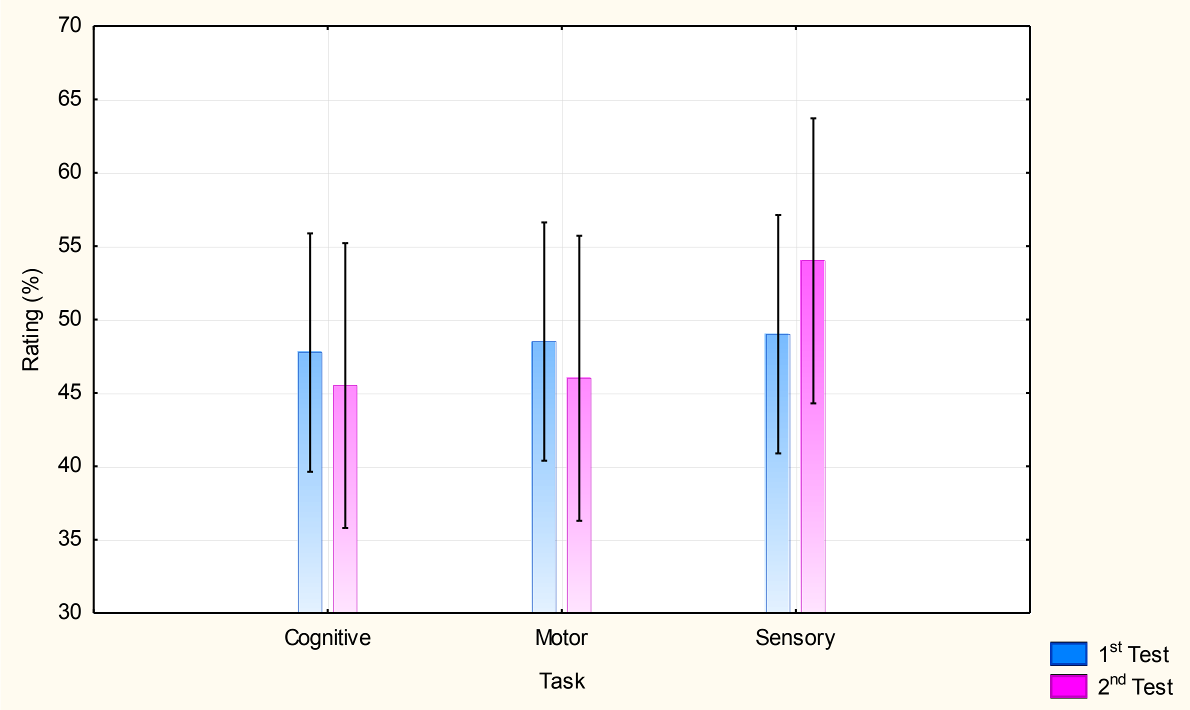

Figure 30: Comparison of NASA-TLX ratings over all tasks for performance. Error bars depict a 95% confidence interval.

Mental Demand

There was a significant TASK TYPE effect ($p < 0.01$) across the three tasks; the cognitive task received the highest mental demand rating followed by the sensory task then lastly by the motor task. There were no significant NASA rating results for the TEST SESSION factor ($p= 0.45$) or the TEST SESSION by TASK TYPE factor ($p= 0.98$).

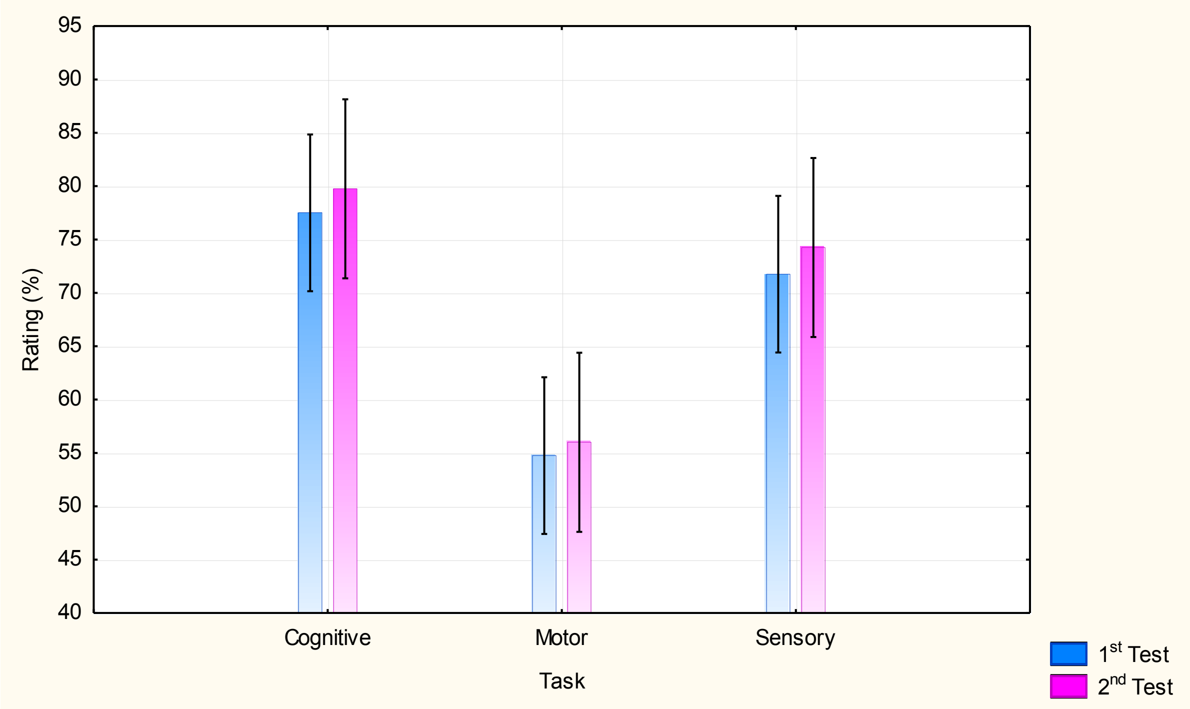

Figure 31: Comparison of NASA-TLX ratings over all tasks for mental demand. Error bars depict a 95% confidence interval.

Frustration

There was a significant TEST SESSION effect ($p < 0.05$) across the three tasks; all tasks elicited higher ratings for the 1st test than the 2nd test. There were no significant NASA rating results for the TASK TYPE factor ($p= 0.09$) or the TEST SESSION by TASK TYPE factor ($p= 0.43$).

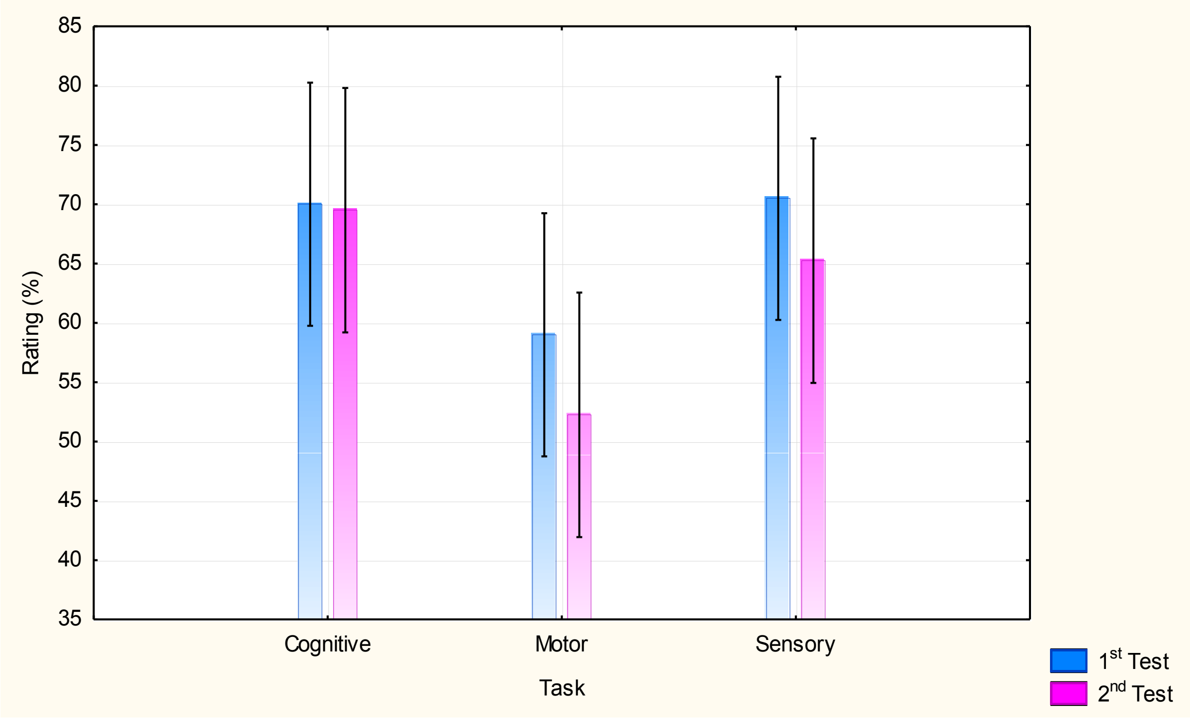

Figure 32: Comparison of NASA-TLX ratings over all tasks for frustration. Error bars depict a 95% confidence interval.

Effort

There was a significant TASK TYPE effect ($p < 0.05$) across the three tasks: the cognitive task received the highest effort rating followed by the sensory task then lastly by the motor task. There were no significant NASA rating results when calculations were made for the TEST SESSION factor ($p = 0.47$) and the TEST SESSION by TASK TYPE factor ($p = 0.35$).

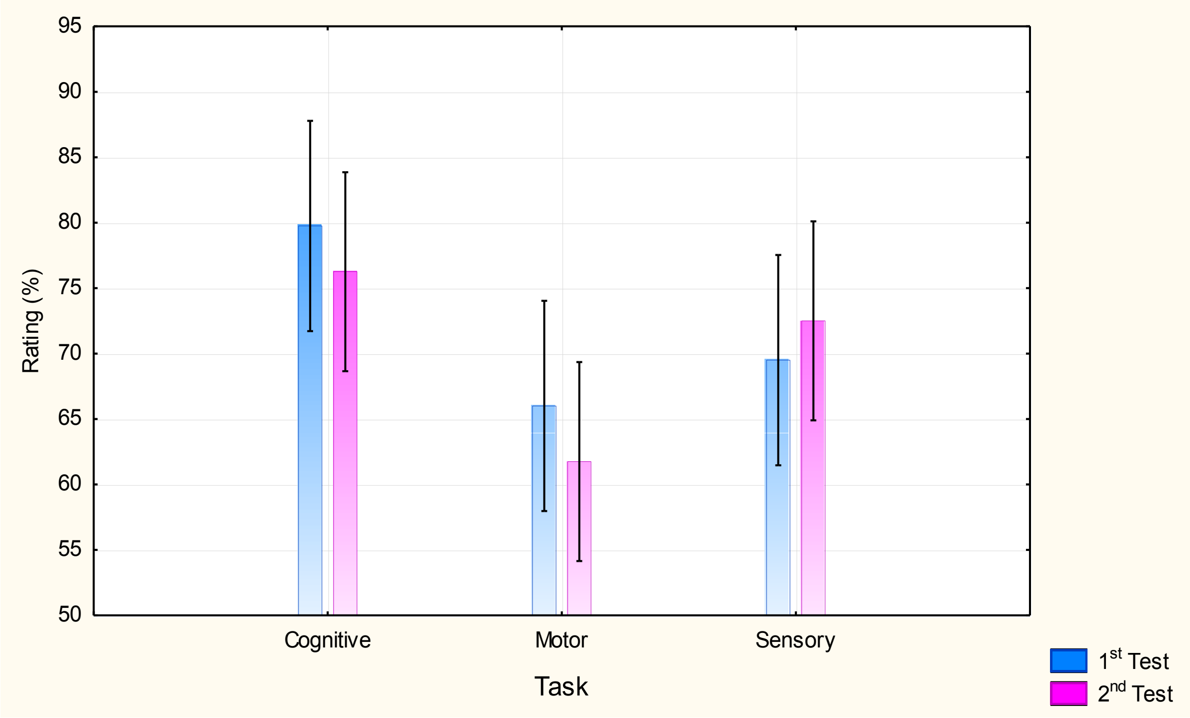

Figure 33: Comparison of NASA-TLX ratings over all tasks for effort. Error bars depict a 95% confidence interval.

Temporal Demand

There was a significant difference between the 1^{st} and 2^{nd} test sessions during the tasks ($p < 0.05$). All tasks elicited slightly higher ratings for the 2^{nd} test than for the 1^{st} test. There were no significant NASA rating results for the TASK TYPE factor ($p = 0.45$) and the TEST SESSION by TASK TYPE factor ($p = 0.93$).

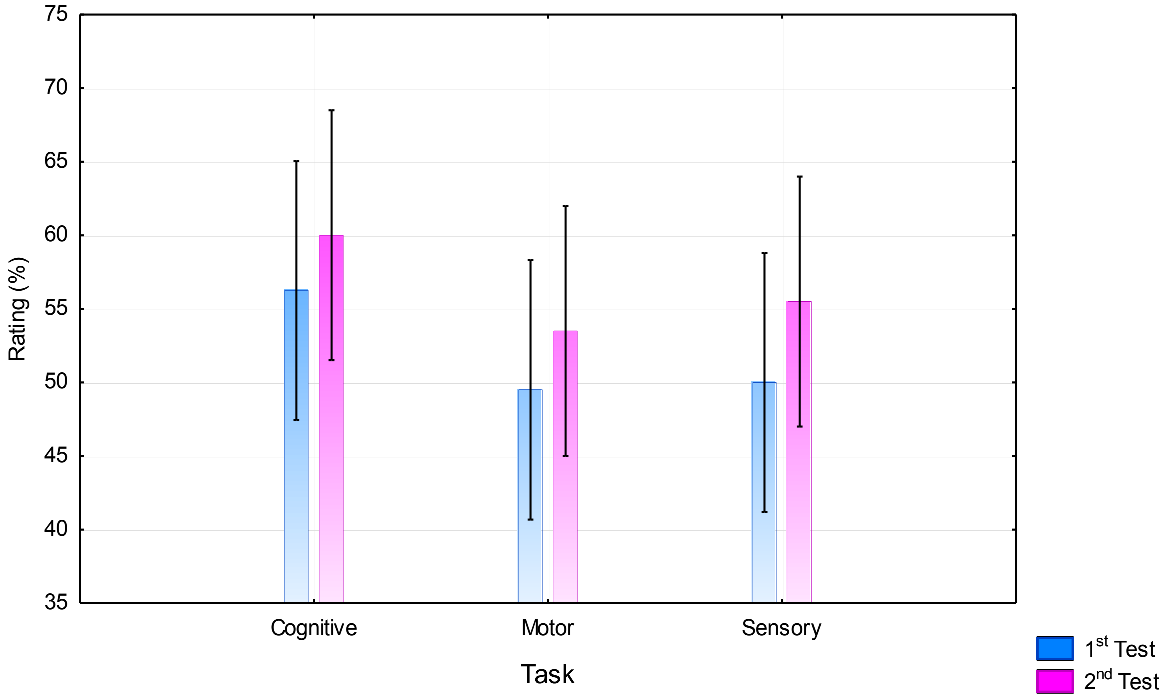

Figure 34: Comparison of NASA-TLX ratings over all tasks for temporal demand. Error bars depict a 95% confidence interval.

Total Workload

There was a significant TASK TYPE effect ($p < 0.01$) for the total workload weighting. The cognitive task was given the highest weighting followed by the motor task then lastly by the sensory task. There were no significant NASA rating results for the TEST SESSION factor ($p= 0.67$) or the TEST SESSION by TASK TYPE factor ($p= 0.71$).

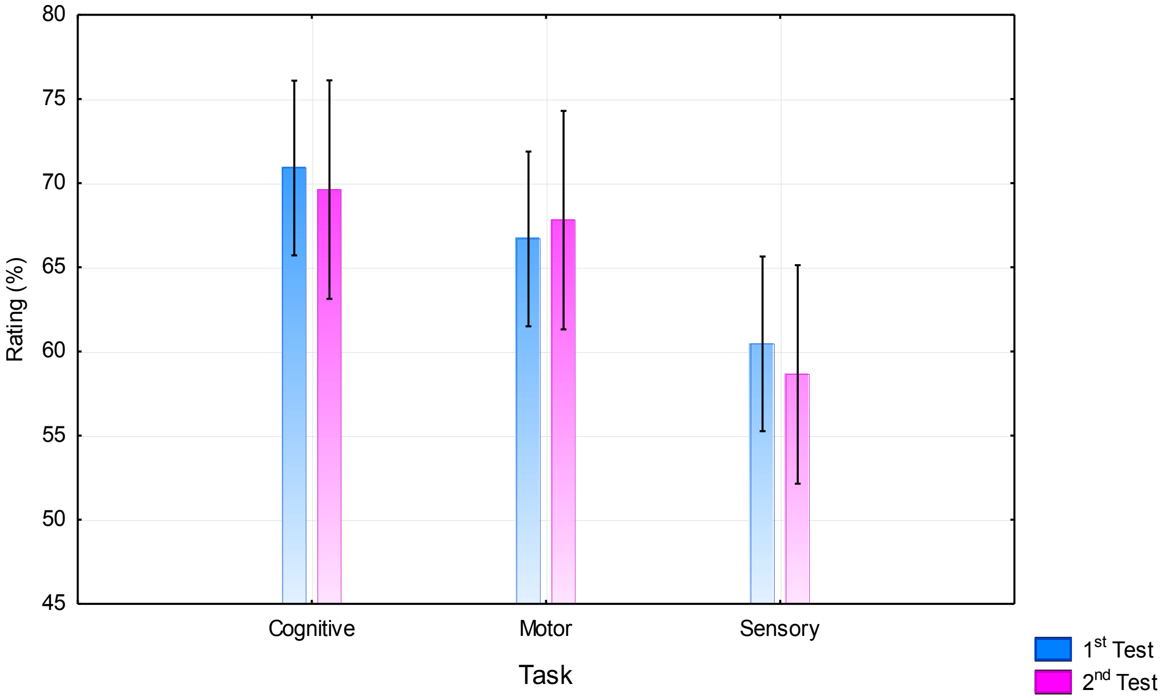

Figure 35: Comparison of NASA-TLX ratings over all tasks for total workload. Error bars depict a 95% confidence interval.

SUMMARY OF GENDER EFFECTS

Ear temperature was found to elicit a gender interaction with both time-on-task and the two test sessions; specifically, females showed higher temperature recordings that differed between the 1st and 2nd tests and over time. The temperature responses of males remained relatively steady over time. Eye blink duration also elicited a gender interaction with both time-on-task and the two test sessions where females showed longer blinks during the motor and cognitive tasks. Furthermore, male and female responses differed between the 1st and 2nd tests. Heart rate variability analysis for low frequency centre frequency responses showed that male and female responses differed between the 1st and 2nd tests; female responses were higher during the 1st test (for both the cognitive and sensory tasks) and lower during the 2nd test (for the cognitive task).

RPE elicited a gender interaction with both time-on-task and the two test sessions in response to the sensory task, where females gave higher ratings during the 1st test session while males gave similar ratings during both test sessions. Both males and females reported an increase in exertion over time. The RPE reports during the cognitive task also showed a gender interaction with the two test sessions, where females reported exerting more effort during the 2nd test session and males reported exerting less effort during the 2nd test session.

Table III shows the statistically significant gender effects recorded for all variables and includes a brief discussion of the recorded data with gender effects.

Table III: Depiction of the significant gender effects for the various variables that related to the study; where **LF cf** denotes the low frequency centre frequency, **RPE** denotes the ratings of perceived exertion

Dependent Variable	Specific Factor with Significant Result	Brief Trend Description
Ear Temperature during the Cognitive Task	TEST SESSION by TIME by gender	Females showed increasing temperature recordings over time during both test sessions while males elicited recordings that remained relatively steady over time.
Eye Blink Duration during:		
1. Cognitive Task	1. TEST SESSION by TIME by gender	Males and females were affected by the test sessions differently with more stable responses over time observed in females.
2. Motor Task	2. TEST SESSION by TIME by gender	Females had longer blink durations and more stable blinks during the 1st test and the 2nd test while male responses followed the opposite trend.
Heart Rate and Heart Rate Variability: **LF cf** during:		
1. Cognitive Task	1. TEST SESSION by gender	Female responses were higher during the 2nd test and lower during the 1st test while male responses followed the opposite trend.
2. Sensory Task	2. TEST SESSION by gender	Male responses were lower during the 2nd test while female responses were higher during the 2nd test.
RPE Rating during:		
1. Cognitive Task	1. TEST SESSION by gender	Females gave higher ratings during the 2nd test while males gave higher ratings during the 1st test.
2. Sensory Task	2. TEST SESSION by TIME by gender	Ratings given by females were higher during the 1st test while males gave similar ratings during the both test sessions. Both male and female ratings of RPE increased over time.

SUMMARY OF RESULTS

Performance response was found to differ between the 1st test and the 2nd test during all measured tasks; particularly, performance (during the 2nd test session) improved during the motor and sensory tasks and declined during the cognitive task. The sensory task showed an improvement in performance over time. In contrast, the cognitive task showed a decline in performance over time and differing performance patterns over time between the 1st test and the 2nd test sessions.

The reaction time tests showed a difference in reaction time values between the first reaction time repetition and the second and third repetitions. The first reaction time repetition elicited different response patterns for the 1st test and for the 2nd test in all three tasks. Reaction time, during the second and third repetitions, was found to differ depending on the type of task.

Reaction time measures during the recovery profile showed that the response pattern during each of the tasks changed over the recovery period. Additionally, reaction time was found to differ depending on the task, with different response patterns measured for the 1st test and for the 2nd test after all three tasks.

Ear temperature responses showed differing trends over time during the two test sessions. Eye blink frequency was found to increase over time during the sensory task and to elicit differing trends over time, while different trends were recorded during the motor task for the 1st test session than for the 2nd test session. Eye blink duration was found to differ depending on the type of task and to increase over time during all three tasks. Eye blink duration and frequency responses were found to have elicited differing response patterns for the 1st test session and for the 2nd test session in all three tasks over time. Heart rate frequency decreased over time and was shown to be sensitive to the type of task being carried out. Furthermore, heart rate responses showed that each task elicited a unique response during the 1st test session and during the 2nd test session over time. Heart rate variability analyses for high and low frequency power and PNN30 increased over time. The SDNN analysis was found to increase over time and to respond in accordance with the task being executed. Moreover, this variable elicited a distinctive response during the 1st test session and during the 2nd test session over time across the different tasks.

The subscales rated as inducing the highest amount of workload (during the completion of the NASA-TLX) after the cognitive task (for both test sessions) were mental demand and effort. Mental demand, effort and frustration were the subscales rated as inducing the highest amount of workload after the sensory task (for both test sessions). Physical demand and own performance were the lowest rated subscales after both the cognitive and sensory tasks (for both test sessions). The sensory task was the only task that showed a significant difference in rating between the 1st and 2nd test; specifically, participants reported exerting themselves more during the 2nd test session. Additionally, the ratings given after the two test sessions differed between the 1st and 2nd test sessions and across the measured subscales.

Statistical analyses comparing the ratings of the each subscale after the three tasks showed that a significant TASK TYPE effect was reported for subscales such as total workload, mental demand, and effort. With regards to total workload, the cognitive task was reported as demanding the highest amount of workload followed by the motor task then lastly by the sensory task. A measure of subscales mental demand and effort showed that participants reported the cognitive task as eliciting the highest amount of mental demand and effort followed by the sensory task then the motor task (in descending order of workload induced). A significant difference in workload rating between the 1st and 2nd test sessions was measured for the subscales frustration and temporal demand. For instance, the 2nd test session was reported as imposing a greater time pressure while the 1st test session was reported as causing more frustration (for all three tasks).

The RPE measure was used to indicate perceived exertion or effort. The 2nd test session was rated (during all three tasks) as requiring less effort, however, this difference was not significant. The RPE rating given by participants increased significantly over the task duration during all three tasks. The sensory task was the only task that showed a significant difference in rating between the 1st and 2nd test over time; specifically, the trends of the two test sessions differed over time.

CHAPTER V

DISCUSSION

INTRODUCTION

This study outlined a number of hypotheses aimed at assessing a fatigue regulatory mechanism. It was proposed that the manner in which fatigue presented (physiologically, subjectively and performance-wise) would differ during two consecutive test sessions relative to each other. Secondly, it was hypothesized that any differences in the manner in which fatigue presented during the 1st test session from the 2nd test session would indicate a fatigue regulatory mechanism. Lastly, it was proposed that a fatigue regulation mechanism would evoke different effects and patterns specific to the task and the past experience gained from that task.

THE EFFECT OF TIME ON THE MEASURED VARIABLES

Although time-on-task effects were noted during a majority of the measured variables, analysing and drawing conclusions on time-on-task effects independently was not an objective of this study. Therefore these effects will only be discussed briefly; strictly those effects that 1) support existing literature regarding the positive causal relationship that exists between time-on-task and fatigue (in that fatigue increases with time-on-task) and 2) confirm that fatigue did indeed occur (indicated by a progressive disruption or reduction of the processes taxed during task execution) will be highlighted briefly.

Since fatigue is a progressive state that limits, reduces and disrupts the functioning of numerous processes (Noy *et al.*, 2011; Brown, 1982), time-on-task effects are an integral part of fatigue analyses. Therefore, the role that time-on-task plays in the development of fatigue cannot be underestimated. Significant decreases in performance and responses, increases in subjective ratings of exertion and alterations in the physiological parameters were expected as fatigue is heavily influenced by time-on-task (Gander *et al.*, 2011); this is because time fundamentally induces fatigue since any activity (that requires effort) being carried out for a long enough period is expected to result in an increased difficulty maintaining the activity (Lal and Craig, 2001; Schmidt, 1982). Furthermore, the imbalance between the intensity, duration and timing of work with recovery time will induce fatigue (Dawson *et al.*, 2011). This is why performance decreases, and activity disruptions will occur as a function of time-on-task (Hartley *et al.*, 2003).

Significant time-on-task effects were recorded during the performance measures of the cognitive and sensory tasks (Table I). In the case of the cognitive task, the measured factor, response delay, showed an increase over time. The measured factor, word count, was reduced over time during the sensory task. This suggests that participants experienced fatigue, marked by the progressive reduction in performance and response speed.

Blink frequency and duration responses also showed significant time-on-task effects (Table II); the sensory task elicited significant increases in blink frequency over time. Blink duration responses over time supported Morris and Miller (1996) and Stern *et al.* (1994)'s assertion about eye blink duration tending to increase with time-on-task because all the measured tasks elicited significant increases in blink duration over time. Eye blink responses have been reported to increase with an increase in fatigue (Craig *et al.*, 2006), and the responses indicate that the participants did experience fatigue during the tasks.

Fairclough *et al.* (2005) noted that increases in heart rate (HR) responses tended to occur with an increase in demand and activation levels. However, the observed tasks all elicited significant time-on-task decreases in HR over time. This suggests that the activation levels and the demand of the activity were reduced progressively with time on task. Significant time-on-task increases in the measured heart rate variability (HRV) parameters were recorded (Table II); high frequency power, low frequency power, SDNN, and PNN 30 were all found to increase over time during all three tasks. According to Boyle *et al.* (2007), an increase in HRV on average serves as an indication of reduced stress, fatigue, vigilance or mental workload associated with a task. Therefore, these results suggest that the participants during this study experienced reduced vigilance and concentration over time possibly due to decreased activation levels (indicated by decreased HR) which in turn reduced vigilance (resulting in increases in HRV over time). Significant time-on-task increases in the ratings of perceived exertion (RPE) during all three tasks were also noted (Figure 25); this indicates that the subjective measures accurately depicted the participants' awareness of increasing effort and fatigue (De Waard, 1996).

Based on the findings, it may be concluded that the tasks became more difficult for the participants (as indicated by the RPE data) while the objective effort applied was reduced (indicated by the HRV results). The body's initiation of reduced effort may be an indicator of a kind of down-regulation due to fatigue; it is possible that this form of down-regulation was initiated as a proactive avoidance of fatigue (or resource depletion) or upcoming fatigue. It may therefore be concluded that the body down-regulated in an effort to preserve its depleting cognitive resources and maintain the task for longer.

The noted reductions in speed (reading speed and response speed), the increase in HRV parameters, the decrease in HR and the reduction in blink durations across the measured tasks indicates not only that fatigue occurred but that the type of fatigue that occurred was as a result of an inclination toward parasympathetic activity (suggested by the fact that all the responses reflected a slowing down of the processes involved) and perhaps then, passive fatigue.

RESPONSE EFFECTS DURING THE MEASURED TASKS

Most studies on fatigue focus on task performance, because it is used to index the level of fatigue (since changes in performance are understood as occurring due to the functional consequences of the physiological effects of fatigue). However, task performance cannot be the sole indicator of fatigue as sometimes (as proposed by Hockey) primary task performance is protected (masking the true effects of fatigue) at a cost to the physiological processes (Williamson *et al.*, 2011; Staal, 2004; Hockey, 1997). Since each task taxed different resources, the tasks were expected to elicit different responses as performance is dependent on factors such as the task and motivational context of the experiment (Nilsson *et al.*, 1997). As stated before, each task was designed to induce a specific cognitive symptom of fatigue; the sensory and cognitive tasks were targeted at monitoring the extent of reduced vigilance and failures in attention and memory respectively while the motor task monitored the extent of movement timing disruption.

The impact that motivation (or the lack of motivation) must be considered as the lack of it could have contributed to a disinterest in applying effort necessary to maintain performance (Matthews and Desmond, 2002). Matthews and Desmond (2002) noted that an individual's performance may be related to their performance goals that may motivate them to actively pursue an ideal state. As participants were not given an incentive to motivate them, their continuing with and the success of the task depended on their ability to co-operate with and internalise the goals set for them so that they could maintain performance at the required target output (Hockey, 1997; Matthews and Desmond, 2002; Hull *et al.*, 2003); it could be hypothesized that this may have contributed to the changes in responses between the two tests sessions (Tables I and II), however, as there was no incentive given (and since the study did not aim to evaluate the impact of motivation), it is assumed that the same motivation that helped the participants complete the 1st test would have functioned during the completion of the 2nd test because the participants were instructed to perform the 2nd test session in exactly the same manner as they did the 1st test session.

It was expected, based on the outlined characteristics of fatigue as reported by Lal and Craig (2001), Bultmann *et al.* (2002), Brown (1982), Hartley *et al.* (2003), Haworth (1998), Thiffault and Bergeron (2003b), Thiffault and Bergeron (2003a) and Matthews and Desmond (2002), that when fatigue did present, it would be cumulative and progressive (increasing with increased time-on-task). It was expected that fatigue would be offset by adequate rest (as it would have emerged in responses to a mismatch between the intensity, duration and timing of work with recovery time). It was expected that fatigue would be subjectively experienced and accompanied by reduced efficiency, attention and alertness. It was further expected that the fatigue that would present would be detrimental to an individual's ability to perform a task, ultimately resulting in a change and decline in task performance over time. Given that one of the hypothesis of the study was that a difference would be found during the 1st test session (in the form of an effect on the performance, subjective and physiological measures) relative to the 2nd test session in all tasks, the significance of the study rested in the manner in which the responses to fatigue changed from the 1st test session to the 2nd test session (Figures 5, 7, 9, 17, 18, 19, and 20).

The following section will therefore examine the responses to the tasks holistically, tying the different components of fatigue (including the physiological, subjective, cognitive and behavioural) together before drawing further conclusions.

Responses during the Cognitive Task

The percentage of correctly identified digits during the cognitive task was found to have decreased over time during both test sessions; with the 2nd test session eliciting an increased reduction in the correct digits percentage (Figure 5). The performance pattern over time during each of the test sessions was also found to have been significantly different. The 2nd test session seems to have elicited a slightly smoother performance pattern over time (with less instances of marked up and down regulation). Additionally, the second measured factor (response delay) during the cognitive task revealed that the 2nd test session elicited slower responses with a marked increase in response delay (Figure 6). As participants were forced to wait 8 seconds before being allowed to type the digits into the laptop, the response delay was a calculation of the additional time (after the programmed 8 second period) that participants took before beginning to type the digits in. It appears that participants took longer during the 2nd test session, indicating an increase in fatigue or the occurrence of a slowing down process where participants may have found it difficult to stay attentive and respond as soon as the waiting period was done. Alternatively, the participants may have found it harder and harder to use their working memory and instead tried to remember the digits based on the phonological loop and rhythm. The 2nd test session led to a decrease in both speed (response delay) and accuracy (correctly identified digits) indicating that it imposed a greater fatigue effect than the 1st test session. The observed increased deterioration in performance during the 2nd test session suggests that this session resulted in greater failures in attention and memory. It could be concluded that this apparent failure during the 2nd test session is attributed to an adaptation that occurred due to the fatigue regulation mechanism as performance did not improve with the past experience (an expected outcome if learning had occurred) but became worse.

The simple reaction time tests (RTT) were used to measure the effects of fatigue on arousal/alertness (and consequently a decrease in responses associated with decreased arousal levels such as vigilance and cognitive attention, situation discernment, slowed motor responses/reactions) and accordingly, attention during task execution (Van Dongen and Dinges, 2000; Schmidt, 1982; Drowatzky, 1981). These measures of arousal and attention were thus used to index the effects of any possible fatigue regulation that may have occurred. The first RTT repetition performed during the cognitive task elicited different significant response patterns during each test session. Furthermore, the responses patterns followed separate trends, converging and diverging at the same intervals (Figure 10). It was expected that RTT performance would deteriorate over time as increases in fatigue and time-on-task have been reported to increase the time it takes to respond to a stimulus (Kosinski, 2010; Hartley *et al.*, 2003). The observed RTT responses during the first RTT repetition performed during the 1st test session elicited somewhat unexpected results, as a decrease in reaction time over the test duration was observed (indicating increased alertness and attention over time); RTT responses during the 2nd test session showed the expected increase in RTT responses. It may be suggested based on the observed results, that participants found it more difficult to stay alert and attentive over the duration of the 2nd test session. Consequently, their mental processes and central nervous system (CNS) may have been reduced over time (as RTTs have been used to gauge the response ability of the mental processes and the CNS) in comparison to the 1st test session. This apparent deterioration in alertness and attention during the 2nd test session could account for the observed significant reduction in response delay and correctly identified digits during the 2nd test session (it seems that the RTT responses during this task correlate with the performance responses); the apparent deterioration in attention and memory noted in the performance tests could have been because the body was operating on a reduced alertness preventing participants from staying attentive to the task being performed. The 1st RTT repetitions were considerably slower than the second and third RTTs, indicating that the change in focus slowed down the ability of the CNS to process information by considerably affecting the speed at which participants perceived and responded to the auditory stimulus, a feature of RTTs reported by Kell (2007) and Drowatzky (1981). The second and third reaction time responses (analysed as 'true' reaction time responses) did not elicit any significant information.

The single RTT performance tests after the test session were used to monitor short term resource recovery to track the potential recovery function of the fatigued resources and to give an indication of whether or not, depending on the speed of recovery, recovery profiles from fatiguing tasks were subject to regulatory patterns. Although there was an observed decrease in reaction time over time during both test sessions, each test session elicited significantly different recovery profiles. The 2nd test recovery profile (in comparison to the 1st test recovery profile) elicited slightly faster reaction time responses over time (Figure 14). This suggests that participants recovered slightly better during the 2nd test session (which is unexpected as they performed worse during the same test session). This finding again points to the possibility that the observed deterioration in performance and reaction time that was measured was due to a fatigue regulation mechanism that may have (based on the noted consequences of the 1st test session) pro-actively reduced the activation levels during the 2nd test session in an attempt to conserve or spare resources to allow to participants to return to their pre test state faster.

The recorded increases in body temperature during the two test sessions were found to differ significantly over time when an analysis on all three tasks was conducted, with the 2nd test session eliciting lower temperature values consistently over time (Figure 17). The increasing temperature values recorded in this study supported Lal and Craig (2001)'s reports about temperature tending to increase in association with fatigue as well as those of Wright *et al.* (2002), Kleitman *et al.* (1963), and Van Dongen and Dinges (2003) regarding the positive relationship that existed between daily rhythms of body temperature and factors such as alertness, cognitive function and performance (with temperature serving as a mechanism underlying performance regulation). As the 1st test session elicited greater temperature increases over time, it could be supposed that the 1st test session was more fatiguing than the 2nd. Furthermore, the lower and decreasing body temperature values elicited during the

2nd test session could be correlated to the alertness, and performance results; an increased performance and reaction time (and consequently alertness and attention) decline was observed more during the 2nd test session than the 1st test session.

The blink frequency responses revealed that although the 1st and 2nd tests initially elicited similar patterns (for half the task duration), both increasing and decreasing at similar points, the two test sessions elicited significantly diverse trends for the other half of the task duration (Figure 18). The 2nd test session (which elicited slightly lower eye blink frequency responses consistently) remained relatively constant (with the exception of the brief mid-task-duration increase in frequency) throughout the testing period while the 1st test session increased over time. An increase in blink frequency has been found to indicate when a person has transitioned from being awake to having reduced vigilance (Schleicher *et al.*, 2008); as such, it seems that both test sessions did educe reduced vigilance. Furthermore, the trend of the 1st test session (the increase in blink frequencies over time) supports the findings of Schleicher *et al.* (2008), Nilsson *et al.* (1997) and Stern *et al.* (1994), who contended that increased blink frequencies were indications of fatigue. As blink frequencies have been found to respond to response and attentional demands of a task, decreasing with decreased attentional demands leading to a reduced blink inhibition (Stern *et al.*, 1984), it may be suggested that the 2nd test session elicited a lower amount of attentional and response demands.

The cognitive task elicited increased blink durations during both test sessions indicating the occurrence of fatigue over time (Bentivoglio *et al.*, 1997). The 2nd test session elicited longer blink durations that increased slightly over time with fewer oscillations while the 1st test elicited blink durations that increased slightly for the first 25 minutes then remained relatively steady before plateauing off (Figure 19). The recorded increases in blink durations may have been due to the occurrence of a deactivation or slowing down process of a number of physiological processes as a result of decreased neuronal firing rates (Schleicher *et al.*, 2008).

According to (Stern *et al.*, 1994), increases in the eye blinks can occur in response to the complexity and nature of a task (with more difficult tasks eliciting an increased blink rate); it may thus be proposed that participants found the 1st test session more difficult than the 2nd test session as increased blink rates were recorded during the 1st test than those recorded during the 2nd test. As a decrease in arousal has been found to be associated with a reduced blink rate (Stern *et al.*, 1984), it may also be proposed that participants experienced a reduction in arousal during the 2nd test session (in comparison to the 1st test). In addition, because blink frequency and duration are used as indicators for alertness/ arousal levels, mental fatigue and an ability to react to environmental stimuli (with increases reflecting a reduction in blink inhibition and fatigue which are both forms of decreased activation), it may be proposed that participants were less alert and fatigued during the 2nd test session. As the 2nd test session elicited lower blink frequencies and longer blink durations over time, it may be proposed that this occurred because the participants (being less alert and experiencing an increased deactivation and lower attentional demands) spent more time with their eyes closed, perhaps taking more micro-sleeps.

The 1st and 2nd test sessions elicited significantly different heart rate (HR) responses patterns over time (Figure 20). Although the observed data for HR responses indicates that there was an initial increase in heart rate frequency during both test sessions (this increase lasted for half the test duration during the 1st test session and only for a third of the test duration during the 2nd test session), this initial increase was followed by decreases in heart rate frequency during both test sessions. The 2nd test session elicited higher heart rate frequencies and lower heart rate frequencies (once the decrease in heart rate occurred). As HR is used to index arousal, task involvement, mental effort and load, it is essentially used to index activation levels in response to the autonomic nervous system or ANS (Jorna, 1992; De Waard, 1996; Choi and Gutierrez-Osuna, 2009). Generally, the relationship between HR responses and activation levels and demand is that HR increases with an increase in demand and activation levels (Fairclough *et al.*, 2005). Furthermore, HR may be used to approximate the activation level of the two main branches of the ANS (Choi and Gutierrez-Osuna, 2009; Brookhuis and De Waard, 2010). As such, based on the observed findings, it may be suggested that the 2nd test session elicited (on average) lower activation levels, arousal/alertness levels and mental effort than the 1st test session. As the parasympathetic nervous system (PNS) serves to reduce activation levels, it may be also suggested that it was more active during the 2nd test than the 1st.

The cognitive task elicited a unique SDNN response pattern that changed differently over time during the 1st test session from the 2nd test session (although both test sessions elicited an increase in the SDNN values over time). Both test sessions seemed to elicit a similar ‘decrease/increase’ pattern over time; this pattern is named thusly according to the unique formation observed- for instance, both SDNN patterns elicit decreases in SDNN values followed by increases in SDNN then decreases then finally increases (Figure 24). Although this pattern was less pronounced during the 1st test session, the author asserts that the pattern was essentially the same. It is further suggested that this pattern was indicative of the changes in mental effort and workload (Brookhuis and De Waard, 2010) experienced by participants during the test duration. The lower SDNN values and less pronounced ‘decrease/increase’ pattern observed during the 1st test session may be an indication not only that the 1st test session was more challenging (as the SDNN values elicited during 1st test session were lower than those in the 2nd test session) but that, according to the SDNN values, participants were unable to exert as much mental effort as they exerted initially with increased time-on-task. Although the SDNN pattern during the 2nd test session had a higher degree of variation over time, the SDNN values were not as low as those during the 1st test session. This indicates that participants may have been able to vary their level of effort more since they did not experience the task as challenging initially. The ‘decrease/increase’ pattern is more pronounced during the 2nd test session, this may be due to fatigue regulation effect. As HRV measures have been used to indicate the point during task execution when fatigue becomes problematic (Boyle *et al.*, 2007), it may be suggested (looking at Figure 24) that fatigue, during the 1st test session, may have set in after 30 minutes on the task. The gradual increase in SDNN values noted after this 30 minute period may have been due to the task becoming too mentally challenging (perhaps with respect to an increased reduction in the resources available) leading to an inability to cope with the effort required (Rowe and Irwin, 1998). Furthermore, as tasks thought to be too mentally challenging are believed to lead to performance decrements and increases in HRV as a result of participants giving up and disengaging in the task (indicative of the investment of less effort), participants may have found the 2nd test session too mentally demanding leading them to disengage from the task (Rowe and Irwin, 1998).

It may be suggested that although participants, during the 2nd test, started out exerting a substantial amount of mental effort while performing the task, their applied effort was reduced (consciously or subconsciously) when it became difficult to maintain their exertion level at the same point. Perhaps this reduction in effort occurred to allow for recovery before the exertion level was increased again (only to be reduced in response to a failure to maintain the exertion level for longer perhaps). This points to a regulation function or effect. The difference in the severity of the regulation function points to it being one that is altered to cope effectively with the task based on past experience.

The subscales rated as inducing the highest amount of workload (during the completion of the NASA-TLX) after the cognitive task (for both test sessions) were mental demand and effort while physical demand and own performance were the lowest rated subscales (for both test sessions) after the cognitive task (Figure 26). Participants reported the 2nd test session as imposing a greater time pressure (Figure 34) possibly because the general slowing down process and decrease in activation they were experiencing during the 2nd test session may have created the feeling of an increased time pressure or an increased task pace. Participants reported the 1st test session as causing them more frustration (Figure 32), perhaps because they were exerting themselves more during this session. It may be suggested that the there was a fatigue regulation effect (supported by all measured variables) that reduced the activation level during the 2nd test session.

In conclusion, the responses to the cognitive task indicate that an overall decrease in activation and a slowing down process (that affected all measured variables) occurred during the 2nd test session. The observed reduced and more constant performance, the reduction in attention and alertness over time (indicated by the increases in RTT responses over time), the less inconsistent and better recovery profile (suggesting that the observed reduction in activation conserved resource use), the reduced attentional and response demands, activation and arousal levels (depicted by the blink frequency and duration responses), as well as the increase in fatigue and the activity of the PNS (in addition to the reduction in mental effort and perception of the 2nd test as more difficult and complex as indicated by HRV and HF responses) all indicate that the 2nd test session was characterised more by a general deactivation. It appears then that the fatigue regulation mechanism during this task reduced the functioning of all processes involved but managed to conserve resource utilization (indicated by the better recovery profile).

Responses during the Motor Task

Although the patterns over time of the 1st and 2nd test session response times were similar (Figure 7), the 2nd test session elicited faster response times. This indicates that the 2nd test session elicited an improved movement timing response perhaps as a result of a learning effect.

The response trends produced for the first RTT repetitions by the two test sessions were significantly different (Figure 10). The first RTT repetition results showed that reaction time responses increased over time during both test sessions, with the 2nd session producing slightly faster reaction time responses (Figure 10). The results indicate that although participants experienced a reduction in arousal and attention over time during both sessions, participants during the 2nd test session were slightly more alert and attentive and better able to shift between stimuli to focus on relevant stimuli (Wei and Salvendy, 2006). As RTTs are used to gauge the response ability of the mental processes and the CNS (Schmidt, 1982), it may be proposed that the mental processes and CNS of participants during the 2nd test session were slightly improved in comparison to the 1st test session. As reported by Van Dongen and Dinges (2000), Schmidt (1982) and Drowatzky (1981), reaction time responses are understood to be positively correlated to arousal levels such as vigilance, attention and slowed motor responses (with decreases in them being associated with decreases in vigilance, and slowed motor responses), it follows that increases in reaction time (however slight) will be associated with (and could possibly lead to) increased vigilance, attention and motor responses. This improvement in the first RTT repetition responses during the 2nd test session could explain the marked

improvement in response time observed in the performance results; it may be proposed then that participants responded faster during the 2nd test session because they experienced increased vigilance, attention and motor responses. This increased vigilance, attention and motor responses could have allowed participants to enhance and develop the mastery on the motor task (Staal, 2004).
As with the cognitive task, the first RTT repetitions were considerably slower than the second and third RTTs, indicating that the change in focus significantly slowed the ability of the CNS to process information by considerably affecting the speed at which participants perceived and responded to the auditory stimulus. The second and third reaction time responses (analysed as ‘true’ reaction time responses) did not elicit any significant information.

The recovery profile during the motor task indicated a task specific decrease in reaction time during both test sessions over time. Each test session elicited significantly different recovery profiles; the 1st test recovery profile (in comparison to the 2nd test recovery profile) elicited slightly slower and more erratic reaction time responses over time suggesting that participants did not recover as well during the 1st test session (Figure 15). This finding could support the fact that participants were more fatigued after the 1st test session as they had to perform the task with lower alertness and attention levels. Furthermore, they may have become more efficient during 2nd test session (having learned how to perform the task efficiently with less effort).

The 2nd test session elicited lower body temperature values consistently over time although there were increases in temperature recorded during the two test sessions. These recorded lower values could be an indication that the participants were less fatigued during this session, as Lal and Craig (2001) reported that temperature tended to increase in association with fatigue. However, these findings are contradictory to those of Wright *et al.* (2002), Kleitman *et al.* (1963), and Van Dongen and Dinges (2003) as while they reported that lower body temperature values were associated with lower performance, the 2nd test session produced improved performance results. It should be noted that no task specific temperature response was recorded as such temperature may not a sensitive measure for differentiating task responses.

The motor task elicited differing blink frequency trends over time during the 1st test and 2nd test session (Figure 18). Eye blink frequency increased over time during the 1st test session and decreased over time during the 2nd test session. As blink frequencies increased during the 1st test session, it may be suggested that this occurred as participants were experiencing reduced vigilance, increased task difficulty and subsequently, fatigue (Schleicher *et al.*, 2008; Stern *et al.*, 1994). As blink frequencies have been found to decrease with decreased attentional demands leading to a reduced blink inhibition (Stern *et al.*, 1984), it may be suggested that the 2nd test session elicited a lower amount of attentional and response demands which may have been due to participants adopting a more efficient strategy that allowed them to master the task (as suggested by the reaction time results). It appears that participants also found the 2nd test session (inclusive of reduced eye blink frequencies) less difficult with fewer reductions in vigilance; this may have hindered the onset of fatigue, allowing them to master the task.

The motor task elicited differing blink duration patterns during the 1st test session from the 2nd test session; specifically, the 2nd test session elicited longer blink durations consistently over the task duration than the 1st test (Figure 19). Although both test sessions induced an increase in blink durations, initially, the 2nd test session lead to a reduction in blink durations over time (although even the shortest blink durations during this session were longer than the longest blink durations during the 1st test). The 1st test session increased consistently throughout the duration of the task; this increase indicates that participants experienced an increase cognitive and subjective fatigue (Schleicher *et al.*, 2008) over time. However, as the 2nd test session elicited longer blink durations over time, it may be proposed that although participants experienced cognitive and subjective fatigue (marked by the initial increase in blink duration), they later experienced reduced fatigue levels (as their blink durations decreased after a certain period).

The motor task elicited a steady decrease in HR responses during the 2nd test session while the 1st test session, with more fluctuations, increased slightly over time

(Figure 20). Although the HR responses during the 2nd test were decreasing, the test session elicited higher HR frequencies. As HR is generally thought to increase with an increase in task demand and activation levels (Fairclough *et al.*, 2005), it may be asserted that the 2nd test session elicited (on average) increased task demands and activation levels. Since the 1st test session produced lower HR frequencies, it may be suggested that it may have elicited lower arousal, mental effort, and task involvement levels initially then increased in arousal, effort and task involvement as the task progressed (Figure 20). While the PNS serves to reduce activation levels, the SNS serves to increase activation levels; it may be said that the 1st test session was innervated both by the PNS and the SNS, first the PNS then the SNS. As the 2nd test session elicited a HR trend with very few fluctuations over time, it may be said that the ANS succeeded, during this session, in maintaining the body at a steady state (homeostasis).

The SDNN pattern over time differed between the test sessions; although both test sessions elicited an increase in the SDNN values over time, their trends diverged and converged at similar points forming a ‘loop trend’ (Figure 24). This observed ‘loop trend’ suggests that, for instance, the points during the 1st test that participants found challenging are the very same points during the 2nd test that they found easier. Since the 2nd test session elicited lower SDNN values (on average), it suggests that it was more challenging and fatiguing as participants had to exert themselves more (Tran *et al.*, 2009). Perhaps it was this apparent extra effort that allowed participants to perform better during the 2nd test session than during the 1st test. As the 1st test session included more increases in HRV, it could be supposed that this test session included reduced vigilance and fatigue (Boyle *et al.*, 2007) and perhaps, the noted increases in HRV were as a result of participants giving up, disengaging in the task and thus investing less effort (Rowe and Irwin, 1998).

Participants reported the 2nd test session as imposing a greater time pressure (Figure 34) and reported the 1st test session as causing them more frustration (Figure 32) because they were exerting themselves more then. It may be suggested that there was a fatigue regulation effect (supported by all measured variables) that led to improved performance, increased activation levels and thus a better fatigue coping mechanism during the 2nd test session.

According to the responses of the motor task, it appears that the noted performance improvement during the 2nd test was as a result of the increased activity of the physiological processes: the recorded lower RTT responses during the 2nd test indicate that there was an increase in alertness and attention levels (with a better ability to shift between stimuli to focus on relevant stimuli, to master the task and an improved ability of the CNS and mental processes), while the lower RTT responses during the recovery period point to a better recovery and possibly, that the strategy adopted to improve performance during the 2nd test was more efficient; the eye blink responses suggest that the participants found this test session less difficult and suggests that the participants may have adopted a more efficient strategy (that may have allowed the participants to master the task), as eye blink responses were observed to decrease over time (a noted indication of a lower amount of attentional and response demand). Further, the HR responses indicate that the ANS maintained the homeostasis of activation levels. It appears then that the fatigue regulation mechanism that occurred during this task functioned in response to a learning effect and efficient effort allocation; it may be suggested that not only were the strategic cognitive adjustments employed effective in ensuring optimal task performance (Hockey, 1997; Fairclough *et al.*, 2005), these adjustments ensured efficient use of the processes involved (as evidenced by the responses that showed a correlation between increased effort and fatigue with better recovery).

Responses during the Sensory Task

Reading speed or word count (the second measured factor during the sensory task), increased significantly during the 2nd session (Figure 9). As the first measured factor of the sensory task (correctly identified errors) did not produce any significant results (for changes over time or between sessions), it is not possible to get an indication of the accuracy and speed trade-off with the measured task; this information could have provided an indication of whether or not participants were reading quickly, but missing the included spelling errors or whether the improved reading speed was accompanied by an improved error identification rate (which would have suggested that the participants had become more efficient at performing the task). As such, the reason for the increase in reading speed during the sensory task will be discussed in relation to reaction time, physiological and subjective results.

The first RTT repetition performed during the sensory task elicited different significant response patterns during each test session (Figure 10). While the observed first RTT responses during the 1st test session elicited unexpected results as a decrease in reaction time over the test duration was observed, the responses during the 2nd test session showed a marked increase in reaction time during minute 30 (this was the sole increase as decreases in reaction time during minutes 10, 20, 40, 50 and 60 were noted) in RTT responses that altered the trend. The 2nd test session produced (on average) faster reaction time responses in comparison to the 1st test. As such, it may be proposed, that participants were more attentive during the 2nd test session, allowing them to exert increased vigilance, cognitive attention and situation discernment. This improvement in reaction time responses during the 2nd test session could account for the noted increase in reading speed as participants were seemingly better able to shift between stimuli to focus on relevant stimuli (Wei and Salvendy, 2006).

As with the cognitive and motor tasks, the first RTT repetitions were considerably slower than the second and third RTTs, indicating that the change in focus significantly slowed the ability of the CNS to process information down by considerably affecting the speed at which participants perceived and responded to the auditory stimulus. The second and third reaction time responses during the 1st and 2nd tests elicited significant and differing trends over time; both test sessions produced increasing RTT responses over time (although the 1st test elicited only slight increases) with the 2nd test producing longer responses. These results contradict those from the first RTT responses and suggest that participants experienced reduced alertness, vigilance and cognitive attention during the 2nd test session. As the second and third RTTs were analysed as ‘true’ reaction time responses, it could be said that participants were less alert and activated but more attentive during the 2nd test session.

Although there was an observed decrease in reaction time over time during both test sessions, each test session elicited significantly different recovery profiles (Figure 16). The 2nd test recovery profile (in comparison to the 1st test recovery profile) elicited slightly slower and more erratic reaction time responses over time, suggesting that participants did not recover as well during the 2nd test session (suggesting also that the recovery profile after the 2nd test session was less smooth). This finding could support the fact that participants were more fatigued after the 2nd test session as they found the 2nd test session more fatiguing possibly because they exerted themselves more (increasing their performance and thus applying more effort).

As with the motor and cognitive tasks, the increases in body temperature during the two test sessions differed significantly over time when an analysis on all three tasks was conducted, with the 2nd test session eliciting lower temperature values consistently over time. Once again, the lower temperature values consistently over time could be an indication that the participants were less fatigued during the 2nd test session but also that they experienced lower alertness, cognitive function and performance (because of the positive relationship that existed between daily rhythms of body temperature and these factors). This suggestion of participants having experienced lower alertness levels correlates with the results from the second and third RTT results and supports literature which stated that lower temperature was associated with decreases in reaction time tests, memory tests, attention maintenance tasks, and subjective alertness (Wright *et al.*, 2002).

Blink frequency responses during the two test sessions followed different trends although they were both increasing over time during the sensory task (Figure 18), with the 2nd test session eliciting significantly lower blink frequencies consistently over time. The results suggest that participants experienced a greater amount of fatigue (Schleicher *et al.*,2008; Nilsson *et al.*, 1997; Stern *et al.*,1994), a greater decrease in vigilance (Schleicher *et al.*, 2008), and a greater level of complexity (Stern *et al.*, 1994) during the 1st test session. It appears that participants also found the 2nd test session (inclusive of reduced eye blink frequencies) less difficult with fewer reductions in vigilance and less fatiguing; this may account for the noted improvement in reading speed.

Blink durations during the 1st test session remained relatively steady throughout the task whereas the 2nd test elicited an increase in blink duration over time. The 1st test session elicited longer blink durations (on average) over time (Figure 19). As increased blink durations are interpreted as an indication of fatigue (Craig *et al.*, 2006; Bentivoglio *et al.*, 1997), it may be proposed that the 2nd test session elicited a lower fatigue effect. Schleicher *et al.* (2008) understood increased duration as reflecting a deactivation or slowing down process of a number of physiological processes as a result of decreased neuronal firing rates. Therefore it may be that the observed increased duration could have been due to an increased slowing down process occurring during the 1st test session.

The reduced blink frequencies and durations during the 2nd test session are an indication of increased attentional demand, leading to an increased blink inhibition (Stern *et al.*, 1994; Schleicher *et al.*, 2008; Recarte *et al.*, 2008).Therefore, the 2nd test session may be interpreted as having been less fatiguing with an increased activation, explaining the performance improvement.

The sensory task elicited similar HR trends over time for both the 1st and 2nd test sessions; both test sessions elicited decreasing HR values over time although the 2nd test session elicited slightly higher HR frequencies after 40 minutes on the task (Figure 20). This suggests that both test sessions may have been primarily innervated by the PNS system that serves to reduce activation levels (Choi and Gutierrez-Osuna, 2009). Since the 2nd test session produced higher HR frequencies than the 1st test, it may be proposed that it elicited higher activation, mental effort and task demand levels (Fairclough *et al.*, 2005; Jorna, 1992).

Each of the test sessions elicited a unique SDNN response pattern that changed differently over time; although both test sessions elicited an increase in the SDNN values over time, the 1st test session produced a steady increase pattern while the 2nd test session elicited lower SDNN values between minutes 10 to 25 before increasing considerably from minute 30 to 45 (Figure 24). The 2nd test session initially produced lower SDNN values, implying that participants found the first third of the task more challenging and fatiguing (than they did the same point during the 1st test); as their SDNN values increased over time, it suggests that the test became less stressful, fatiguing and vigilance intensive (Boyle *et al.*, 2007).

Participants rated mental demand, frustration and effort (Figure 28) as inducing the highest amount of workload (for both test sessions) when comparing the workload ratings given for all measured subscales; physical demand and own performance were the lowest rated subscales (for both test sessions). The ratings given after the two test sessions differed significantly between the 1st and 2nd test sessions across the measured subscales with participants reporting having exerted themselves more during the 2nd test session for all subscales except for the subscale frustration (Figure 28). As with the other tasks, participants found the 2nd test session to have imposed a greater time pressure (Figure 34), while they found the 1st test session to have caused them more frustration (Figure 32). This is possibly because, as interpreted from the eye blink and HR responses, participants completed this test session with reduced activation levels and thus may have had to exert more effort to sustain task performance. The sensory task showed a significant difference in the RPE rating between the 1st and 2nd test over time (Figure 25); specifically, the trends of the two test sessions differed over time with the 2nd test session being rated as requiring less cognitive exertion.

Participants during the sensory task gave contradictory results; during task execution, they gave the 1st test higher RPE ratings (signifying that if required more effort), yet rated the 2nd test as inducing more effort, total workload, mental demand, temporal demand, physical demand and performance (during the completion of the NASA-TLX). This supports a criticism of subjective measures of fatigue by Rokicki (1995) and Brown (1982) who posited that the successful completion of a task tended to reduce the impact of the task in the operator's mind shortly after the event thus changing the operator's propensity to report symptoms. It is because of this that subjective measures cannot be the sole or dominant data collection method (Rokicki, 1995).

Since the 2nd test session resulted in improved performance, increased attention (as indicated by the first RTT responses), slower reaction time responses during recovery (indicating a poorer recovery profile), increased blink inhibition, activation and attentional demands (as indicated by the blink frequency and duration responses), increased activation, mental effort and task demand levels (as indicated by the higher HR frequencies), lower SDNN values (implying that participants found the task more challenging and fatiguing) and lower subjective cognitive exertion reports (as indicated by the RPE ratings), it may be concluded that although participants showed an improved performance during this test session, it came at a cost (an occurrence suggested by Hockey in his 1997 paper to occur). This cost was evidenced by the physiological responses which indicated that the improved performance was possible due to the observed increased activation, attention and effort (in response to the task and attentional demands of the task) of the physiological processes (in support of the performance). Furthermore, the increase in physiological effort (to maintain performance) resulted in a poorer recovery function, possibly because a longer recovery period was needed to compensate for the less efficient strategies (in the form of the physiological response patterns) during the 2nd test session. Moreover, the rating of the 2nd test session as requiring less cognitive exertion suggests that the participants were not aware that they were working harder during the 2nd test session. However, the fact that participants perceived their performance as better after the 2nd test session (Figure 28) suggests that the perceived emphasis on improving performance at the expense of all other variables was initiated on purpose and points to the influence (to an extent) of self regulation. It may be added then that, in this instance, primary task performance was maintained at the expense of the physiological processes, therefore, the fatigue regulation mechanism that occurred here functioned as a compensatory control mechanism that (instead of responding to feedback from a single task) responded to previous experience of having performed an identical fatiguing task to adjust the involved energetical resources.

A COMPARISON OF THE RESPONSES TO THE THREE TASKS

It was observed (Figures 10, 11 and 12) that each task elicited distinctive reaction time responses during both test sessions. The responses of the first RTT showed that while the 2nd test session responses tended to educe less irregular (with fewer instances of up and down regulation in comparison to the 1st tests) increases over time, the 1st test session educed inconsistent patterns characterised by distinct peaks in RTT at unpredictable times. The first RTT responses during the motor task show clear reductions in attention and arousal over time (during both test sessions) while the patterns depicted by the sensory and cognitive tasks point to (in both tasks) decreased RTT responses during the 1st test session and increases in RTT during the 2nd test. As the 1st test responses elicited highly unpredictable patterns, it may be suggested that these results were influenced less by improving arousal and attention levels over time and more by the influence of inaccurate and unintentional responses. The measured activity of the RTT tests point to the fact that changes occurred in response to learning because while the 1st test responses (serving as the initial learning stages) resulted in inaccurate and irregular patterns, the 2nd test responses appear to have been as the result of intentional processes possibly mediated by strategy formulations aimed at supporting effective performance (Fairclough *et al.*, 2005). The recovery profiles of each task were also distinct (Figure 13). As each of the recovery profiles depict differing patterns over time (just like the RTT response patterns), it implies that the recovery profiles were correlated to the amount of effort exerted and activation as well as adaptation and learning mechanisms encountered during the task executed; participants conducting the sensory task appear to have recovered better after the 1st test followed by participants executing the cognitive task then lastly, by those conducting the motor task. After the 2nd test session, participants performing the motor task recovered faster followed by those performing the cognitive task then those performing the sensory task.

Each of the tasks were expected to elicit differing eye movement responses; the cognitive task (understood as the more cognitively taxing and complex task) was expected to elicit the highest eye blinks while the sensory and motor tasks (as the tasks that required constant visual fixation) were expected to elicit the lowest eye movement responses. This was based on reports from Stern *et al.* (1994) about the eye blink responding to the complexity and nature of a task; specifically, it was reported that cognitive tasks (such as those involving memory) tended to elicit increased blink rates while tasks that only required visual fixation (such as reading and detecting targets) elicited reduced blink rates as they were not as cognitively demanding as they were visually demanding (Bentivoglio *et al.*, 1997) and Recarte *et al.*, 2008). Furthermore, as the endogenous eye blink also responds to whether or not tasks being performed require vocalisation - with those that do educing increased blink rates (Stern *et al.*, 1984), the sensory task was expected to elicit different eye blink patterns.

Each of the studied tasks elicited blink duration and frequency patterns that were not only unique to the task being executed, but that changed depending on the test session and over time. Eye frequency and duration responses during each of the tasks (for the 1st and 2nd test sessions) were unique (Figures 18 and 19). The sensory task elicited the lowest blink frequency and duration responses; this was expected as the sensory task was not only a visually demanding task, but it required vocalisation. The motor task elicited the highest blink durations during the 2nd test and the highest blink frequencies during the 1st test (it elicited responses which were comparable to the cognitive task during the 1st test, for blink duration responses, and the 2nd test, for eye frequency responses). This was an unexpected finding as the cognitive task, being the more cognitively taxing and complex task, was expected to elicit the highest blink frequencies and durations; the motor task, being a more visually and vigilance intensive task, was expected to elicit lower blink frequencies and durations than those recorded during the cognitive task but higher than those of the sensory task (as it was performed silently and was not as visually demanding as the sensory task).

Since increases in blink frequencies and durations are able to adequately indicate increasing mental fatigue and arousal levels (Craig *et al.*, 2006; Sullivan, 2008), it is plausible to suggest that the 1st test session, during all tasks, elicited increasing fatigue and arousal levels over time. The 2nd test session elicited lower blink frequencies than the 1st test session during all three tasks suggesting less fatigue and alertness reductions during this test. The 2nd test session, as observed in the eye blink duration responses, elicited longer blink durations during the cognitive and motor tasks (suggesting an increased deactivation during these tests) and shorter blink durations during the sensory task (suggesting a decreased deactivation during this test).

Each task had a unique SDNN response (Figure 24); all tasks show an increase in SDNN values over time (during both test sessions). Since the extent of the response patterns will depend on the amount and type of effort required by the task (Brookhuis and De Waard, 2010), the motor task (having elicited the lowest SDNN values consistently) appears to have been the task during which participants experienced increased stress, fatigue, vigilance or mental workload associated with the task (Boyle *et al.*, 2007; Tran *et al.*, 2009). The cognitive task (as indicated by SDNN responses), followed lastly by the sensory task, elicited second highest increases in stress, fatigue, vigilance or mental workload.

All of the tasks elicited a unique heart rate response pattern that changed over time: the cognitive task and the sensory task elicited a decline in heart rate over time whereas the motor task elicited a steady heart rate over time (Figure 20). Heart rate (HR) has been used historically to index arousal level, mental effort and load, anxiety and task involvement (Jorna, 1992; De Waard, 1996). The motor task (having elicited the highest HR frequencies) may be said to have also been the more demanding (Fairclough *et al.*, 2005) task that resulted in the highest activation levels (Choi and Gutierrez-Osuna, 2009) followed by the cognitive task then, lastly, by the sensory task. Brookhuis and De Waard (2010) noted that increases in HR and decreases HRV were typically clear when participants had to spend mental effort; as this was the observed response during the motor task, it may be concluded that this task required the highest amount of mental effort.

As research has indicated that mental effort expended by the operator is not automatically determined by the task load but more by internal goals and criteria they decided to adopt (Rowe and Irwin, 1998), it may suggested that the eye movement, HR and HRV responses suggesting that the motor task elicited the highest amount of effort, fatigue and demand were observed not necessarily because the motor task did indeed induce a higher task load, but rather due to the participants executing the motor task choosing to expand more effort in response to their internal goals. This may be the case especially since the motor task had a physical component; the physical nature of the task may be the reason why it elicited higher HR, HRV and eye movement responses.

Statistical analyses comparing the ratings of the each subscale after the three tasks showed that the cognitive task (after both test sessions) was reported as demanding the highest amount of total workload, mental demand, and effort. The motor task was reported to have required the second highest amount of total workload, followed by the sensory task. A measure of the NASA-TLX subscales for mental demand and effort showed that participants reported the sensory task as eliciting the second highest amount of mental demand and effort followed by the motor task. As such, it may be proposed that the cognitive task induced the highest workload. While the motor task received the second highest rating of total workload, it is suggested that this was due to the added physical aspect of the task. Participants conducting the cognitive and sensory tasks gave similar ratings during the completion of the NASA-TLX; the highest rated subscales (for both test sessions of the tasks) were mental demand and effort while physical demand and own performance were the lowest rated subscales (Figures 31, 33 and 35). This (along with the similar responses derived from the HRV, HR, and RTT measures) suggests that the tasks induced similar workload demands, with the cognitive task inducing the highest workload followed closely by the sensory task. The absence of significant results indicating a dominant (and non-dominant) workload demanding subscale during the motor task indicates that the task did not require the use of one specific resource over another.
Participants may have reported the 1st test as being more frustrating because they (having never had the experience of performing each task for that long) did not know how much longer they had execute the tasks (which may have made them feel uneasy) and possibly because they were fatigued at the end, meaning that they may have been experiencing a certain level of stress and irritation.

Since the subjective data was not able to accurately index the differences between the two test sessions, it may be concluded that the subtle effects of cognitive fatigue (unlike those of physical fatigue) are not easily accessible to the consciousness. However, participants, after cognitive and sensory tasks (during the completion of the NASA-TLX), were able to discriminate between task demands, suggesting that there are certain aspects of cognitive fatigue that are available to the consciousness.

THE EFFECT OF GENDER ON THE MEASURED VARIABLES

Gender responses during the Cognitive Task

Ear temperature responses (Appendix D1) during the cognitive task show that while the ear temperatures of male participants remained relatively steady during the 1st test, they decreased slightly during the 2nd test (with the 2nd test eliciting lower temperature responses consistently). These responses indicate that male temperature values correlated with performance responses (Figure 5) because lower performance during the 2nd test session is correlated with lower temperature values during the same test session; Kleitman *et al.* (1963), Van Dongen and Dinges (2003) and Wright *et al.* (2002) posited that temperature values tended to correlate positively with performance because temperature served as a mechanism underlying performance regulation. It seems that males experienced a distinct slowing down process during the 2nd test (as observed in the performance and temperature responses). Female participants elicited increasing ear temperature responses during both test sessions, with the two test sessions showing a ‘loop effect’ (as temperature was increasing during the 2nd test session at intervals when it was observed to be decreasing during the 1st test session). As temperature responses of female participants showed a general increase during both test sessions, while performance was decreasing, this increase may be interpreted as an indication of fatigue; thus, female responses confirm the findings of Lal and Craig (2001) who noted that temperature values tended to increase in association with fatigue.

Eye blink duration responses (Appendix D 2.1) indicate another ‘loop effect’ as increases in blink duration were noted during both test sessions for male participants. As male responses depicted longer blink durations during the 2nd test session (an indication of increased fatigue and a correlation with performance responses) it may be suggested that male responses depict the slowing down process that occurred

during the 2nd test session. Eye blink duration responses for female participants show that the 2nd test session produced steady blink durations over time (although it produced consistently higher eye blink durations over time) while the 1st test session produced increasing blink durations. The steady and higher responses during the 2nd test session (a session observed to have been more fatiguing) indicate that an adaptation to the test session may have occurred because, although the responses elicited were higher (an indication of an increase in fatigue effects), no further increase was noted with increased time-on-task; this indicates a coping mechanism that may have limited the extent of reductions in blink inhibition (noted to occur with increased blink durations) perhaps to have allowed for continued task performance.
Low frequency centre frequency (Lf cf) responses indicate that the 2nd test session elicited lower Lf cf values than 1st test session in female participants while a higher Lf cf frequency (on average) was elicited during the 2nd test session in male participants (Appendix D 3.1). As noted in the aforementioned sections, decreased HRV responses indicate increased effort and fatigue (Rowe and Irwin, 1998; Fairclough *et al.*, 2005), therefore the responses of the female participants point towards an increase in fatigue during the 2nd test session. While female participants gave higher RPE ratings during that 2nd test session (on average) than the 1st test session, males rated the 1st test session as more fatiguing. These gender-based differences in perceived effort suggest that effort perception is gender-dependent (Appendix D 4.1). Since female RPE responses are comparable to the performance, HR, blink duration and Lf cf responses (which also indicated that a greater fatigue effect was experienced during the 2nd test session), it may be assumed that female participants were more aware (than their male counterparts) of the increase in fatigue that appears to have occurred (De Waard, 1996).

Gender responses during the Motor Task

Eye blink duration responses indicate that longer blink durations (during both test sessions) were observed in female participants, with increasing blink durations during the 1st test and decreasing blink durations during the 2nd test (Appendix D2). Although increases in eye blink durations over time were also observed in male participants during both test sessions, the 2nd test session elicited higher blink durations consistently over time. As eye blink durations increase with an increase in fatigue, the responses from male participants suggest that the 2nd test session required more effort and was more fatiguing while those acquired from female participants suggest that the 2nd test session was initially more fatiguing before becoming less fatiguing. Since performance responses indicate that participants performed better during the 2nd test session (with SDNN and HR responses indicating that this improved performance was at the expense of increased effort and fatigue), the gender responses support previously noted responses.

Gender responses during the Sensory Task

Lf cf responses indicate that the 2nd test session elicited lower Lf cf values than 1st test session in male participants while a higher Lf cf frequency (on average) was elicited during the 2nd test session in female participants (Appendix D 3.2). The responses of female participants indicate that an increase in fatigue occurred during the 1st test session. RPE responses indicate that although increases in RPE were observed for both male and female responses, females gave higher ratings during the 1st test session while males gave similar ratings during both test sessions. These RPE responses also suggest a gender-based difference in perceived effort (Appendix D 4.2). Since female RPE responses correlate with the SDNN, HR, performance and blink duration responses in suggesting that the 1st test session required more effort and was more fatiguing; it may be suggested, again, that female participants were more aware (than their male counterparts) of the change in the extent of fatigue experienced that appears to have occurred during the 1st test session (De Waard, 1996).

CONCLUSIONS

A decrease in responses, indicative of fatigue, was observed in the assessed performance (including response delay and correctly identified digits during the cognitive task and word count during the sensory task), reaction time, and blink frequency and duration measures. This suggests that the resources assigned with executing the task were depleted over the task duration (Norman and Borrow, 1975).

The two successive, but otherwise identical test sessions led to different fatigue intensities and patterns over time; whether the differences in responses occurred as a result of learning, adaptive or compensatory behaviour, this, according to the aim of this study, has been tentatively attributed to a fatigue regulation mechanism. It appears that there indeed is a mechanism that alters how the body functions during a fatiguing task. The fact that the mechanism appears to alter performance through modifying activation levels (leading to alerted alertness and attention levels), suggests that the CNS and mental processes are sensitive to the influences of this regulatory mechanism. Furthermore, as this mechanism appears to function through activation levels, it essentially functions by modifying a person’s attentiveness, discernment, vigilance and responsiveness, factors which greatly influence performance (Wei and Salvendy, 2006).

As noted, the regulatory mechanism active during the sensory task was found to have improved performance at the expense of the other processes involved in the maintenance of the sustained task. It may be suggested that the goal of the regulator, based on previous experience, was to protect primary task performance. Once this goal was formulated, the relevant mental and physiological processes were activated accordingly to produce the desired result (even at the cost of adopting a less efficient resource utilisation strategy that increased the impact and negative effects of the fatiguing task). The fact that participants correctly reported having performed better during the 2nd test session suggests that the decision to protect primary performance was accessible to consciousness, pointing towards an influence of self-regulation (a possible aspect of the regulation mechanism).

The regulatory mechanism active during the cognitive task was found to have reduced and maintained performance at a constant level during the 2nd test session. This was done by initiating an overall decrease in activation resulting in a slowing down process of all the relevant mental and physiological processes. It appears then, that the goal during this task was to elicit a better coping response to fatigue through resource sparing, as (although the altered performance did not produce better results) a better recover profile (indicative of more efficient resource utilisation) was observed. Since the regulator here appears to have slowed down and spared all processes involved in task execution to elicit a more controlled performance output without necessarily increasing the effort and activation levels, it may be suggested that the goal of the regulator was to manage performance in a way that ensured that the mental and physiological processes involved were protected.

The fatigue regulation mechanism that occurred during the motor task appears to have elicited an increase in both task performance and efficient effort allocation; the noted increases in effort and fatigue resulted in a better recovery function. Essentially, the regulation mechanism, in this instance, appears to have managed to protect and improve primary task performance by adopting strategies that ensured efficient use of the processes involved in task execution. This suggests that a positive learning response occurred that allowed for the attainment of the set goals at no cost to the mental and physiological processes.

This regulatory mechanism may again be likened both to the effort theory and the compensatory control theory since alterations to the effort, activation and performance levels were determined after having executed the 1st test (with the unique alterations during the three tasks indicating that the type of change depended on nature and complexities of the task) (Kahneman, 1973; Fairclough *et al.*, 2005). The results from the three tasks suggest that this mechanism does not function in a predictable manner but is altered depending on the task demands, past experience with the task and the goals set by the individual (whether consciously or subconsciously).

It should be noted that this proposed account of how the regulatory mechanism functions is not only an oversimplification of a probably complex mechanism but one that is based purely on the findings of the study as interpreted by the author (mostly based on the seemingly similar features of the regulatory mechanism observed from the three tasks). It is unlikely that only these three factors affect this mechanism because this mechanism (simply based on the fact that it is part of the complex fatigue state) must be subjected to and affected by all other factors that influence fatigue. Therefore, just as there are many factors that contribute to fatigue (each factor changing the degree of fatigue, the rate of fatigue onset and the type of fatigue experienced) this will most certainly be the case for the fatigue regulation mechanism; however, as the task of trying to incorporate all known factors that influence fatigue along with the potential influences of each task (based on the task demands) into the proposed functionality of the fatigue regulation mechanism proved extremely challenging (and would have included vast inaccuracies and unsupported assumptions), a simplified proposal of the fatigue regulation mechanism is offered (one that, although possibly inclusive of inaccuracies, contains a few unsupported assumptions).

The above named regulation mechanism factors (task demands, past experience with the task and the goals set by the individual) seem to be interrelated; it appears that the goals determined (possibly before the execution of the 2nd test) may have been formulated in response to the collected information from past experience. Within this regard, it is proposed that the regulatory mechanism may have used the 1st test session as a feedback signal (Matthews and Desmond, 2002). It is proposed that analysing this feedback signal (inclusive of using it to perform initial assessments and to collect information about the overall task demands, effects and responses), was used to formulate the target goals. It is suggested that the regulator used the information from the feedback signals to draw conclusions and make decisions regarding the ways of modifying and monitoring the processes involved in task execution (Matthews and Desmond, 2002) based on a consideration of the task demands, the available resources to support the task and the capability of the individual; perhaps the target goals for the execution of the task in future were made based on these. Then, it appears, the mechanism (functioning in a similar pattern to the effort theory and the compensatory control theory) then initiated alterations at a physiological level and strategic adjustments at a cognitive level to adjust performance (Hockey, 1997; Fairclough *et al.*, 2005; Fairclough and Houston, 2004). Therefore, the regulatory mechanism, once having assessed the feedback signals, monitors the signals to allow for an assessment and rectification of any existing discrepancies between actual performance levels and the target level of functioning (Matthews and Desmond, 2002).

As each task elicited a different experience and included different demands, the regulator may have drawn different conclusions and thus formulated different goals.

It appears that the fatigue regulatory mechanism is a protective and proactive mechanism, however, what it is protective and proactive of, depends again on the goals set in response to the task demands of a past task; in one aspect, it can behave as an efficient effort regulator (resulting in improved performance and resource utilisation), in another, as a compensatory control mechanism (protecting primary task performance at all costs) and in another aspect, a process aimed at conserving resource utilisation (even at the expense improved task performance).

It may be that the efficient resource utilisation alongside an increase in task performance observed during the motor task was indicative of the ultimate target of the fatigue regulation mechanism: to use the allocation of energetical resources to ensure optimal performance (Kahneman, 1973; Hockey, 1997). Perhaps then, the adjustments made to the cognitive and sensory tasks would (supposedly after repeat tests) result in the same improvement in efficiency observed during the motor task. Nevertheless, what appears to be clear is that the goals of the regulation mechanism are centred on initiating adaptations to improve an aspect of either task performance or the processes responsible for supporting task performance. Furthermore, as the extent of performance deterioration was monitored in all cases, it is not implausible to suggest that the regulatory mechanism is responsible for monitoring and controlling the extent of deterioration.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Since the processes involved in the manifestation and management of fatigue are still not well understood, the current study set out to assess whether or not a mechanism that regulated fatigue during sustained task execution could be identified. As such, the protocol used in this study aimed at inducing task-related fatigue twice at different times in the same participants and evaluating the resultant changes in fatigue manifestation. A wide range of variables were measured to allow for a complete and accurate depiction of fatigue and fatigue regulation.

SUMMARY OF PROCEDURES

The research design aimed to assess the participants' ability to cope with fatigue as a result of previous experience. This was done by asking each participant to perform two identical test sessions; the responses to the identical test sessions were then compared. Three different resource-specific tasks were designed and tested; each task was performed twice for 60 minutes (each task was repeated thus each task had two identical test sessions). The three tasks represented the three broad information processing categories: the sensory resource (consisting of a reading task measuring visual scanning and perception, where performance was measured as the amount of correctly identified errors and reading speed), the cognitive resource (consisting of a memory recall task that relied on working memory, where performance was measured as the amount of correctly identified digits and response delay) and the motor resource (consisting of a modified Fitts' stimulus response task, where performance was measured as response time). 60 participants were recruited and divided into three groups consisting of 20 participants; each group of 20 participants was assigned to each resource-specific task and asked to perform the task twice (test session one and test session two). The measured variables included physiological, subjective and performance measures, all utilized to allow for a holistic representation of fatigue. Measurements of reaction time, heart rate, heart rate variability, temperature, task performance, subjective ratings and eye movements were recorded throughout the protocol. Reaction time tests were initiated at 10 minute intervals during the tasks and then again, for 15 minutes at 30 second intervals, at the end of each task. The subjective ratings used included the RPE CR 10 scale to measure cognitive exertion (recorded every 10 minutes during the tasks) and the NASA-TLX to index mental workload (completed after each task).

SUMMARY OF RESULTS

The results indicated that each task not only elicited distinct fatigue development and recovery patterns, but that these patterns differed between the two measured test sessions. Furthermore, the measured parameters were able to depict each unique task response pattern. Task performance was found to decrease over time during the cognitive and sensory tasks. Differing task performance responses were measured between the 1st test session and the 2nd test session during all tasks; while performance was found to improve during the 2nd test session for the motor and sensory tasks, it declined during the cognitive task.

Reaction time tests during the tasks and those during the recovery profile showed not only that the response pattern during each of the tasks changed over the task duration and the recovery period, but that the response pattern also depended on the task (because distinct response patterns for the 1st test and for the 2nd test were elicited during all three tasks). The recovery profile was shown to have been proportional to the exertion level of each task and test session. While ear temperature responses showed differing trends over time during the two test sessions (with no sensitivity for the type of task executed), other physiological measures such as eye blink frequency and duration, heart rate frequency and heart rate variability were sensitive to the type of task executed and showed distinctive trends over time during the test sessions. Eye blink frequency and duration were found to increase over time and to elicit differing response patterns both over the different tasks and over the two test sessions. Heart rate frequency decreased over time and was shown to be sensitive to both the type of task and the test session being carried out. With regards to heart rate variability, only the SDNN analysis was found to increase over time and to respond in accordance with the task and test session being executed. Heart rate variability analyses for high and low frequency power and PNN30 showed sensitivity only to time-on-task effects, increasing over time. The subjective measures indicated increasing RPE CR 10 ratings over time in all tasks. The cognitive task was reported to have induced the highest amount of total workload, mental demand and effort. The motor task was reported to have elicited the second highest total workload demand while the sensory task was rated as inducing the second highest mental demand and effort ratings. Participants who performed the cognitive and sensory tasks reported having exerted a considerable amount of mental demand and effort during both test sessions of these tasks. The workload rating between the 1st and 2nd test sessions indicated that the 2nd test session imposed a greater time pressure while the 1st test session was more frustrating (for all three tasks).

Ear temperature, eye blink duration, heart rate variability analysis for centre frequency and RPE showed sensitivity to gender effects. Ear temperature responses showed that females elicited higher temperature recordings over time during both test sessions of the cognitive task. Eye blink duration responses showed male and female responses differed between the two test sessions with females showing longer blinks during the motor and cognitive tasks. Heart rate variability analysis for low frequency centre frequency responses showed that male and female responses differed between the two tests with females eliciting higher responses during the 1st test (for both the cognitive and sensory tasks) and lower responses during the 2nd test (for the cognitive task). The RPE ratings during the sensory task showed that increases in RPE rating over time were specific to gender. The RPE reports during the cognitive task indicated a significant difference in exertion rating between males and females specific to the test session being executed.

RESPONSES TO HYPOTHESES

A difference was expected in the effect of the first test session on the performance, subjective and physiological measures from the effect of the second test session on the performance, subjective and physiological measures during all tasks. It was further expected that fatigue regulation would evoke different effects during the first test session and the second test session during all tasks comparable to the level of fatigue induced as indicated by the performance and response measures.

Hypothesis 1:

The hypothesis tested was that there would be no differences in the responses to all variables during the fatiguing task between the 1st test and the 2nd test sessions:

H_o: μ 1st Test fatiguing task $_{\text{sensory}}$ = μ 2nd Test fatiguing task $_{\text{sensory}}$
μ 1st Test fatiguing task $_{\text{cognitive}}$ = μ 2nd Test fatiguing task $_{\text{cognitive}}$
μ 1st Test fatiguing task $_{\text{motor}}$ = μ 2nd Test fatiguing task $_{\text{motor}}$

Therefore, as there were differences for heart rate frequency, heart rate, reaction time test, task performance, eye blink frequency and duration and ear temperature between the 1st test and the 2nd test sessions, the null hypothesis was tentatively rejected.

Alternatively, due to the lack of significant overall differences for high frequency power, low frequency power, low frequency centre frequency, high frequency centre frequency and PNN 30 responses, the null hypothesis was tentatively accepted for these variables.

Hypothesis 2:

The hypothesis tested was that there would be neither any differences in the responses to all variables when comparing the responses during the first test session of all the three tasks nor any differences in the responses to all variables when comparing the responses during the second test session of all the three tasks:

H_O: μ 1st Test fatiguing task $_{\text{sensory}}$ = μ 1st Test 1 fatiguing task $_{\text{cognitive}}$ = μ 1st Test fatiguing task $_{\text{motor}}$
μ 2nd Test fatiguing task $_{\text{sensory}}$ = μ 2nd Test fatiguing task $_{\text{cognitive}}$ = μ 2nd Test fatiguing task $_{\text{motor}}$

Therefore, as there were differences for heart rate frequency, heart rate, reaction time test, task performance, eye blink frequency and duration and ear temperature between the 1st test and the 2nd test sessions and among the different tasks, the null hypothesis was tentatively rejected.
Alternatively, the null hypothesis was tentatively accepted for all other measured variables.

Hypothesis 3:
The hypothesis tested proposed that there would be no differences in the responses to all variables when comparing responses from each of the three tasks during the first test and the second test sessions:

H_O: μ 1st Test fatiguing task $_{\text{sensory}}$ = μ 2nd Test fatiguing task $_{\text{sensory}}$ = μ 1st Test fatiguing task $_{\text{cognitive}}$ = μ 2nd Test fatiguing task $_{\text{cognitive}}$ = μ 1st Test fatiguing task $_{\text{motor}}$ = μ 2nd Test fatiguing task $_{\text{motor}}$

The null hypothesis was tentatively rejected as there were differences in the responses to all variables when comparing the task responses during all conditions during the 1st test and the 2nd test sessions. Alternatively, the null hypothesis was tentatively accepted for all other measured variables.

CONCLUSIONS

Based on the proposed aims of the study, it appears that there indeed was a regulatory mechanism for cognitive fatigue that altered the manner in which performance, psychophysical and subjective variables were modified over time, initiating a different regulation pattern for each variable. While instances of down and up regulation occurred during the fatiguing task, these instances occurred until the end of task execution. Furthermore, while this study showed that each task elicited a unique fatigue regulation pattern, this pattern (it was deduced) functioned seemingly in accordance with a fatigue regulation mechanism.

This study also highlighted the importance of examining the short-term recovery profile of fatigued resources; studies often neglect to evaluate the recovery period as an indicator of exertion and activation levels (and therefore the functioning of the central nervous system and its processes) during task execution. This study drew attention to the importance of considering the recovery of tasks as an additional source of information on the task effects by evaluating the recovery duration as an indicator of the severity of the task on the human information processing system. The importance of assessing fatigue holistically was also emphasized within this study. It was found that the impact of fatigue was better understood when a collection of measures assessing the functionality of the different processes involved in task execution, were considered; drawing conclusions on a single variable may have produced inaccurate depictions of fatigue manifestation.

It was observed (during the study) that mental fatigue can take on different degrees and severities depending on the resource being taxed and the task being completed. This has practical implications for fatigue management strategies such as work schedule designs (particularly for job rotation and work/rest schedules) because cognitive tasks taxing different resources may require different management techniques. For instance, workers stationed at tasks that tax the memory resource may need to be rotated or allowed to rest sooner than those stationed at more sensory (visually demanding) oriented tasks.

The results of this study indicated that the regulation mechanism did have a considerable impact on fatigue, specifically, on how the body adapted to and coped with fatigue; this was inferred from the finding that the participants' experience with the tasks determined their performance, effort, alertness and arousal levels, consequently affecting their experience and perception of the task.

Further, it was noted that the impact and control of the regulation mechanism functioned beneath the scope of consciousness. This mechanism could, therefore, have practical implications on work output during work tasks; if a proactive and protective (protective of either task performance or operational processes) mechanism exists that functions through reducing a person's ability to be vigilant, attentive, to exercise discernment, and to increase or direct their level of responsiveness, then (like fatigue), it can affect productivity. The effect on productivity and performance may be negative or positive; performance may be reduced as a result of the mechanism preventing workers from exerting themselves above a set level (a level they may have worked at the first time the task was performed); performance and work efficiency increases may be observed as a result of the mechanism adjusting the operational processes to allow for improved performance at no extra cost to the cognitive and physiological processes.

RECOMMENDATIONS

Any study, in future, looking to evaluate the existence of a fatigue regulatory mechanism ought to consider the following recommendations:

1. Conducting the investigation in the field would be useful as workers may, in an attempt to perform better and override the negative effects of fatigue, be inclined to initiate a greater compensatory effect thus altering the type of fatigue regulation mechanism observed. This compensatory effect may be targeted more at performing the task efficiently, perhaps by conserving resources and maintaining primary task performance. Further, workers in a field are more motivated to exert themselves continually to maintain performance at the required level therefore, an indication of the role that motivation plays in fatigue regulation could be assessed.
2. A more detailed analysis of the measured parameters over time would be useful in analysing and counting the numerous fluctuations to allow for a better comparison of change in the instances of up and down regulation over the test sessions; specifically, a tool designed to analyse the oscillation frequencies during each measured parameter could be developed to make it easier to draw conclusions on the differences in trends and patterns of the tests sessions.

3. Future investigations should consider having participants come for a third test session to address the question of whether or not the fatigue regulation mechanism is one that adapts continually every time a task is performed. In addition, the third test session would bring clarity into whether the responses during the 1st test session were true responses or responses reflective of the participants' expedition to getting a sense (via experience) of the actual task demands and requirements.
4. Consider screening the personality types of participants and matching them to the tasks given to reduce intra-individual variability. During this study, participants were randomly assigned to each task: some participants struggled with the level of monotony of the motor task and could not cope because of this; others disliked reading altogether and thus disliked the sensory task; and others, with a short attention span, found it nearly impossible to perform the cognitive task. Therefore, affordances should be made for personality types to allow for a better understanding of the factors that influence the fatigue regulation mechanism.

REFERENCES

Abbiss CR and Laursen PB. (2007). Is part of the mystery surrounding fatigue complicated by context? *Journal of Science and Medicine in Sport. 10*: 277 - 279.

Balci R and Aghazadeh F (2004). Effects of exercise breaks on performance, muscular load and perceived discomfort in data entry and cognitive tasks. *Computers and Industrial Engineering, 46:* 399 - 411.

Barry RJ, Clarke AR, McCarthy R, Selikowitz M and Rushby JA (2005). Arousal and activation in a continuous performance task: an exploration of state effects in normal children. *Journal of Psychophysiology. 19(2)*: 91 - 99.

Bentivoglio AR, Bressman SB, Cassetta E, Carretta D, Tonali P and Albanese A (1997). Analysis of blink rate patterns in normal subjects. *Movement Disorders*, *12* (6): 1028 - 1034.

Boeree CG (2009). *The Emotional Nervous System*. URL: http://webspace.ship.edu/cgboer/limbicsystem.html. Last accessed: 20 November 2011.

Boksem MAS, Meijman TF and Lorist MM (2006). Mental fatigue, motivation and action monitoring. *Biological Psychology, 72*: 123 - 132.

Borg G (1990). Psychophysical scaling with applications in physical work and the perception of exertion. *Scandinavian Journal of Work, Environment & Health, 16* (1): 55 - 58.

Boucsein W and Thum M (1997). Design of work/rest schedules for computer work based on psychophysiological recovery measures. *International Journal of Industrial Ergonomics 20:* 51 - 57.

Boyle L, Hill J, Tippin J, Faber K and Rizzo M (2007). The effects of sleep apnea on heart rate variability in a simulator. *Proceedings: The 4th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*: 306 - 313.

Brandt T, Stemmer R and Rakotonirainy A (2004). Affordable visual driver monitoring system for fatigue and monotony. *Proceedings: The IEEE International Conference on Systems, Man and Cybernetics*, 7: 6451 - 6456.

Brinnel H and Cabanac M (1989). Tympanic temperature is a core temperature in humans. *Journal of Thermal. Biology. 14 (I):* 47 - 53.

Brookhuis KA and De Waard D (2010). Monitoring drivers’ mental workload in driving simulators using physiological measures. *Accident Analysis and Prevention 42*: 898 - 903.

Brown ID (1982). Driving fatigue. *Endeavour, New Series, 6 (2):* 83 - 90.

Bultmann U, Kant I, Kasl SV, Beurskens AJHM and van den Brandt PA (2002). Fatigue and psychological distress in the working population psychometrics, prevalence, and correlates. *Journal of Psychosomatic Research, 52*: 445 - 452.

Chamberlin JM, Terndrup TE, Alexander DT, Silverstone FA, Wolk-Klein G, O’Donnell R and Grandner J (1995). Determination of normal ear temperature with an infrared emission detection thermometer. *Annals of Emergency Medicine, 25 (1):* 15 - 20.

Choi J and Gutierrez-Osuna R (2009). Using heart rate monitors to detect mental stress. *Proceedings: The 2009 Sixth International Workshop on Wearable and Implantable Body Sensor Networ,* 3rd to 5 th June 2009; Berkley, Claifornia, IEEE Computer Society, Washington, pp. 219 - 223.

Craig A, Tran Y, Wijesuriya N and Boord P (2006). A controlled investigation into the psychological determinants of fatigue. *Biological Psychology, 72:* 78 - 87.

Czaja SJ and Sharit J (1993). Age differences in the performance of computer-based work. *Psychology and Aging, 8 (1):* 59 - 67.

Dawson D, Noy YI, Härmä M, Åkerstedt T, and Belenky G (2011). Modelling fatigue and the use of fatigue models in work settings. *Accident Analysis and Prevention, 43:* 549 - 564.

Desmond PA and Hancock PA (2001). Active and passive fatigue states. In PA Hancock and PA Desmond (eds.) *Stress, Workload and Fatigue.* Lawrence Erlbaum Associates, inc: New Jersey

De Waard D (1996). *The measurement of drivers' mental workload*. Unpublished Doctoral thesis, University of Groningen: Netherlands.

Di Milia L, Smolensky MH, Costa G, Howarth HD, Ohayon MM and Philip P (2011). Demographic factors, fatigue, and driving accidents: An examination of the published literature. *Accident Analysis and Prevention, 43:* 516 - 532.

Dinges, DF and Kribbs, NB (1991). Performing while sleepy: effects of experimentally induced sleepiness. In TH Monk (ed.), *Sleep, Sleepiness and Performance*. John Wiley & Sons: Chichester, pp. 97 - 128.

Drowatzky JN (1981). *Motor learning principles and practices***.** Second Edition. Burgess Publishing Company: Minneapolis.

Eston R (2012). Use of ratings of perceived exertion in sports. *International Journal of Sports Physiology and Performance*, *7*: 175 - 182.

Fairclough SH and Houston K (2004). A metabolic measure of mental effort. *Biological Psychology, 66*: 177 - 190.

Fairclough SH, Venables L and Tattersall A (2005). The influence of task demand and learning on the psychophysiological response. *International Journal of Psychophysiology, 56*: 171 - 184.

Faulkner F and Eston RG (2008). Perceived exertion research in the 21st century: developments, reflections and questions for the future. *Journal of Exercise Science and Fitness, 6 (1)*: 1 - 14.

Fleury M (2010). *Effects of alcohol on driving performance*. In Substance Abuse, URL: www.medichatmd.com/blogs/effects-of-alcohol-on-driving-performance.html. Last accessed: 23 January 2012.

Gander P, Hartley L, Powell D, Cabon P, Hitchcock E, Mills A and Popkin S (2011). Fatigue risk management: Organizational factors at the regulatory and industry/company level. *Accident Analysis and Prevention, 43*: 573 - 590.

Gomberg W (1947). Measuring the fatigue factor. *Industrial and Labor Relations Review, 1 (1):* 80 - 93.

Hammel HT, Jackson DC, Stolwijk JAJ, Hardy JD, and Strømme SB (1963). Temperature regulation by hypothalamic proportional control with an adjustable set point. *Journal of Applied Physiology*, *18 (6):* 1146 - 1154.

Hancock PA, Williams G, Manning CM and Miyake S (1995). Influence of task demand characteristics on workload and performance. *The International Journal of Aviation Psychology, 5 (1):* 63 - 86.

Hart SG (2006). NASA-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings: Human Factors and Ergonomics Society 50th Annual Meeting*. HFES 904 - 908: Santa Monica.

Hart SG and Staveland LE (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In PA Hancock and N Meshkati (eds.), *Human Mental Workload*. North Holland Press: Amsterdam.

Hartley LR, Penna F, Corry A and Feyer AM (2003).Comprehensive review of fatigue research. *Institute for Research in Safety & Transport Report, 116*:1 - 95.

Haworth N (1998). Fatigue and fatigue research: the Australian experience. *Proceedings: The 7th Biennial Australasian Traffic Education Conference: Speed, Alcohol, Fatigue, Effects.* Brisbane. URL: http://www.monash.edu.au/muarc/reports/papers/fatigue.html. Last accessed: 20 January 2012.

Heitmann A, Guttkuhn R, Aguirre A, Trutschel U, Moore-Ede M (2001). Technologies for the monitoring and prevention of driver fatigue. *Proceedings: The First International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*: pp 81 - 86.

Hockey GRJ (1997). Compensatory control in the regulation of human performance under stress and high workload: A cognitive-energetical framework. *Biological Psychology, 45 (1):* 73 - 93.

Hull JT, Wright KP Jr. and Czeisler CA (2003). The influence of subjective alertness and motivation on human performance independent of circadian and homeostatic regulation. *Journal of Biological Rhythms, 18*: 329 - 338.

Jansen NWH, van Amelsvoort LGPM, Kristensen TS, van den Brandt PA and Kant IJ (2003). Work schedules and fatigue: a prospective cohort study. *Occupational and Environmental Medicine, 60:* 47 - 53.

Jorna PGAM (1992). Spectral analysis of heart rate and psychological state: a review of its validity as a workload index. *Biological Psychology, 34:* 237 - 257.

Kahneman D (1973). *Attention and effort*. Prentice-Hall, Inc: Englewood Cliffs, New Jersey.

Kell J (2007). *Reaction times and hypothesis testing*. URL www.radford.edu/jkell/Reaction%20Times.pdf. Last accessed: 23 January 2012.

Kleitman, N (1963). *Sleep and Wakefulness*. Second Edition. University of Chicago Press. (see Johnson MP, Duffy JF, Dijk DJ, Monda JM, Dyal CM and Czeisler CA (1992). Short-term memory, alertness and performance: a reappraisal of their relationship to body temperature. *Journal of Sleep Research, 1*: 24 - 29.

Koisinski RJ (2010). *A literature review on reaction time*. URL: http://biology.clemson.edu/bpc/bp/Lab/110/reaction.htm#Arousal. Last accessed: 18 July 2011.

Lal SK.L and. Craig A (2001). Review: A critical review of the psychophysiology of driver fatigue. *Biological Psychology*, *55*: 173 - 194.

Larue GS, Rakotonirainy A and Pettitt AN (2010). Predicting driver's hypovigilance on monotonous roads. Literature review. *Proceedings: the First International Conference on Driver Distraction and Inattention*, pp 1 - 13.

Lee KA, Hicks G and Nino-Murcia G (1990). Validity and reliability of a scale to assess fatigue. *Psychiatry Research, 36*: 291 - 298.

Levy MN, Stanton BA and Koeppen BM (2006). *Berne and Levy principles of physiology*. Fourth Edition. Elsevier Mosby: Philadelphia.

Lewis G and Wessely S (1992). The epidemiology of fatigue: more questions than answers. *Journal of Epidemiology and Community Health, 46:* 92 - 97.

Mallo J, Nordstrom CR, Bartels LK and Traxler A (2007). The effect of age and task difficulty. *Performance Improvement Quarterly*, *20 (1):* 49 - 63.

Marteniuk RG (1976). *Information processing in motor skills*. Holt, Rinehart and Winston: New York.

Matthews G, Campbell SE, Desmond PA, Huggins J, Falconer S and Joyner LA (1999). Assessment of Task-Induced State Change: Stress, Fatigue and Workload Components. In MW Scerbo and M Mouloua (eds.), *Automation technology and human performance: current research and trends*. Lawrence Erlbaum Associates Publishers: New Jersey, pp. 199 - 203.

Matthews G and Desmond PA (2002). Task-induced fatigue states and simulated driving performance. *The Quarterly Journal of Experimental Psychology, 55A (2):* 659 - 686.

Milroy TH (1909). Fatigue studied in reaction time experiments. *Experimental Physiology*: 277 - 282.

Moran JL, Peter JV, Solomon PJ, Grealy B, Smith T, Ashforth W, Wake M, Peake SL and Peisach AR (2007). Tympanic temperature measurements: Are they reliable in the critically ill? A clinical study of measures of agreement. *Critical Care Medical*, 35 (1): 155 - 164.

Morris TL and Miller JC (1996). Electrooculographic and performance indices of fatigue during simulated flight*. Biological Psychology, 42:* 343 - 360.

Mulder G (1986). The concept and measurement of mental effort. In GRJ Hockey, AWK Gaillard and MGH. Coles (eds*.), Energetics and Human Information Processing*. Martinus Nijhoff Publishers: Dordrecht, pp. 175 - 198.

Navon D and Gopher D (1979). On the economy of the human-processing system. *Psychological Review, 86 (3):* 214 - 255.

Nilsson T, Nelson TM and Carlson D (1997). Development of fatigue symptoms during simulated driving. *Accident Analysis and Prevention, 29 (4):* 479 - 488.

Norman DA and Bobrow DG (1975). On data-limited and resource-limited processes. *Cognitive Psychology, 7:* 44 - 64.

Noy YI, Horrey WJ, Popkin SM, Folkard S, Howarth HD and Courtney TK (2011). Future directions in fatigue and safety research. *Accident Analysis and Prevention, 43*: 495 - 497.

Oken BS, Salinsky MC and Elsas SM (2006). Vigilance, alertness, or sustained attention: physiological basis and measurement. *Clinical Neurophysiology, 117 (9)*: 1885 - 1901.

Palinko O, Kun AL, Shyrokov A and Heeman P (2010). Estimating cognitive load using remote eye tracking in a driving simulator. *Eye Tracking Research and Applications Symposium, 54*: pp. 141 - 144.

Recarte MA, Pérez E, Conchillo Á and Nunes LM (2008). Mental workload and visual impairment: differences between pupil, blink and subjective rating. *The Spanish Journal of Psychology, 11 (2):* 374 - 385.

Redondo M and Valle-Inclan FD (1992). Decrements in heart rate variability during memory search. *International Journal of Psychophysiology, 13*: 29 - 35.

Reilly T and Waterhouse J (2009). Circadian aspects of body temperature regulation in exercise. *Journal of Thermal Biology, 34*: 161 - 170.

Robertson J (2009). The effects of fatigue on saccade latency and precision performance. *Unpublished Honours thesis*, Rhodes University.

Robertson R and Noble BJ (1997). Perception of physical exertion: methods, mediators and applications. *Exercises and Sport Sciences Reviews, 25*: 407 - 452.

Rokicki SM (1995). Psychophysiological measures applied to operational test and evaluation. *Biological Psychology, 40*: 223 - 228.

Rowe DW, Sibert J, and Irwin D (1998). Heart rate variability: indicator of user state as an aid to human-computer interaction. *CHI, 98*: 18 - 23.

Saxby D, Matthews G, Hitchcock EM and Warm JS (2007). Development of active and passive fatigue manipulations using a driving simulator. *Proceedings: Human Factors and Ergonomics Society Annual Meeting, 51*: 1237 - 1241.

Schleicher R, Galley N, Briest S and Galley L (2008). Blinks and saccades as indicators of fatigue in sleepiness warnings: looking tired? *Ergonomics, 51 (7):* 982 - 1010.

Schmidt RA (1982). *Motor control and learning: a behavioural emphasis***.** Human Kinetics Publishers: Champaign, Illinois.

Schneider AM and Tarshis B (1975). An introduction to physiological psychology. Random House: New York.

Schoenfeld VS and MW Scerbo (1999). The effects of search differences for the presence and absence of features on vigilance performance and mental workload. In MW Scerbo and M Mouloua (eds.), *Automation technology and human performance: current research and trends*. Lawrence Erlbaum Associates Publishers: New Jersey, pp. 177 - 182.

Sluiter JK, de Croon EM, Meijman TF and Frings-Dresen MHW (2003).Need for recovery from work related fatigue and subjective health complaints its role in the development and prediction of subjective health complaints. *Occupational and Environmental Medicine, 60:* 62 - 70.

Smolensky MH, Milia LD, Ohayon MM and Philip P (2011). Sleep disorders, medical conditions, and road accident risk. *Accident Analysis and Prevention, 43:* 533 - 548.

Spurgeon A, Harrington JM and Cooper CL (1997). Health and safety problems associated with long working hours: a review of the current position. *Occupational and Environmental Medicine, 54*: 367 - 375.

Stern JA, Boyer D, Schroeder D, Touchstone M and Stoliarov N (1994). Blinks, saccades, and fixation pauses during vigilance task performance: I. Time on task. . *Report No. DOT/FAA/ AM-94/26. US Department of Transportation. Federal Aviation Administration*.

Stern JA, Walrath LC, Golstein R (1984). The endogenous eyeblink. *Psychophysiology, 21* (1): 22 - 33.

Stolwijk JAJ and Hardy JD (1966). Temperature regulation in man - A theoretical study. *Pfliigers Archive, 291:* 129 - 162.

Sullivan JM (2008). Visual fatigue and the driver. *Report No. UMTRI-2008-50. Transportation Research Institute*: The University of Michigan.

Thiffault P and Bergeron J (2003a). Monotony of road environment and driver fatigue: a simulator study. *Accident Analysis and Prevention, 35:* 381 - 391.

Thiffault P and Bergeron J (2003b). Fatigue and individual differences in monotonous simulated driving. *Personality and Individual Differences, 34:* 159 - 176.

Tran Y, Wijesuriya N, Tarvainen M, Karjalainen P, and Craig A (2009). The relationship between spectral changes in heart rate variability and fatigue. *Journal of Psychophysiology, 23* (3):143 - 151.

VaezMousavi SM, Barry RJ, Rushby JA, and Clarke AR (2007). Arousal and activation effects on physiological and behavioural responding during a continuous performance task. *Acta Neurobiologiae Experimentalis, 67*: 461 - 470.

Van Dongen HPA and Dinges DF (2000).Circadian rhythms in fatigue, alertness and performance. In: M. H. Kryger, T. Roth & W. C. Dement (eds.), *Principles and Practice of Sleep Medicine* (3rd ed.), pp. 391 - 399. W. B. Saunders: Philadelphia, Pennsylvania.

Van Orden KF, Jung TP and Makeig S (2000). Combined eye activity measures accurately estimate changes in sustained visual task performance. *Biological Psychology, 52*: 221 - 240.

Wei J and Salvendy G (2006). Development of a human information processing model for cognitive task analysis and design. *Theoretical Issues in Ergonomics Science, 7 (4)*: 345 - 370.

Wickens CD (1980). The structure of attentional resources, in R. Nickerson (ed.), *Attention and Performance VIII*, pp. 239 - 25. Lawrence Erlbaum: Hillsdale, New Jersey.

Wickens CD (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics*, 3 *(2)*: 159 - 177.

Williamson A, Lombardi DA, Folkard S, Stutts J, Courtney TK, and Connor JL (2011). The link between fatigue and safety. *Accident Analysis and Prevention, 43:* 498 - 515.

Wright Jr. KP, Hull JT and Czeisler CA (2002). Relationship between alertness, performance, and body temperature in humans. *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology, 283*: R1370 - R1377.

Zengyong L, Wang C, Mak AFT and Chow DHK (2005). Effects of acupuncture on heart rate variability in normal subjects under fatigue and non-fatigue state. *European Journal of Applied Physiology, 94*: 633 - 640.

APPENDIX A: General Information

1. Information to Participants
2. Consent Form

APPENDIX A 1

INFORMATION TO PARTICIPANTS

Dear Participant

Thank you for agreeing to participate in this study. This document contains information regarding the research entitled “Fatigue development and down-regulation in endogenous resources and the design of job rotation schedules” that will be carried out and how you will be assisting in this regard. Also attached to this document is a consent form which you have to sign prior to commencing with the testing. Please ensure that you read everything carefully before signing.

Purpose of study

The purpose of this study is to acquire a better understanding of fatigue and the way in which the human body regulates fatigue through down-regulation. This project is concerned with studying fatigue and recovery characteristics of selected sensory, cognitive and motor resources used during task performance and focusing on the impact of alternating/rotating different tasks on fatigue characteristics and recovery.

Relevance

Although fatigue is a common feature of industrial work (and other forms of daily activities), this phenomenon is still not yet well understood and lacks clarify particularly with regards to fatigue of cognitive processes. As a consequence, the fatigue implications of designing and organising tasks are not adequately considered thus rendering fatigue management interventions (such as job rotation) ineffective. In assisting with this problem, the current research intends to deliver quantitative accounts of fatigue at a resource level detailing how resource fatigue develops, the extent to which resources interact with each other, how long resources take to recover and whether rotating between tasks is an effective principle for fatigue management. Additionally, the differentiation regarding whether fatigue is actual resource depletion as opposed to a protective proactive down-regulation of activity level in order to delay fatigue will be investigated.

It is hoped that the results that will be delivered by this study will provide additional information required to design more effective work tasks and fatigue management tools.

Procedure

This research study is a laboratory based investigation of task induced fatigue and its effects on performance and individual responses. The diagram below outlines the procedure that will be followed during testing. In the first instance, you will perform a battery of resource specific tests in succession followed by one of the six fatiguing tasks (outlined in the diagram) performed for one hour. Straight after the fatiguing task, the battery of resource specific tests performed initially will be repeated. Thereafter, you will complete a series of reaction time tests every 30 seconds for 15 minutes while you rest.

Therefore, the total time commitment required of you as a participant is four and a half hours split over two sessions: habituation session = 2 hours (117minutes) and testing session = 2 and a half hours (147 minutes). Both sessions will be on different non-consecutive days at the same time of day for both sessions (8:00–10:30; 10:30–13:00; 13:30–16:00; 16:00–18:30).

Total time commitment for each participant:
147min (habituation session) + 117min (testing session) = 264 min (4 hours 30 minutes)

Tasks

The tasks you will be required to perform include a combination of the tasks described below.

Sensory resource tests: Reading task

This task is a visually demanding reading task testing visual scanning and perception/ object recognition where you will read and identify errors (double characters e.g. bookk) in a text set at a high (simple version of test) and low resolution (complex version of test) (300 dpi and 60dpi respectively). Your performance will be measured by noting the number of correctly identified errors and reading speed (assessed through recording the number of words read).

Cognitive resource test: Memory recall task

This task entails you performing a short number memory recall task. With regards to the short-term memory recall test, an auditory memory program will call 5 digits (simple version of the test) out which you have to recite in the correct order after 10 seconds. The complex version of the test will require that you recite 7 digits, with a 10 second break in between). Your performance will be measured by noting the number of correctly recalled numbers.

Motor resource test: Fitts' stimulus response task

The Fitts' stimulus response test measures motor program formation (the planning and execution of different movement patterns). You will be requested to respond to targets appearing in random positions on a touch screen as fast and as accurately as you can, using one finger. The simple version of this task provides fewer options movement available for you to respond while the complex version of this task has more movement options available.)

Fatiguing task and Battery of resource tests

The tasks described above will be arranged to form three different fatiguing task conditions. You will be allocated randomly to one of the three fatiguing task conditions. Conditions 1, 2, and 3 consist of any of the three tasks performed for 1 hour. The battery of resource tests consists of 2 variations for each of the tasks described above making 6 tests overall. Each of the six resource tests will be performed in succession (with a 30 second break in between) for 3 minutes before and after the fatiguing task. The duration of the battery of resource tests is 21 minutes such that the total time spent performing the battery of tests twice is 42 minutes.

Duration of the battery of resource tests

(3min × 3 Simple resource tests) + (3min × 3 Complex resource tests) + (6 × 30s breaks) = 21 min

THEREFORE:

21min (Test Battery Pre fatiguing task) + 21min (Test Battery Post fatiguing task) = 42 min

Duration of each condition:

21min battery test + 60min fatiguing task + 21min battery test + 15min recovery (RT series) = 117 min

(+ 30min if habituation session = 147min)

What will be measured?

Performance changes throughout all the tests will be monitored in order to track fatigue development. Your subjective perceptions of how the task impacts on you and the effort you need to invest in the task will be assessed at 10 minute intervals using a Rating of perceived exertion (RPE) scale and you will be asked to complete the NASA Task Load Index (NASA TLX) questionnaire after testing is completed. A heart rate monitor will be used to record heart rate and heart rate variability (objective measure of mental effort) throughout the protocols. Temperature (using skin and ear temperature sensors) and eye blink frequency and duration (using the eye tracker) will also be assessed. Simple reaction time tests will be performed during the fatiguing task, in between the battery of resource tests and the fatiguing tasks and during the 15 minute rest period at the end of the protocol to measure the level of alertness and resource state.

Risks and Benefits

The tasks you will be required to perform are simple and comparable to tasks you would perform on a daily basis (e.g. reading, memory recall). Temporary visual, mental, muscular and postural discomfort that accompanies fatigue may be incurred from engaging in the resource tests and the tasks for a duration of two hours. This discomfort is fully reversible when task performance is discontinued and rest follows. In order to limit the effects of fatigue on you, and as an added precaution, only one session will be carried out each day.

One of the benefits of participating in this study is that you will gain an understanding of the manner in which your body reacts to fatigue in conditions that you may encounter in your daily tasks. It is also hoped that, if you are interested, you may gain a better understanding of research methodology and how it can be applied in fatigue research the Ergonomics field.

'Dos' and 'Donts' prior to testing

In the interests of limiting the effects of extraneous variables you are asked to please refrain from the following at least 24 hours before coming for your data collection:

- consuming alcohol
- strenuous physical and cognitive exercise/ activities (i.e. no physical and cognitive work performed continuously for more than an hour at least 2 hours before testing)
- medication such as stimulants or performance enhancers (e.g. high energy drinks such as red bull and play and coffee (at least 6 hours before)
- not having sufficient sleep the night before

If you do any of the above, please inform the researcher prior to starting your testing session so that another testing session can be organised.

Compensation

Please note that no payment will be issued for participation.

Confidentiality

Your identity will be protected by assigning a code to you instead of using your real name. As such, none of the data collected will be in any way linked back to you. Information obtained about you for this study will be kept private to the extent allowed by law. However, research information that identifies you may be shared with the HKE ethics committee and others who are responsible for ensuring compliance with laws and regulations related to research. The aggregated results will be archived to be used by other researchers in the department. Two copies of the data collected will be kept in electronic form by the researchers (one copy in the researchers' personal computer and another in the researchers' external hard drive). The Supervisor will also be given an electronic copy of the data. The data will be stored indefinitely by the researchers.

Please be aware that you are free to withdraw from this research study at any time and there will be no penalty if you opt out. Should you have any questions, concerns or complaints regarding the study, please feel free to communicate these to the researchers (contact information is provided below) or the Head of Department Prof Matthias Göbel at 046-603-8468 or m.goebel@ru.ac.za.

Thank you once again for participating in this study. Your contribution is invaluable and greatly appreciated!

Yours sincerely

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APPENDIX A 2

CONSENT FORM FOR RESEARCH STUDY

I ……………………………………………… confirm that I have been informed (verbally and in writing) and fully understand the procedures, benefits, potential risks of the study entitled:.

Fatigue development and down-regulation in endogenous resources and the design of job rotation schedules (Nokubonga ‘Sma’ Ngcamu AND Sethunya Tau)

I have been informed that my identity will be kept anonymous at all times and agree that all the information collected may be used and published in journals and presented at research seminars, workshops and conferences for statistical and scientific purposes. I realise the importance of promptly reporting to the researchers any signs or symptoms indicating any abnormality or distress. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason. I agree to take part in the above research study and waive any legal recourse against the researchers and Rhodes University from any and all claims resulting from personal injuries sustained while partaking in the investigation. This waiver shall be binding upon my heirs and personal representatives.

___________________________________ ________________
Name of Participant Date

____
Signature

_______________________________ ________________
Name and signature of Researcher Date

________________________________ ________________
Name and signature of Witness 1 Date

________________________________ ________________
Name and signature of Witness 2 Date

APPENDIX B: Data Collection Methods

1. Data Collection Sheet
2. Readings Data Collection Sheet
3. Borg CR-10 Scale

APPENDIX B 1

DATA COLLECTION SHEET

Participant: ____________________________________

Condition & Session: ________________________

Sex & Age: ____________________________________
HR Start __________ HR Stop __________
Temp Start __________ Temp Stop __________
ET Start __________ ET Stop __________

RPE RECORDINGS

	RPE Score	Comments
Before Pre test 1		
After Pre Test 1		
After Pre Test 2		
After Pre Test 3		
After Pre Test 4		
After Pre Test 5		
10mins		
20mins		
30mins		
40mins		
50mins		
60mins		
After Post Test 1		
After Post Test 2		
After Post Test 3		
After Post Test 4		
After Post Test 5		
5 min after Post Test 5		
10min after Post Test 5		
15min after Post Test 5		

APPENDIX B 2

READINGS DATA COLLECTION SHEET

Condition & Session:________________________

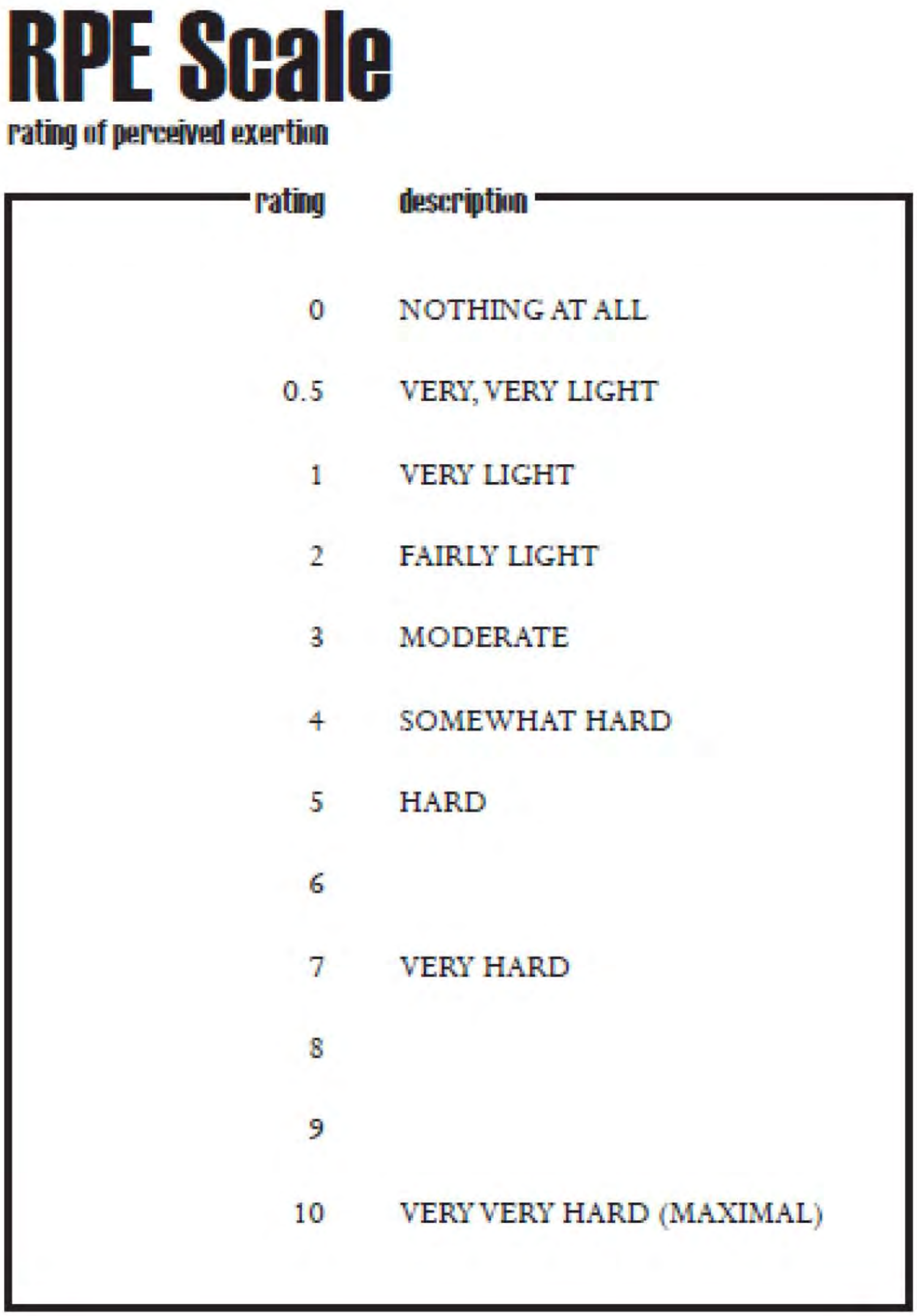
Participant:______________________________

Reading title: ____________________________

READINGS RECORDINGS

TIME	WORD		TIME	WORD		TIME	WORD	

APPENDIX B 3



RPE Scale

rating of perceived exertion

rating	description
0	NOTHING AT ALL
0.5	VERY, VERY LIGHT
1	VERY LIGHT
2	FAIRLY LIGHT
3	MODERATE
4	SOMEWHAT HARD
5	HARD
6	
7	VERY HARD
8	
9	
10	VERY VERY HARD (MAXIMAL)

APPENDIX C: Summary Reports

1. Response Effects
    1.1. Performance Parameters
    1.2. Reaction Time Test Parameters
    1.3. Temperature Parameters
    1.4. Cardiovascular Parameters
    1.5. Oculomotor Parameters
    1.6. Subjective Parameters

APPENDIX C

Response Effects

Three-way factorial ANOVAs were conducted to determine the effect of the experience of having performed a similar session before (TEST SESSION, technically processed by considering the difference between the ‘1st test’ session and the ‘2nd test’ session), the effect of time-on-task over the 60 minutes (TIME, technically processed by 12 intervals of average values of 5 minutes each or by 6 intervals of average values of 10 minutes respectively), and the effect of the different tasks (technically processed by comparing the effects of the cognitive, motor and sensory resources). See Chapter III.

1. Performance Parameters

Since the performance data of each task included different performance criteria, the data could not be directly compared. As such, three two-way ANOVAs were analysed (with factors TIME and TEST SESSION) for these parameters.

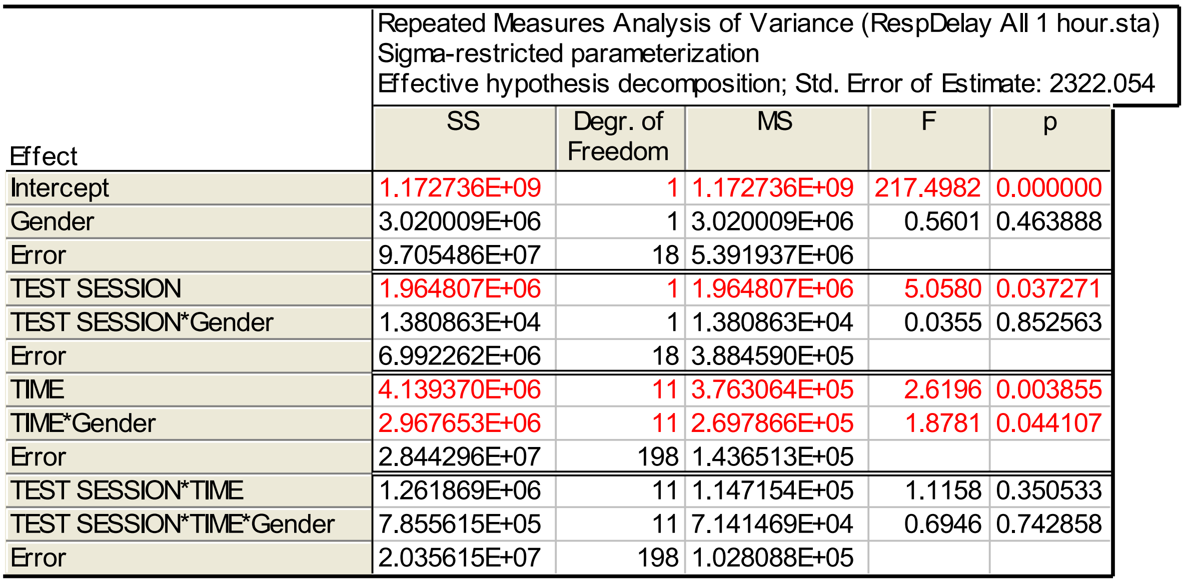
a. Cognitive Task

i. Correctly identified digits

Repeated Measures Analysis of Variance (Correct % All 1 Hour.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 75.03760

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	3569270	1	3569270	633.9010	0.000000
Gender	9851	1	9851	1.7496	0.202491
Error	101352	18	5631		
TEST SESSION	31	1	31	0.0915	0.765778
TEST SESSION*Gender	38	1	38	0.1127	0.741022
Error	6068	18	337		
TIME	1118	11	102	1.4187	0.166680
TIME*Gender	1464	11	133	1.8583	0.046877
Error	14184	198	72		
TEST SESSION*TIME	790	11	72	2.0924	0.022419
TEST SESSION*TIME*Gender	608	11	55	1.6086	0.098529
Error	6799	198	34		

ii. Response delay

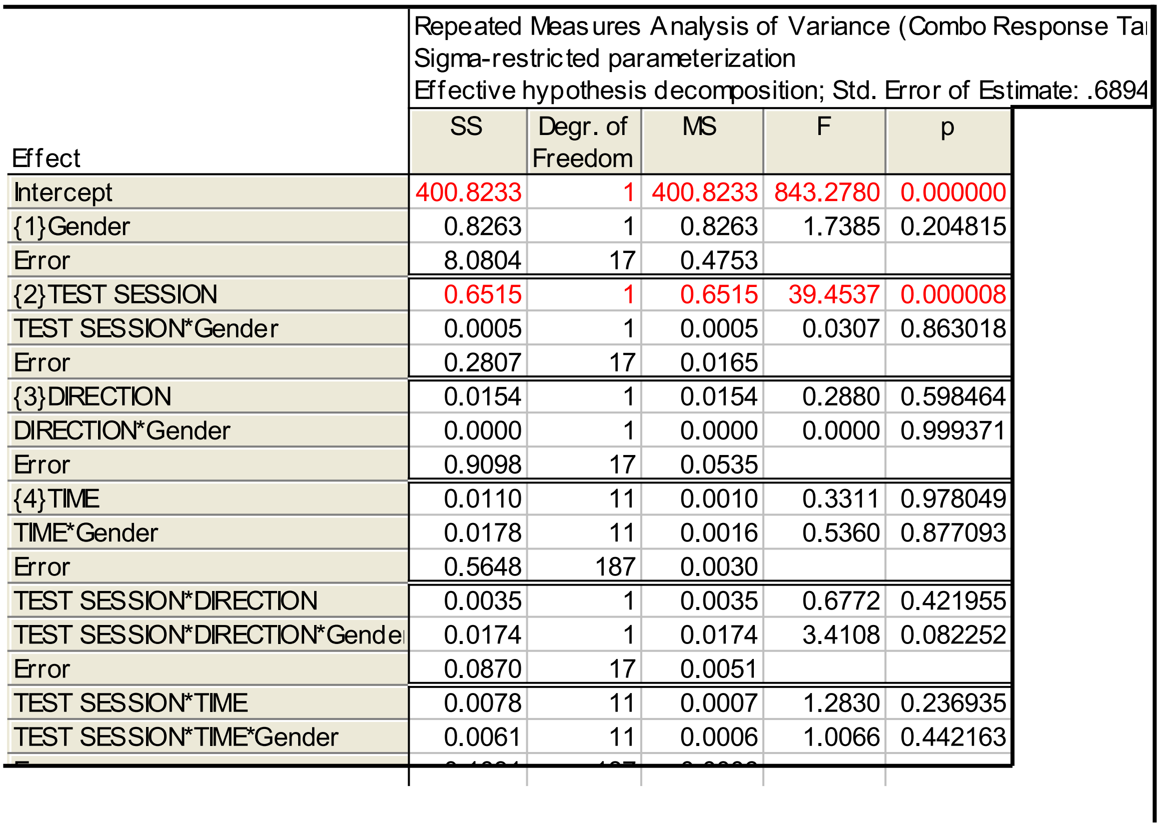


Repeated Measures Analysis of Variance (RespDelay All 1 hour.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 2322.054

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1.172736E+09	1	1.172736E+09	217.4982	0.000000
Gender	3.020009E+06	1	3.020009E+06	0.5601	0.463888
Error	9.705486E+07	18	5.391937E+06		
TEST SESSION	1.964807E+06	1	1.964807E+06	5.0580	0.037271
TEST SESSION*Gender	1.380863E+04	1	1.380863E+04	0.0355	0.852563
Error	6.992262E+06	18	3.884590E+05		
TIME	4.139370E+06	11	3.763064E+05	2.6196	0.003855
TIME*Gender	2.967653E+06	11	2.697866E+05	1.8781	0.044107
Error	2.844296E+07	198	1.436513E+05		
TEST SESSION*TIME	1.261869E+06	11	1.147154E+05	1.1158	0.350533
TEST SESSION*TIME*Gender	7.855615E+05	11	7.141469E+04	0.6946	0.742858
Error	2.035615E+07	198	1.028088E+05		

b. Motor Task

i. Response time

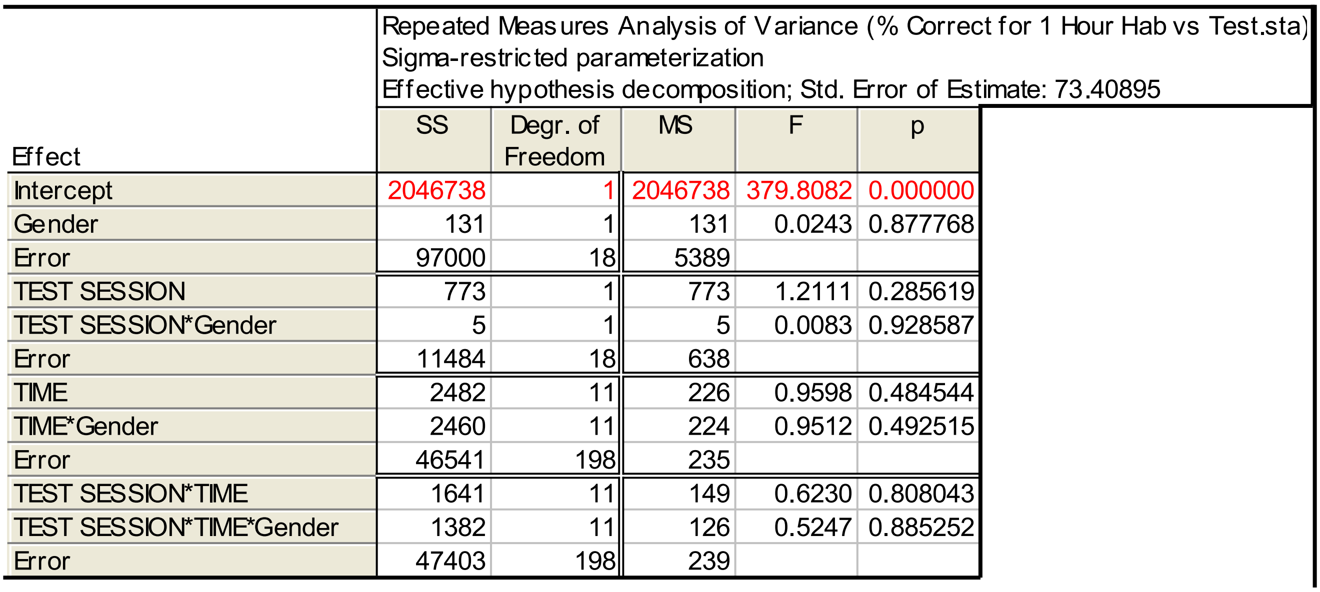


Repeated Measures Analysis of Variance (Combo Response Ta
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .6894

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	400.8233	1	400.8233	843.2780	0.000000
{1}Gender	0.8263	1	0.8263	1.7385	0.204815
Error	8.0804	17	0.4753		
{2}TEST SESSION	0.6515	1	0.6515	39.4537	0.000008
TEST SESSION*Gender	0.0005	1	0.0005	0.0307	0.863018
Error	0.2807	17	0.0165		
{3}DIRECTION	0.0154	1	0.0154	0.2880	0.598464
DIRECTION*Gender	0.0000	1	0.0000	0.0000	0.999371
Error	0.9098	17	0.0535		
{4}TIME	0.0110	11	0.0010	0.3311	0.978049
TIME*Gender	0.0178	11	0.0016	0.5360	0.877093
Error	0.5648	187	0.0030		
TEST SESSION*DIRECTION	0.0035	1	0.0035	0.6772	0.421955
TEST SESSION*DIRECTION*Gende	0.0174	1	0.0174	3.4108	0.082252
Error	0.0870	17	0.0051		
TEST SESSION*TIME	0.0078	11	0.0007	1.2830	0.236935
TEST SESSION*TIME*Gender	0.0061	11	0.0006	1.0066	0.442163

c. Sensory Task

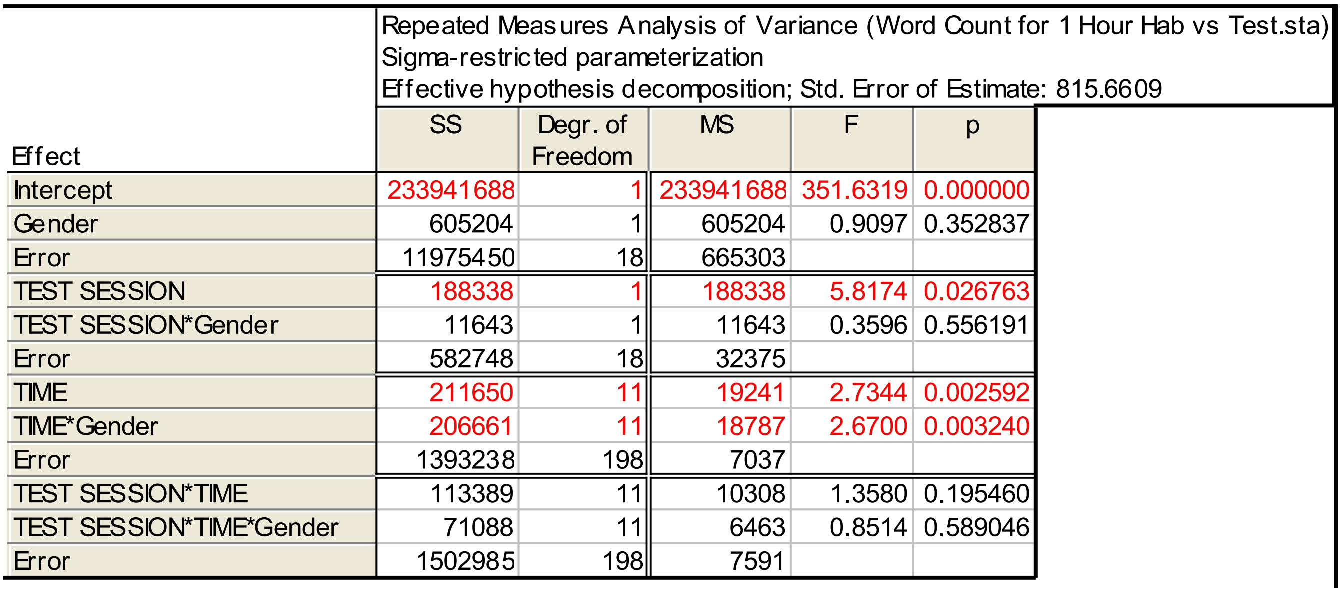
i. Correctly identified errors



Repeated Measures Analysis of Variance (% Correct for 1 Hour Hab vs Test.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 73.40895

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2046738	1	2046738	379.8082	0.000000
Gender	131	1	131	0.0243	0.877768
Error	97000	18	5389		
TEST SESSION	773	1	773	1.2111	0.285619
TEST SESSION*Gender	5	1	5	0.0083	0.928587
Error	11484	18	638		
TIME	2482	11	226	0.9598	0.484544
TIME*Gender	2460	11	224	0.9512	0.492515
Error	46541	198	235		
TEST SESSION*TIME	1641	11	149	0.6230	0.808043
TEST SESSION*TIME*Gender	1382	11	126	0.5247	0.885252
Error	47403	198	239		

ii. Word count/reading speed



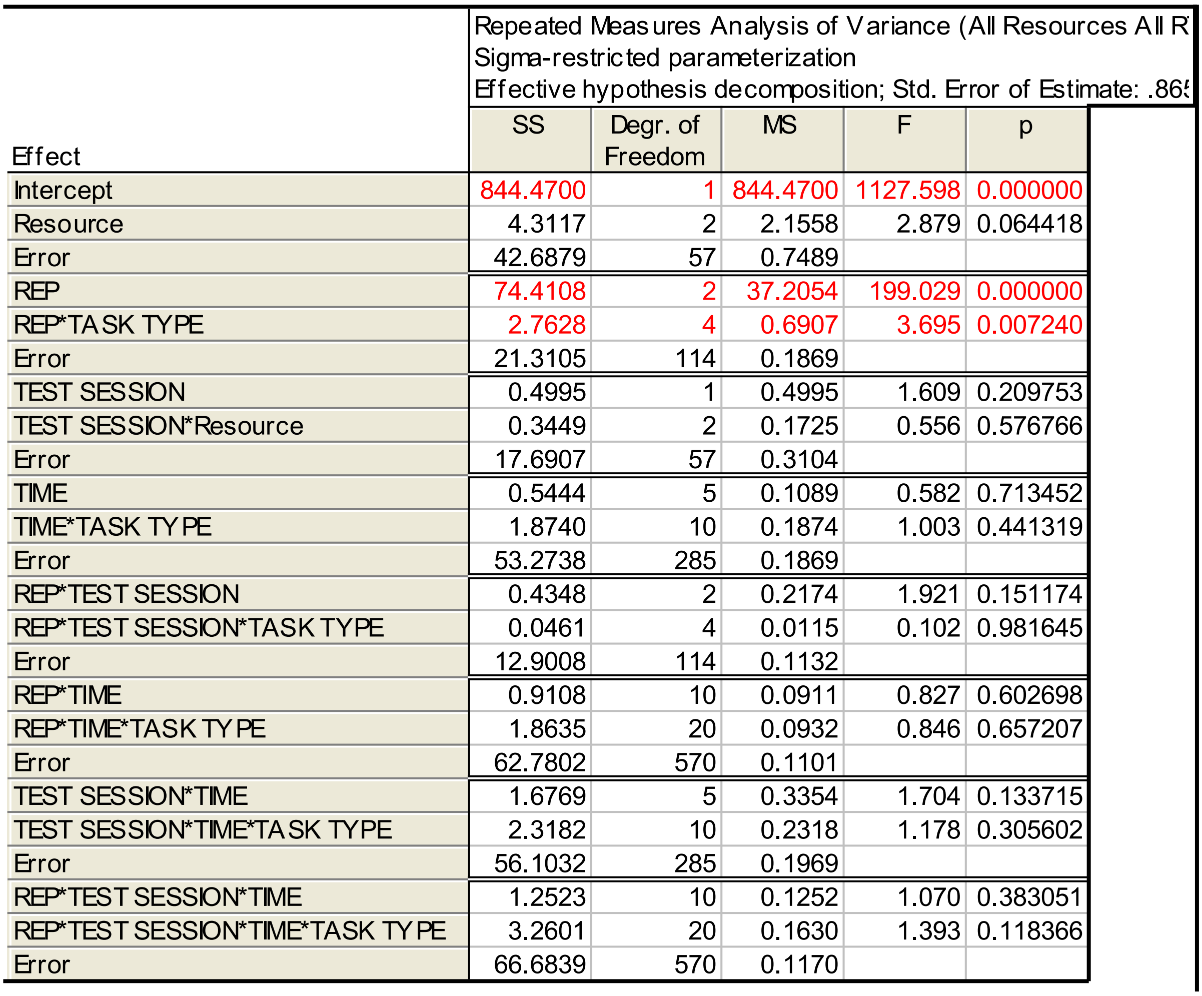
Repeated Measures Analysis of Variance (Word Count for 1 Hour Hab vs Test.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 815.6609

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	233941688	1	233941688	351.6319	0.000000
Gender	605204	1	605204	0.9097	0.352837
Error	11975450	18	665303		
TEST SESSION	188338	1	188338	5.8174	0.026763
TEST SESSION*Gender	11643	1	11643	0.3596	0.556191
Error	582748	18	32375		
TIME	211650	11	19241	2.7344	0.002592
TIME*Gender	206661	11	18787	2.6700	0.003240
Error	1393238	198	7037		
TEST SESSION*TIME	113389	11	10308	1.3580	0.195460
TEST SESSION*TIME*Gender	71088	11	6463	0.8514	0.589046
Error	1502985	198	7591		

2. Reaction Time Test Parameters

A four-way factorial ANOVA was analysed (where factor 1 considered the differences in responses of the three reaction time repetitions (called the REPETITION effect), factor 2 considered the TASK TYPE effect, factor 3 considered the TEST SESSION effect and factor 4 considered the TIME effect) to determine the general effects of the tasks and to incorporate the 3 repetitions. Then post hoc analyses were calculated using either two-way factorial ANOVAs (with factors TIME and TEST SESSION) or three-way factorial ANOVAs (with factors TASK TYPE, TIME and TEST SESSION).

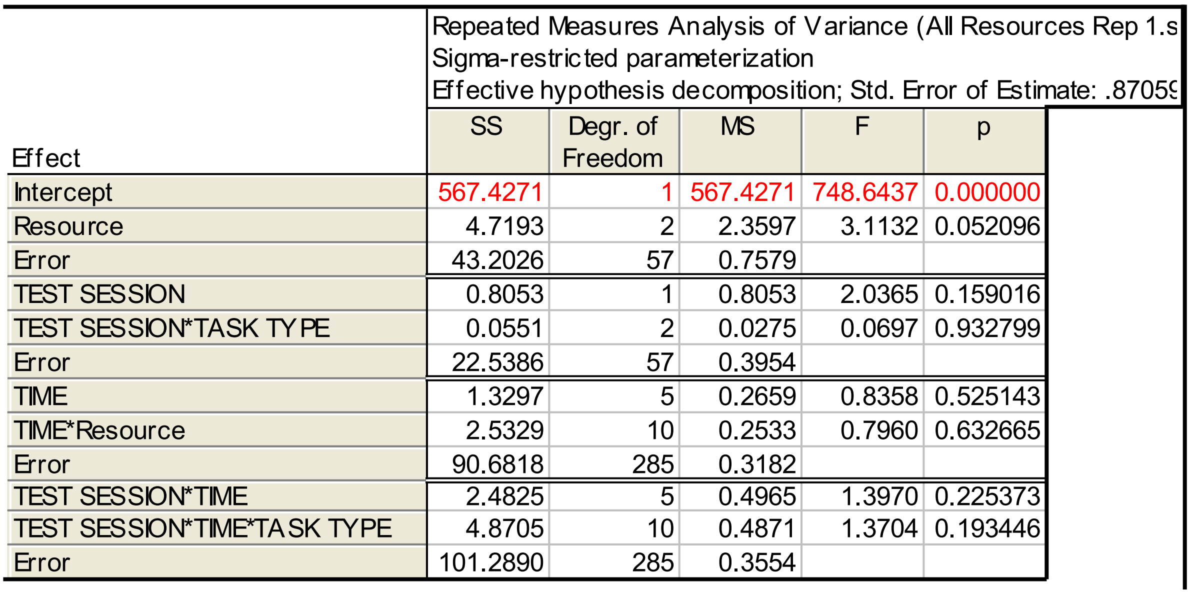
a. General Effects



Repeated Measures Analysis of Variance (All Resources All R
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .86

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	844.4700	1	844.4700	1127.598	0.000000
Resource	4.3117	2	2.1558	2.879	0.064418
Error	42.6879	57	0.7489		
REP	74.4108	2	37.2054	199.029	0.000000
REP*TASK TYPE	2.7628	4	0.6907	3.695	0.007240
Error	21.3105	114	0.1869		
TEST SESSION	0.4995	1	0.4995	1.609	0.209753
TEST SESSION*Resource	0.3449	2	0.1725	0.556	0.576766
Error	17.6907	57	0.3104		
TIME	0.5444	5	0.1089	0.582	0.713452
TIME*TASK TYPE	1.8740	10	0.1874	1.003	0.441319
Error	53.2738	285	0.1869		
REP*TEST SESSION	0.4348	2	0.2174	1.921	0.151174
REP*TEST SESSION*TASK TYPE	0.0461	4	0.0115	0.102	0.981645
Error	12.9008	114	0.1132		
REP*TIME	0.9108	10	0.0911	0.827	0.602698
REP*TIME*TASK TYPE	1.8635	20	0.0932	0.846	0.657207
Error	62.7802	570	0.1101		
TEST SESSION*TIME	1.6769	5	0.3354	1.704	0.133715
TEST SESSION*TIME*TASK TYPE	2.3182	10	0.2318	1.178	0.305602
Error	56.1032	285	0.1969		
REP*TEST SESSION*TIME	1.2523	10	0.1252	1.070	0.383051
REP*TEST SESSION*TIME*TASK TYPE	3.2601	20	0.1630	1.393	0.118366
Error	66.6839	570	0.1170		

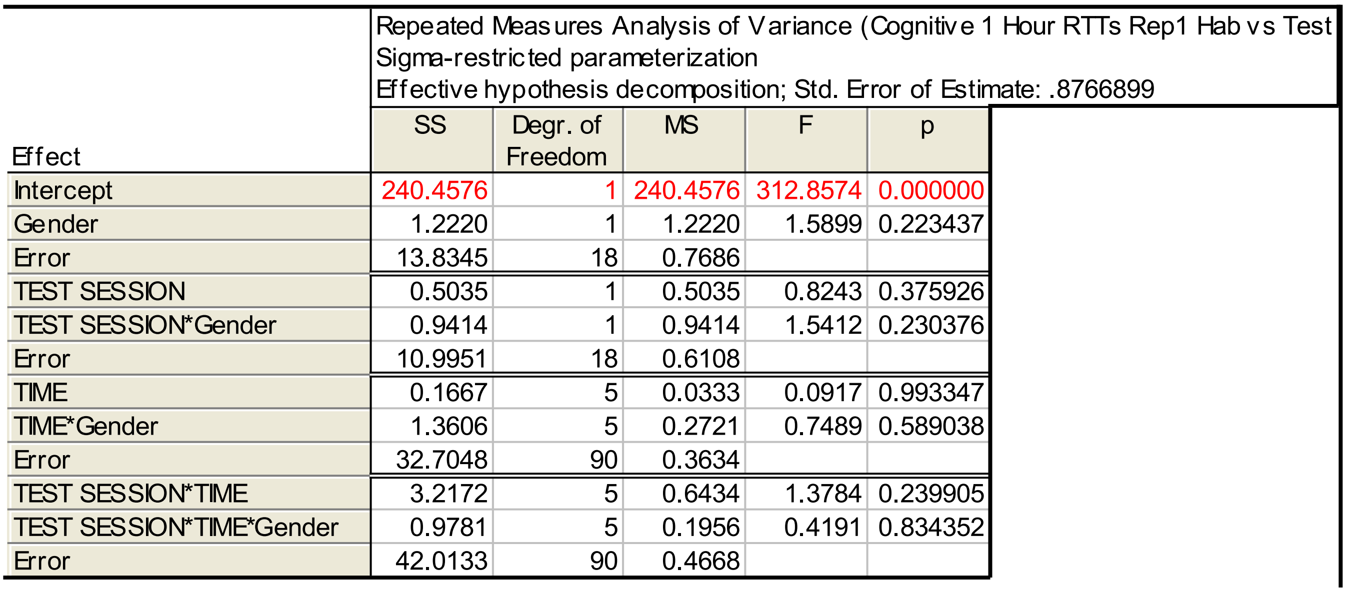
b. First Simple Reaction Time Repetition



Repeated Measures Analysis of Variance (All Resources Rep 1.s
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .87059

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	567.4271	1	567.4271	748.6437	0.000000
Resource	4.7193	2	2.3597	3.1132	0.052096
Error	43.2026	57	0.7579		
TEST SESSION	0.8053	1	0.8053	2.0365	0.159016
TEST SESSION*TASK TYPE	0.0551	2	0.0275	0.0697	0.932799
Error	22.5386	57	0.3954		
TIME	1.3297	5	0.2659	0.8358	0.525143
TIME*Resource	2.5329	10	0.2533	0.7960	0.632665
Error	90.6818	285	0.3182		
TEST SESSION*TIME	2.4825	5	0.4965	1.3970	0.225373
TEST SESSION*TIME*TASK TYPE	4.8705	10	0.4871	1.3704	0.193446
Error	101.2890	285	0.3554		

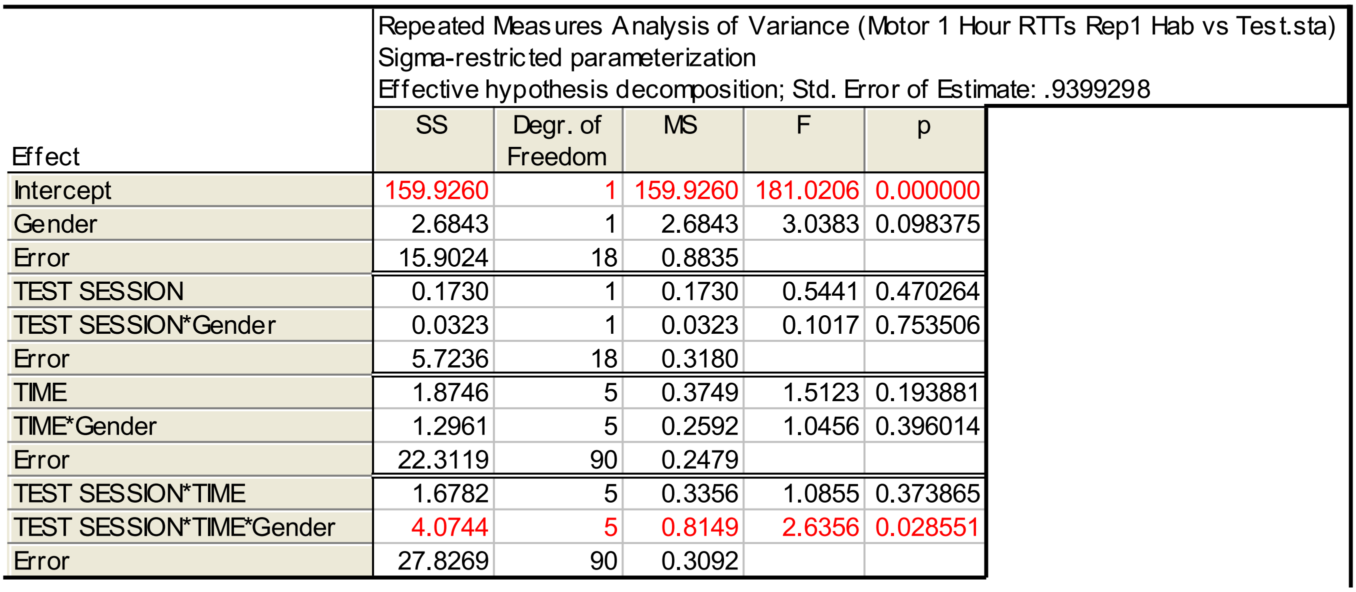
i. First Simple Reaction Time Repetition during Cognitive Task



Repeated Measures Analysis of Variance (Cognitive 1 Hour RTTs Rep1 Hab vs Test
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .8766899

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	240.4576	1	240.4576	312.8574	0.000000
Gender	1.2220	1	1.2220	1.5899	0.223437
Error	13.8345	18	0.7686		
TEST SESSION	0.5035	1	0.5035	0.8243	0.375926
TEST SESSION*Gender	0.9414	1	0.9414	1.5412	0.230376
Error	10.9951	18	0.6108		
TIME	0.1667	5	0.0333	0.0917	0.993347
TIME*Gender	1.3606	5	0.2721	0.7489	0.589038
Error	32.7048	90	0.3634		
TEST SESSION*TIME	3.2172	5	0.6434	1.3784	0.239905
TEST SESSION*TIME*Gender	0.9781	5	0.1956	0.4191	0.834352
Error	42.0133	90	0.4668		

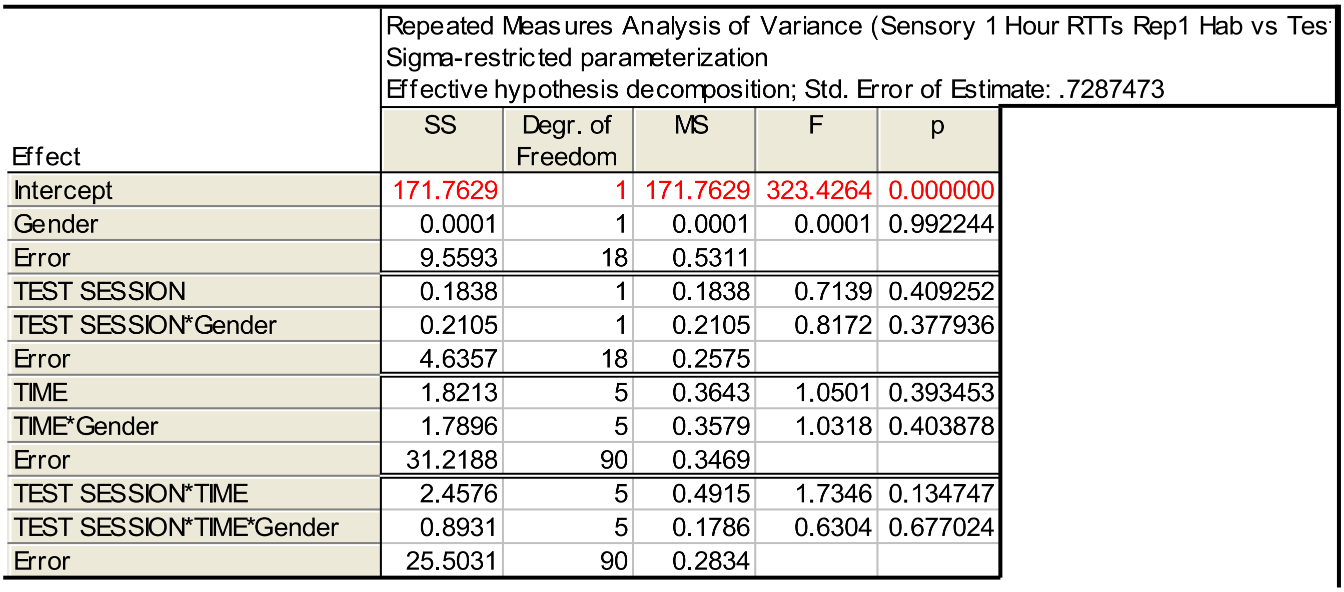
ii. First Simple Reaction Time Repetition during Motor Task



Repeated Measures Analysis of Variance (Motor 1 Hour RTTs Rep1 Hab vs Test.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .9399298

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	159.9260	1	159.9260	181.0206	0.000000
Gender	2.6843	1	2.6843	3.0383	0.098375
Error	15.9024	18	0.8835		
TEST SESSION	0.1730	1	0.1730	0.5441	0.470264
TEST SESSION*Gender	0.0323	1	0.0323	0.1017	0.753506
Error	5.7236	18	0.3180		
TIME	1.8746	5	0.3749	1.5123	0.193881
TIME*Gender	1.2961	5	0.2592	1.0456	0.396014
Error	22.3119	90	0.2479		
TEST SESSION*TIME	1.6782	5	0.3356	1.0855	0.373865
TEST SESSION*TIME*Gender	4.0744	5	0.8149	2.6356	0.028551
Error	27.8269	90	0.3092		

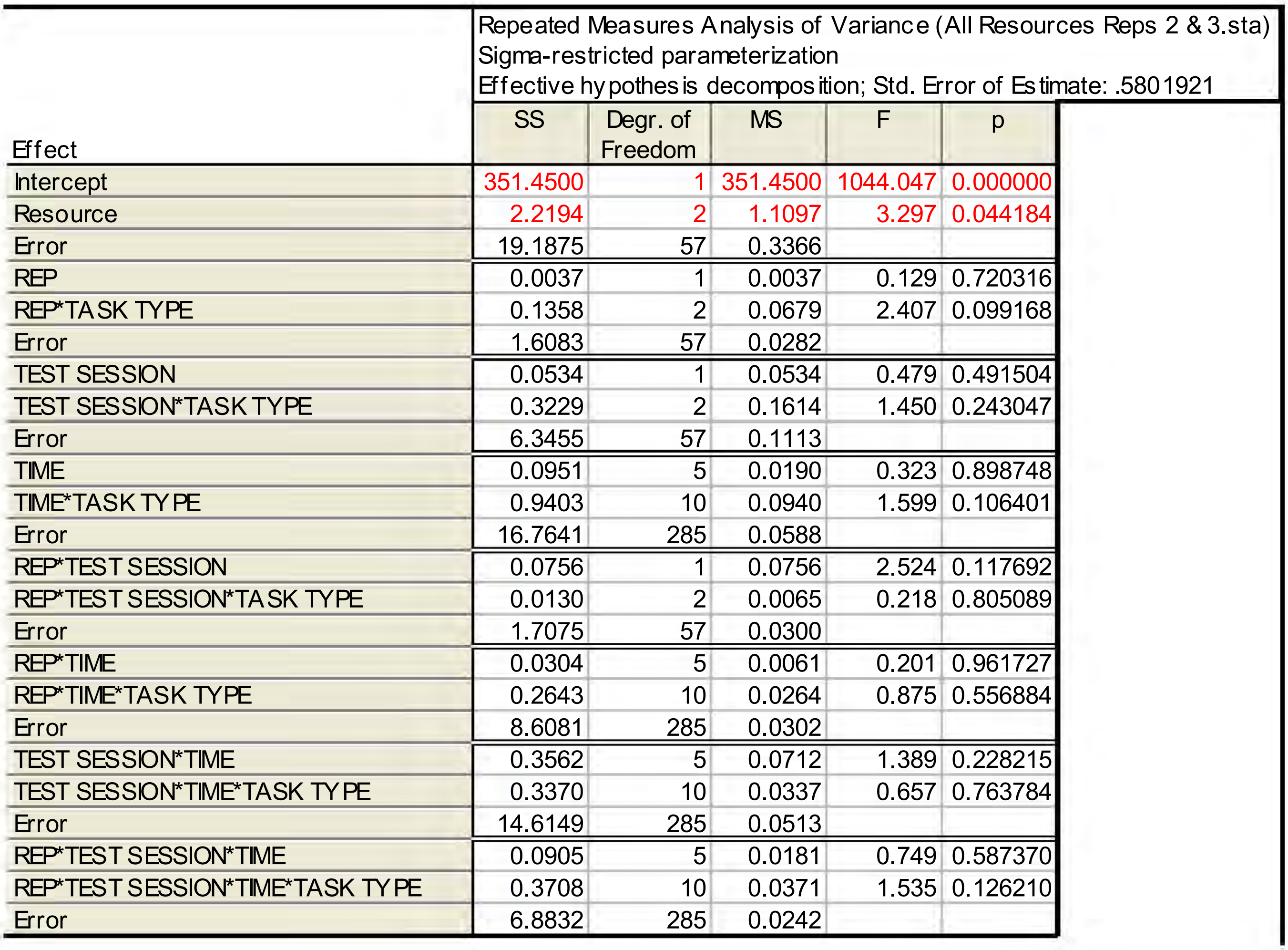
iii. First Simple Reaction Time Repetition during Sensory Task



Repeated Measures Analysis of Variance (Sensory 1 Hour RTTs Rep1 Hab vs Tes
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .7287473

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	171.7629	1	171.7629	323.4264	0.000000
Gender	0.0001	1	0.0001	0.0001	0.992244
Error	9.5593	18	0.5311		
TEST SESSION	0.1838	1	0.1838	0.7139	0.409252
TEST SESSION*Gender	0.2105	1	0.2105	0.8172	0.377936
Error	4.6357	18	0.2575		
TIME	1.8213	5	0.3643	1.0501	0.393453
TIME*Gender	1.7896	5	0.3579	1.0318	0.403878
Error	31.2188	90	0.3469		
TEST SESSION*TIME	2.4576	5	0.4915	1.7346	0.134747
TEST SESSION*TIME*Gender	0.8931	5	0.1786	0.6304	0.677024
Error	25.5031	90	0.2834		

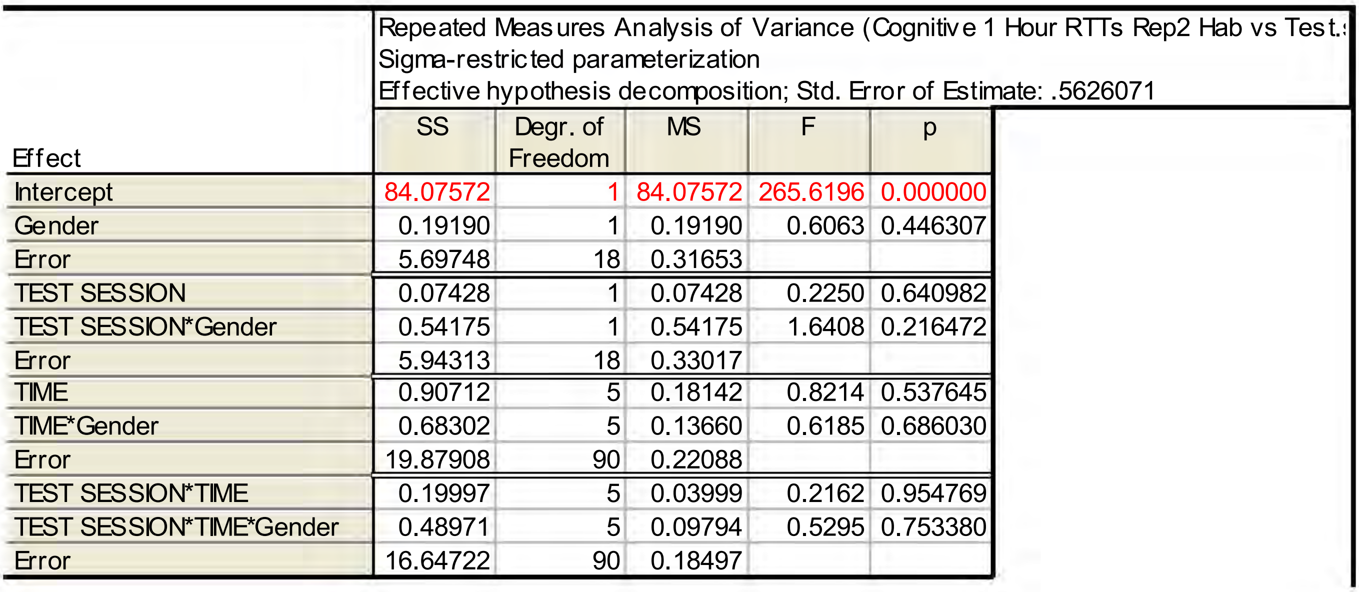
c. Second and Third Simple Reaction Time Repetition



Repeated Measures Analysis of Variance (All Resources Reps 2 & 3.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .5801921

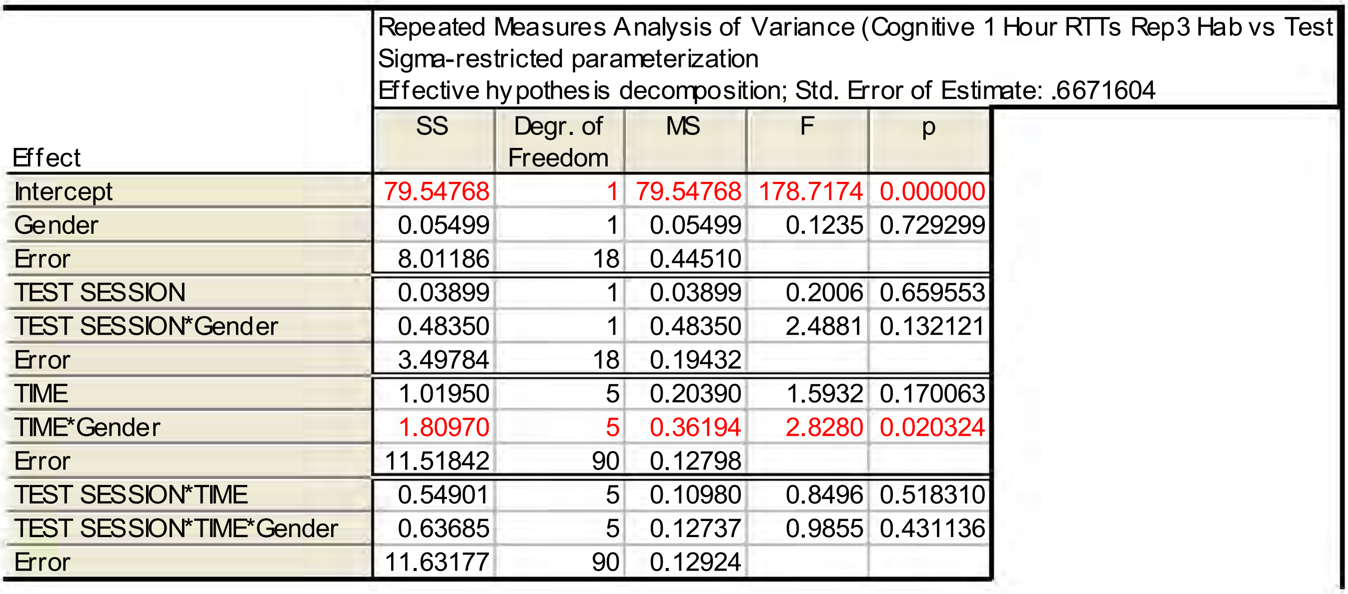
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	351.4500	1	351.4500	1044.047	0.000000
Resource	2.2194	2	1.1097	3.297	0.044184
Error	19.1875	57	0.3366		
REP	0.0037	1	0.0037	0.129	0.720316
REP*TASK TYPE	0.1358	2	0.0679	2.407	0.099168
Error	1.6083	57	0.0282		
TEST SESSION	0.0534	1	0.0534	0.479	0.491504
TEST SESSION*TASK TYPE	0.3229	2	0.1614	1.450	0.243047
Error	6.3455	57	0.1113		
TIME	0.0951	5	0.0190	0.323	0.898748
TIME*TASK TYPE	0.9403	10	0.0940	1.599	0.106401
Error	16.7641	285	0.0588		
REP*TEST SESSION	0.0756	1	0.0756	2.524	0.117692
REP*TEST SESSION*TASK TYPE	0.0130	2	0.0065	0.218	0.805089
Error	1.7075	57	0.0300		
REP*TIME	0.0304	5	0.0061	0.201	0.961727
REP*TIME*TASK TYPE	0.2643	10	0.0264	0.875	0.556884
Error	8.6081	285	0.0302		
TEST SESSION*TIME	0.3562	5	0.0712	1.389	0.228215
TEST SESSION*TIME*TASK TYPE	0.3370	10	0.0337	0.657	0.763784
Error	14.6149	285	0.0513		
REP*TEST SESSION*TIME	0.0905	5	0.0181	0.749	0.587370
REP*TEST SESSION*TIME*TASK TYPE	0.3708	10	0.0371	1.535	0.126210
Error	6.8832	285	0.0242		

b. Second and Third Simple Reaction Time Repetition during Cognitive Task



Repeated Measures Analysis of Variance (Cognitive 1 Hour RTTs Rep2 Hab vs Test.
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .5626071

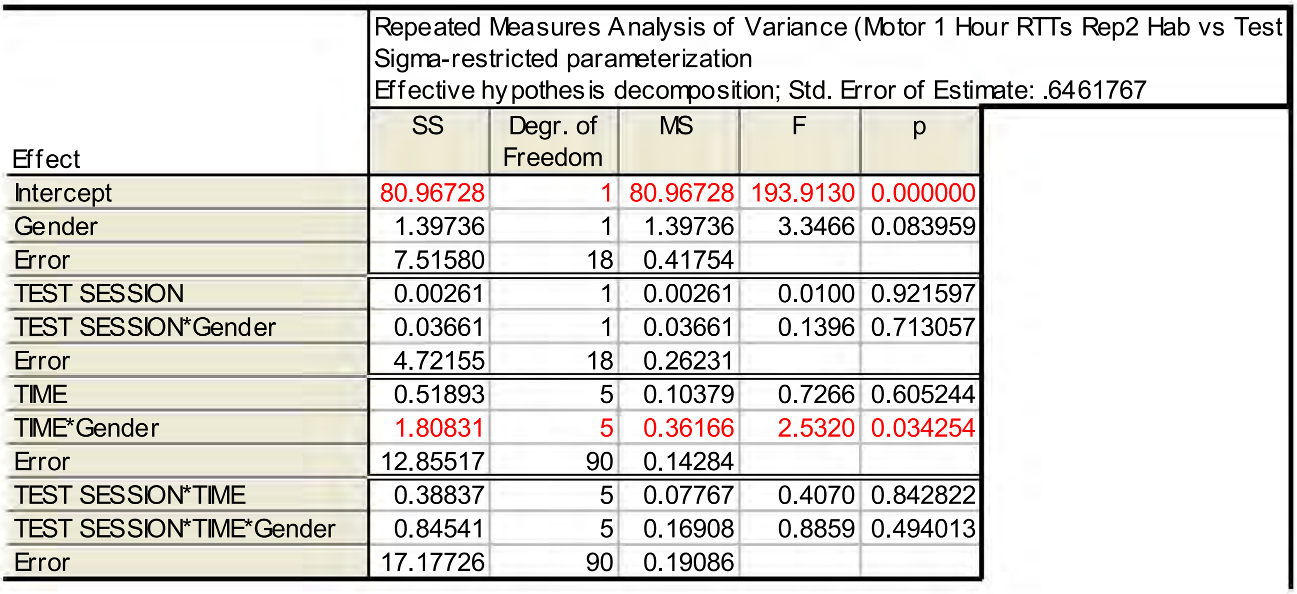
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	84.07572	1	84.07572	265.6196	0.000000
Gender	0.19190	1	0.19190	0.6063	0.446307
Error	5.69748	18	0.31653		
TEST SESSION	0.07428	1	0.07428	0.2250	0.640982
TEST SESSION*Gender	0.54175	1	0.54175	1.6408	0.216472
Error	5.94313	18	0.33017		
TIME	0.90712	5	0.18142	0.8214	0.537645
TIME*Gender	0.68302	5	0.13660	0.6185	0.686030
Error	19.87908	90	0.22088		
TEST SESSION*TIME	0.19997	5	0.03999	0.2162	0.954769
TEST SESSION*TIME*Gender	0.48971	5	0.09794	0.5295	0.753380
Error	16.64722	90	0.18497		



Repeated Measures Analysis of Variance (Cognitive 1 Hour RTTs Rep3 Hab vs Test
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .6671604

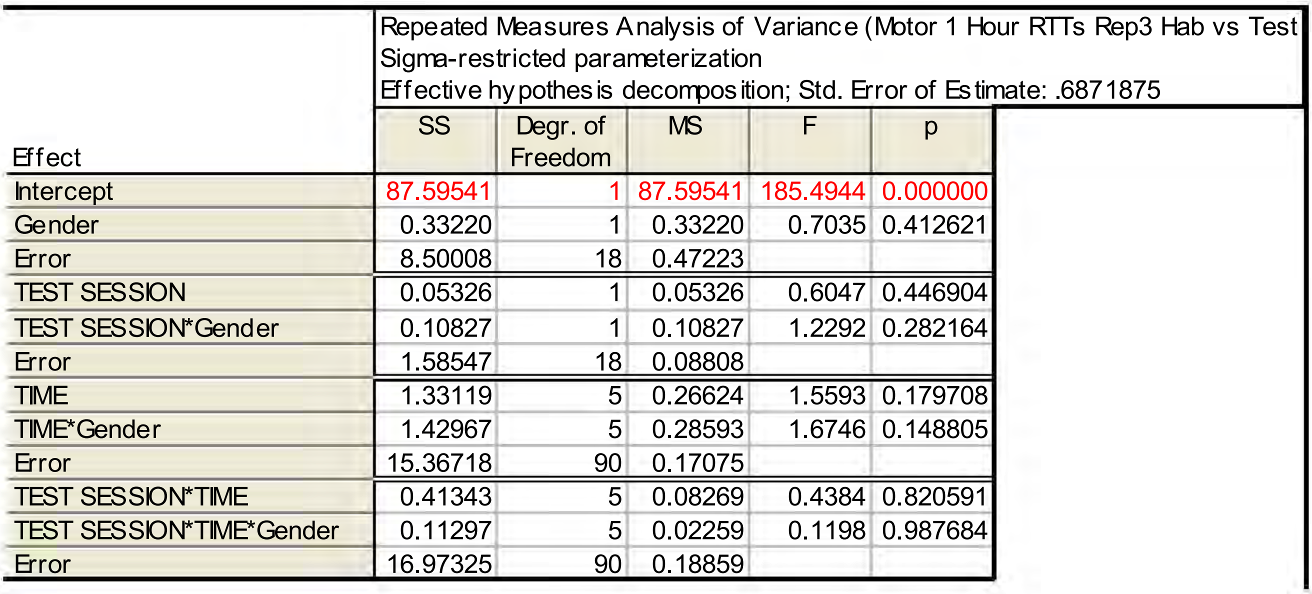
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	79.54768	1	79.54768	178.7174	0.000000
Gender	0.05499	1	0.05499	0.1235	0.729299
Error	8.01186	18	0.44510		
TEST SESSION	0.03899	1	0.03899	0.2006	0.659553
TEST SESSION*Gender	0.48350	1	0.48350	2.4881	0.132121
Error	3.49784	18	0.19432		
TIME	1.01950	5	0.20390	1.5932	0.170063
TIME*Gender	1.80970	5	0.36194	2.8280	0.020324
Error	11.51842	90	0.12798		
TEST SESSION*TIME	0.54901	5	0.10980	0.8496	0.518310
TEST SESSION*TIME*Gender	0.63685	5	0.12737	0.9855	0.431136
Error	11.63177	90	0.12924		

c. Second and Third Simple Reaction Time Repetition during Motor Task



Repeated Measures Analysis of Variance (Motor 1 Hour RTTs Rep2 Hab vs Test
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .6461767

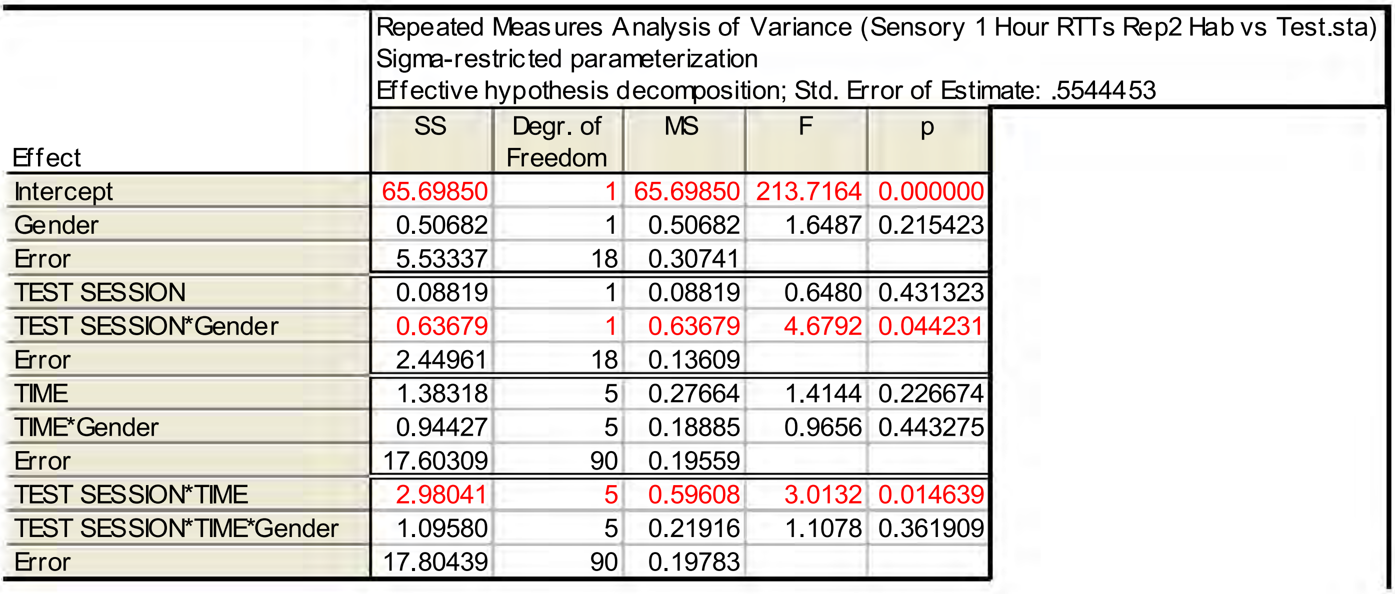
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	80.96728	1	80.96728	193.9130	0.000000
Gender	1.39736	1	1.39736	3.3466	0.083959
Error	7.51580	18	0.41754		
TEST SESSION	0.00261	1	0.00261	0.0100	0.921597
TEST SESSION*Gender	0.03661	1	0.03661	0.1396	0.713057
Error	4.72155	18	0.26231		
TIME	0.51893	5	0.10379	0.7266	0.605244
TIME*Gender	1.80831	5	0.36166	2.5320	0.034254
Error	12.85517	90	0.14284		
TEST SESSION*TIME	0.38837	5	0.07767	0.4070	0.842822
TEST SESSION*TIME*Gender	0.84541	5	0.16908	0.8859	0.494013
Error	17.17726	90	0.19086		



Repeated Measures Analysis of Variance (Motor 1 Hour RTTs Rep3 Hab vs Test
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .6871875

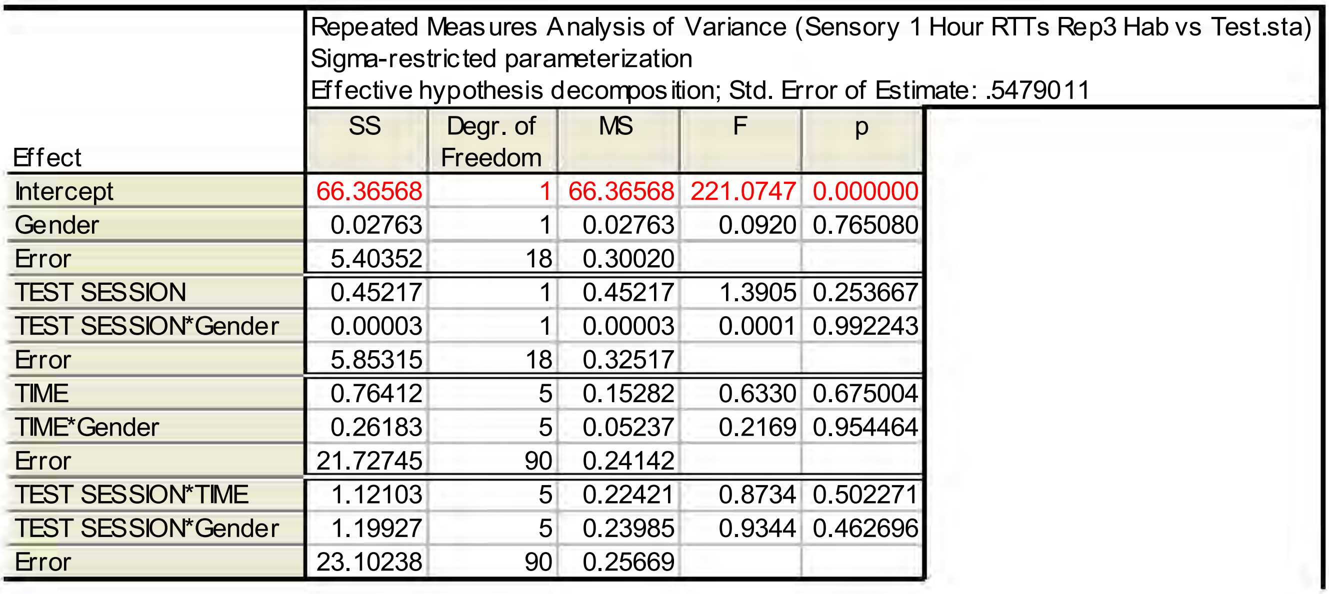
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	87.59541	1	87.59541	185.4944	0.000000
Gender	0.33220	1	0.33220	0.7035	0.412621
Error	8.50008	18	0.47223		
TEST SESSION	0.05326	1	0.05326	0.6047	0.446904
TEST SESSION*Gender	0.10827	1	0.10827	1.2292	0.282164
Error	1.58547	18	0.08808		
TIME	1.33119	5	0.26624	1.5593	0.179708
TIME*Gender	1.42967	5	0.28593	1.6746	0.148805
Error	15.36718	90	0.17075		
TEST SESSION*TIME	0.41343	5	0.08269	0.4384	0.820591
TEST SESSION*TIME*Gender	0.11297	5	0.02259	0.1198	0.987684
Error	16.97325	90	0.18859		

d. Second and Third Simple Reaction Time Repetition during Sensory Task



Repeated Measures Analysis of Variance (Sensory 1 Hour RTTs Rep2 Hab vs Test.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .5544453

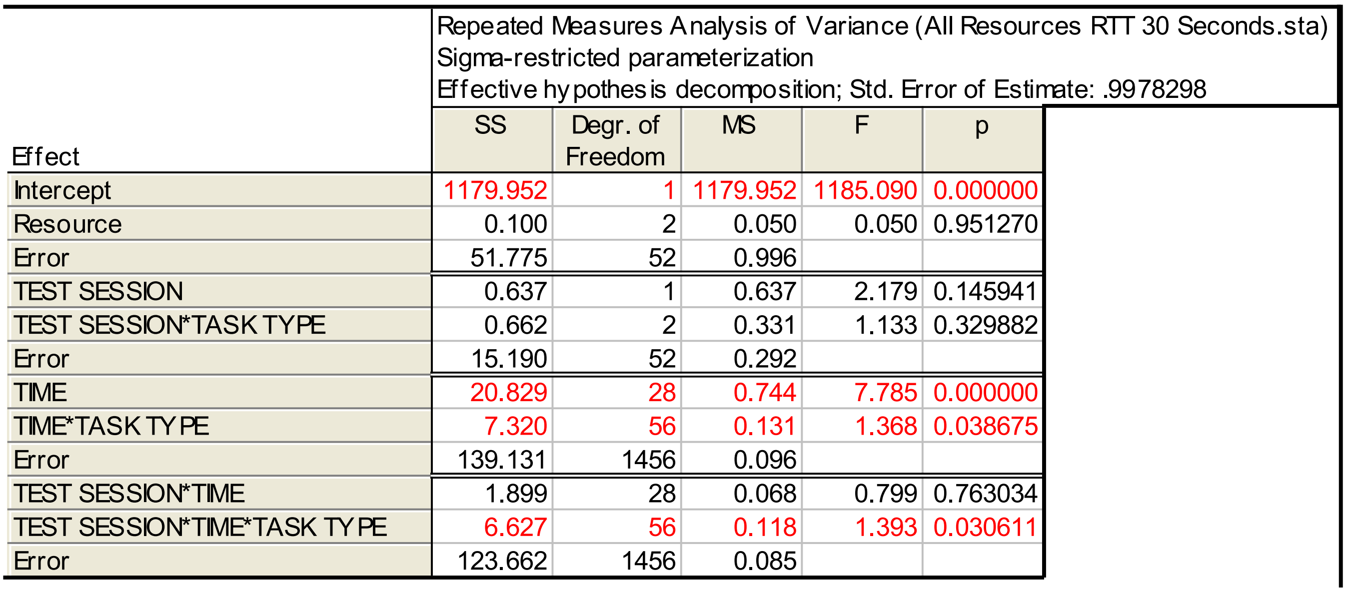
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	65.69850	1	65.69850	213.7164	0.000000
Gender	0.50682	1	0.50682	1.6487	0.215423
Error	5.53337	18	0.30741		
TEST SESSION	0.08819	1	0.08819	0.6480	0.431323
TEST SESSION*Gender	0.63679	1	0.63679	4.6792	0.044231
Error	2.44961	18	0.13609		
TIME	1.38318	5	0.27664	1.4144	0.226674
TIME*Gender	0.94427	5	0.18885	0.9656	0.443275
Error	17.60309	90	0.19559		
TEST SESSION*TIME	2.98041	5	0.59608	3.0132	0.014639
TEST SESSION*TIME*Gender	1.09580	5	0.21916	1.1078	0.361909
Error	17.80439	90	0.19783		



Repeated Measures Analysis of Variance (Sensory 1 Hour RTTs Rep3 Hab vs Test.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .5479011

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	66.36568	1	66.36568	221.0747	0.000000
Gender	0.02763	1	0.02763	0.0920	0.765080
Error	5.40352	18	0.30020		
TEST SESSION	0.45217	1	0.45217	1.3905	0.253667
TEST SESSION*Gender	0.00003	1	0.00003	0.0001	0.992243
Error	5.85315	18	0.32517		
TIME	0.76412	5	0.15282	0.6330	0.675004
TIME*Gender	0.26183	5	0.05237	0.2169	0.954464
Error	21.72745	90	0.24142		
TEST SESSION*TIME	1.12103	5	0.22421	0.8734	0.502271
TEST SESSION*Gender	1.19927	5	0.23985	0.9344	0.462696
Error	23.10238	90	0.25669		

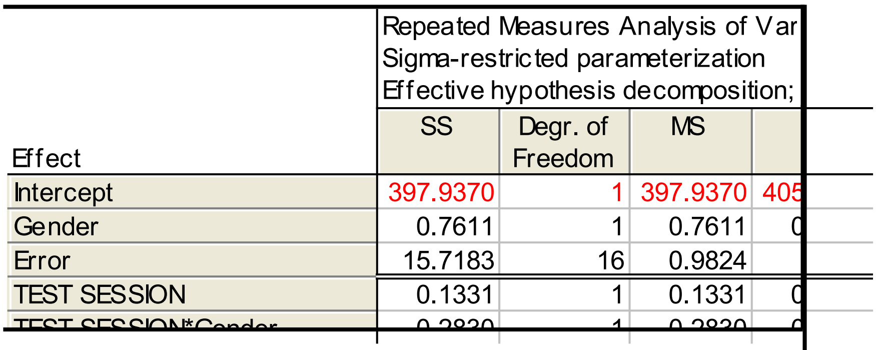
d. General Effects for Reaction Time Test Responses during recovery period



Repeated Measures Analysis of Variance (All Resources RTT 30 Seconds.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .9978298

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1179.952	1	1179.952	1185.090	0.000000
Resource	0.100	2	0.050	0.050	0.951270
Error	51.775	52	0.996		
TEST SESSION	0.637	1	0.637	2.179	0.145941
TEST SESSION*TASK TYPE	0.662	2	0.331	1.133	0.329882
Error	15.190	52	0.292		
TIME	20.829	28	0.744	7.785	0.000000
TIME*TASK TYPE	7.320	56	0.131	1.368	0.038675
Error	139.131	1456	0.096		
TEST SESSION*TIME	1.899	28	0.068	0.799	0.763034
TEST SESSION*TIME*TASK TYPE	6.627	56	0.118	1.393	0.030611
Error	123.662	1456	0.085		

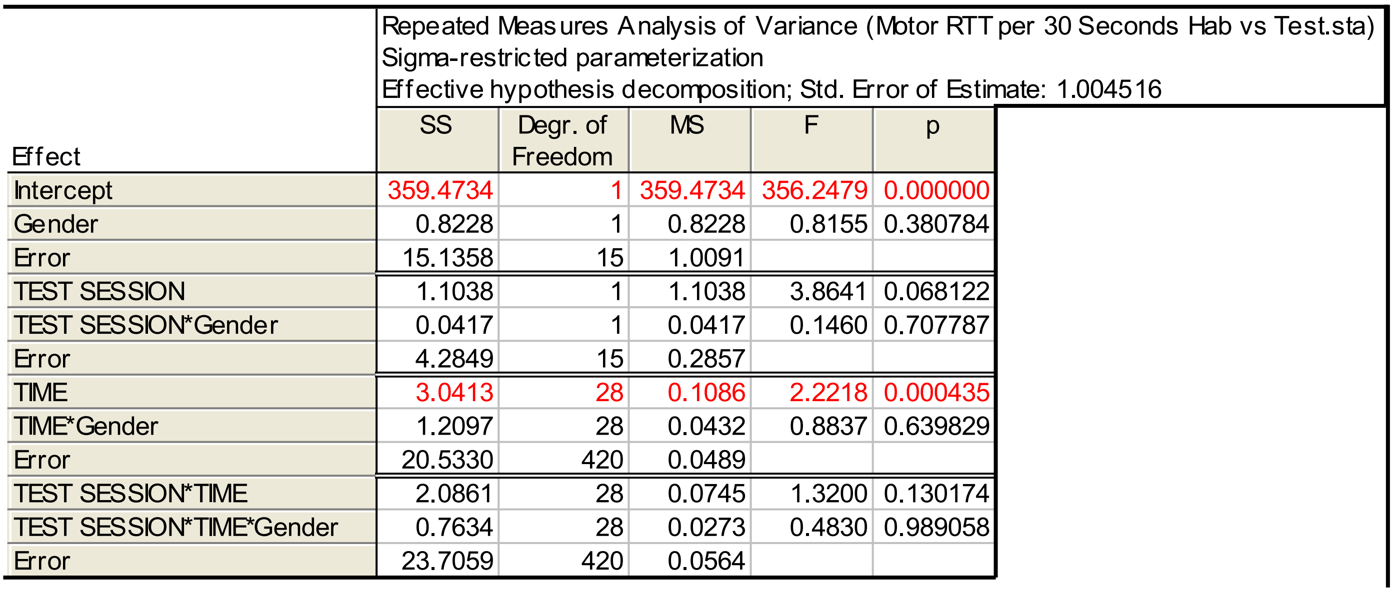
e. Recovery responses during the Cognitive Tasks



Repeated Measures Analysis of Var
Sigma-restricted parameterization
Effective hypothesis decomposition;

Effect	SS	Degr. of Freedom	MS	
Intercept	397.9370	1	397.9370	405
Gender	0.7611	1	0.7611	0
Error	15.7183	16	0.9824	
TEST SESSION	0.1331	1	0.1331	0
TEST SESSION*Gender	0.2830	1	0.2830	0

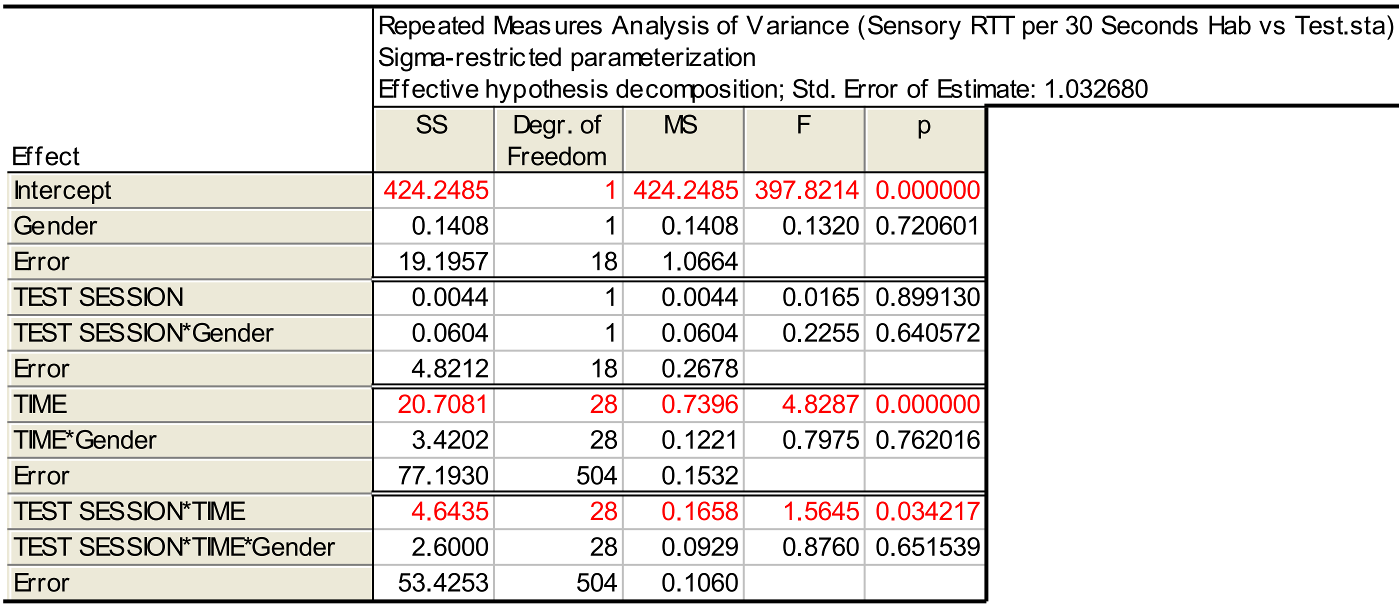
f. Recovery responses during the Motor Tasks



Repeated Measures Analysis of Variance (Motor RTT per 30 Seconds Hab vs Test.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 1.004516

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	359.4734	1	359.4734	356.2479	0.000000
Gender	0.8228	1	0.8228	0.8155	0.380784
Error	15.1358	15	1.0091		
TEST SESSION	1.1038	1	1.1038	3.8641	0.068122
TEST SESSION*Gender	0.0417	1	0.0417	0.1460	0.707787
Error	4.2849	15	0.2857		
TIME	3.0413	28	0.1086	2.2218	0.000435
TIME*Gender	1.2097	28	0.0432	0.8837	0.639829
Error	20.5330	420	0.0489		
TEST SESSION*TIME	2.0861	28	0.0745	1.3200	0.130174
TEST SESSION*TIME*Gender	0.7634	28	0.0273	0.4830	0.989058
Error	23.7059	420	0.0564		

g. Recovery responses during the Sensory Tasks

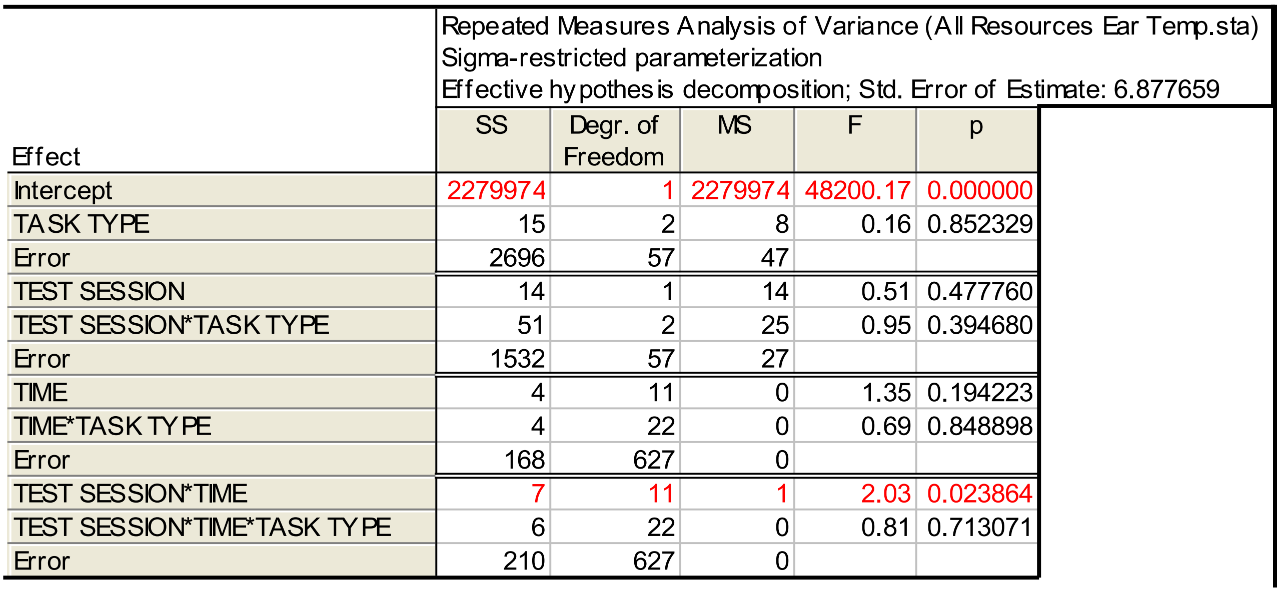


Repeated Measures Analysis of Variance (Sensory RTT per 30 Seconds Hab vs Test.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 1.032680

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	424.2485	1	424.2485	397.8214	0.000000
Gender	0.1408	1	0.1408	0.1320	0.720601
Error	19.1957	18	1.0664		
TEST SESSION	0.0044	1	0.0044	0.0165	0.899130
TEST SESSION*Gender	0.0604	1	0.0604	0.2255	0.640572
Error	4.8212	18	0.2678		
TIME	20.7081	28	0.7396	4.8287	0.000000
TIME*Gender	3.4202	28	0.1221	0.7975	0.762016
Error	77.1930	504	0.1532		
TEST SESSION*TIME	4.6435	28	0.1658	1.5645	0.034217
TEST SESSION*TIME*Gender	2.6000	28	0.0929	0.8760	0.651539
Error	53.4253	504	0.1060		

1. Temperature Parameters

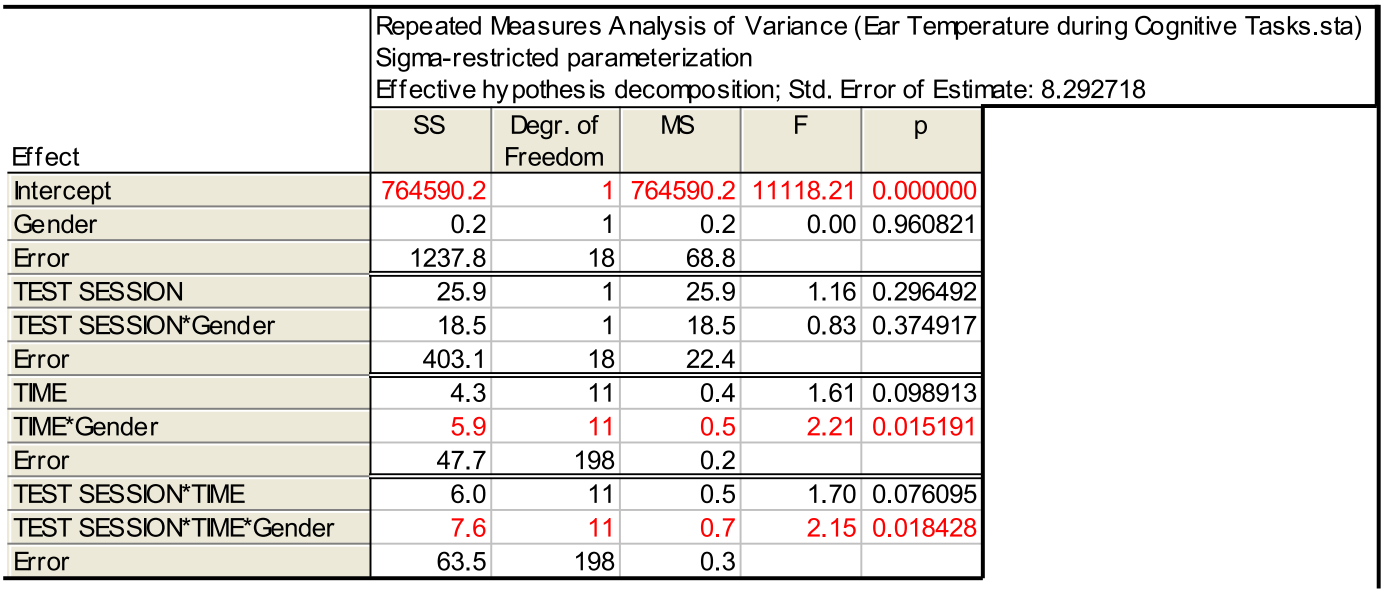
a. General Ear Temperature Effects



Repeated Measures Analysis of Variance (All Resources Ear Temp.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 6.877659

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2279974	1	2279974	48200.17	0.000000
TASK TYPE	15	2	8	0.16	0.852329
Error	2696	57	47		
TEST SESSION	14	1	14	0.51	0.477760
TEST SESSION*TASK TYPE	51	2	25	0.95	0.394680
Error	1532	57	27		
TIME	4	11	0	1.35	0.194223
TIME*TASK TYPE	4	22	0	0.69	0.848898
Error	168	627	0		
TEST SESSION*TIME	7	11	1	2.03	0.023864
TEST SESSION*TIME*TASK TYPE	6	22	0	0.81	0.713071
Error	210	627	0		

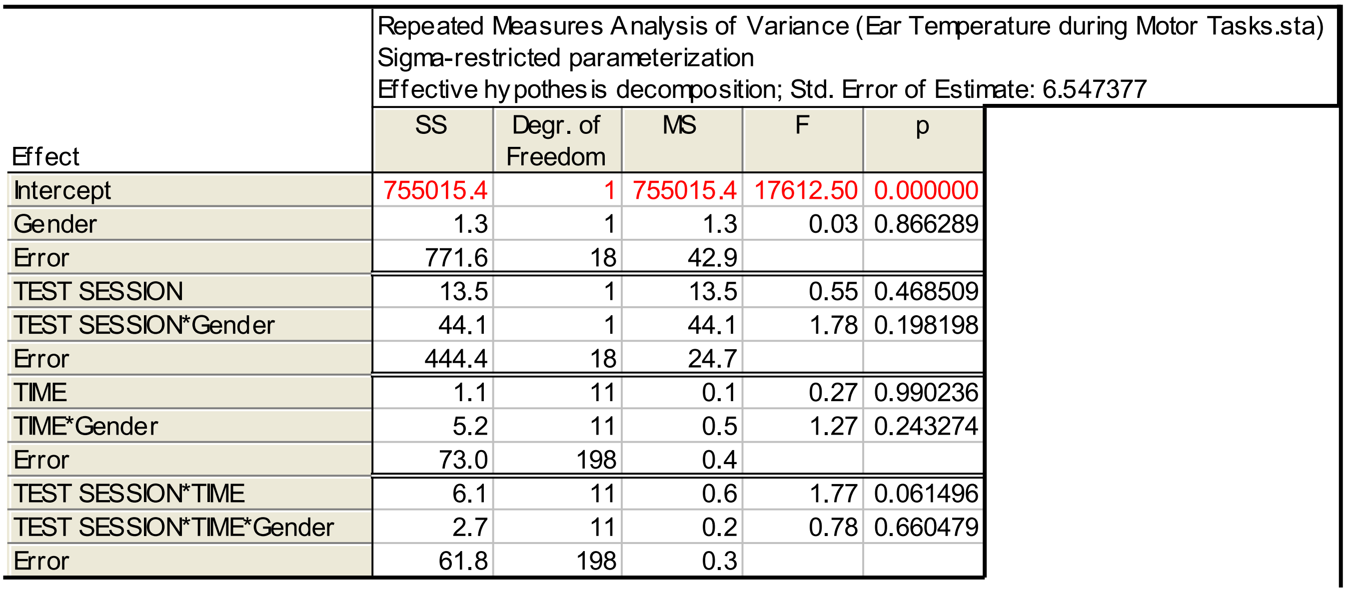
b. Ear Temperature Effects during Cognitive Task



Repeated Measures Analysis of Variance (Ear Temperature during Cognitive Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 8.292718

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	764590.2	1	764590.2	11118.21	0.000000
Gender	0.2	1	0.2	0.00	0.960821
Error	1237.8	18	68.8		
TEST SESSION	25.9	1	25.9	1.16	0.296492
TEST SESSION*Gender	18.5	1	18.5	0.83	0.374917
Error	403.1	18	22.4		
TIME	4.3	11	0.4	1.61	0.098913
TIME*Gender	5.9	11	0.5	2.21	0.015191
Error	47.7	198	0.2		
TEST SESSION*TIME	6.0	11	0.5	1.70	0.076095
TEST SESSION*TIME*Gender	7.6	11	0.7	2.15	0.018428
Error	63.5	198	0.3		

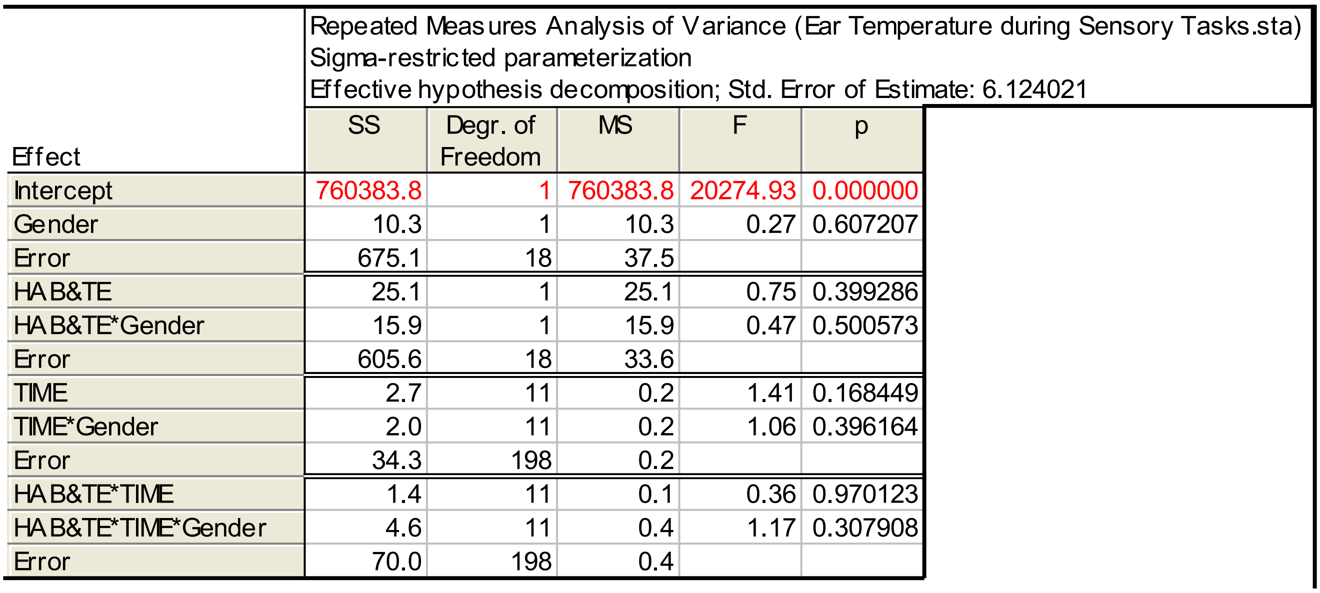
c. Ear Temperature Effects during Motor Task



Repeated Measures Analysis of Variance (Ear Temperature during Motor Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 6.547377

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	755015.4	1	755015.4	17612.50	0.000000
Gender	1.3	1	1.3	0.03	0.866289
Error	771.6	18	42.9		
TEST SESSION	13.5	1	13.5	0.55	0.468509
TEST SESSION*Gender	44.1	1	44.1	1.78	0.198198
Error	444.4	18	24.7		
TIME	1.1	11	0.1	0.27	0.990236
TIME*Gender	5.2	11	0.5	1.27	0.243274
Error	73.0	198	0.4		
TEST SESSION*TIME	6.1	11	0.6	1.77	0.061496
TEST SESSION*TIME*Gender	2.7	11	0.2	0.78	0.660479
Error	61.8	198	0.3		

d. Ear Temperature Effects during Sensory Task



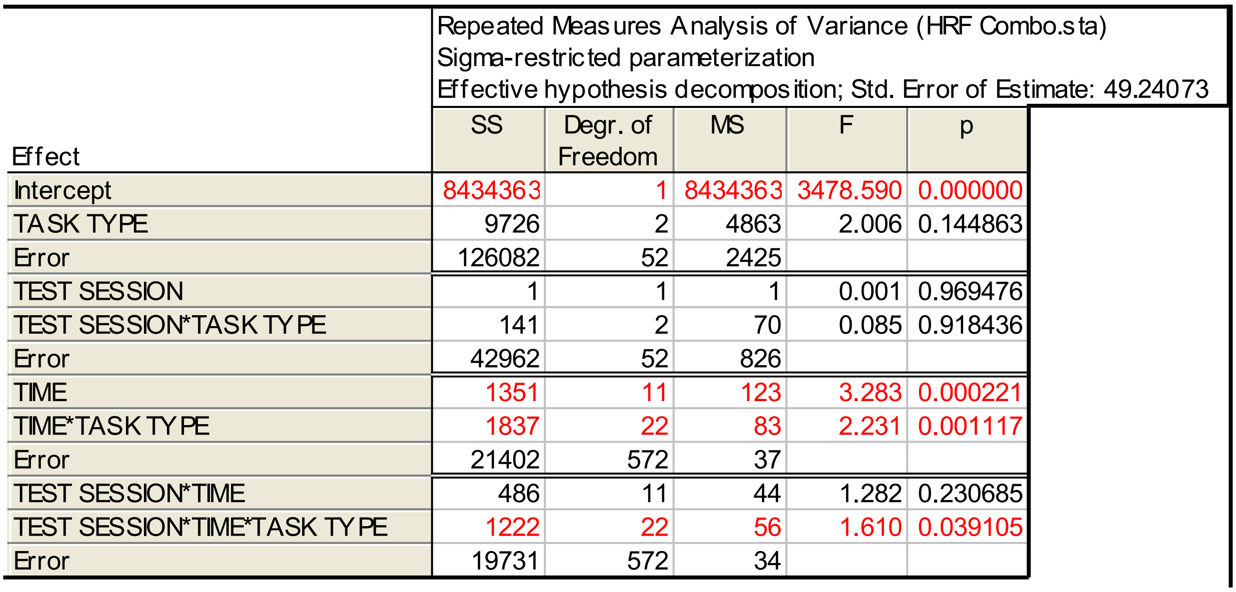
Repeated Measures Analysis of Variance (Ear Temperature during Sensory Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 6.124021

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	760383.8	1	760383.8	20274.93	0.000000
Gender	10.3	1	10.3	0.27	0.607207
Error	675.1	18	37.5		
HAB&TE	25.1	1	25.1	0.75	0.399286
HAB&TE*Gender	15.9	1	15.9	0.47	0.500573
Error	605.6	18	33.6		
TIME	2.7	11	0.2	1.41	0.168449
TIME*Gender	2.0	11	0.2	1.06	0.396164
Error	34.3	198	0.2		
HAB&TE*TIME	1.4	11	0.1	0.36	0.970123
HAB&TE*TIME*Gender	4.6	11	0.4	1.17	0.307908
Error	70.0	198	0.4		

2. Cardiovascular Parameters

a. Heart Rate Frequency

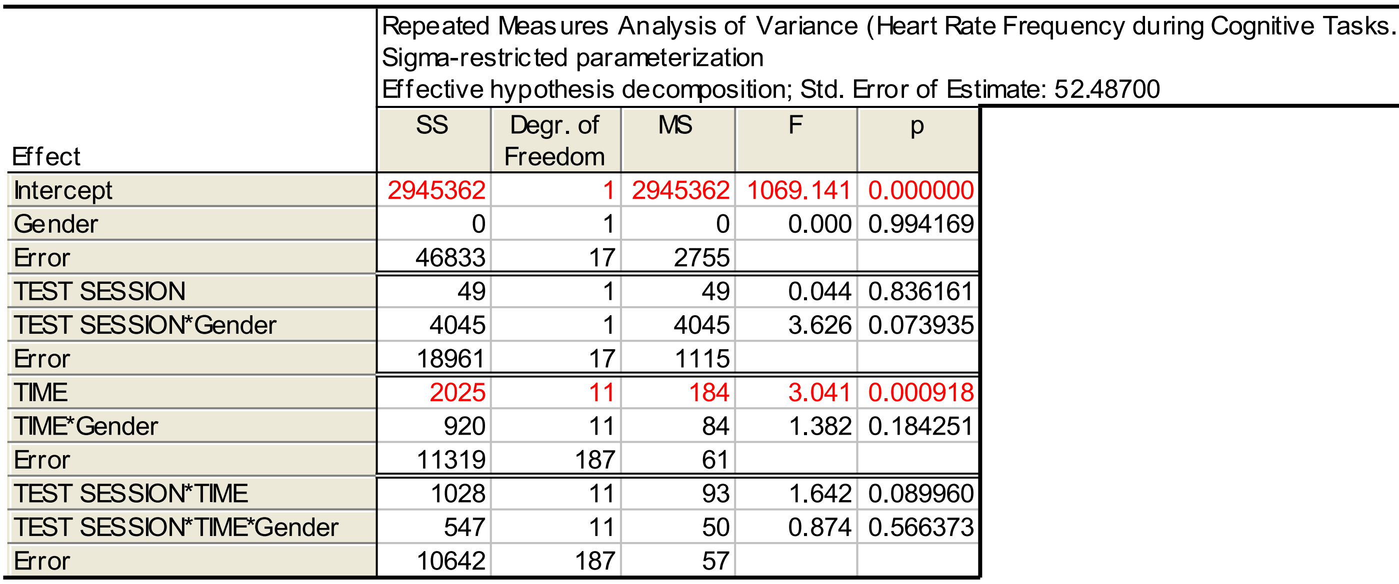
i. General Heart Rate Frequency Effects



Repeated Measures Analysis of Variance (HRF Combo.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 49.24073

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	8434363	1	8434363	3478.590	0.000000
TASK TYPE	9726	2	4863	2.006	0.144863
Error	126082	52	2425		
TEST SESSION	1	1	1	0.001	0.969476
TEST SESSION*TASK TYPE	141	2	70	0.085	0.918436
Error	42962	52	826		
TIME	1351	11	123	3.283	0.000221
TIME*TASK TYPE	1837	22	83	2.231	0.001117
Error	21402	572	37		
TEST SESSION*TIME	486	11	44	1.282	0.230685
TEST SESSION*TIME*TASK TYPE	1222	22	56	1.610	0.039105
Error	19731	572	34		

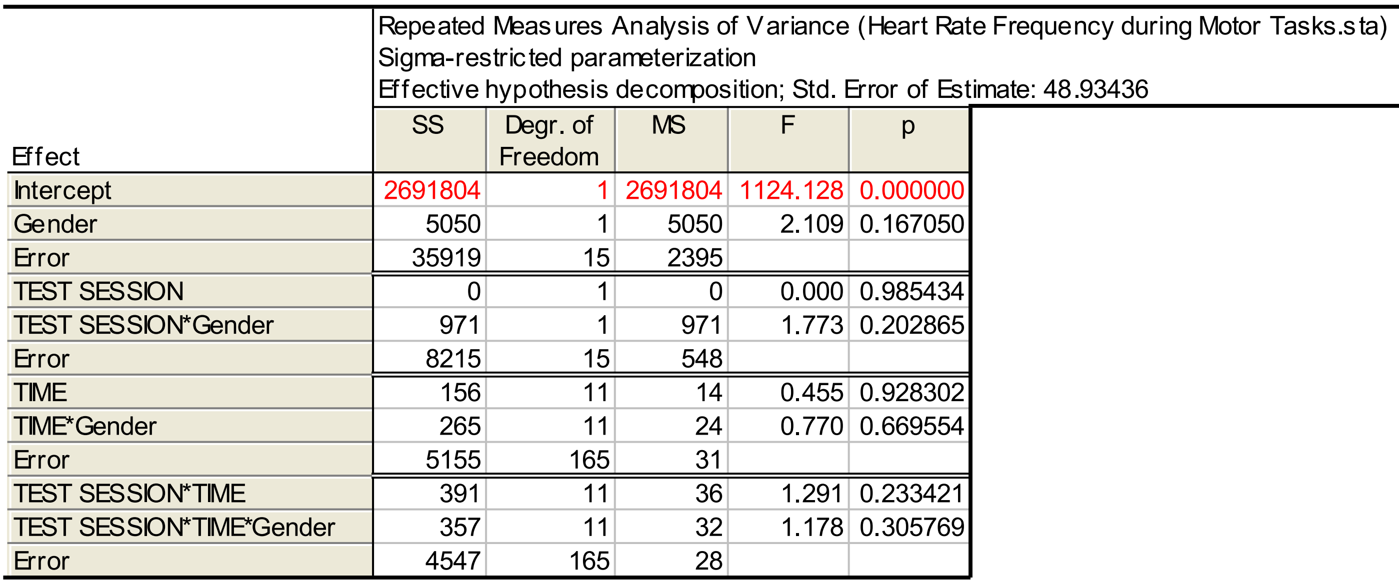
ii. Heart Rate Frequency Effects during Cognitive Task



Repeated Measures Analysis of Variance (Heart Rate Frequency during Cognitive Tasks.
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 52.48700

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2945362	1	2945362	1069.141	0.000000
Gender	0	1	0	0.000	0.994169
Error	46833	17	2755		
TEST SESSION	49	1	49	0.044	0.836161
TEST SESSION*Gender	4045	1	4045	3.626	0.073935
Error	18961	17	1115		
TIME	2025	11	184	3.041	0.000918
TIME*Gender	920	11	84	1.382	0.184251
Error	11319	187	61		
TEST SESSION*TIME	1028	11	93	1.642	0.089960
TEST SESSION*TIME*Gender	547	11	50	0.874	0.566373
Error	10642	187	57		

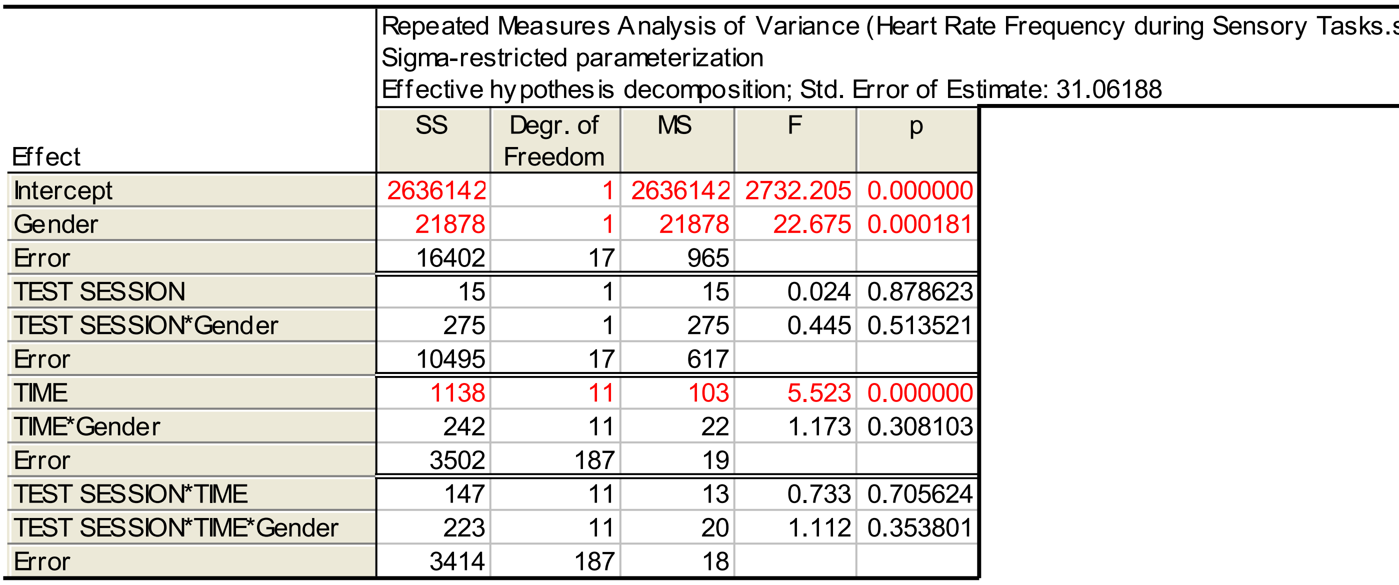
iii. Heart Rate Frequency Effects during Motor Task



Repeated Measures Analysis of Variance (Heart Rate Frequency during Motor Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 48.93436

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2691804	1	2691804	1124.128	0.000000
Gender	5050	1	5050	2.109	0.167050
Error	35919	15	2395		
TEST SESSION	0	1	0	0.000	0.985434
TEST SESSION*Gender	971	1	971	1.773	0.202865
Error	8215	15	548		
TIME	156	11	14	0.455	0.928302
TIME*Gender	265	11	24	0.770	0.669554
Error	5155	165	31		
TEST SESSION*TIME	391	11	36	1.291	0.233421
TEST SESSION*TIME*Gender	357	11	32	1.178	0.305769
Error	4547	165	28		

iv. Heart Rate Frequency Effects during Sensory Task

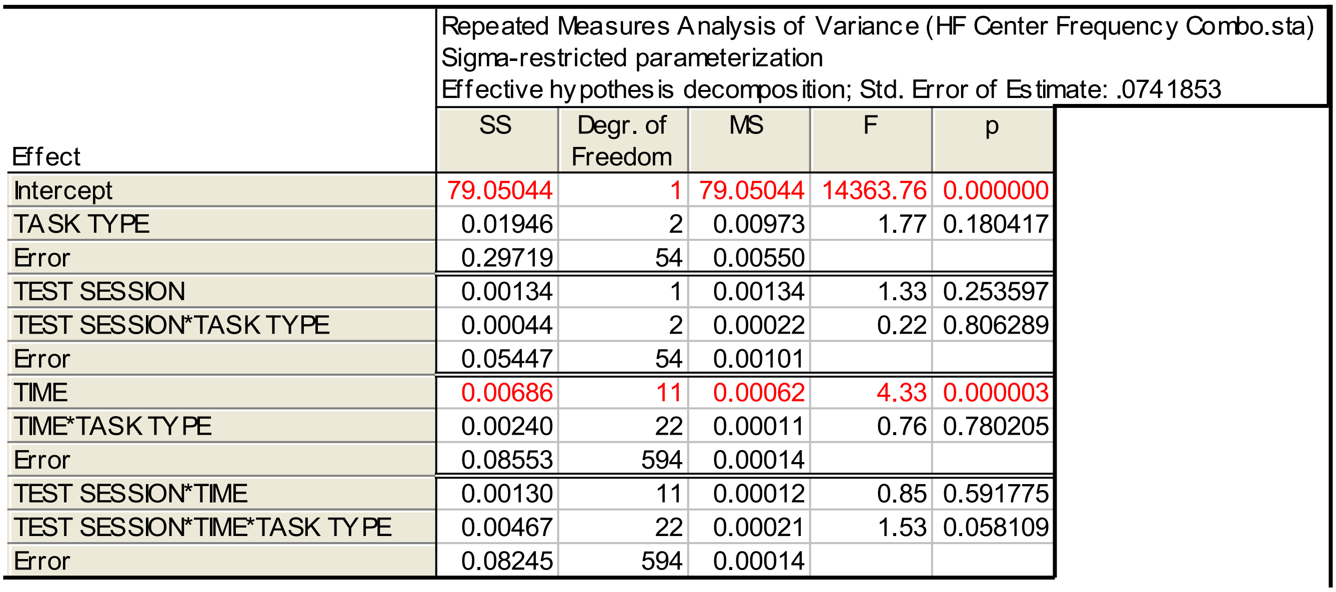


Repeated Measures Analysis of Variance (Heart Rate Frequency during Sensory Tasks.s
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 31.06188

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2636142	1	2636142	2732.205	0.000000
Gender	21878	1	21878	22.675	0.000181
Error	16402	17	965		
TEST SESSION	15	1	15	0.024	0.878623
TEST SESSION*Gender	275	1	275	0.445	0.513521
Error	10495	17	617		
TIME	1138	11	103	5.523	0.000000
TIME*Gender	242	11	22	1.173	0.308103
Error	3502	187	19		
TEST SESSION*TIME	147	11	13	0.733	0.705624
TEST SESSION*TIME*Gender	223	11	20	1.112	0.353801
Error	3414	187	18		

b. High Frequency Centre Frequency

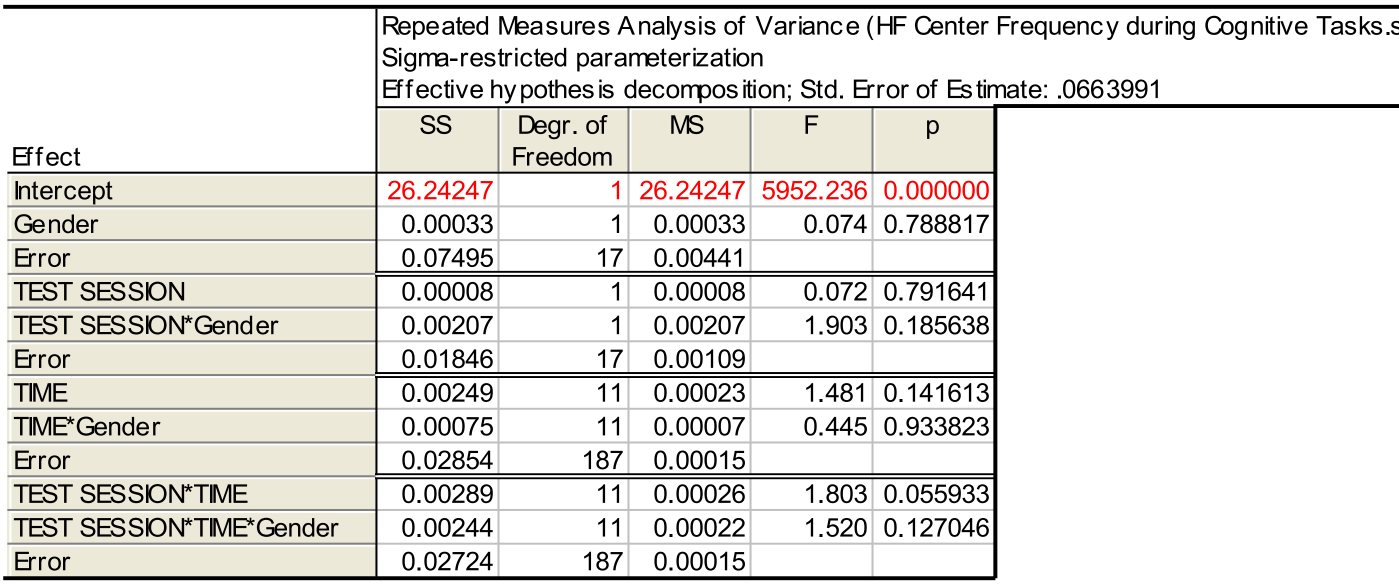
i. General High Frequency Centre Frequency Effects



Repeated Measures Analysis of Variance (HF Center Frequency Combo.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .0741853

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	79.05044	1	79.05044	14363.76	0.000000
TASK TYPE	0.01946	2	0.00973	1.77	0.180417
Error	0.29719	54	0.00550		
TEST SESSION	0.00134	1	0.00134	1.33	0.253597
TEST SESSION*TASK TYPE	0.00044	2	0.00022	0.22	0.806289
Error	0.05447	54	0.00101		
TIME	0.00686	11	0.00062	4.33	0.000003
TIME*TASK TYPE	0.00240	22	0.00011	0.76	0.780205
Error	0.08553	594	0.00014		
TEST SESSION*TIME	0.00130	11	0.00012	0.85	0.591775
TEST SESSION*TIME*TASK TYPE	0.00467	22	0.00021	1.53	0.058109
Error	0.08245	594	0.00014		

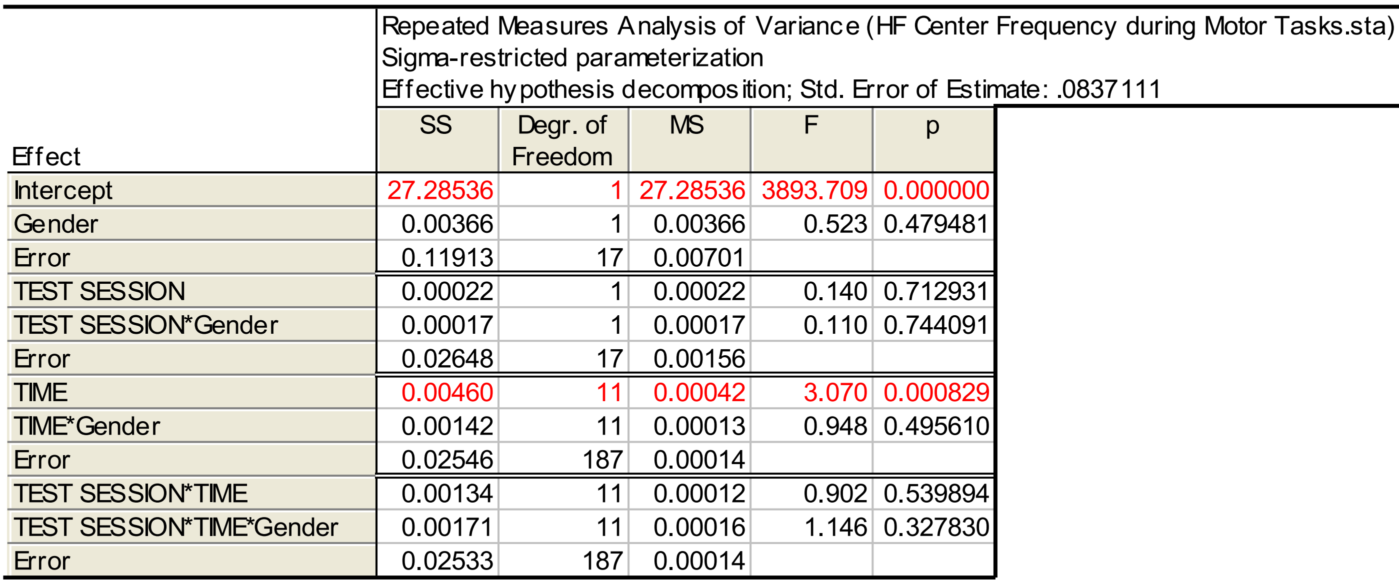
ii. High Frequency Centre Frequency Effects during Cognitive Task



Repeated Measures Analysis of Variance (HF Center Frequency during Cognitive Tasks.s
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .0663991

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	26.24247	1	26.24247	5952.236	0.000000
Gender	0.00033	1	0.00033	0.074	0.788817
Error	0.07495	17	0.00441		
TEST SESSION	0.00008	1	0.00008	0.072	0.791641
TEST SESSION*Gender	0.00207	1	0.00207	1.903	0.185638
Error	0.01846	17	0.00109		
TIME	0.00249	11	0.00023	1.481	0.141613
TIME*Gender	0.00075	11	0.00007	0.445	0.933823
Error	0.02854	187	0.00015		
TEST SESSION*TIME	0.00289	11	0.00026	1.803	0.055933
TEST SESSION*TIME*Gender	0.00244	11	0.00022	1.520	0.127046
Error	0.02724	187	0.00015		

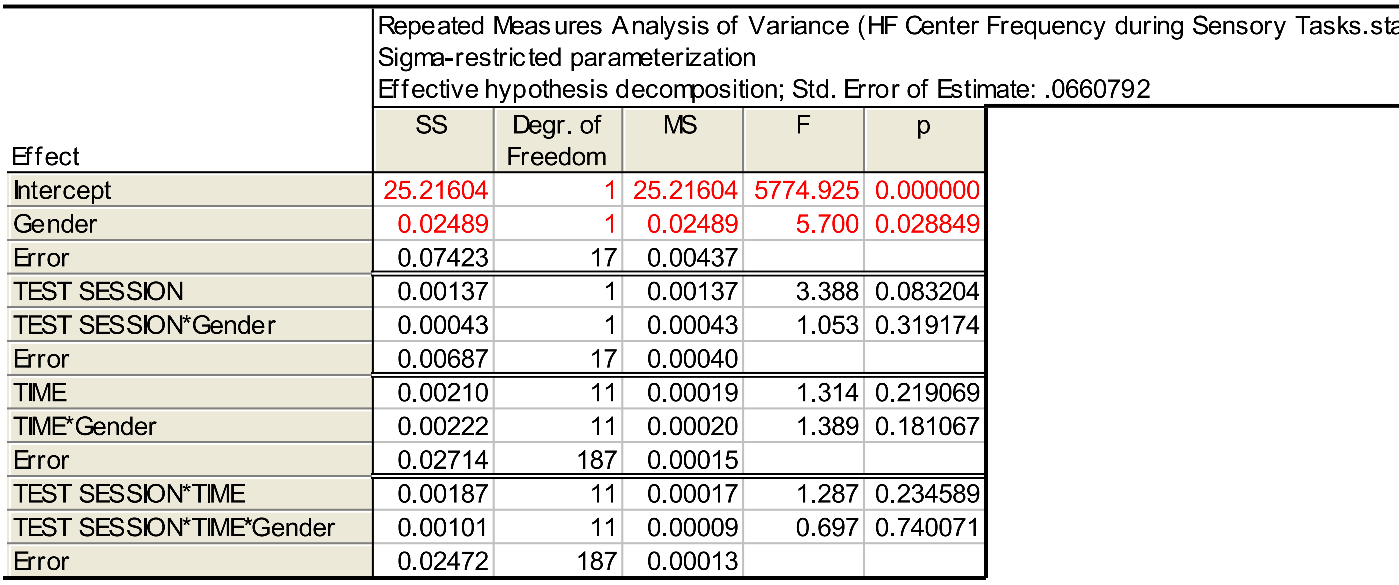
iii. High Frequency Centre Frequency Effects during Motor Task



Repeated Measures Analysis of Variance (HF Center Frequency during Motor Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .0837111

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	27.28536	1	27.28536	3893.709	0.000000
Gender	0.00366	1	0.00366	0.523	0.479481
Error	0.11913	17	0.00701		
TEST SESSION	0.00022	1	0.00022	0.140	0.712931
TEST SESSION*Gender	0.00017	1	0.00017	0.110	0.744091
Error	0.02648	17	0.00156		
TIME	0.00460	11	0.00042	3.070	0.000829
TIME*Gender	0.00142	11	0.00013	0.948	0.495610
Error	0.02546	187	0.00014		
TEST SESSION*TIME	0.00134	11	0.00012	0.902	0.539894
TEST SESSION*TIME*Gender	0.00171	11	0.00016	1.146	0.327830
Error	0.02533	187	0.00014		

iv. High Frequency Centre Frequency Effects during Sensory Task

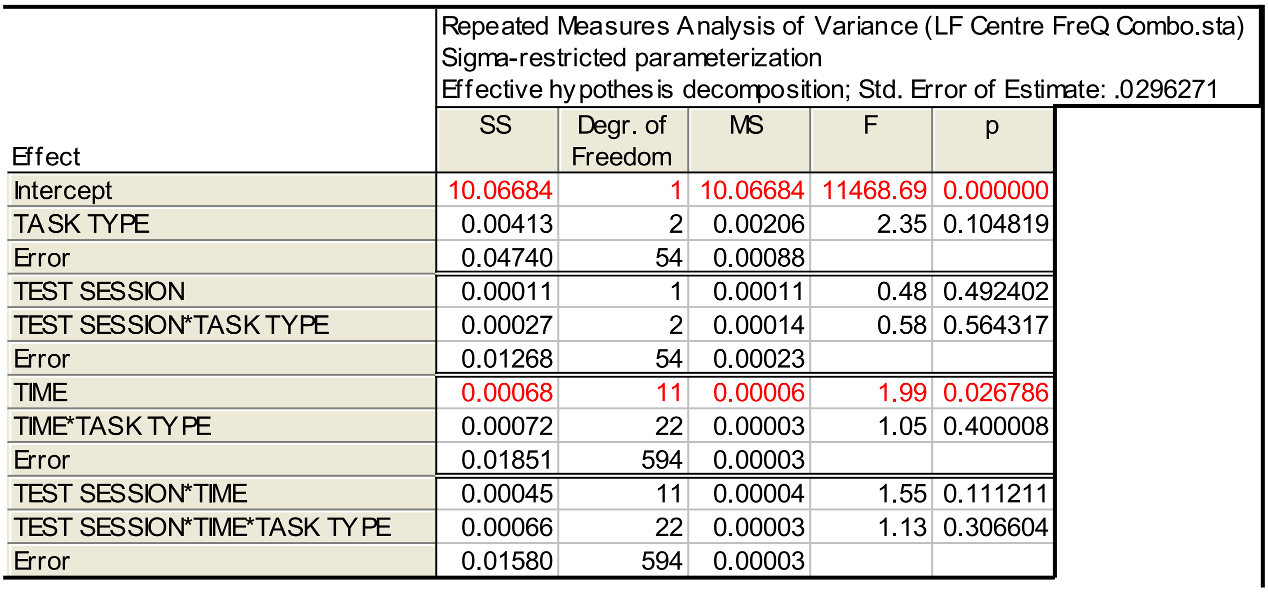


Repeated Measures Analysis of Variance (HF Center Frequency during Sensory Tasks.sta
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .0660792

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	25.21604	1	25.21604	5774.925	0.000000
Gender	0.02489	1	0.02489	5.700	0.028849
Error	0.07423	17	0.00437		
TEST SESSION	0.00137	1	0.00137	3.388	0.083204
TEST SESSION*Gender	0.00043	1	0.00043	1.053	0.319174
Error	0.00687	17	0.00040		
TIME	0.00210	11	0.00019	1.314	0.219069
TIME*Gender	0.00222	11	0.00020	1.389	0.181067
Error	0.02714	187	0.00015		
TEST SESSION*TIME	0.00187	11	0.00017	1.287	0.234589
TEST SESSION*TIME*Gender	0.00101	11	0.00009	0.697	0.740071
Error	0.02472	187	0.00013		

c. Low Frequency Centre Frequency

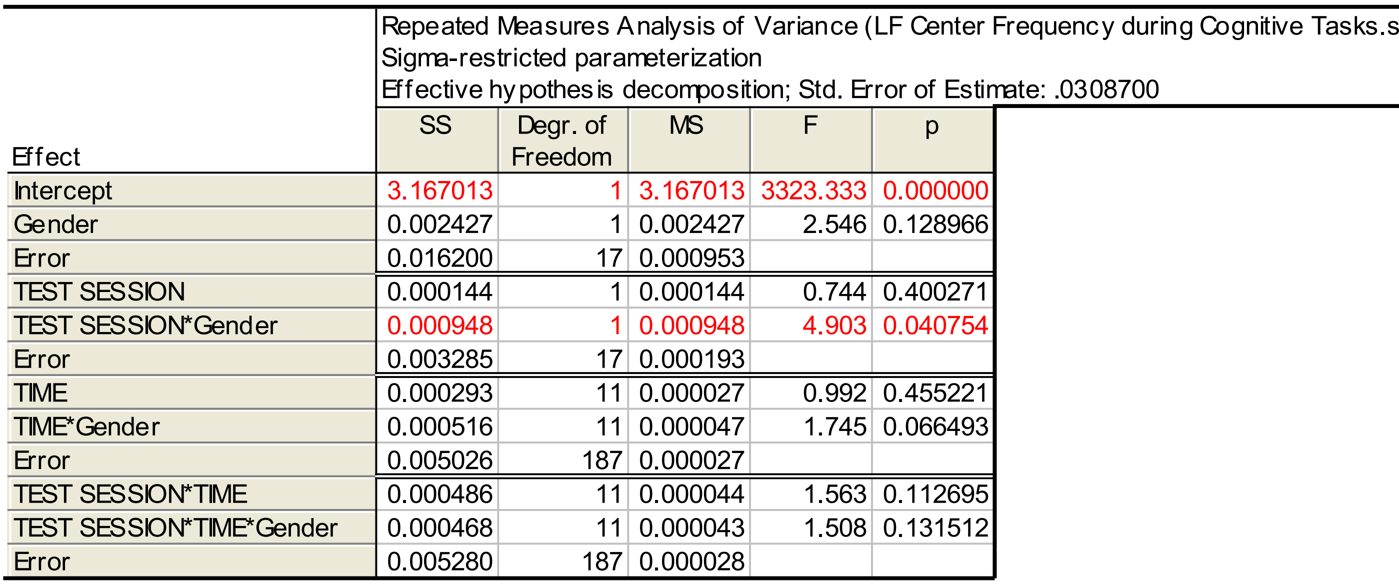
i. General Low Frequency Centre Frequency Effects



Repeated Measures Analysis of Variance (LF Centre FreQ Combo.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .0296271

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	10.06684	1	10.06684	11468.69	0.000000
TASK TYPE	0.00413	2	0.00206	2.35	0.104819
Error	0.04740	54	0.00088		
TEST SESSION	0.00011	1	0.00011	0.48	0.492402
TEST SESSION*TASK TYPE	0.00027	2	0.00014	0.58	0.564317
Error	0.01268	54	0.00023		
TIME	0.00068	11	0.00006	1.99	0.026786
TIME*TASK TYPE	0.00072	22	0.00003	1.05	0.400008
Error	0.01851	594	0.00003		
TEST SESSION*TIME	0.00045	11	0.00004	1.55	0.111211
TEST SESSION*TIME*TASK TYPE	0.00066	22	0.00003	1.13	0.306604
Error	0.01580	594	0.00003		

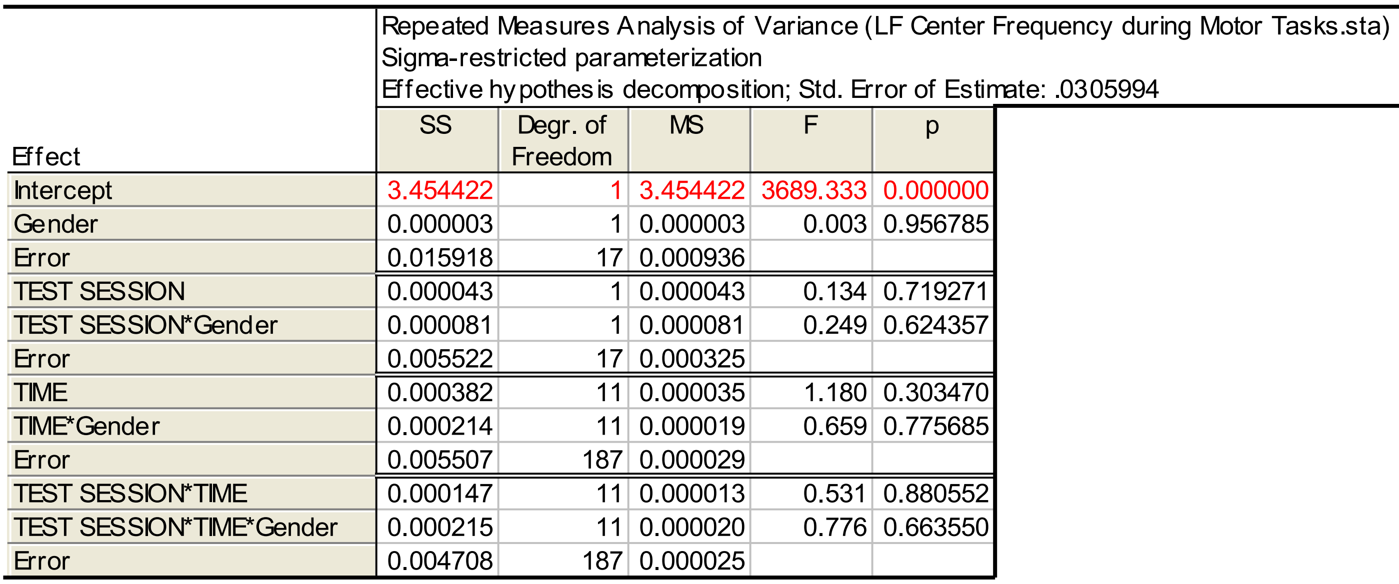
ii. Low Frequency Centre Frequency Effects during Cognitive Task



Repeated Measures Analysis of Variance (LF Center Frequency during Cognitive Tasks.s
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .0308700

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	3.167013	1	3.167013	3323.333	0.000000
Gender	0.002427	1	0.002427	2.546	0.128966
Error	0.016200	17	0.000953		
TEST SESSION	0.000144	1	0.000144	0.744	0.400271
TEST SESSION*Gender	0.000948	1	0.000948	4.903	0.040754
Error	0.003285	17	0.000193		
TIME	0.000293	11	0.000027	0.992	0.455221
TIME*Gender	0.000516	11	0.000047	1.745	0.066493
Error	0.005026	187	0.000027		
TEST SESSION*TIME	0.000486	11	0.000044	1.563	0.112695
TEST SESSION*TIME*Gender	0.000468	11	0.000043	1.508	0.131512
Error	0.005280	187	0.000028		

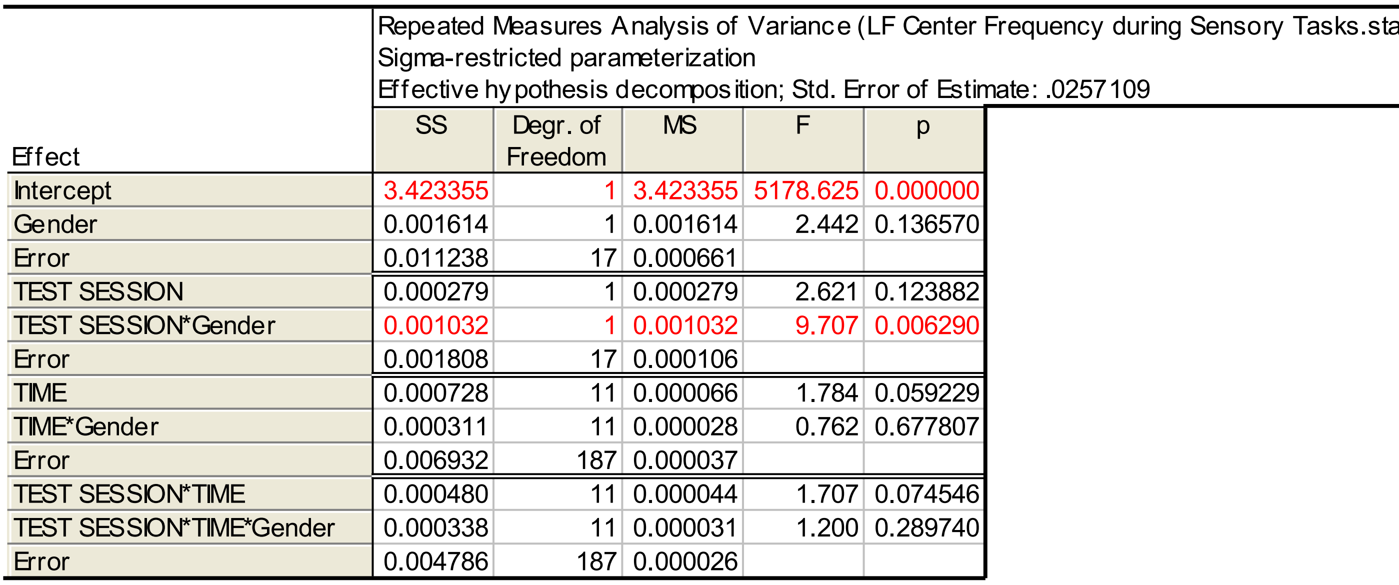
iii. Low Frequency Centre Frequency Effects during Motor Task



Repeated Measures Analysis of Variance (LF Center Frequency during Motor Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .0305994

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	3.454422	1	3.454422	3689.333	0.000000
Gender	0.000003	1	0.000003	0.003	0.956785
Error	0.015918	17	0.000936		
TEST SESSION	0.000043	1	0.000043	0.134	0.719271
TEST SESSION*Gender	0.000081	1	0.000081	0.249	0.624357
Error	0.005522	17	0.000325		
TIME	0.000382	11	0.000035	1.180	0.303470
TIME*Gender	0.000214	11	0.000019	0.659	0.775685
Error	0.005507	187	0.000029		
TEST SESSION*TIME	0.000147	11	0.000013	0.531	0.880552
TEST SESSION*TIME*Gender	0.000215	11	0.000020	0.776	0.663550
Error	0.004708	187	0.000025		

iv. Low Frequency Centre Frequency Effects during Sensory Task

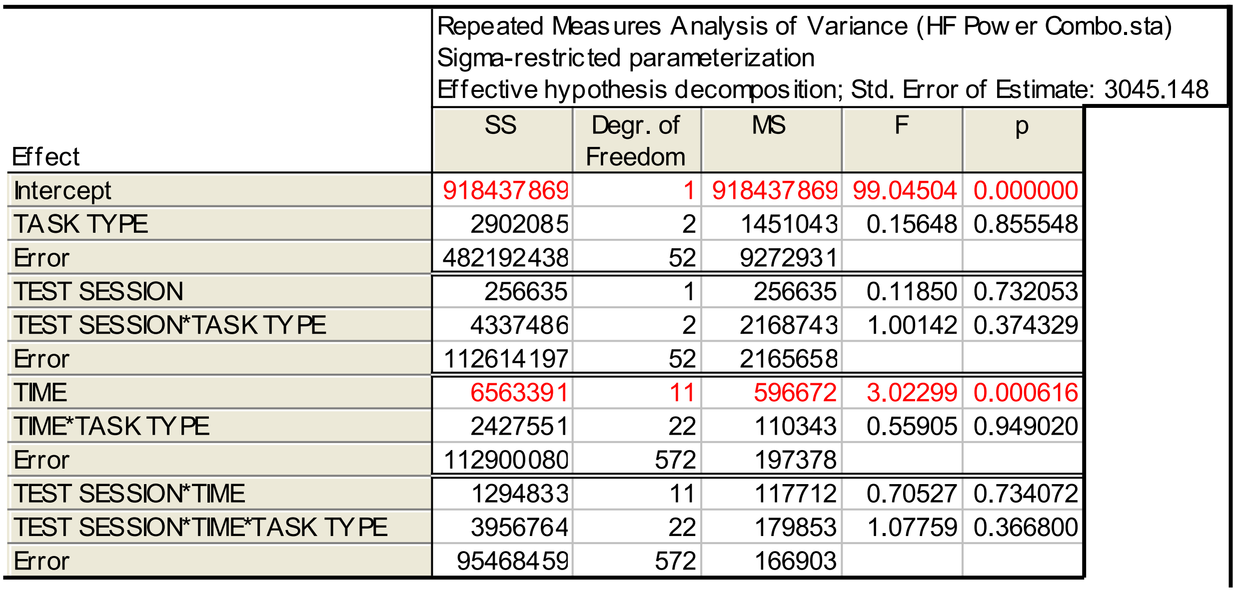


Repeated Measures Analysis of Variance (LF Center Frequency during Sensory Tasks.sta
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .0257109

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	3.423355	1	3.423355	5178.625	0.000000
Gender	0.001614	1	0.001614	2.442	0.136570
Error	0.011238	17	0.000661		
TEST SESSION	0.000279	1	0.000279	2.621	0.123882
TEST SESSION*Gender	0.001032	1	0.001032	9.707	0.006290
Error	0.001808	17	0.000106		
TIME	0.000728	11	0.000066	1.784	0.059229
TIME*Gender	0.000311	11	0.000028	0.762	0.677807
Error	0.006932	187	0.000037		
TEST SESSION*TIME	0.000480	11	0.000044	1.707	0.074546
TEST SESSION*TIME*Gender	0.000338	11	0.000031	1.200	0.289740
Error	0.004786	187	0.000026		

d. High Frequency Power

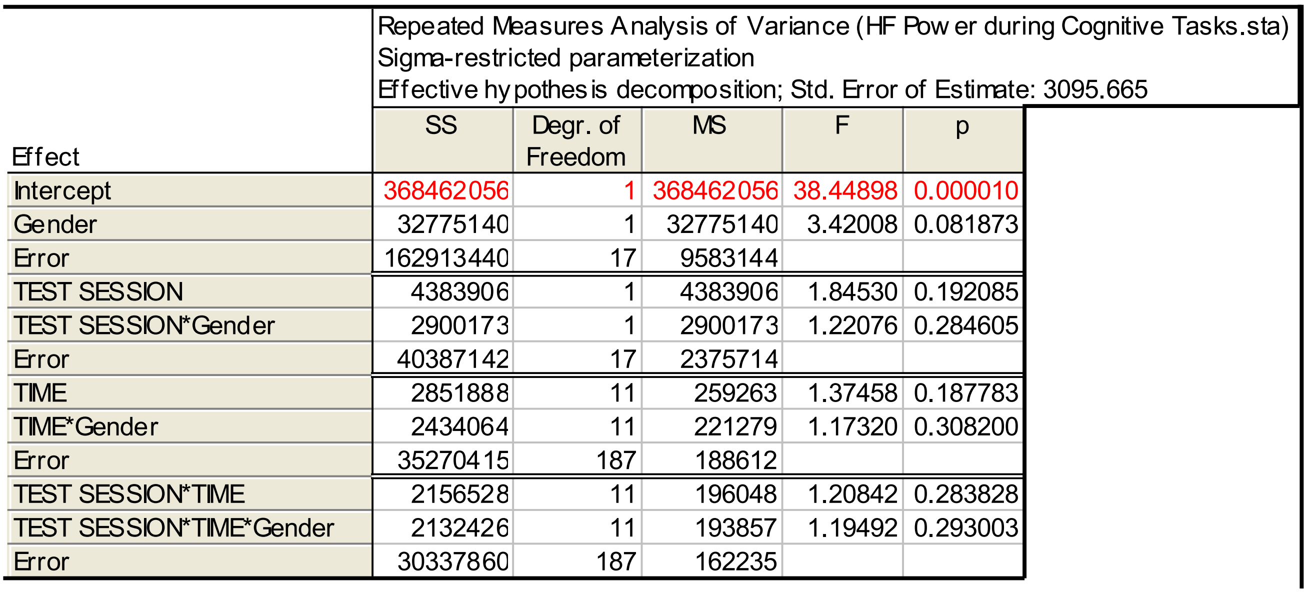
i. General High Frequency Power Effects



Repeated Measures Analysis of Variance (HF Power Combo.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 3045.148

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	918437869	1	918437869	99.04504	0.000000
TASK TYPE	2902085	2	1451043	0.15648	0.855548
Error	482192438	52	9272931		
TEST SESSION	256635	1	256635	0.11850	0.732053
TEST SESSION*TASK TYPE	4337486	2	2168743	1.00142	0.374329
Error	112614197	52	2165658		
TIME	6563391	11	596672	3.02299	0.000616
TIME*TASK TYPE	2427551	22	110343	0.55905	0.949020
Error	112900080	572	197378		
TEST SESSION*TIME	1294833	11	117712	0.70527	0.734072
TEST SESSION*TIME*TASK TYPE	3956764	22	179853	1.07759	0.366800
Error	95468459	572	166903		

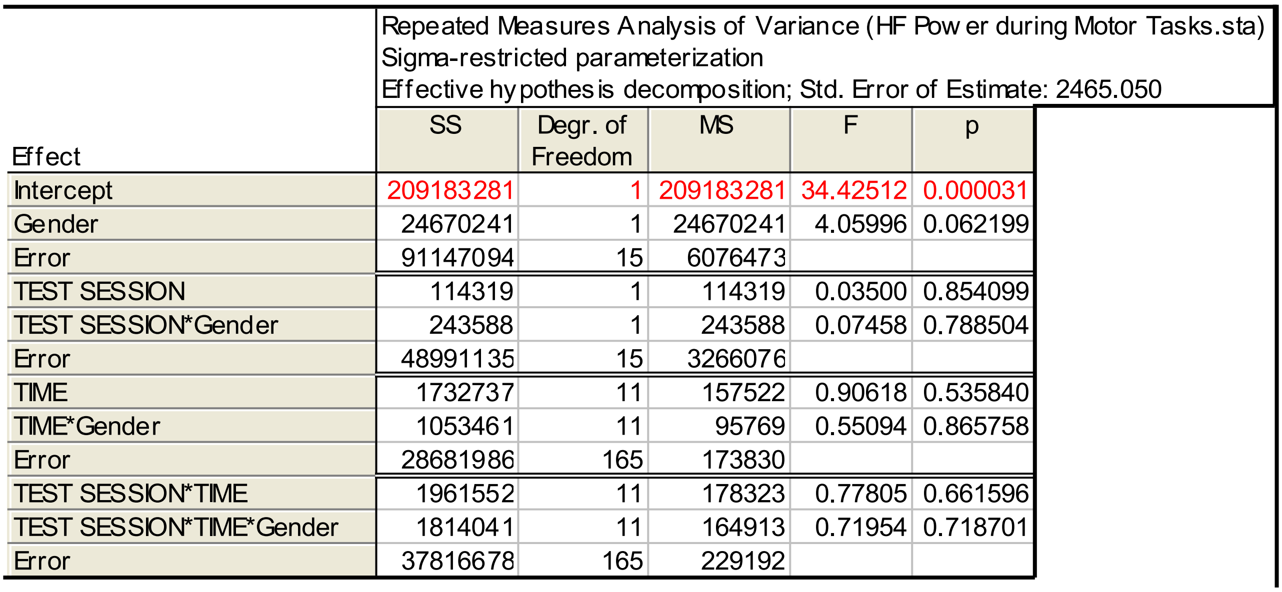
ii. High Frequency Power Effects during Cognitive Task



Repeated Measures Analysis of Variance (HF Power during Cognitive Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 3095.665

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	368462056	1	368462056	38.44898	0.000010
Gender	32775140	1	32775140	3.42008	0.081873
Error	162913440	17	9583144		
TEST SESSION	4383906	1	4383906	1.84530	0.192085
TEST SESSION*Gender	2900173	1	2900173	1.22076	0.284605
Error	40387142	17	2375714		
TIME	2851888	11	259263	1.37458	0.187783
TIME*Gender	2434064	11	221279	1.17320	0.308200
Error	35270415	187	188612		
TEST SESSION*TIME	2156528	11	196048	1.20842	0.283828
TEST SESSION*TIME*Gender	2132426	11	193857	1.19492	0.293003
Error	30337860	187	162235		

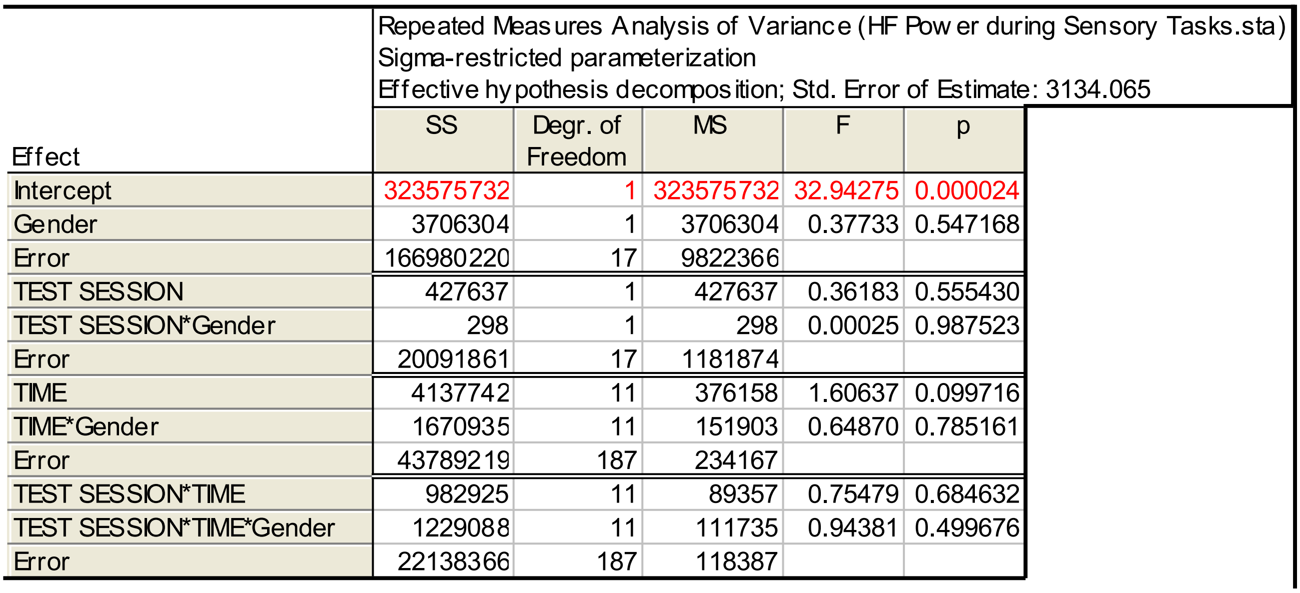
iii. High Frequency Power Effects during Motor Task



Repeated Measures Analysis of Variance (HF Power during Motor Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 2465.050

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	209183281	1	209183281	34.42512	0.000031
Gender	24670241	1	24670241	4.05996	0.062199
Error	91147094	15	6076473		
TEST SESSION	114319	1	114319	0.03500	0.854099
TEST SESSION*Gender	243588	1	243588	0.07458	0.788504
Error	48991135	15	3266076		
TIME	1732737	11	157522	0.90618	0.535840
TIME*Gender	1053461	11	95769	0.55094	0.865758
Error	28681986	165	173830		
TEST SESSION*TIME	1961552	11	178323	0.77805	0.661596
TEST SESSION*TIME*Gender	1814041	11	164913	0.71954	0.718701
Error	37816678	165	229192		

iv. High Frequency Power Effects during Sensory Task

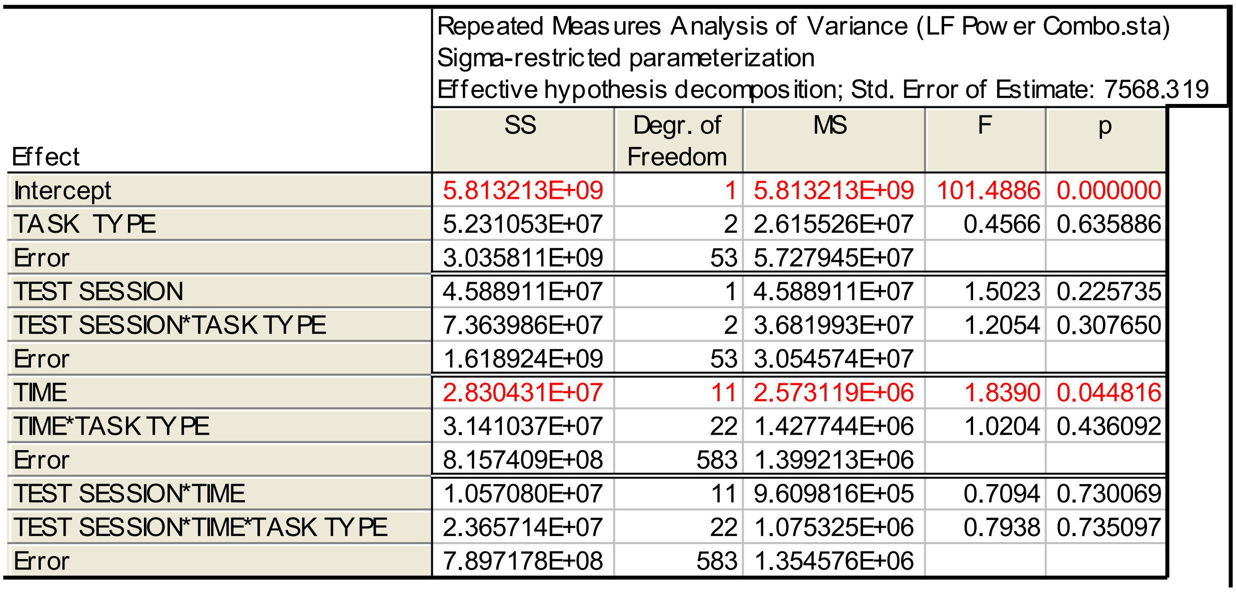


Repeated Measures Analysis of Variance (HF Power during Sensory Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 3134.065

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	323575732	1	323575732	32.94275	0.000024
Gender	3706304	1	3706304	0.37733	0.547168
Error	166980220	17	9822366		
TEST SESSION	427637	1	427637	0.36183	0.555430
TEST SESSION*Gender	298	1	298	0.00025	0.987523
Error	20091861	17	1181874		
TIME	4137742	11	376158	1.60637	0.099716
TIME*Gender	1670935	11	151903	0.64870	0.785161
Error	43789219	187	234167		
TEST SESSION*TIME	982925	11	89357	0.75479	0.684632
TEST SESSION*TIME*Gender	1229088	11	111735	0.94381	0.499676
Error	22138366	187	118387		

e. Low Frequency Power

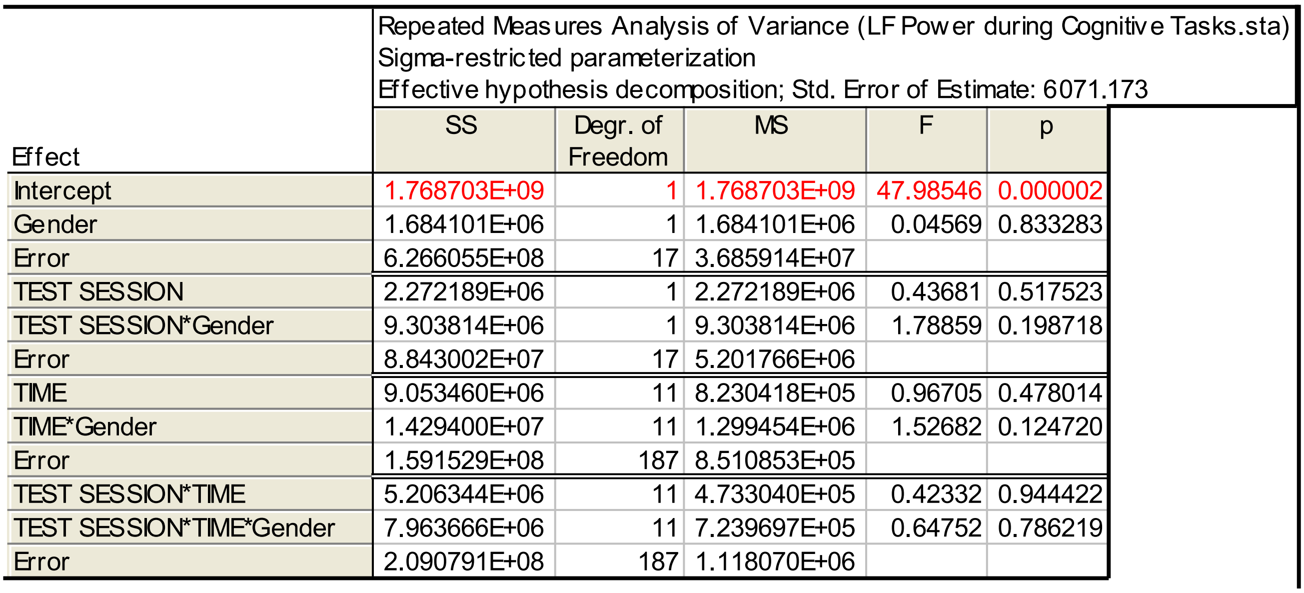
i. General Low Frequency Power Effects



Repeated Measures Analysis of Variance (LF Power Combo.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 7568.319

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	5.813213E+09	1	5.813213E+09	101.4886	0.000000
TASK TYPE	5.231053E+07	2	2.615526E+07	0.4566	0.635886
Error	3.035811E+09	53	5.727945E+07		
TEST SESSION	4.588911E+07	1	4.588911E+07	1.5023	0.225735
TEST SESSION*TASK TYPE	7.363986E+07	2	3.681993E+07	1.2054	0.307650
Error	1.618924E+09	53	3.054574E+07		
TIME	2.830431E+07	11	2.573119E+06	1.8390	0.044816
TIME*TASK TYPE	3.141037E+07	22	1.427744E+06	1.0204	0.436092
Error	8.157409E+08	583	1.399213E+06		
TEST SESSION*TIME	1.057080E+07	11	9.609816E+05	0.7094	0.730069
TEST SESSION*TIME*TASK TYPE	2.365714E+07	22	1.075325E+06	0.7938	0.735097
Error	7.897178E+08	583	1.354576E+06		

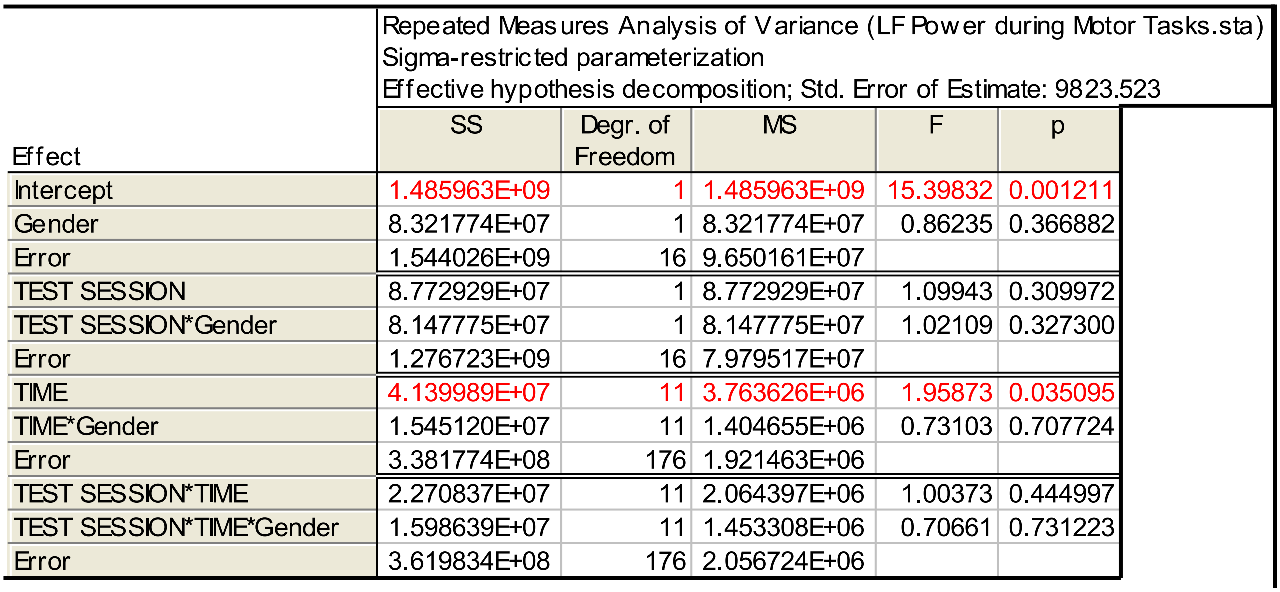
ii. Low Frequency Power Effects during Cognitive Task



Repeated Measures Analysis of Variance (LF Power during Cognitive Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 6071.173

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1.768703E+09	1	1.768703E+09	47.98546	0.000002
Gender	1.684101E+06	1	1.684101E+06	0.04569	0.833283
Error	6.266055E+08	17	3.685914E+07		
TEST SESSION	2.272189E+06	1	2.272189E+06	0.43681	0.517523
TEST SESSION*Gender	9.303814E+06	1	9.303814E+06	1.78859	0.198718
Error	8.843002E+07	17	5.201766E+06		
TIME	9.053460E+06	11	8.230418E+05	0.96705	0.478014
TIME*Gender	1.429400E+07	11	1.299454E+06	1.52682	0.124720
Error	1.591529E+08	187	8.510853E+05		
TEST SESSION*TIME	5.206344E+06	11	4.733040E+05	0.42332	0.944422
TEST SESSION*TIME*Gender	7.963666E+06	11	7.239697E+05	0.64752	0.786219
Error	2.090791E+08	187	1.118070E+06		

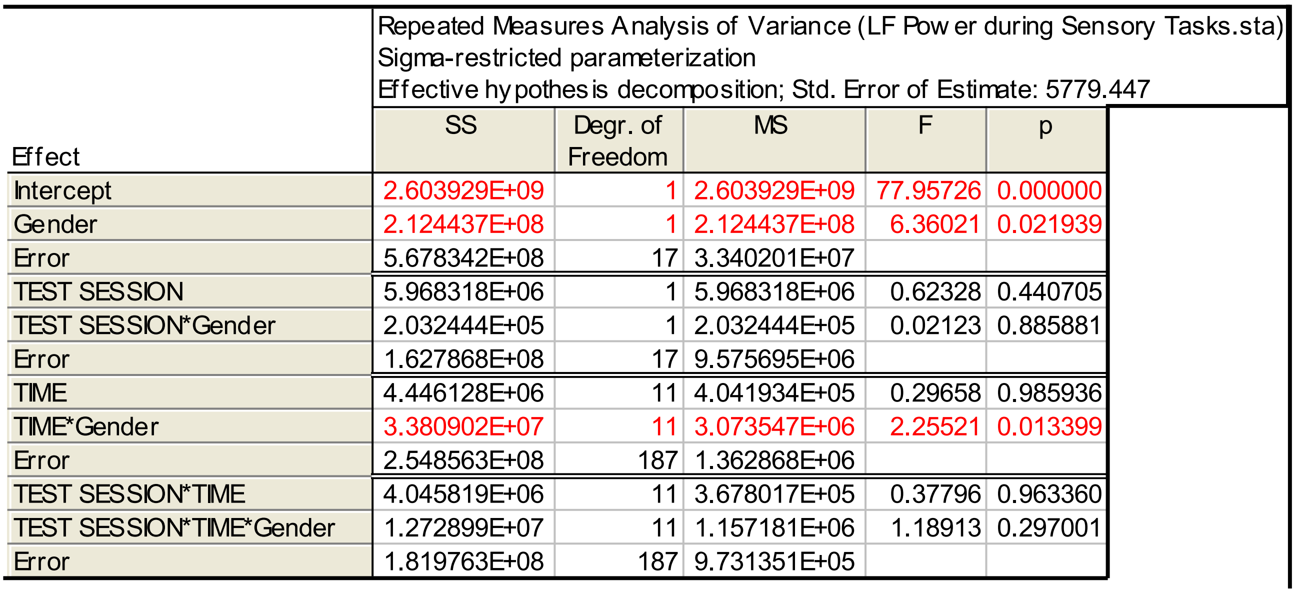
iii. Low Frequency Power Effects during Motor Task



Repeated Measures Analysis of Variance (LF Power during Motor Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 9823.523

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1.485963E+09	1	1.485963E+09	15.39832	0.001211
Gender	8.321774E+07	1	8.321774E+07	0.86235	0.366882
Error	1.544026E+09	16	9.650161E+07		
TEST SESSION	8.772929E+07	1	8.772929E+07	1.09943	0.309972
TEST SESSION*Gender	8.147775E+07	1	8.147775E+07	1.02109	0.327300
Error	1.276723E+09	16	7.979517E+07		
TIME	4.139989E+07	11	3.763626E+06	1.95873	0.035095
TIME*Gender	1.545120E+07	11	1.404655E+06	0.73103	0.707724
Error	3.381774E+08	176	1.921463E+06		
TEST SESSION*TIME	2.270837E+07	11	2.064397E+06	1.00373	0.444997
TEST SESSION*TIME*Gender	1.598639E+07	11	1.453308E+06	0.70661	0.731223
Error	3.619834E+08	176	2.056724E+06		

iv. Low Frequency Power Effects during Sensory Task

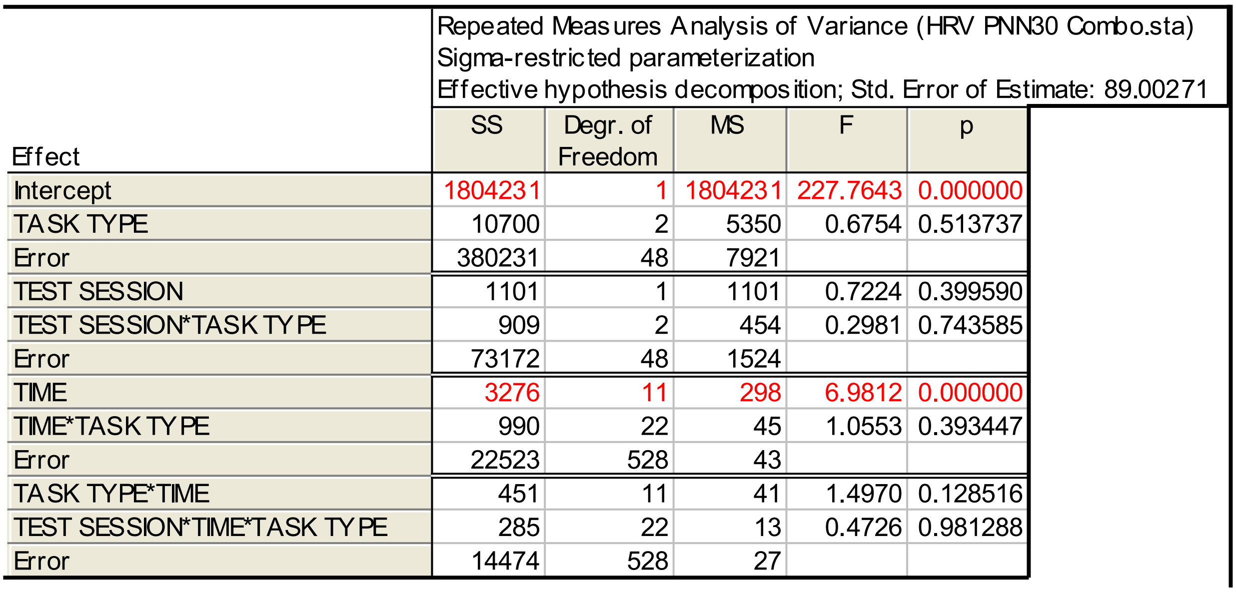


Repeated Measures Analysis of Variance (LF Power during Sensory Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 5779.447

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2.603929E+09	1	2.603929E+09	77.95726	0.000000
Gender	2.124437E+08	1	2.124437E+08	6.36021	0.021939
Error	5.678342E+08	17	3.340201E+07		
TEST SESSION	5.968318E+06	1	5.968318E+06	0.62328	0.440705
TEST SESSION*Gender	2.032444E+05	1	2.032444E+05	0.02123	0.885881
Error	1.627868E+08	17	9.575695E+06		
TIME	4.446128E+06	11	4.041934E+05	0.29658	0.985936
TIME*Gender	3.380902E+07	11	3.073547E+06	2.25521	0.013399
Error	2.548563E+08	187	1.362868E+06		
TEST SESSION*TIME	4.045819E+06	11	3.678017E+05	0.37796	0.963360
TEST SESSION*TIME*Gender	1.272899E+07	11	1.157181E+06	1.18913	0.297001
Error	1.819763E+08	187	9.731351E+05		

f. PNN 30

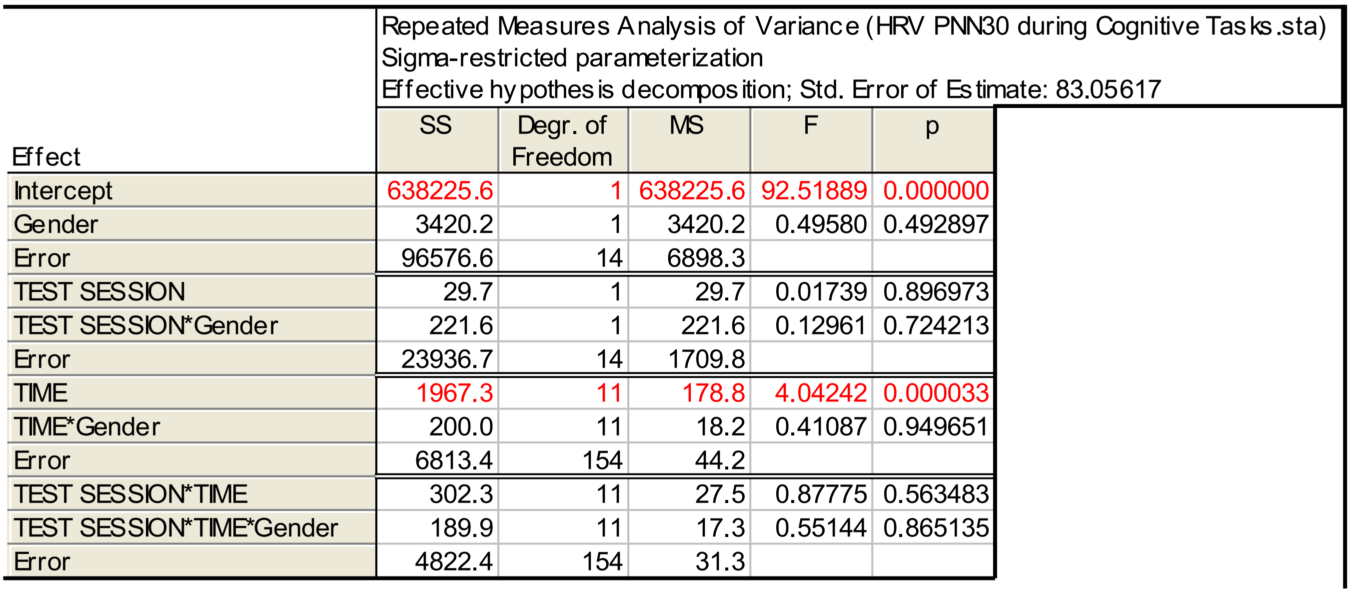
i. General PNN 30 Effects



Repeated Measures Analysis of Variance (HRV PNN30 Combo.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 89.00271

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1804231	1	1804231	227.7643	0.000000
TASK TYPE	10700	2	5350	0.6754	0.513737
Error	380231	48	7921		
TEST SESSION	1101	1	1101	0.7224	0.399590
TEST SESSION*TASK TYPE	909	2	454	0.2981	0.743585
Error	73172	48	1524		
TIME	3276	11	298	6.9812	0.000000
TIME*TASK TYPE	990	22	45	1.0553	0.393447
Error	22523	528	43		
TASK TYPE*TIME	451	11	41	1.4970	0.128516
TEST SESSION*TIME*TASK TYPE	285	22	13	0.4726	0.981288
Error	14474	528	27		

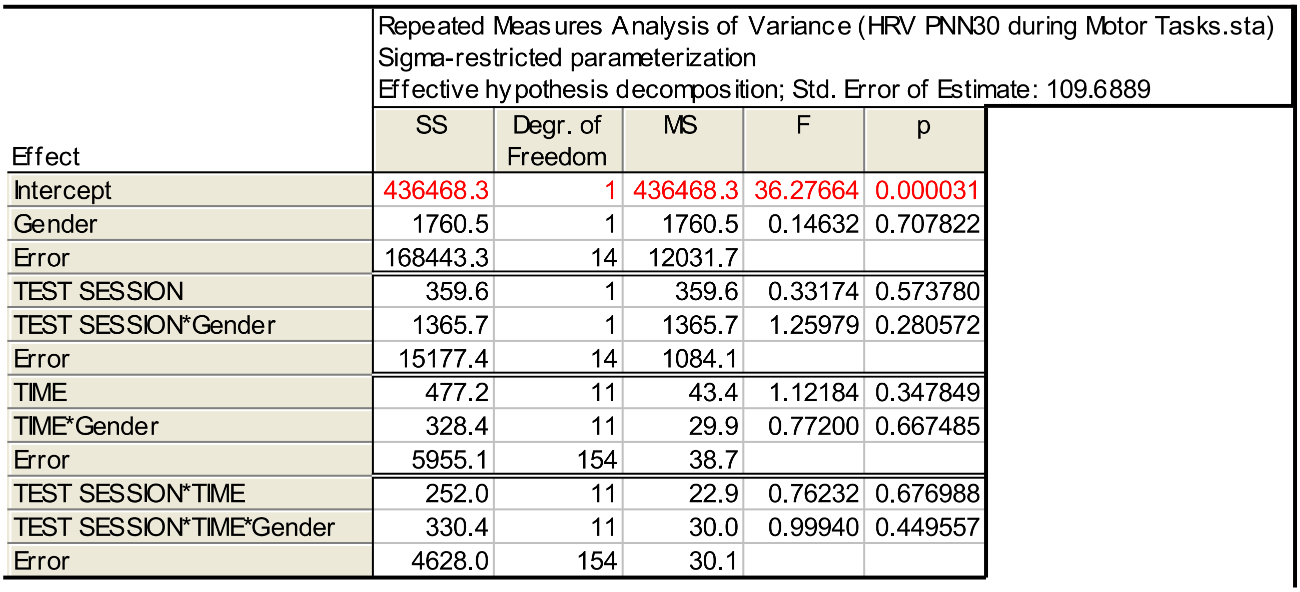
ii. PNN 30 Effects during Cognitive Task



Repeated Measures Analysis of Variance (HRV PNN30 during Cognitive Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 83.05617

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	638225.6	1	638225.6	92.51889	0.000000
Gender	3420.2	1	3420.2	0.49580	0.492897
Error	96576.6	14	6898.3		
TEST SESSION	29.7	1	29.7	0.01739	0.896973
TEST SESSION*Gender	221.6	1	221.6	0.12961	0.724213
Error	23936.7	14	1709.8		
TIME	1967.3	11	178.8	4.04242	0.000033
TIME*Gender	200.0	11	18.2	0.41087	0.949651
Error	6813.4	154	44.2		
TEST SESSION*TIME	302.3	11	27.5	0.87775	0.563483
TEST SESSION*TIME*Gender	189.9	11	17.3	0.55144	0.865135
Error	4822.4	154	31.3		

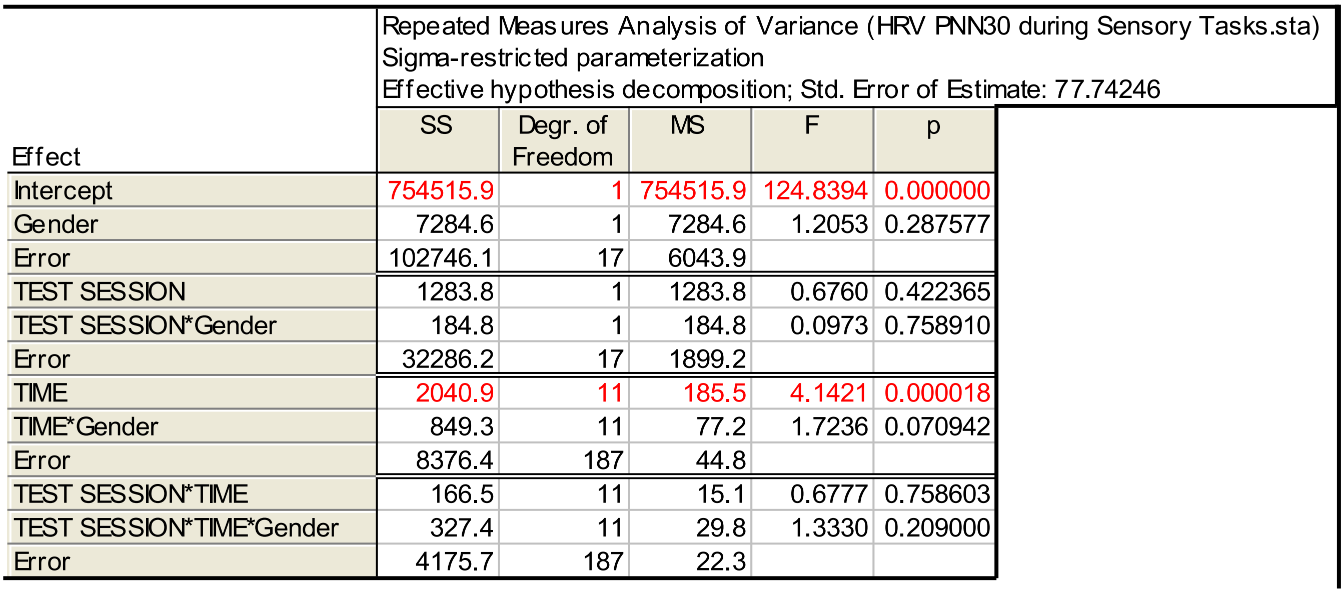
iii. PNN 30 Effects during Motor Task



Repeated Measures Analysis of Variance (HRV PNN30 during Motor Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 109.6889

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	436468.3	1	436468.3	36.27664	0.000031
Gender	1760.5	1	1760.5	0.14632	0.707822
Error	168443.3	14	12031.7		
TEST SESSION	359.6	1	359.6	0.33174	0.573780
TEST SESSION*Gender	1365.7	1	1365.7	1.25979	0.280572
Error	15177.4	14	1084.1		
TIME	477.2	11	43.4	1.12184	0.347849
TIME*Gender	328.4	11	29.9	0.77200	0.667485
Error	5955.1	154	38.7		
TEST SESSION*TIME	252.0	11	22.9	0.76232	0.676988
TEST SESSION*TIME*Gender	330.4	11	30.0	0.99940	0.449557
Error	4628.0	154	30.1		

iv. PNN 30 Effects during Sensory Task

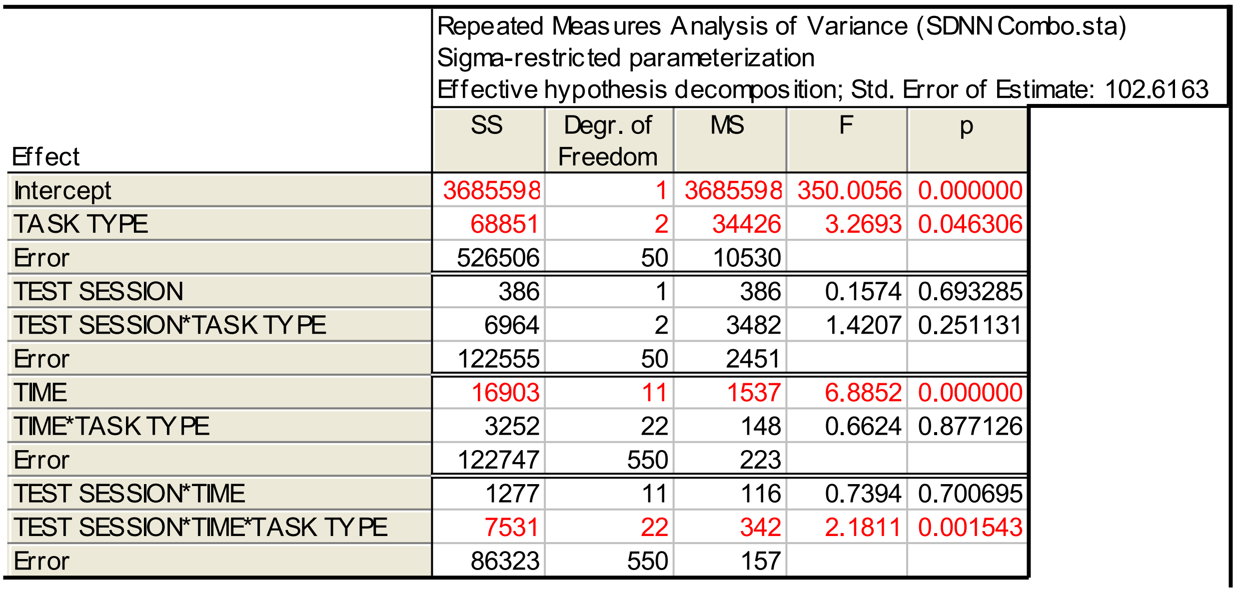


Repeated Measures Analysis of Variance (HRV PNN30 during Sensory Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 77.74246

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	754515.9	1	754515.9	124.8394	0.000000
Gender	7284.6	1	7284.6	1.2053	0.287577
Error	102746.1	17	6043.9		
TEST SESSION	1283.8	1	1283.8	0.6760	0.422365
TEST SESSION*Gender	184.8	1	184.8	0.0973	0.758910
Error	32286.2	17	1899.2		
TIME	2040.9	11	185.5	4.1421	0.000018
TIME*Gender	849.3	11	77.2	1.7236	0.070942
Error	8376.4	187	44.8		
TEST SESSION*TIME	166.5	11	15.1	0.6777	0.758603
TEST SESSION*TIME*Gender	327.4	11	29.8	1.3330	0.209000
Error	4175.7	187	22.3		

g. SDNN

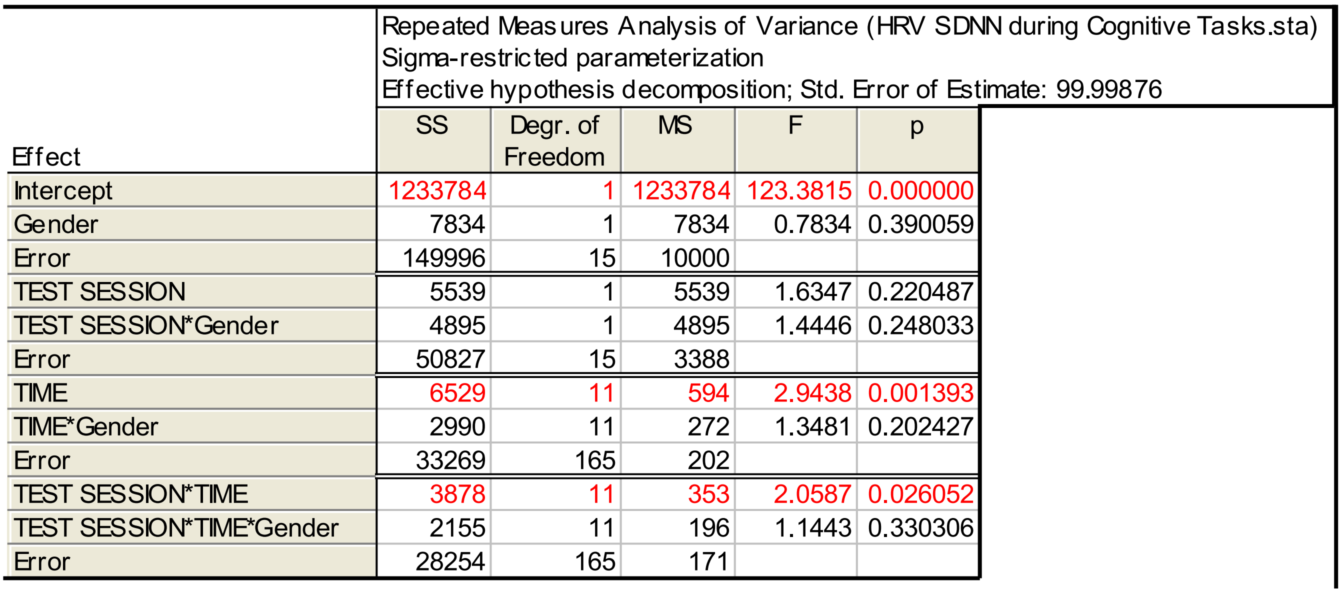
i. General SDNN Effects



Repeated Measures Analysis of Variance (SDNN Combo.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 102.6163

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	3685598	1	3685598	350.0056	0.000000
TASK TYPE	68851	2	34426	3.2693	0.046306
Error	526506	50	10530		
TEST SESSION	386	1	386	0.1574	0.693285
TEST SESSION*TASK TYPE	6964	2	3482	1.4207	0.251131
Error	122555	50	2451		
TIME	16903	11	1537	6.8852	0.000000
TIME*TASK TYPE	3252	22	148	0.6624	0.877126
Error	122747	550	223		
TEST SESSION*TIME	1277	11	116	0.7394	0.700695
TEST SESSION*TIME*TASK TYPE	7531	22	342	2.1811	0.001543
Error	86323	550	157		

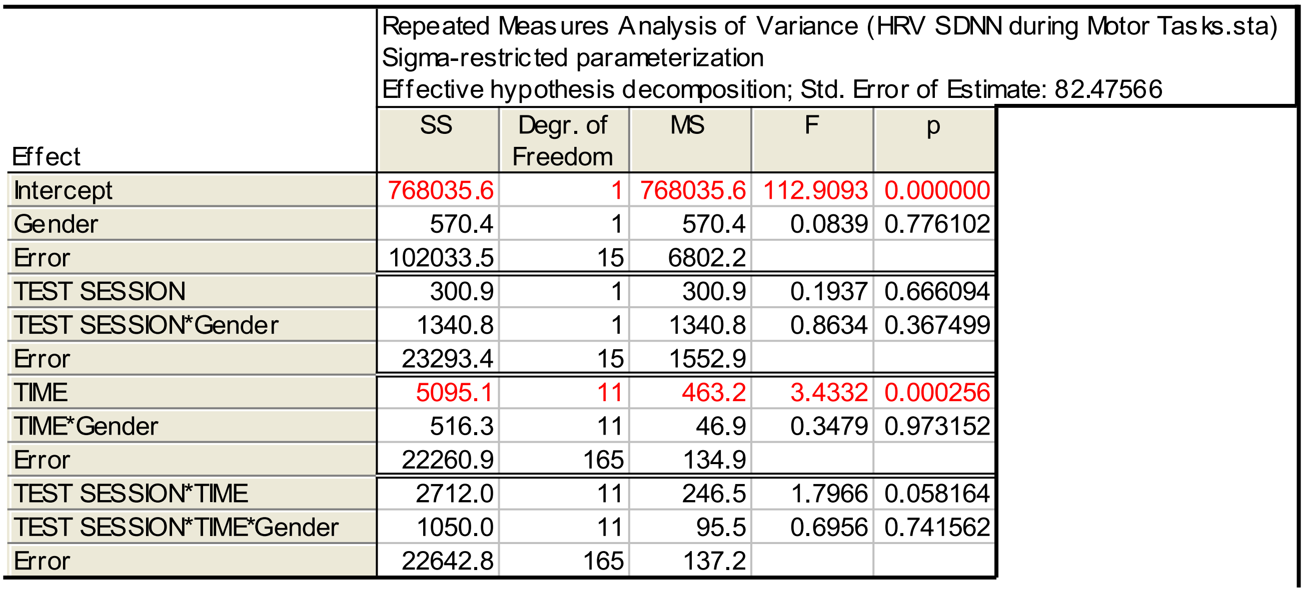
ii. SDNN Effects during Cognitive Task



Repeated Measures Analysis of Variance (HRV SDNN during Cognitive Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 99.99876

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1233784	1	1233784	123.3815	0.000000
Gender	7834	1	7834	0.7834	0.390059
Error	149996	15	10000		
TEST SESSION	5539	1	5539	1.6347	0.220487
TEST SESSION*Gender	4895	1	4895	1.4446	0.248033
Error	50827	15	3388		
TIME	6529	11	594	2.9438	0.001393
TIME*Gender	2990	11	272	1.3481	0.202427
Error	33269	165	202		
TEST SESSION*TIME	3878	11	353	2.0587	0.026052
TEST SESSION*TIME*Gender	2155	11	196	1.1443	0.330306
Error	28254	165	171		

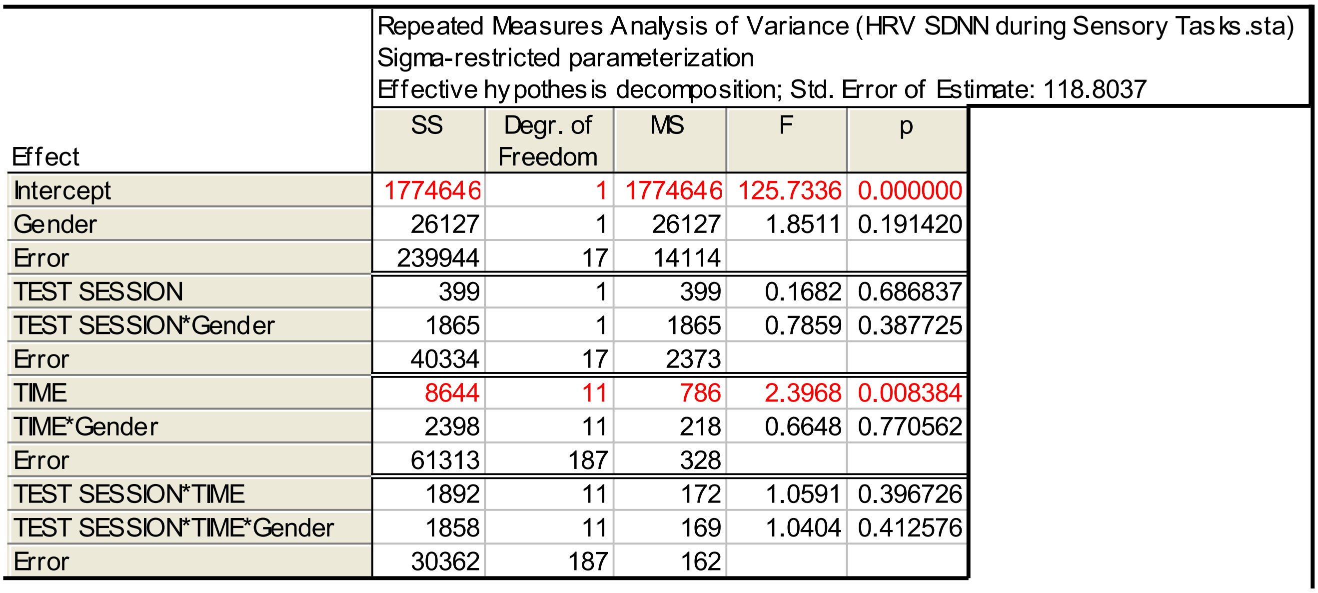
iii. SDNN Effects during Motor Task



Repeated Measures Analysis of Variance (HRV SDNN during Motor Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 82.47566

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	768035.6	1	768035.6	112.9093	0.000000
Gender	570.4	1	570.4	0.0839	0.776102
Error	102033.5	15	6802.2		
TEST SESSION	300.9	1	300.9	0.1937	0.666094
TEST SESSION*Gender	1340.8	1	1340.8	0.8634	0.367499
Error	23293.4	15	1552.9		
TIME	5095.1	11	463.2	3.4332	0.000256
TIME*Gender	516.3	11	46.9	0.3479	0.973152
Error	22260.9	165	134.9		
TEST SESSION*TIME	2712.0	11	246.5	1.7966	0.058164
TEST SESSION*TIME*Gender	1050.0	11	95.5	0.6956	0.741562
Error	22642.8	165	137.2		

iv. SDNN Effects during Sensory Task

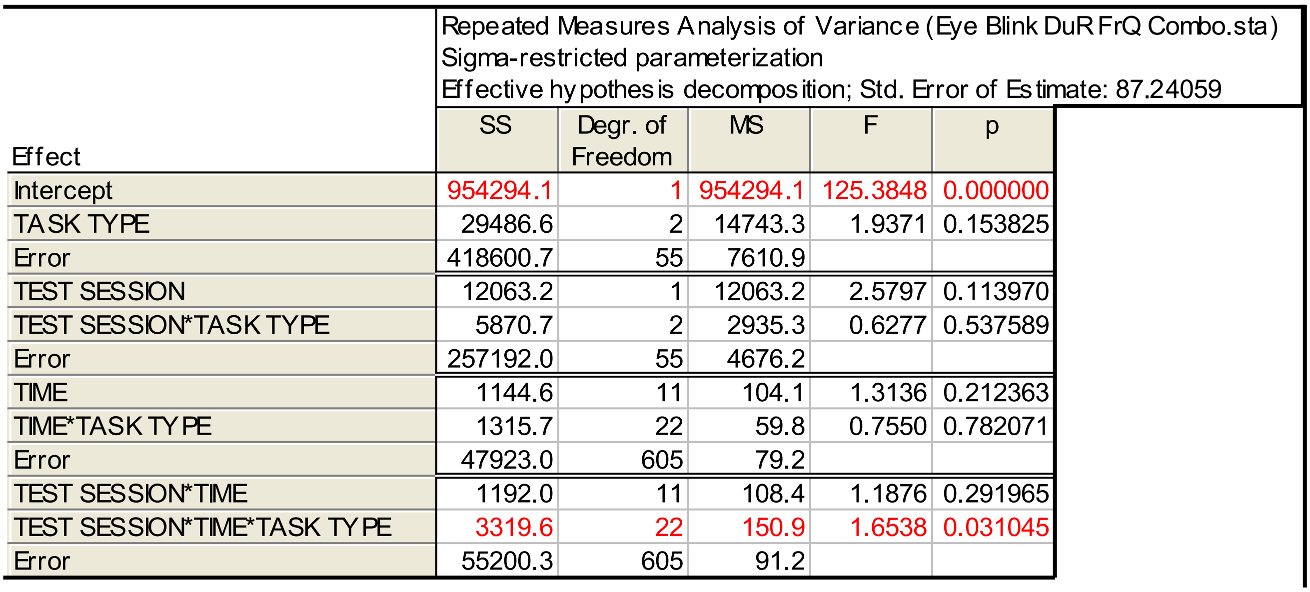


Repeated Measures Analysis of Variance (HRV SDNN during Sensory Tasks.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 118.8037

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1774646	1	1774646	125.7336	0.000000
Gender	26127	1	26127	1.8511	0.191420
Error	239944	17	14114		
TEST SESSION	399	1	399	0.1682	0.686837
TEST SESSION*Gender	1865	1	1865	0.7859	0.387725
Error	40334	17	2373		
TIME	8644	11	786	2.3968	0.008384
TIME*Gender	2398	11	218	0.6648	0.770562
Error	61313	187	328		
TEST SESSION*TIME	1892	11	172	1.0591	0.396726
TEST SESSION*TIME*Gender	1858	11	169	1.0404	0.412576
Error	30362	187	162		

3. Oculomotor Parameters

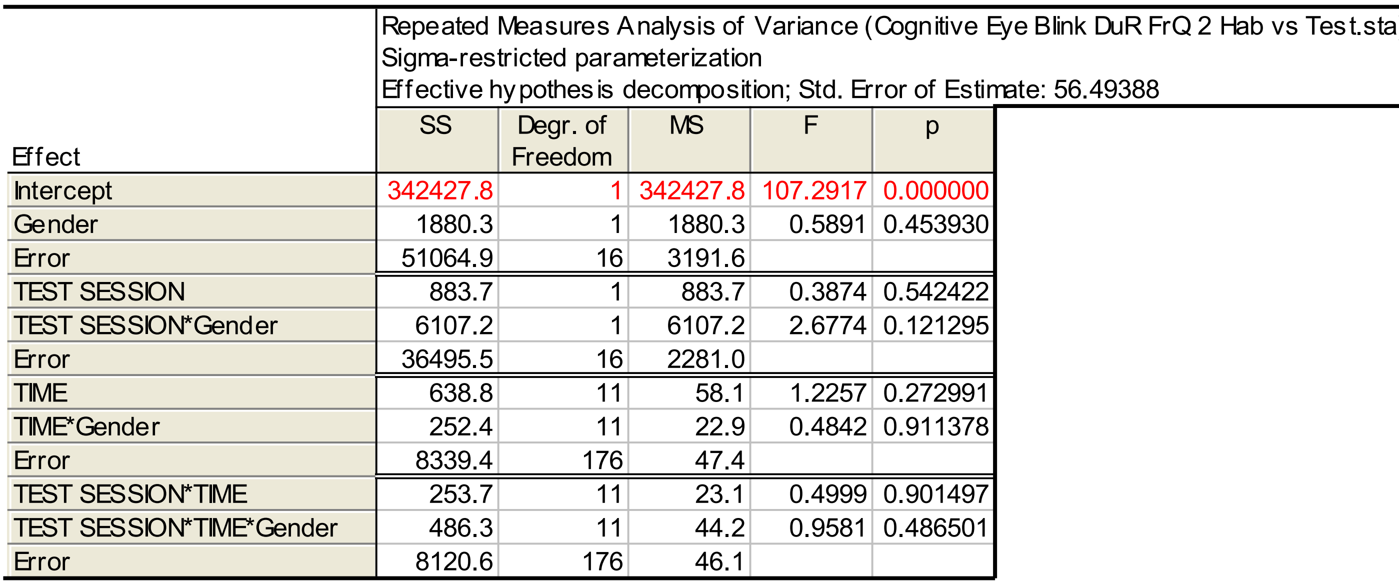
a. General Eye Blink Frequency Effects



Repeated Measures Analysis of Variance (Eye Blink DuR FrQ Combo.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 87.24059

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	954294.1	1	954294.1	125.3848	0.000000
TASK TYPE	29486.6	2	14743.3	1.9371	0.153825
Error	418600.7	55	7610.9		
TEST SESSION	12063.2	1	12063.2	2.5797	0.113970
TEST SESSION*TASK TYPE	5870.7	2	2935.3	0.6277	0.537589
Error	257192.0	55	4676.2		
TIME	1144.6	11	104.1	1.3136	0.212363
TIME*TASK TYPE	1315.7	22	59.8	0.7550	0.782071
Error	47923.0	605	79.2		
TEST SESSION*TIME	1192.0	11	108.4	1.1876	0.291965
TEST SESSION*TIME*TASK TYPE	3319.6	22	150.9	1.6538	0.031045
Error	55200.3	605	91.2		

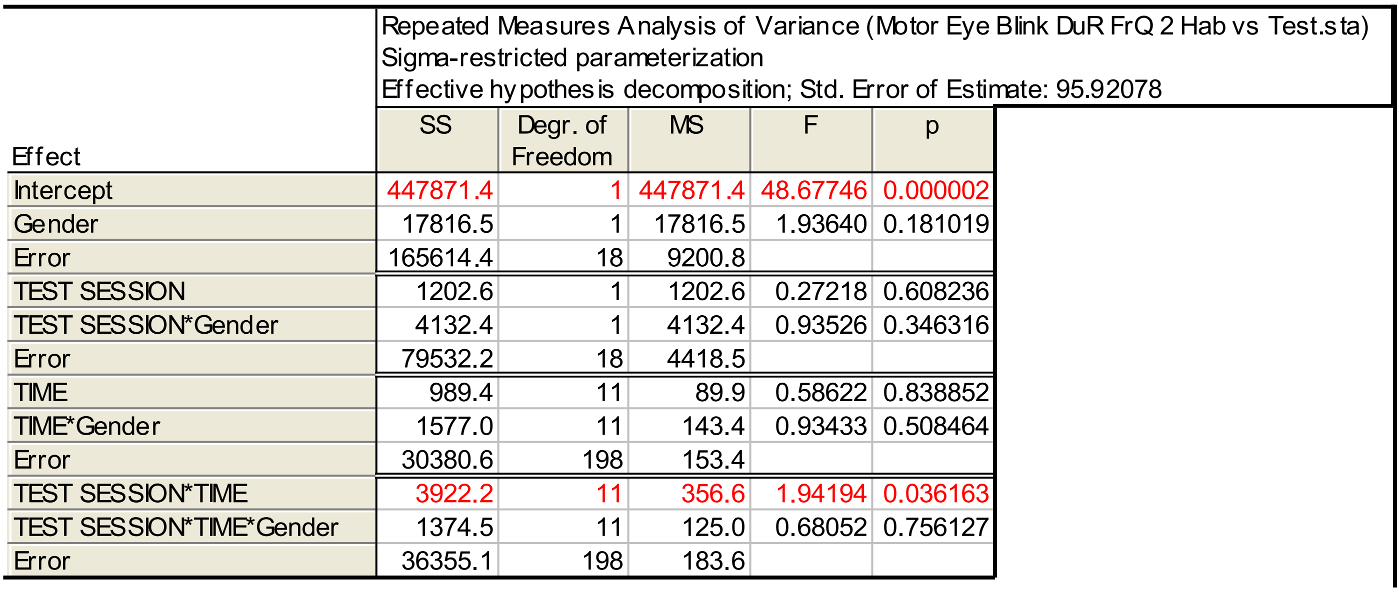
b. Eye Blink Frequency Effects during Cognitive Task



Repeated Measures Analysis of Variance (Cognitive Eye Blink DuR FrQ 2 Hab vs Test.sta
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 56.49388

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	342427.8	1	342427.8	107.2917	0.000000
Gender	1880.3	1	1880.3	0.5891	0.453930
Error	51064.9	16	3191.6		
TEST SESSION	883.7	1	883.7	0.3874	0.542422
TEST SESSION*Gender	6107.2	1	6107.2	2.6774	0.121295
Error	36495.5	16	2281.0		
TIME	638.8	11	58.1	1.2257	0.272991
TIME*Gender	252.4	11	22.9	0.4842	0.911378
Error	8339.4	176	47.4		
TEST SESSION*TIME	253.7	11	23.1	0.4999	0.901497
TEST SESSION*TIME*Gender	486.3	11	44.2	0.9581	0.486501
Error	8120.6	176	46.1		

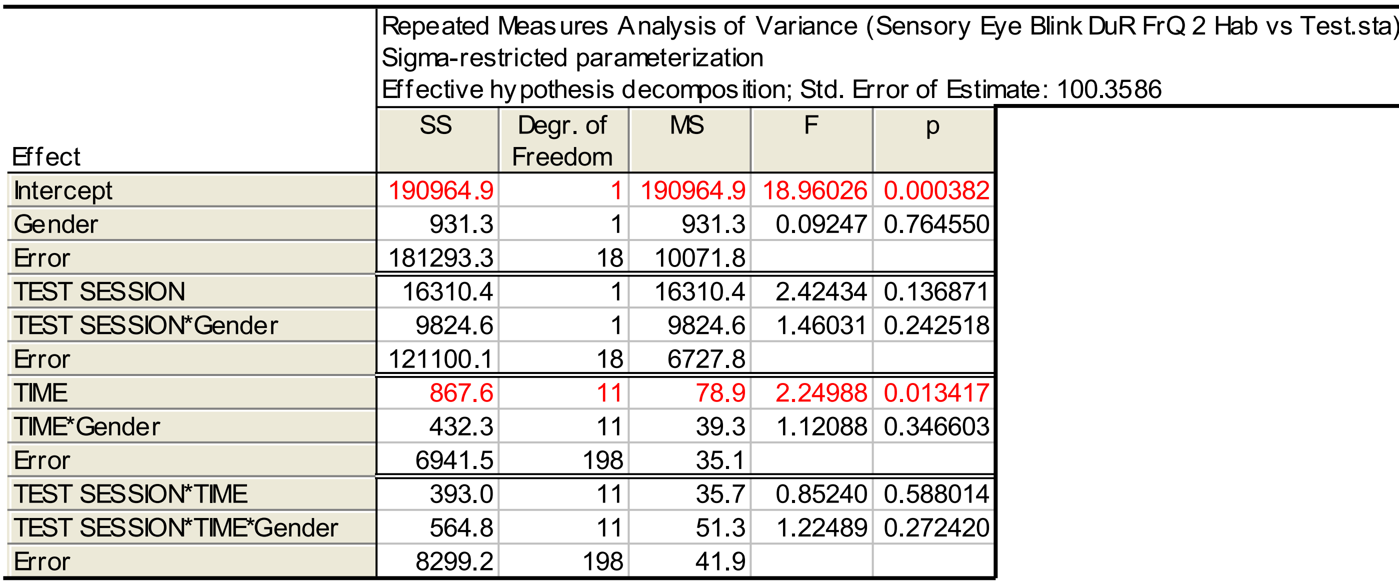
c. Eye Blink Frequency Effects during Motor Task



Repeated Measures Analysis of Variance (Motor Eye Blink DuR FrQ 2 Hab vs Test.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 95.92078

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	447871.4	1	447871.4	48.67746	0.000002
Gender	17816.5	1	17816.5	1.93640	0.181019
Error	165614.4	18	9200.8		
TEST SESSION	1202.6	1	1202.6	0.27218	0.608236
TEST SESSION*Gender	4132.4	1	4132.4	0.93526	0.346316
Error	79532.2	18	4418.5		
TIME	989.4	11	89.9	0.58622	0.838852
TIME*Gender	1577.0	11	143.4	0.93433	0.508464
Error	30380.6	198	153.4		
TEST SESSION*TIME	3922.2	11	356.6	1.94194	0.036163
TEST SESSION*TIME*Gender	1374.5	11	125.0	0.68052	0.756127
Error	36355.1	198	183.6		

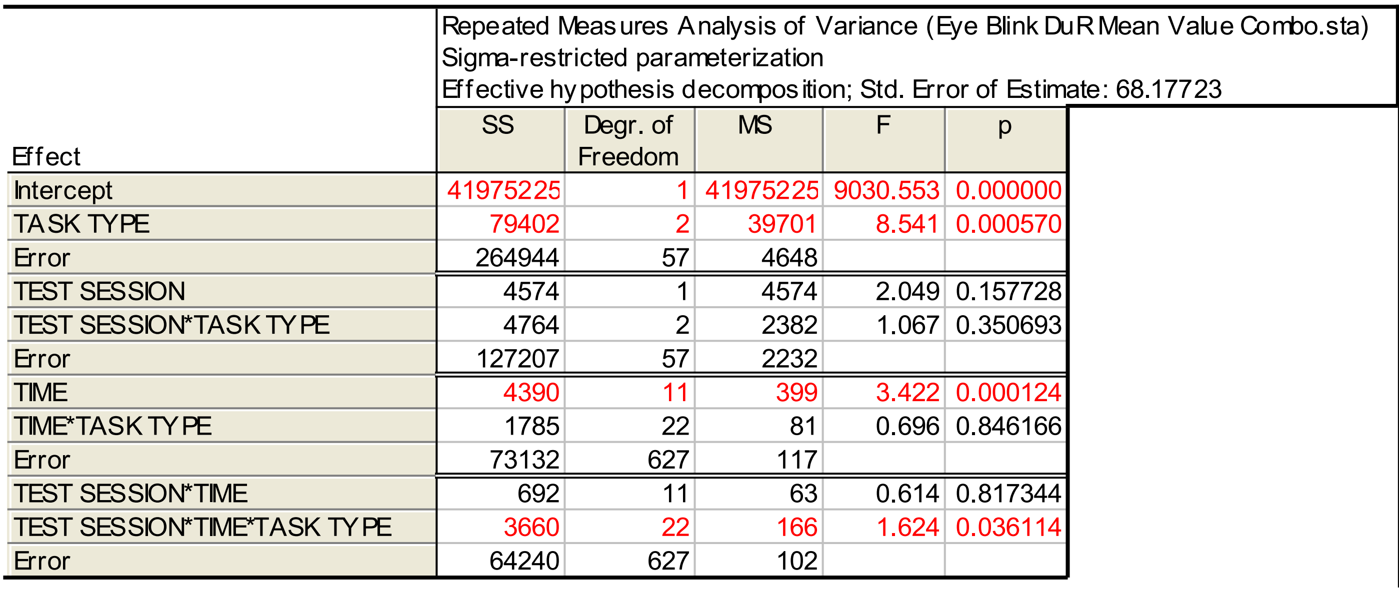
d. Eye Blink Frequency Effects during Sensory Task



Repeated Measures Analysis of Variance (Sensory Eye Blink DuR FrQ 2 Hab vs Test.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 100.3586

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	190964.9	1	190964.9	18.96026	0.000382
Gender	931.3	1	931.3	0.09247	0.764550
Error	181293.3	18	10071.8		
TEST SESSION	16310.4	1	16310.4	2.42434	0.136871
TEST SESSION*Gender	9824.6	1	9824.6	1.46031	0.242518
Error	121100.1	18	6727.8		
TIME	867.6	11	78.9	2.24988	0.013417
TIME*Gender	432.3	11	39.3	1.12088	0.346603
Error	6941.5	198	35.1		
TEST SESSION*TIME	393.0	11	35.7	0.85240	0.588014
TEST SESSION*TIME*Gender	564.8	11	51.3	1.22489	0.272420
Error	8299.2	198	41.9		

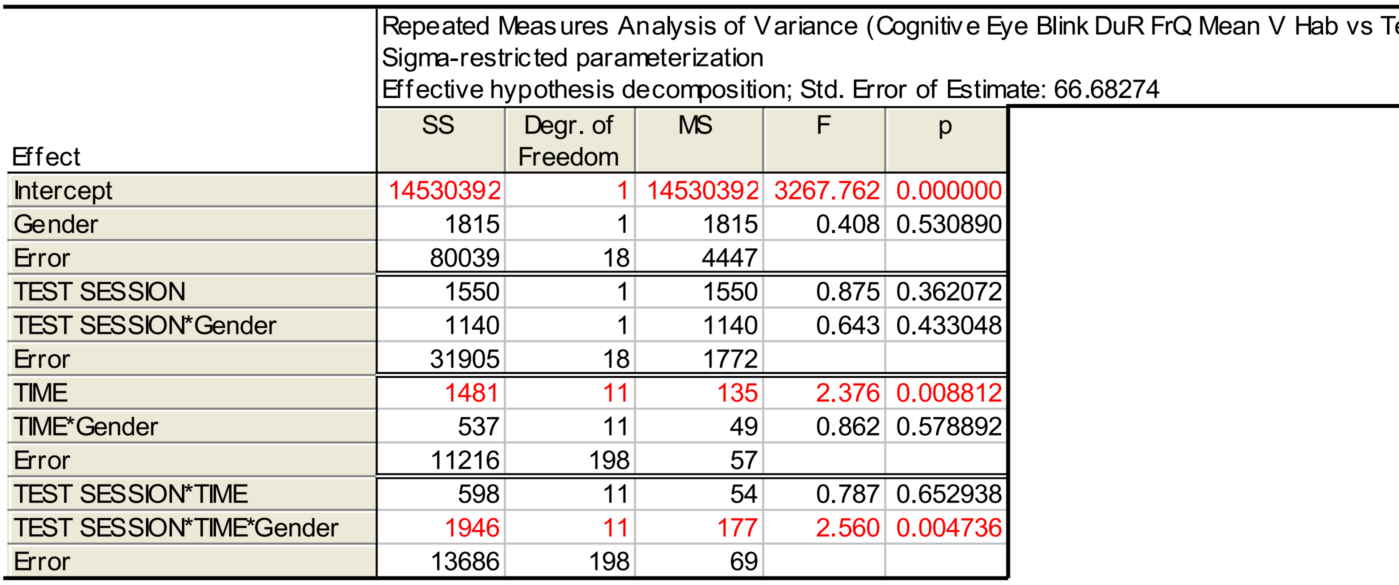
e. General Eye Blink Duration Effects



Repeated Measures Analysis of Variance (Eye Blink DuR Mean Value Combo.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 68.17723

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	41975225	1	41975225	9030.553	0.000000
TASK TYPE	79402	2	39701	8.541	0.000570
Error	264944	57	4648		
TEST SESSION	4574	1	4574	2.049	0.157728
TEST SESSION*TASK TYPE	4764	2	2382	1.067	0.350693
Error	127207	57	2232		
TIME	4390	11	399	3.422	0.000124
TIME*TASK TYPE	1785	22	81	0.696	0.846166
Error	73132	627	117		
TEST SESSION*TIME	692	11	63	0.614	0.817344
TEST SESSION*TIME*TASK TYPE	3660	22	166	1.624	0.036114
Error	64240	627	102		

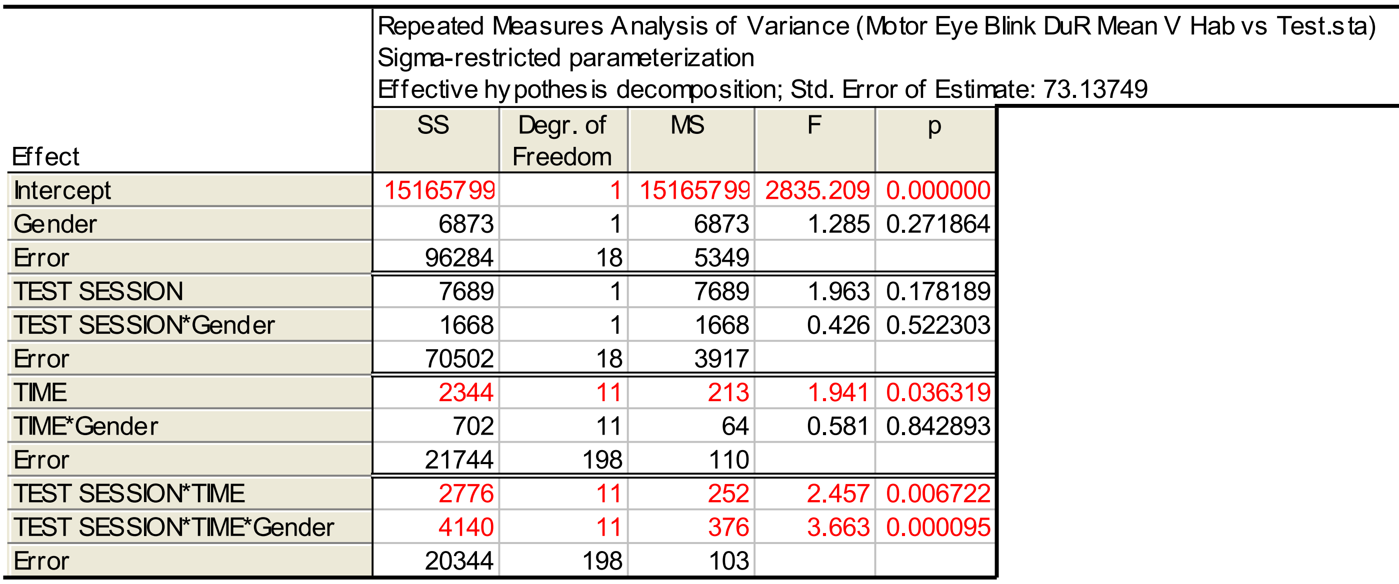
f. Eye Blink Duration Effects during Cognitive Task



Repeated Measures Analysis of Variance (Cognitive Eye Blink DuR FrQ Mean V Hab vs T
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 66.68274

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	14530392	1	14530392	3267.762	0.000000
Gender	1815	1	1815	0.408	0.530890
Error	80039	18	4447		
TEST SESSION	1550	1	1550	0.875	0.362072
TEST SESSION*Gender	1140	1	1140	0.643	0.433048
Error	31905	18	1772		
TIME	1481	11	135	2.376	0.008812
TIME*Gender	537	11	49	0.862	0.578892
Error	11216	198	57		
TEST SESSION*TIME	598	11	54	0.787	0.652938
TEST SESSION*TIME*Gender	1946	11	177	2.560	0.004736
Error	13686	198	69		

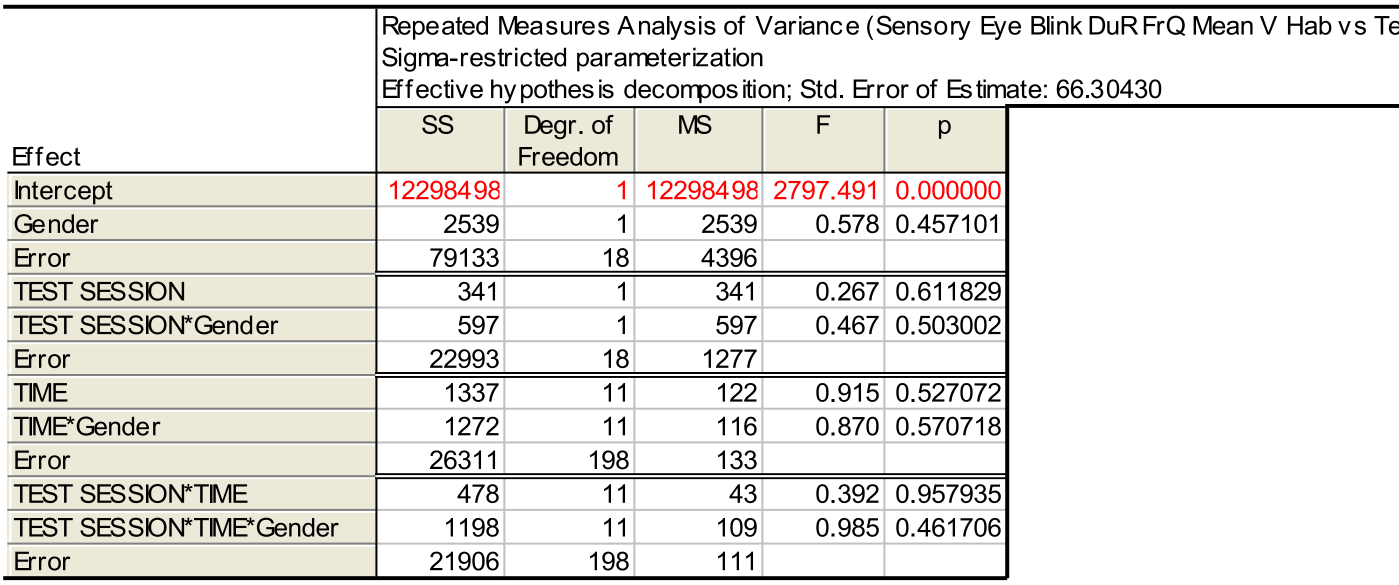
g. Eye Blink Duration Effects during Motor Task



Repeated Measures Analysis of Variance (Motor Eye Blink DuR Mean V Hab vs Test.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 73.13749

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	15165799	1	15165799	2835.209	0.000000
Gender	6873	1	6873	1.285	0.271864
Error	96284	18	5349		
TEST SESSION	7689	1	7689	1.963	0.178189
TEST SESSION*Gender	1668	1	1668	0.426	0.522303
Error	70502	18	3917		
TIME	2344	11	213	1.941	0.036319
TIME*Gender	702	11	64	0.581	0.842893
Error	21744	198	110		
TEST SESSION*TIME	2776	11	252	2.457	0.006722
TEST SESSION*TIME*Gender	4140	11	376	3.663	0.000095
Error	20344	198	103		

h. Eye Blink Duration Effects during Sensory Task



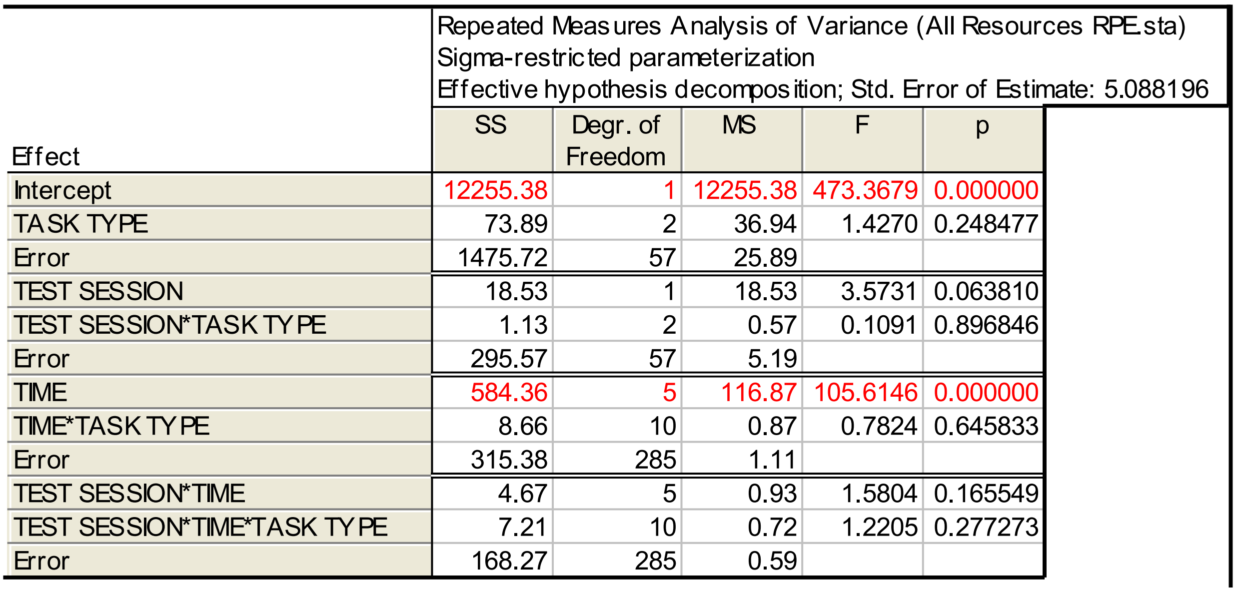
Repeated Measures Analysis of Variance (Sensory Eye Blink DuR FrQ Mean V Hab vs Te
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 66.30430

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	12298498	1	12298498	2797.491	0.000000
Gender	2539	1	2539	0.578	0.457101
Error	79133	18	4396		
TEST SESSION	341	1	341	0.267	0.611829
TEST SESSION*Gender	597	1	597	0.467	0.503002
Error	22993	18	1277		
TIME	1337	11	122	0.915	0.527072
TIME*Gender	1272	11	116	0.870	0.570718
Error	26311	198	133		
TEST SESSION*TIME	478	11	43	0.392	0.957935
TEST SESSION*TIME*Gender	1198	11	109	0.985	0.461706
Error	21906	198	111		

4. Subjective Parameters

a. RPE

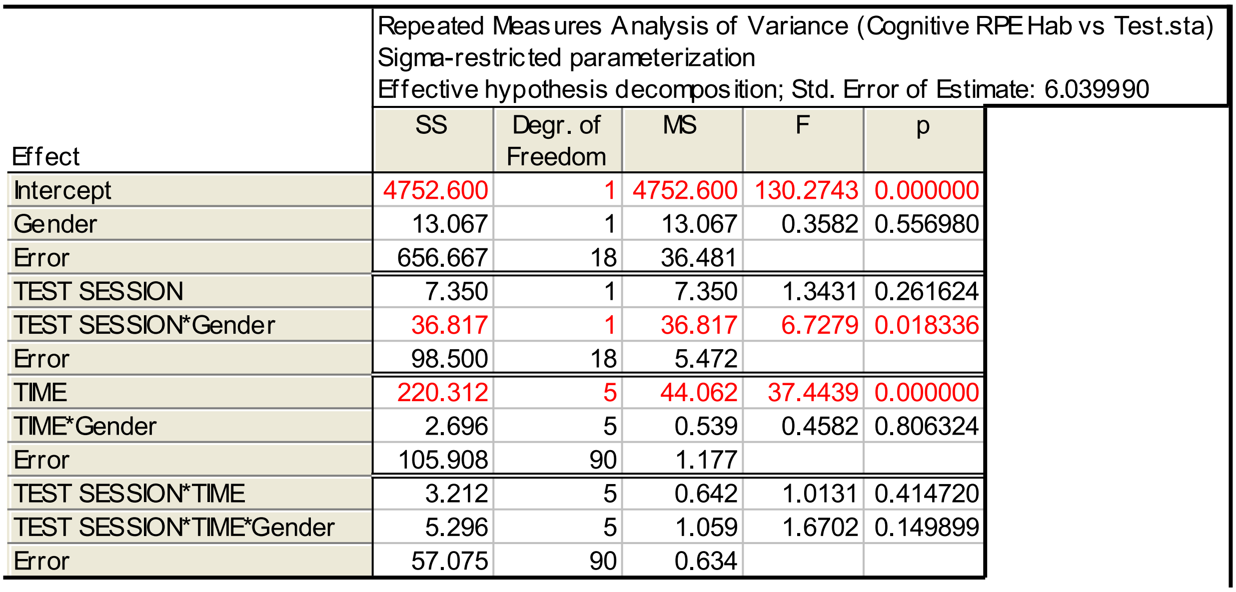
i. General RPE Effects



Repeated Measures Analysis of Variance (All Resources RPE.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 5.088196

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	12255.38	1	12255.38	473.3679	0.000000
TASK TYPE	73.89	2	36.94	1.4270	0.248477
Error	1475.72	57	25.89		
TEST SESSION	18.53	1	18.53	3.5731	0.063810
TEST SESSION*TASK TYPE	1.13	2	0.57	0.1091	0.896846
Error	295.57	57	5.19		
TIME	584.36	5	116.87	105.6146	0.000000
TIME*TASK TYPE	8.66	10	0.87	0.7824	0.645833
Error	315.38	285	1.11		
TEST SESSION*TIME	4.67	5	0.93	1.5804	0.165549
TEST SESSION*TIME*TASK TYPE	7.21	10	0.72	1.2205	0.277273
Error	168.27	285	0.59		

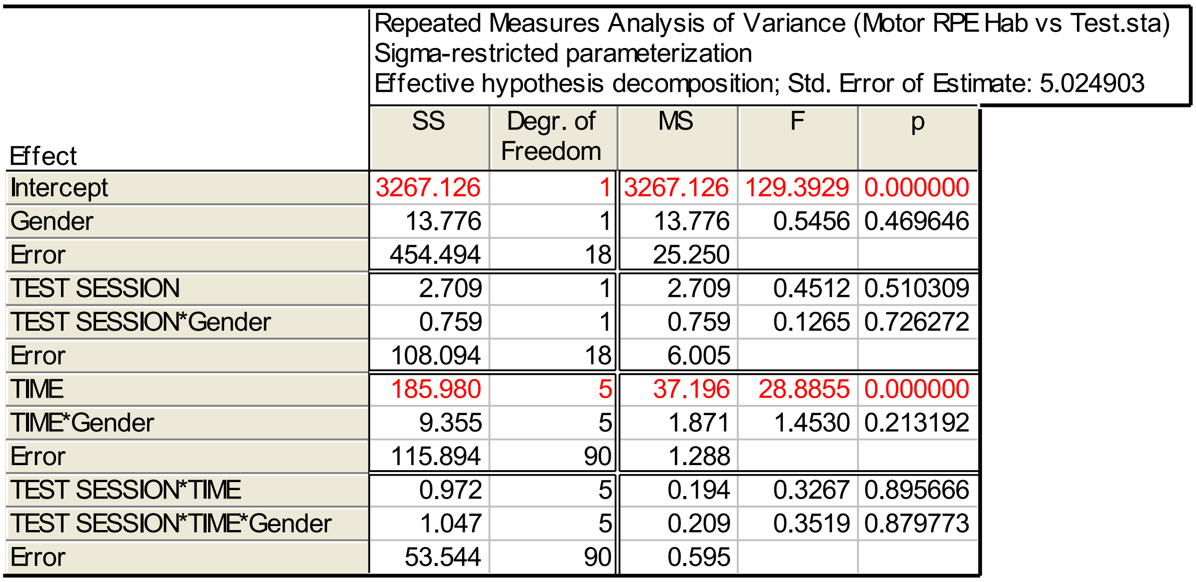
ii. RPE Effects during Cognitive Task



Repeated Measures Analysis of Variance (Cognitive RPE Hab vs Test.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 6.039990

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	4752.600	1	4752.600	130.2743	0.000000
Gender	13.067	1	13.067	0.3582	0.556980
Error	656.667	18	36.481		
TEST SESSION	7.350	1	7.350	1.3431	0.261624
TEST SESSION*Gender	36.817	1	36.817	6.7279	0.018336
Error	98.500	18	5.472		
TIME	220.312	5	44.062	37.4439	0.000000
TIME*Gender	2.696	5	0.539	0.4582	0.806324
Error	105.908	90	1.177		
TEST SESSION*TIME	3.212	5	0.642	1.0131	0.414720
TEST SESSION*TIME*Gender	5.296	5	1.059	1.6702	0.149899
Error	57.075	90	0.634		

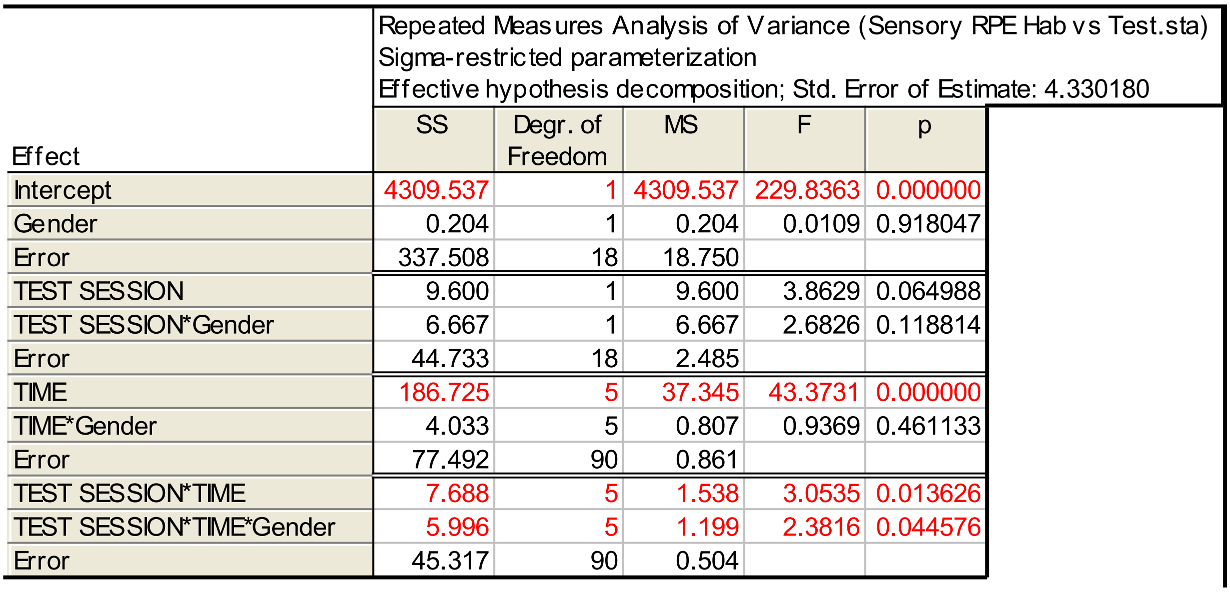
iii. RPE Effects during Motor Task



Repeated Measures Analysis of Variance (Motor RPE Hab vs Test.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 5.024903

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	3267.126	1	3267.126	129.3929	0.000000
Gender	13.776	1	13.776	0.5456	0.469646
Error	454.494	18	25.250		
TEST SESSION	2.709	1	2.709	0.4512	0.510309
TEST SESSION*Gender	0.759	1	0.759	0.1265	0.726272
Error	108.094	18	6.005		
TIME	185.980	5	37.196	28.8855	0.000000
TIME*Gender	9.355	5	1.871	1.4530	0.213192
Error	115.894	90	1.288		
TEST SESSION*TIME	0.972	5	0.194	0.3267	0.895666
TEST SESSION*TIME*Gender	1.047	5	0.209	0.3519	0.879773
Error	53.544	90	0.595		

iv. RPE Effects during Sensory Task

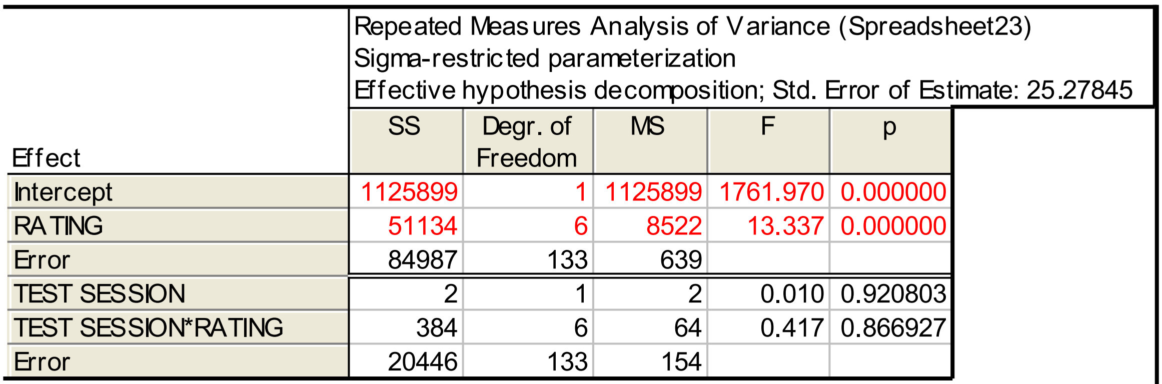


Repeated Measures Analysis of Variance (Sensory RPE Hab vs Test.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 4.330180

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	4309.537	1	4309.537	229.8363	0.000000
Gender	0.204	1	0.204	0.0109	0.918047
Error	337.508	18	18.750		
TEST SESSION	9.600	1	9.600	3.8629	0.064988
TEST SESSION*Gender	6.667	1	6.667	2.6826	0.118814
Error	44.733	18	2.485		
TIME	186.725	5	37.345	43.3731	0.000000
TIME*Gender	4.033	5	0.807	0.9369	0.461133
Error	77.492	90	0.861		
TEST SESSION*TIME	7.688	5	1.538	3.0535	0.013626
TEST SESSION*TIME*Gender	5.996	5	1.199	2.3816	0.044576
Error	45.317	90	0.504		

b. NASA-TLX

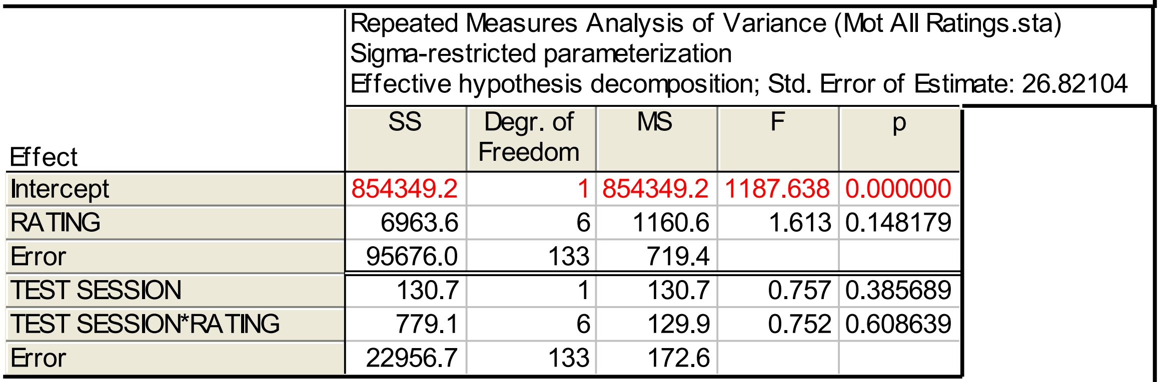
i. NASA-TLX Ratings after the Cognitive Task



Repeated Measures Analysis of Variance (Spreadsheet23)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 25.27845

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1125899	1	1125899	1761.970	0.000000
RATING	51134	6	8522	13.337	0.000000
Error	84987	133	639		
TEST SESSION	2	1	2	0.010	0.920803
TEST SESSION*RATING	384	6	64	0.417	0.866927
Error	20446	133	154		

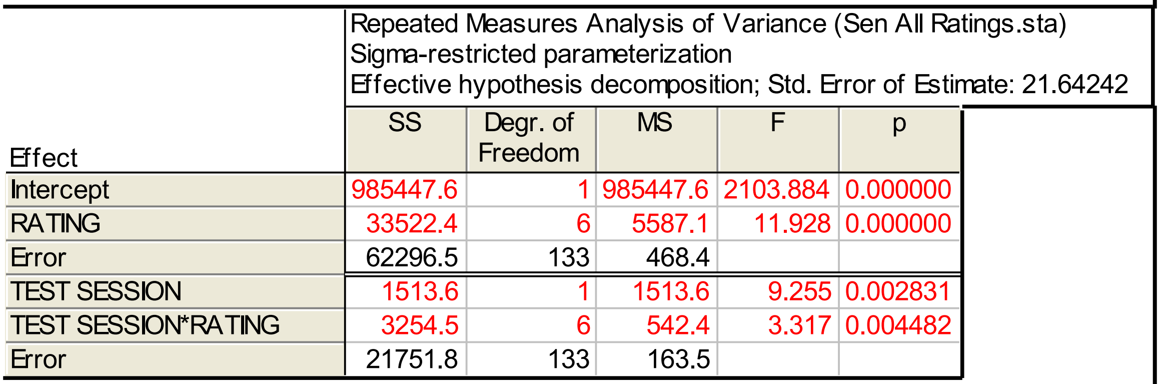
ii. NASA-TLX Ratings after the Motor Task



Repeated Measures Analysis of Variance (Mot All Ratings.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 26.82104

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	854349.2	1	854349.2	1187.638	0.000000
RATING	6963.6	6	1160.6	1.613	0.148179
Error	95676.0	133	719.4		
TEST SESSION	130.7	1	130.7	0.757	0.385689
TEST SESSION*RATING	779.1	6	129.9	0.752	0.608639
Error	22956.7	133	172.6		

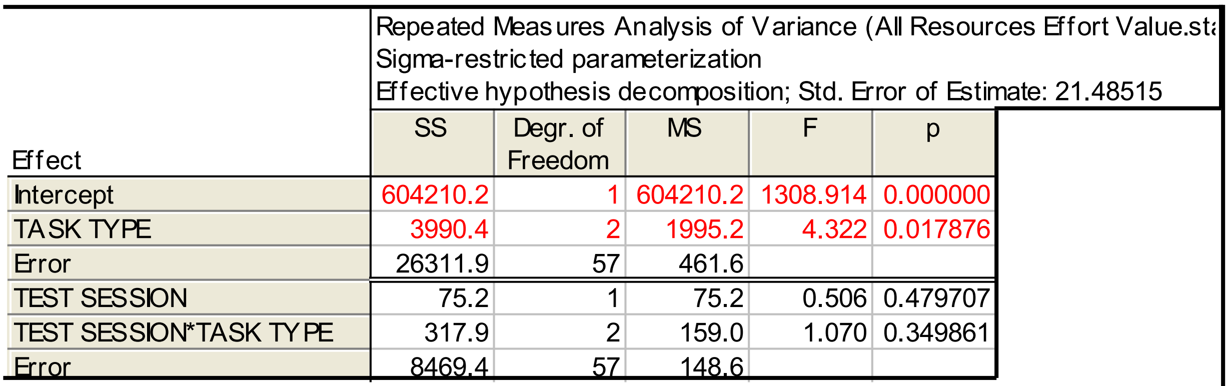
iii. NASA-TLX Ratings after the Sensory Task



Repeated Measures Analysis of Variance (Sen All Ratings.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 21.64242

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	985447.6	1	985447.6	2103.884	0.000000
RATING	33522.4	6	5587.1	11.928	0.000000
Error	62296.5	133	468.4		
TEST SESSION	1513.6	1	1513.6	9.255	0.002831
TEST SESSION*RATING	3254.5	6	542.4	3.317	0.004482
Error	21751.8	133	163.5		

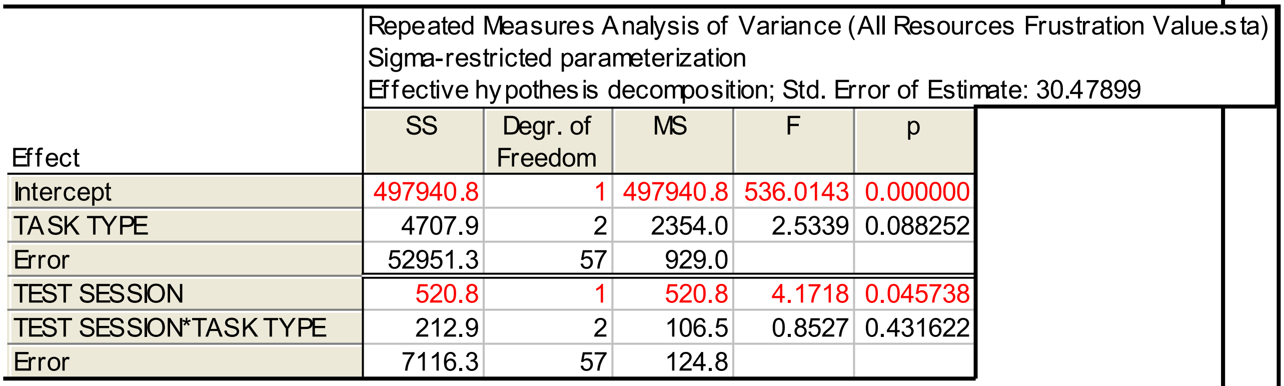
iv. Effort Value after all Tasks



Repeated Measures Analysis of Variance (All Resources Effort Value.st
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 21.48515

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	604210.2	1	604210.2	1308.914	0.000000
TASK TYPE	3990.4	2	1995.2	4.322	0.017876
Error	26311.9	57	461.6		
TEST SESSION	75.2	1	75.2	0.506	0.479707
TEST SESSION*TASK TYPE	317.9	2	159.0	1.070	0.349861
Error	8469.4	57	148.6		

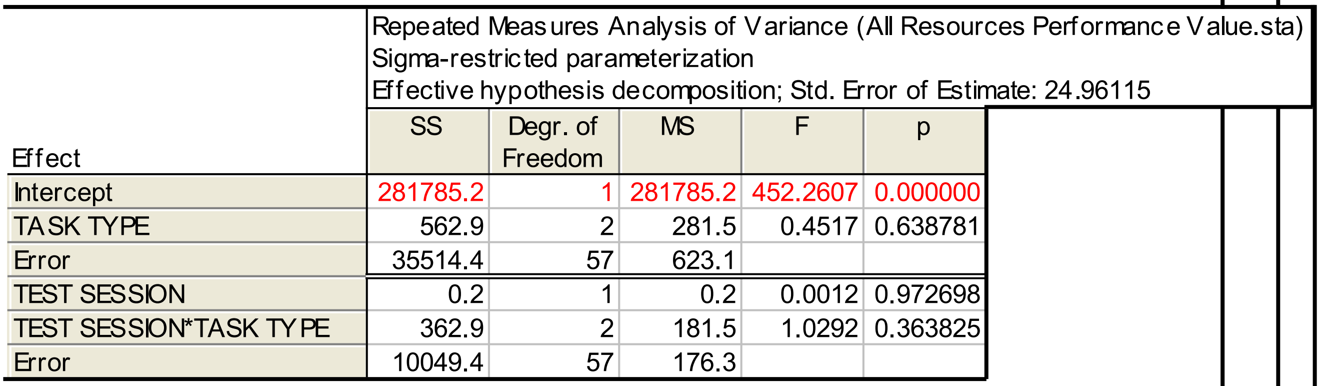
v. Frustration Value after all Tasks



Repeated Measures Analysis of Variance (All Resources Frustration Value.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 30.47899

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	497940.8	1	497940.8	536.0143	0.000000
TASK TYPE	4707.9	2	2354.0	2.5339	0.088252
Error	52951.3	57	929.0		
TEST SESSION	520.8	1	520.8	4.1718	0.045738
TEST SESSION*TASK TYPE	212.9	2	106.5	0.8527	0.431622
Error	7116.3	57	124.8		

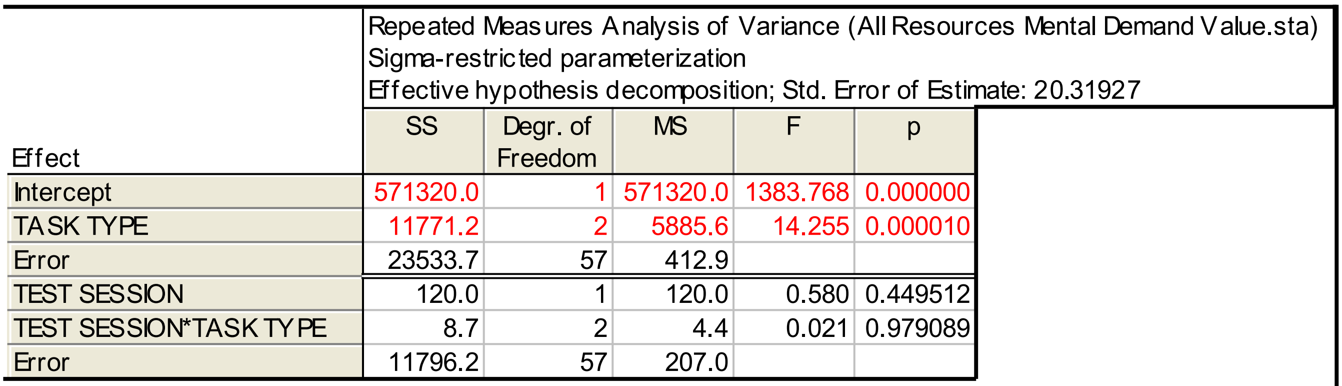
vi. Performance Value after all Tasks



Repeated Measures Analysis of Variance (All Resources Performance Value.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 24.96115

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	281785.2	1	281785.2	452.2607	0.000000
TASK TYPE	562.9	2	281.5	0.4517	0.638781
Error	35514.4	57	623.1		
TEST SESSION	0.2	1	0.2	0.0012	0.972698
TEST SESSION*TASK TYPE	362.9	2	181.5	1.0292	0.363825
Error	10049.4	57	176.3		

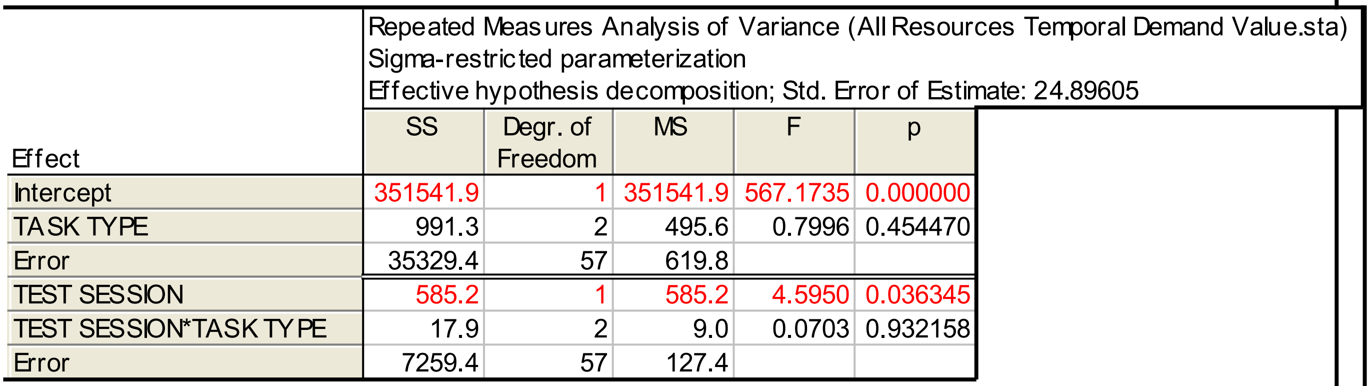
vii. Mental Demand Value after all Tasks



Repeated Measures Analysis of Variance (All Resources Mental Demand Value.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 20.31927

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	571320.0	1	571320.0	1383.768	0.000000
TASK TYPE	11771.2	2	5885.6	14.255	0.000010
Error	23533.7	57	412.9		
TEST SESSION	120.0	1	120.0	0.580	0.449512
TEST SESSION*TASK TYPE	8.7	2	4.4	0.021	0.979089
Error	11796.2	57	207.0		

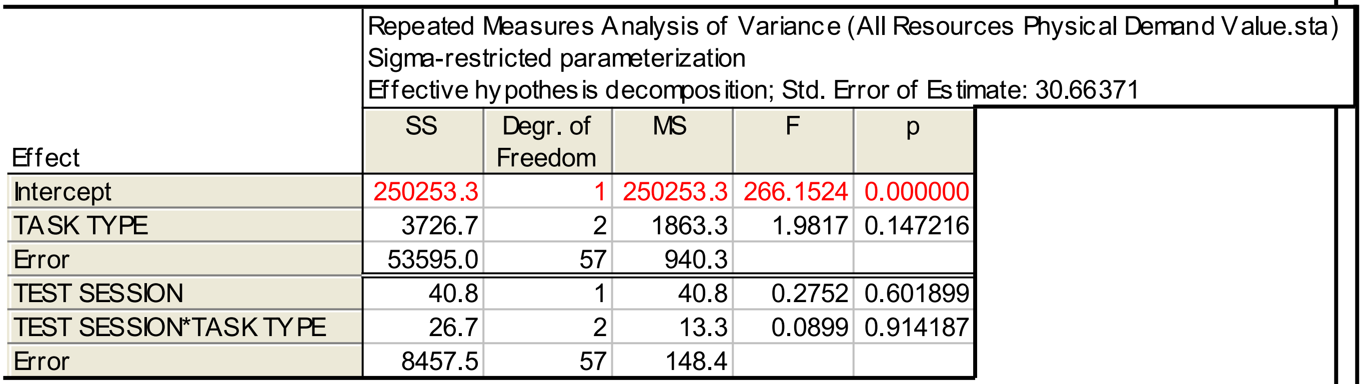
viii. Temporal Demand Value after all Tasks



Repeated Measures Analysis of Variance (All Resources Temporal Demand Value.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 24.89605

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	351541.9	1	351541.9	567.1735	0.000000
TASK TYPE	991.3	2	495.6	0.7996	0.454470
Error	35329.4	57	619.8		
TEST SESSION	585.2	1	585.2	4.5950	0.036345
TEST SESSION*TASK TYPE	17.9	2	9.0	0.0703	0.932158
Error	7259.4	57	127.4		

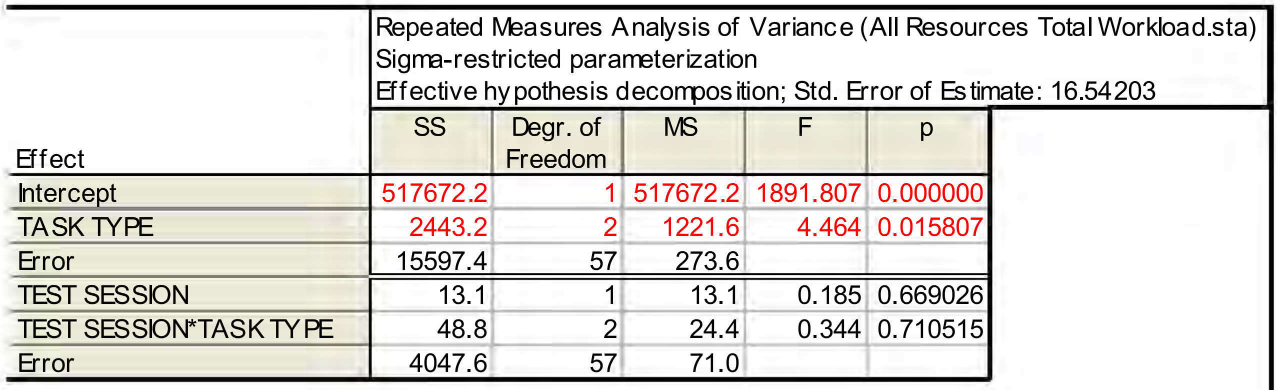
ix. Physical Demand Value after all Tasks



Repeated Measures Analysis of Variance (All Resources Physical Demand Value.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 30.66371

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	250253.3	1	250253.3	266.1524	0.000000
TASK TYPE	3726.7	2	1863.3	1.9817	0.147216
Error	53595.0	57	940.3		
TEST SESSION	40.8	1	40.8	0.2752	0.601899
TEST SESSION*TASK TYPE	26.7	2	13.3	0.0899	0.914187
Error	8457.5	57	148.4		

x. Total Workload after all Tasks



Repeated Measures Analysis of Variance (All Resources Total Workload.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 16.54203

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	517672.2	1	517672.2	1891.807	0.000000
TASK TYPE	2443.2	2	1221.6	4.464	0.015807
Error	15597.4	57	273.6		
TEST SESSION	13.1	1	13.1	0.185	0.669026
TEST SESSION*TASK TYPE	48.8	2	24.4	0.344	0.710515
Error	4047.6	57	71.0		

APPENDIX D: Figures Depicting Gender Effects

1. Temperature
2. Eye Blink Duration
3. Heart Rate Variability
4. RPE Ratings
5. Gender Effects that did not relate to the hypothesis of the study

APPENDIX D1

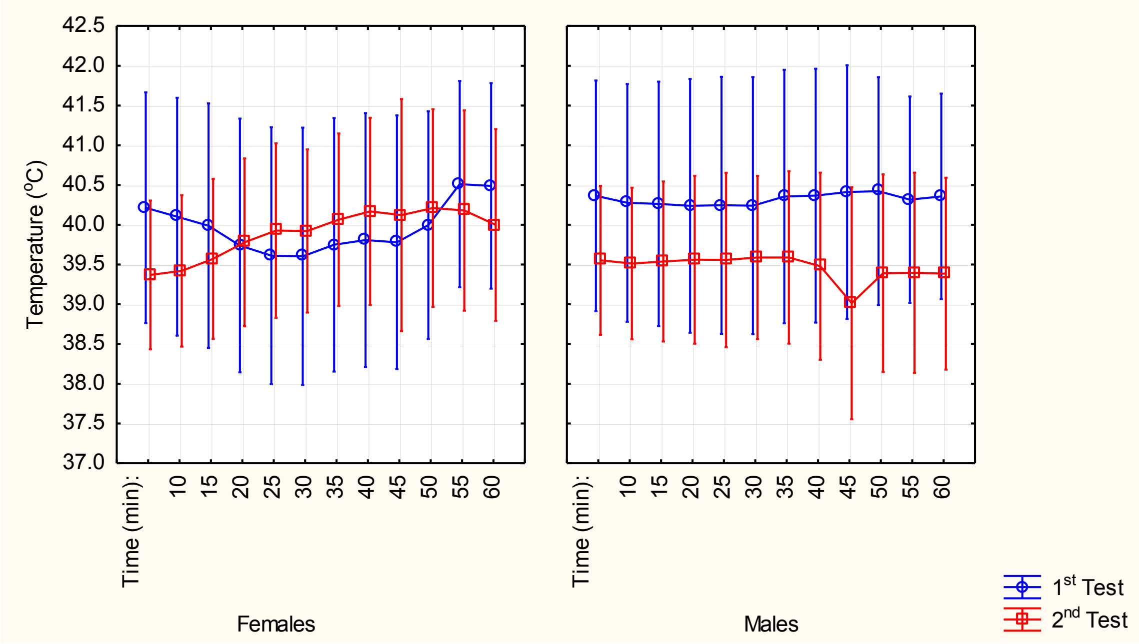


Figure 1: Ear temperature responses for males and females as a function of time-on-task for the cognitive task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

APPENDIX D 2.1

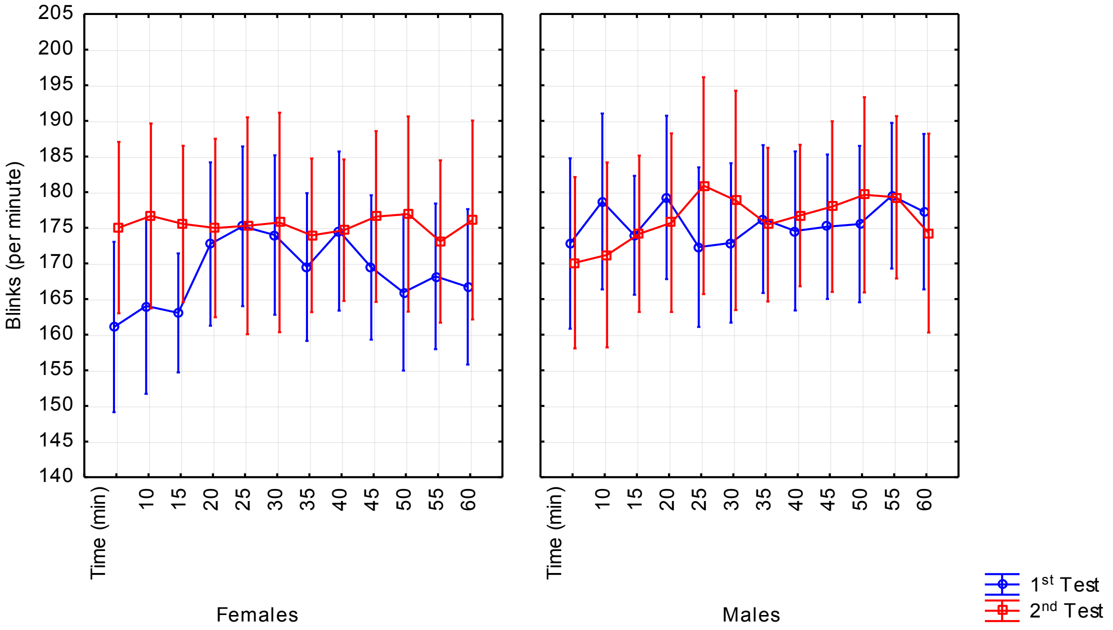


Figure 2: Eye blink duration responses for males and females as a function of time-on-task for the cognitive task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

APPENDIX D 2.2

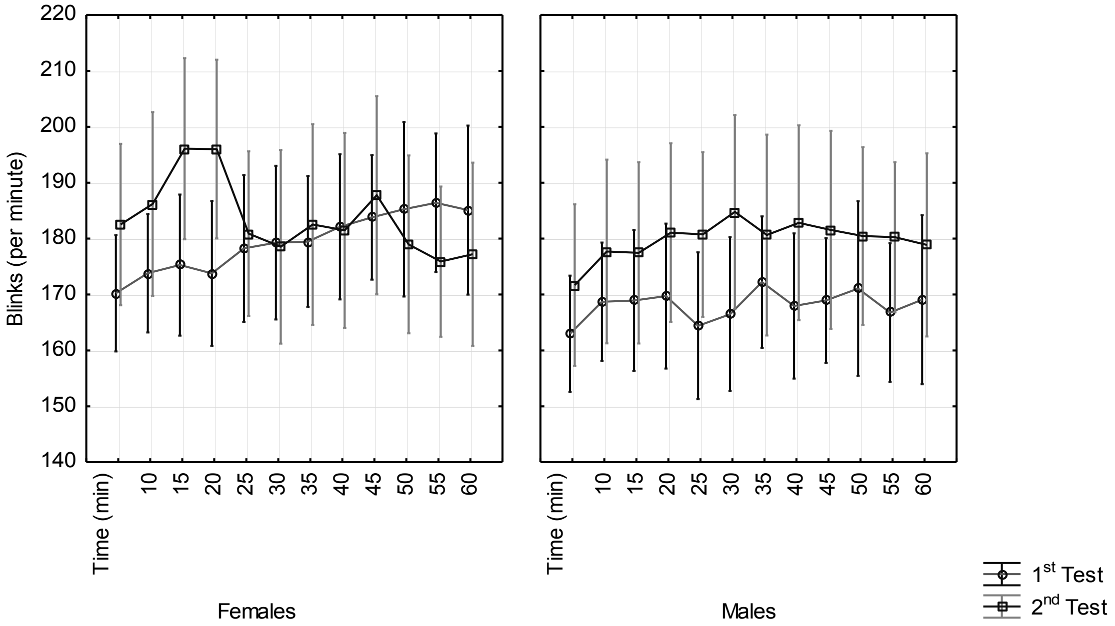


Figure 3: Eye blink duration responses for males and females as a function of time-on-task for the motor task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

APPENDIX D 3.1

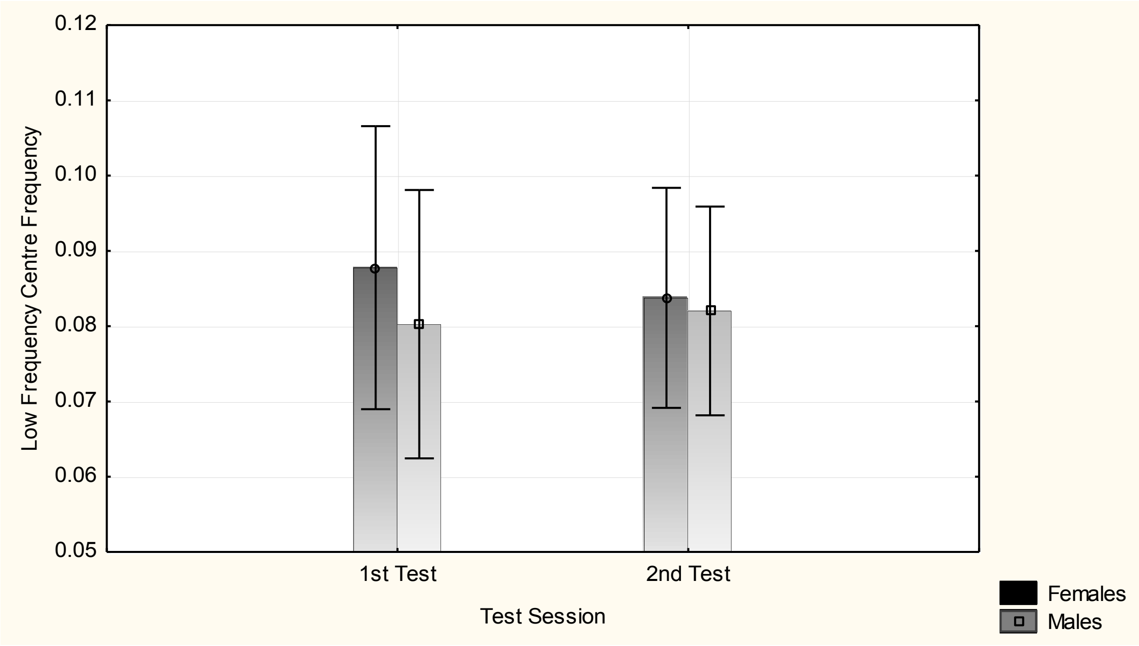


Figure 4: Low frequency centre frequency responses for males and females for the cognitive task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

APPENDIX D 3.2

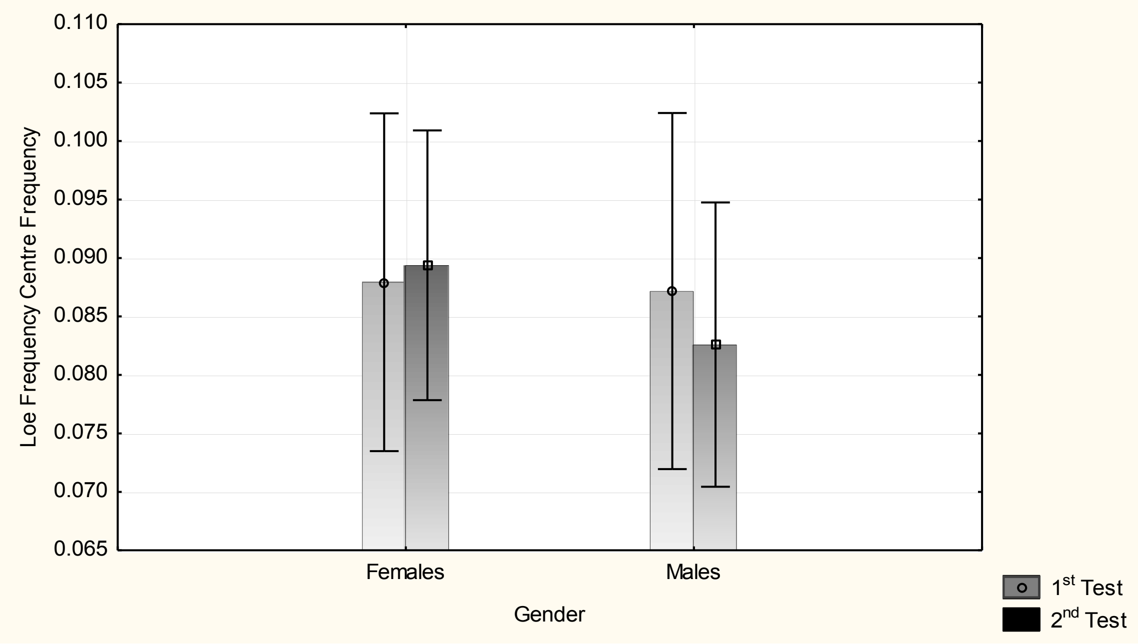


Figure 5: Low frequency centre frequency responses for males and females for the sensory task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

APPENDIX D 4.1

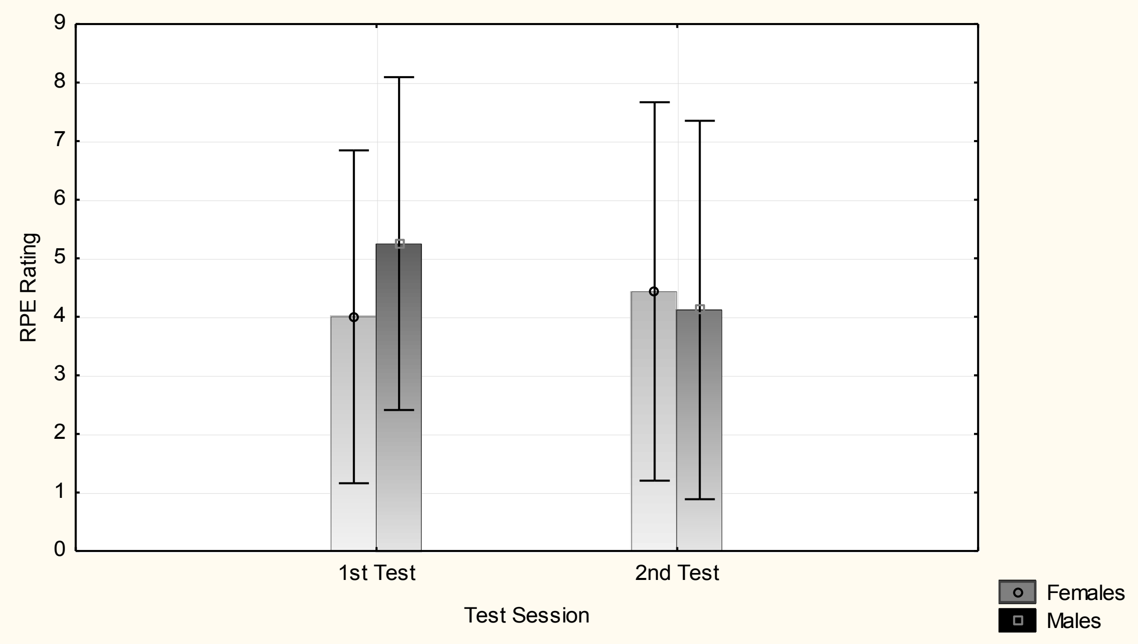


Figure 6: RPE responses for males and females for the cognitive task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

APPENDIX D 4.2

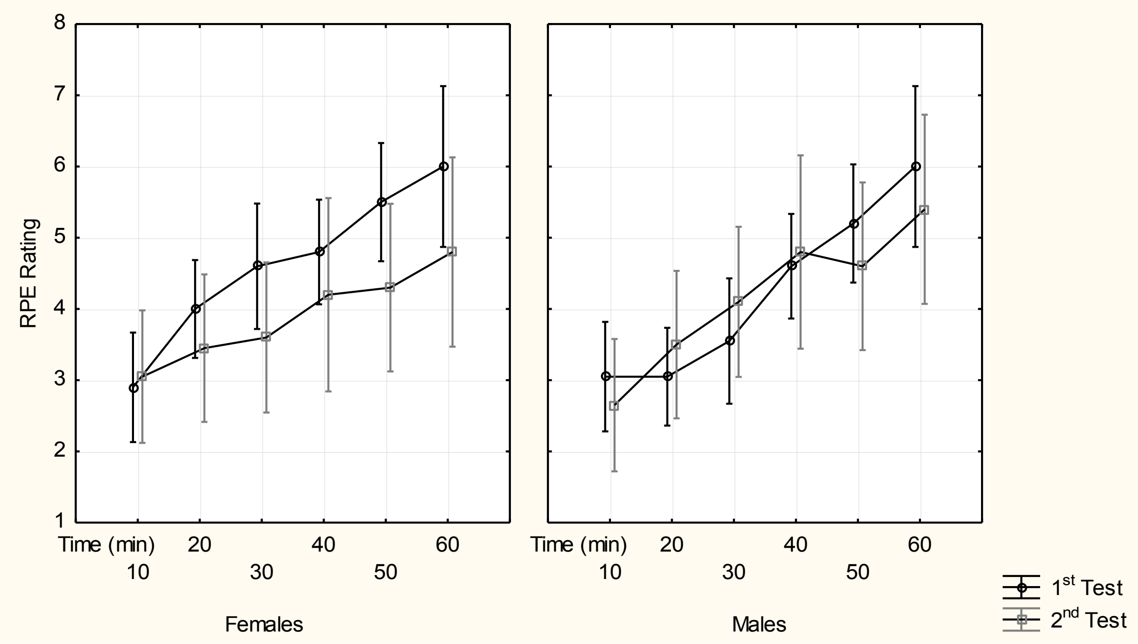


Figure 7: RPE responses for males and females for the sensory task during the 1st test and the 2nd test. Error bars depict a 95% confidence interval.

APPENDIX D 5

Table I: Depiction of gender effects for the various variables; where **HF cf** denotes the high frequency centre frequency, **LF Power** denotes low frequency power, **LF PR** denotes the low frequency power relative component, **HRF** denotes Heart Rate Frequency, **RTT** denotes simple reaction time tests.

Dependent Variable	Specific Factor with Significant Result	Brief Trend Description
Task Performance: Cognitive:		
c) Correct number recall	1. TIME by gender	Males had a lower number recall rate than females over time.
d) Response delay	2. TIME by gender	Males elicited a higher response over time.
Sensory:		
1. Word count	1. TIME by gender	Females elicited a higher reading speed over time.
Ear Temperature during the Cognitive Task	TIME by gender	Males showed higher temperature recordings.
Heart Rate and Heart Rate Variability:		
a) **HF cf** during the Sensory Task	gender	Females elicited higher high frequency responses than their male counterparts.
b) **LF PR** during:		
1. Motor Task	1. gender	Females produced lower values than males
2. Sensory Task	2. gender	Females produced lower values than males.
c) **LF Power** during Sensory Task	TIME by gender	Male responses were higher over time than female responses
d) **HRF** during Sensory Task	gender	Females had higher heart rate values.
e) **LF PR** during:		
1. Motor Task	1. gender	Females produced lower values than males
2. Sensory Task	2. gender	Females produced lower values than males
RTT responses during:		
1. Motor task	1. TIME by gender	Males performed faster over the time.
2. Cognitive task	2. TIME by gender	Males performed faster over the time.