# THE FACTORS AFFECTING SELF-REGULATION THROUGH THE ANALYSIS OF PHYSIOLOGICAL, PSYCHOLOGICAL AND BEHAVIOURAL MEASURES DURING TASK-SWITCHING

**BY**

**CALEY CHAPLIN**

**THESIS**

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

**Department of Human Kinetics and Ergonomics**

**Rhodes University, 2013**

**Grahamstown, South Africa**

# ABSTRACT

Individuals are required to manage multiple tasks which require strategic allocation of time and effort to ensure goals are reached efficiently. By providing the worker with autonomy over their work, performance and worker well-being have improved. This increased control allows individuals to organize work according to the needs of the body, which prevents fatigue leading to improved productivity.

When given the option, humans tend to switch between tasks frequently. This behaviour can be used to determine the change in self-regulation strategies. An understanding of human task-switching behaviour is important for the design of job rotation systems. However, there is a lack of evidence explaining the factors motivating the need to switch between tasks. This study aims to use physiological, subjective and behavioural measures to explain the factors influencing self-regulation through the act of task-switching.

Three primary hypotheses were developed to explain the factors underlying task-switching behaviour. It was hypothesized that the degree of boredom experienced, the effort required to perform the task and the resource usage induced by the task are factors responsible in deciding task switching behaviour.

Participants (17 males and 17 females) switched freely between five different information-processing tasks for the 45 minutes. Participants were allowed to switch back and forth between tasks and did not have to conduct all five tasks. The following measures were recorded during the experiment: subjective measures of boredom, mental effort, task frustration and perceived performance of the tasks; energy consumption and physiological measures of effort (HR, HRV and body temperature) and behavioural measures, including duration and frequency of task.

Perceived boredom was found to differ among the tasks and before and after the experiment. The average boredom rating at each task transition for all tasks exceeded a score of 2.5 out of a possible 4. There were no significant changes in physiological measures between the beginning and end of the task trials. However, changes in physiological measures showed a decrease in effort investment following task transition. Heart rate variability was lower for externally-paced tasks than for self-paced tasks, despite the differences in cognitive demands. The most frequent task-switch combination occurred between tasks of high and low cognitive demand. The least frequent task-switching combination occurred between tasks of similar characteristics, which produced no differences in physiological responses.

Task-switching behaviour was influenced by the degree of boredom, and therefore more time was spent on less monotonous tasks. The level of physiological effort required for the task affected task-switching behaviour. Task switches were made before any changes in effort took place in an attempt to maintain task efficiency. It appears plausible that a task switch was made to reduce effort investment and activation levels. The type of information processing resources used by different tasks affected the task-switching combinations. Individuals tended to switch between tasks of differing resources so that those in limited supply were able to replenish. Therefore the findings from this study can potentially be used to improve the design of job rotation systems. Such improvements may enhance productivity and worker well-being by inhibiting the onset of down regulation and fatigue processes. This study showed that autonomy is necessary for individuals to regulate behaviour to suit human needs.

# ACKNOWLEDGEMENTS

I would like to take this opportunity to thank the following people who guided and supported me through the duration of my thesis.

To my supervisor, Professor Matthias Goebel, for his guidance and continued dedication throughout the research process. Your assistance in developing the research concept and executing the statistical analyses was much appreciated. Thank you for teaching me invaluable academic skills and introducing me to an area of research I have grown passionate about.

To both Dr Swantje Zchernack and Jono Davy for their suggestions, advise and continued assistance throughout.

To Ergonomics Technologies (Armscor) and Rhodes University for assisting me financially during my Masters and therefore making my thesis a possibility.

To my fellow classmates and friends for their friendship and encouragement, especially through the difficult times.

Finally, to my family, Jem, Sandy, Greg and Dave who have shown me unconditional love and kept me motivated throughout this journey. Your faith in my ability encouraged me to maintain focus and determination right to the end.

# TABLE OF CONTENTS

## LIST OF FIGURES

**LIST OF TABLES**

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND TO STUDY

The modern working office jobs have become more complex (Maume and Purcell, 2007) and often require the processing of abstract information (Meijman, 1997). The increase in work stress and mental effort caused by greater productivity demands can lead to fatigue, if not managed properly by the individual (Flynn and James, 2009). Office workers are faced with multiple tasks to be completed most efficiently (Gonzalez and Mark, 2005), therefore the strategies used to allocate attention and effort to achieve these goals have become increasingly important. Research has shown that by freeing office workers from excessive external control, job performance and worker well-being has increased (Jermier and Michaels, 2001). An increase in worker autonomy allows for the organization of work to be adapted to suit the human needs. This may help in preventing the adverse effects of fatigue and stress on human performance, and improving productivity (Jermier and Michaels, 2001).

The work environment survey (2005), highlighted an increase in workload, a decrease in control over work pace and less support from fellow employees and managers, leading to more adverse working conditions (taken from Lundberg, 2007). More specifically, there has been an increase in percentage of workers indicating no control over pace of work for at least half their working time, from 49% in 2003 to 52% in 2005 (Lundberg, 2007). The modern working environment limits the workers' the flexibility to switch between tasks when desired. This lack of control over one's actions may result in compromised job satisfaction and human well-being (Parkes *et al.*, 1990). Certain jobs have become more specialized, resulting in workers conducting one rather than numerous tasks (for example in production line systems) (Lord *et al.*, 2010). This has limited the options available for regulating performance because there are fewer tasks to switch to when fatigue or monotony sets in. In contrast to this, Gonzalez and Mark (2005) found that people are responsible for managing multiple activities in their everyday jobs. These studies have not identified the strategies used to cope with the stress and strain induced by multiple activities. Job stress and work-related illness has become an increasing concern (Schmidt *et al.,* 2007). Steptoe *et al.* (1997) stated that job strain causes health risks which are highest in individuals who have a mismatch between task demands and task control, where demands exceed the level of control individuals have over their work. In production line work, the worker is required to complete the task in the assigned cycle time. This limits the options to regulate performance due to the lack of control by the worker (Knight and Salvendy, 1981, Flynn and James, 2009).

In reality, individuals switch back and forth between tasks (Gonzales and Mark, 2005), and this can be seen as a means of escaping adverse conditions such as monotony induced by the task. Task-switching is a type of strategy used to self-regulate behaviour and performance. Self-regulation refers to an internal process that enables an individual to guide their behaviour towards a desired goal over time and with changing contexts (Luszczynska *et al.,* 2004). It involves setting goals, planning actions, monitoring performance progress and controlling and regulating cognitive activities and behaviour (Karoly, 1993). These processes are based on feedback from the information processing system with the intention of maintaining a level of performance necessary to reach the task goal (Pintrich *et al.,* 1993).

Little research has attempted to use physiological, subjective and behavioural measures to explain the need for task-switching to occur. From this, information can be gained about the criterion used to decide on the appropriate self-regulation strategy during task-switching. There are explanations as to how psychology plays a role in regulating performance, but this is qualitatively-based research and relates mainly to learning and self-control (Karoly, 1993). Karoly (1993, pg. 45) states that “self-regulation has, until recently, defied experimental analysis, perhaps because of its uncertain epistemological status” and that “self-regulation has not achieved a simple or uniform paradigmatic embodiment.” Hockey’s model (1997) proposes that individuals unconsciously alter their performance, for example with regard to speed and accuracy, as resources become limited in order to prevent the depletion of resources. Chaplin and Goebel (2011) conducted a study in which a prolonged reading task resulted in significantly increased performance decrements over time; however there were no significant changes in physiological measures. It was concluded that with time on task, resources became fatigued; hence the individual regulated reading performance to maintain a constant strain on the physiological system. The lack of understanding about factors responsible for task-switching, motivated the need for further research on self-regulation strategies pertaining purely to information-processing tasks.

## 1.2 STATEMENT OF THE PROBLEM

Interventions, such as job rotation, are commonly used to overcome the challenges of performance decrements by reducing fatigue (resource depletion) and counteracting monotony (task disengagement) (Jahandideh, 2012). However, there are conflicting proposals as to the most effective job rotation design. Furthermore, most of the evidence supporting these designs pertains to physical rather than cognitive tasks. In an attempt to resolve these inconsistencies, an understanding needs to be gained of the factors responsible for causing a switch between tasks. Once these factors are identified, the task/job can be manipulated to avoid the resultant adverse effects of these factors on task performance.

Individuals are designed to self-regulate and adjust performance based on internal feedback about the system's state (Lord *et al*., 2010). If self-regulation processes are restricted by external factors such as time pressure, it poses the risk of human performance being compromised by human error and inefficiency, and health and safety being jeopardised (Schmidt *et al.,* 2007). A more sound understanding of self-regulation and its effect on behavioural, physiological and subjective responses is essential for optimizing work systems relating to job rotation and managing work schedules (Oshuga *et al.,* 2001). This study therefore uses task-switching as a means of representing internal self-regulation processes. Task-switching could be an option for individuals to escape the negative effects associated with the current task so as to prevent performance decrements.

The aim of this study was to determine the factors responsible for causing individuals to switch between tasks. Physiological, behavioural and subjective responses were monitored in an attempt to explain the task-switching behaviour of individuals when allowed to switch freely between tasks.

## 1.3 RESEARCH HYPOTHESES

The study aimed to investigate three main hypotheses proposed to explain self-regulation through the act of task-switching.

### 1.3.1 Perceived boredom

Perceived boredom is caused by a lack of stimulation by the task, which generally leads to task aversion. The accumulation of monotony occurs more quickly during simple repetitive tasks. Therefore persistence on a monotonous task tends to be more difficult and may cause discomfort. This suggests that individuals would choose to spend less time on monotonous tasks and switch away from a task when the perceived boredom was too high to continue. The study hypothesized that perceived boredom motivated the need to switch between tasks.

A significant difference in perceived boredom was expected before and after the experiment. Perceived boredom was expected to be greater during the task transitions than the corresponding baseline measure. It was expected that less time would be spent on monotonous task.

### 1.3.2 Effort regulation

Physiological effort is required to perform an information-processing task. The amount of effort depends on a number of factors such as task complexity, resource demands and motivation. With time, the strain induced by the task accumulates, therefore to maintain the performance level more effort is invested in the task. Alternatively, the individual can decide to switch to another task rather than invest more effort. The regulation of effort was hypothesized to have an influence on task-switching behaviour.

It was expected that there would be a significant difference in physiological responses (measure of effort) between the beginning and end of the task trial, and before and after the task transition. This would indicate that a task switch occurred in response to changes in effort based on the effort regulation strategy used to self-regulate performance. It was expected that more time would be spent on tasks requiring less effort.

### 1.3.3 Resource use

Resources are said to be finite, and the type of resource used differs according to the processes required by the task. Therefore, depending on the task, some resources will be more demanded than others. The longer the time spent on the task, the longer the strain on the resources. The body protects the resource supply from becoming depleted by a change in behaviour, such as switching to another task. It is expected that a switch to a task demanding different resources will allow for a replenishment of the previously taxed resources. It was therefore hypothesized that the type and amount of resources required by the task would affect the task-switching behavior.

It was expected that certain task switch combinations would occur more frequently than others. It was expected that a task switch would occur between tasks demanding different resource types. It would be expected that the type of resources required by one task may be more efficient than another, resulting in more time being spent on that particular task.

## 1.4 DELIMITATIONS

This study analyzed behaviour regulation during information-processing tasks. The study consisted of the option of five different information-processing tasks to switch between as desired for 45 minutes. Four of the tasks were performed on the computer and one task was performed using a pen and paper. The dependent variables included energy expenditure, respiration rate, heart rate, heart rate variability, body temperature and performance measures, where only accuracy and speed were measured. In addition, subjective measures of boredom, mental effort, task frustration and perceived task performance were recorded. Boredom ratings were also taken during each task transition and so the participant verbally stated the rating to avoid any physical movement involved in writing.

The sample used in this study consisted of 34 Rhodes University students, who ranged between the ages of 18 to 22 years. Equal numbers of males (n=17) and females (n=17) were used in the investigation. Exclusion criteria for participation in the project included: participants who were dyslexic or had any attention or learning disorder. Participants were excluded if they had prior experience with the information tasks as this would influence the task-switching behaviour and performance output. Participants were required to be in good health and ensure that sufficient sleep (8 hours) occurred the night before testing.

Data collection took place in a controlled laboratory setting in order to control potentially confounding environmental factors such as lighting and temperature. This also ensured that the protocol remained consistent among participants. Furthermore, because cardiovascular measures (heart rate and heart rate variability) were recorded, it was vital to ensure conditions were kept constant. These measures are highly sensitive to external factors such as noise and any stimulus that may cause an emotional response. The experimental setup was designed to ensure that the tasks involved as little physical movement as possible as this would interfere with the physiological measures. This was achieved by setting up the tasks on a round rotating table so that individuals could remain in a fixed seat, while the task was moved in front of them.

### 1.5 LIMITATIONS

This experimental investigation aimed to control all variables that could potentially influence the final results. However, due to the multiple and complex factors affecting human behaviour and performance, certain limitations present in this investigation could not be eliminated. These are highlighted below.

The participants used in the study were limited to students from Rhodes University who volunteered to participate. They were representative of the educated population of this particular age group. The study did not include males or females younger than 18 or older than 22 years.

The regulation of behaviour was manipulated by the experimental setup rather than a real-life working situation. The laboratory settings may have reduced motivation and effort invested in the experiment in comparison with what might have occurred in the field. In a real-life working situation, the tasks would have greater importance to the participants, thus increasing the levels of effort and attention. Hockey (1997) stated that performance decrements are more common in laboratory versus field setting due to the higher levels of motivation in a real job.

Participants may have felt anxious and uncomfortable during the experiment as unfamiliar equipment was fitted to them and individual performance was monitored during the tasks. This may have influenced performance output and physiological responses, as opposed to what would have been encountered in a real working life scenario.

Prior to testing, participants were told to adhere to a set of requirements. The researcher could not be certain that these instructions were followed, except by verbal confirmation, and this may have affected the behaviour of the individual.

A limiting factor in the method was that one particular task may have been more popular and more attractive than another. Alternatively, some tasks may have discouraged the individual from choosing them, leaving the experimenter with results showing a very high percentage of time on task x, for example, and very little time on task y. As the experimental setup allowed individuals to switch freely between tasks, a transition may have occurred without a designated factor motivating the need for it.

Subjective measures were used to rate perceived boredom and attitude towards the tasks. These measures could be seen as a limitation to the study, because individual interpretations may differ, leading to less reliable results despite prior explanation about the use of the scales.

The experimental setup aimed to reduce all physical movement as much as possible to prevent this from confounding the physiological measurement of mental effort. However, it was a methodological limitation, as all physical movement, such as a postural change, could not be completely eradicated from the experiment. Additionally, the type and rate of motor response differed among the tasks. That being said, additional measures of mental effort such as subjective rating of mental effort of each task, heart rate variability and temperature were recorded to support the findings of energy consumption.

# CHAPTER 2

# REVIEW OF LITERATURE

## 2.1 INTRODUCTION

The shift in work character over the years, has led to an increase in strain on the information processing system which is made up of the perceptual, cognitive and motor sub-systems (Meijman, 1997). Meijman (1997, p.32) states that the concept of 'work' has changed from the act of manipulating tangible objects to the "mental processing of abstract data". According to Singh et al. (2010) this revolution in technology has caused humans to become passive observers of automated systems rather than active controllers which can both increase and decrease mental workload. Self-regulation has therefore become increasingly important in influencing human performance. A more sound understanding of the underlying factors causing individuals to switch tasks can be used to improve job rotation systems. This can ensure that a task/job is switched away from before the occurrence of performance decrements or the requirement of excessive effort. The intention of this research was to allow individuals to regulate behaviour through the act of task-switching.

This chapter introduces and develops the concept of self-regulation and explains the mechanisms responsible for this process. The factors affecting self-regulation are addressed with particular focus on boredom, resource use and effort investment. The measurement and testing of self-regulation will be discussed, where both task-switching and the level of control over an individual's own actions are included. This study hypothesized that boredom, resource use and the amount of effort required for the task are responsible for causing changes in control strategies, more commonly known as self-regulation. These factors are proposed to cause fluctuations in physiological responses which may in turn influence behaviour and performance (Van der Linden *et al*., 2003). Therefore a detailed review of the types of measures used to measure mental effort concludes this chapter.

## 2.2 SELF REGULATION

### 2.2.1 Definition of self-regulation

Self-regulation can be interpreted in a number of ways depending on the context and circumstances. A general definition of self-regulation is that it is an internal process enabling an individual to guide their behavior towards a desired goal over time and with changing contexts (Luszczynska *et al.,* 2004). More specifically, it involves the modulation of attention and behavior in response to feedback signals automatically sent to the brain (Behncke, 2011). Pintrich *et al*. (1993) define self-regulation more simply as the ability to set goals, plan actions, monitor progress and control and regulate cognitive activities and behaviour. Behncke (2011) states that self-regulation controls behavior along a specific path with the intention of achieving a target. It is proposed that self-regulation prevents degradation of performance by altering the level of effort invested in the task (Meijman, 1997). Self-regulation is described as “voluntary action management” by the individual (Karoly, 1993, p.24). Tanner and Jones (2003) describe an example of a self-regulation strategy where during a reading task, individuals will change the pace based on whether the text is less familiar and thus more difficult. Self-regulation is thought to differ in strength among humans (Karoly, 1993). It can be described as a resource that is drawn upon in order to complete a task and meet self-regulatory demands such as persisting in a difficult task (Segerstrom and Solberg Nes, 2007). Self-regulation is an internal process that causes the individual to alter and adjust performance and actions through observable behaviour changes.

### 2.2.2 Behaviour regulation strategies

Where individuals are faced with highly demanding tasks, a variety of strategies are used to cope with these demands. Cnossen *et al*. (2000) describes three possible performance regulation strategies: firstly one can invest more effort in the task. Performance is compared to the goal state and if discrepancies exist, more effort is invested. This process is controlled automatically until the amount of effort increases beyond a threshold, after which the process must be controlled by higher cognitive functions (Singh *et al.,* 2010). Secondly, one can adapt the working strategy to be less demanding by reducing the work speed and working less accurately. A driving simulator study proved that an increase in task demands resulted in a decrease in driving speed (Cnossen *et al.,* 2000). Thirdly, one can focus on the main task while paying less attention to subsidiary tasks that are not essential in achieving the desired task goal. This was shown in a driving simulator study where individuals checked the rear-view mirror less frequently as the task demands increased due to increased traffic (Brookhuis *et al.,* 1991)

Another type of regulation strategy used by individuals is known as the promotion or prevention strategy (Keller and Bless, 2006). Humans generally act by avoiding pain and moving towards pleasure. Therefore, in terms of self-regulation, individuals will choose tasks that provide satisfaction and avoid those that result in discomfort (Keller and Bless, 2006). The same applies to performance in that as soon as a level of discomfort is reached, individuals will adapt their behaviour by reducing motivation and effort which may result in performance decrements. This is known as task aversion, where individuals become unwilling to continue with the task and task disengagement occurs (Matthews *et al*., 2010). Singh *et al*. (2010) describe a regulation strategy where experienced workers will work ahead of what is required during periods of low workload so as to prevent peaks of high workload. Lorist *et al* (2000) describe a strategy where modifications in speed and accuracy occurred. The primary goal was to maintain speed of performance, therefore with time on task, errors increased, while speed was kept constant. However, after one hour on the task, both speed and accuracy were compromised.

### 2.2.3 The role of feedback

A feedback loop involves a series of events where the condition of the body is monitored, evaluated, adjusted, re-monitored and re-evaluated (Tortora and Derrickson, 2006). The majority of physiological systems are closed-loop negative-feedback systems (Bahill and Hamm, 1989). Constant feedback, regarding the system state, is used to regulate performance in order to protect the system from exhaustion and system failure (Kahneman, 1971). Prior to starting a task, individuals will set a goal or standard in which they aim to achieve throughout the task (Karoly, 1993). Feedback loops allow the individual to adjust the level of performance where necessary to ensure the goal or standard is reached. Feedback loops are made up of four components; the input function, reference value, comparator and the output function (Karoly, 1993., Carver and Scheier, 1998., Boekaerts *et al*., 2000). According to Karoly (1993) and Boekaerts *et al*. (2000) the input function relies on the sensory system to collect information and is referred to as perception. The reference value is referred to as the goal or standard to be achieved. The comparator compares the actual state to the desired state and determines whether a discrepancy exists or not. The output function refers to the behaviour of the individual which is mostly external; however it can also be an internal response such as an increase in heart rate (Figure 1).

During a task, an individual will perceive how one is currently performing (input function) and compare this state to the desired state (goal) by the use of the comparator (Lord *et al.,* 2010). If there is no discrepancy between the two, the behaviour (output function) will remain the same. However, if a discrepancy is detected the behaviour will change (Boekaerts *et al.,* 2000). Negative feedback loops refer to those that aim to eliminate any discrepancy between the two states, thus self-regulation uses negative feedback loops to change the output with the intention of reducing discrepancy between actual and desired state (Carver and Scheier, 1998, Lord *et al*., 2010). The change in output may involve behavioural changes which either increases or decreases effort invested in the task. In addition, cognitive changes can occur to change the interpretation of the goal, input or the discrepancy (Lord *et al.,* 2010).

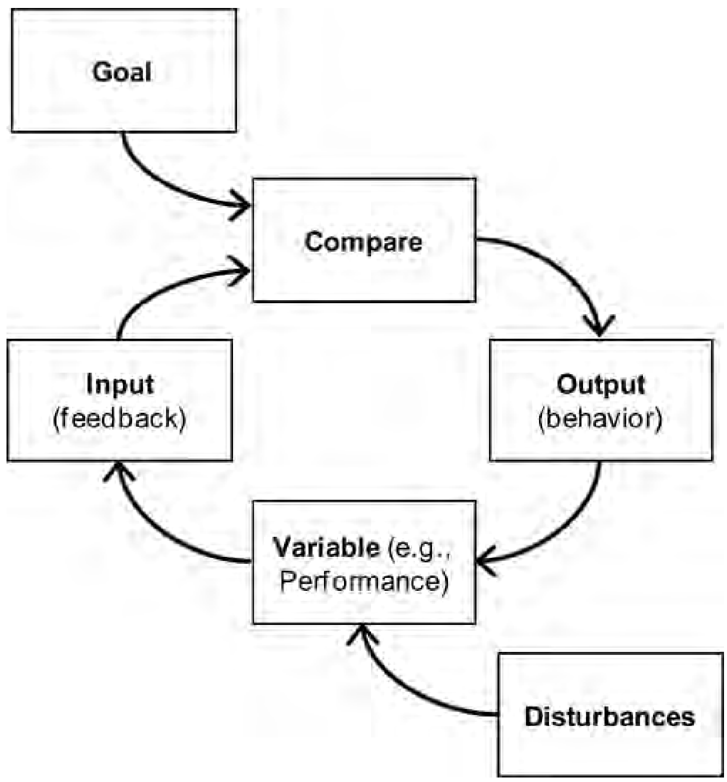


Figure 1: Simplified feedback loop used to regulate behaviour during information-processing tasks (Sources from Gregory *et al*., 2011)

In summary, the process of self-regulation is known to be managed consciously by the executive control system, however, in addition to this, goal structures (in the frontal lobe) and affective systems (in the midbrain) work together to unconsciously control goal maintenance, the access of information and regulation of attention (Lord *et al.,* 2010).

## 2.3 THE EXECUTIVE CONTROL

The executive control is an area in the frontal region of the brain responsible for changing the way an individual deals with the task demands and is thus responsible for regulating performance (Rubinstein *et al.,* 2001). The function of the executive control is to “regulate perceptual and motor processes to respond in an adaptive way to changing circumstances” (Van der Linden *et al*., 2003, pg. 47). In terms of task-switching, Rubinstein *et al* (2001) stated that the executive control manages the selection, initiation, execution and termination of tasks. The executive control is responsible for both the goal shifting and rule activation processes that are required during task-switching, however these processes are separable from the perceptual, motor and cognitive processes required in completing the task at hand (Rubinstein *et al*., 2001).

If a task becomes more complex; the number of distractions increases or fatigue sets in and therefore the executive control must decide on an action plan (DeShon *et al.,* 1996). This may, for example, involve increasing the mobilization of energy to sustain the level of performance required to reach the goal (DeShon *et al.,* 1996, Hockey, 1997). The executive control can also choose to not increase the effort level, resulting in a decreased performance level and thus failure to reach the desired target (Hockey, 1997). This may be favourable in conditions where the outcome is not worth the cost of the increased effort. The executive function adjusts the input of effort based on the output while taking into account feedback from the body (Hockey, 1997). If the individual is willing to invest more effort in the task, performance impairments, as a sign of fatigue, will not be present (Meijman, 1997). This indicates that self-regulation acts against down regulation and the onset of fatigue. Mental fatigue prevents the ability of the central executive to manage task demands effectively and therefore this state must be avoided by the individual. Meijman (1997) concludes that to maintain required performance levels, one must invest more effort. That being said, by sustaining increased mental effort, one is sustaining activation of physiological systems which increases stress reactions leading to negative health and well-being consequences (Meijman, 1997)

## 2.4 FACTORS AFFECTING SELF REGULATION

Behaviour regulation is ultimately controlled by an optimization criterion developed by the individual depending on the task goals. The strategy adopted by the individual will be influenced by a number of factors such as energy consumed, effort, resource usage, task boredom, fatigue, and motivation and activation level. These factors help us to understand why individuals choose to switch among tasks and regulate performance over time.

### 2.4.1 Energy consumption and effort

It is known that the activity of the brain relies on glucose as an energy source (Gailliot *et al*., 2007). It makes up 2% of the body’s mass but uses 20% of the body's total calories (Dunbar, 1998). Consequently, it is hypothesized that individuals select and switch tasks based on the perceived energy costs required during the task. Lorist *et al* (2000) suggest that sufficient functioning of cognitive control mechanisms depends on the energetics of the human information processing system. The ratio hypothesis states that the optimum ratio of output to energy consumption is a factor in deciding which task alternation profile to choose. Individuals will strive to choose a task that is the least taxing or enduring in terms of effort, fatigue and boredom (Lorist *et al*., 2000). Gailliot *et al* (2007), state that generally cognitive processes are not affected by slight changes in glucose levels, although processes that depend on the executive function are effortful and thus susceptible to fluctuations in glucose. Kennedy and Scholey (2000) suggested that increased heart rate during cognitive tasks may be an attempt to increase delivery of glucose to the active neural substrates involved in the cognitive processing. Gailliot *et al* (2007) found that participants made more errors during a stroop task[1] when glucose levels were lower. However, Owens and Benton (1994) found that low glucose levels impaired performance only during complex tasks (controlled processing) and not simple tasks (automatic processing). Because self-regulation is an effortful process, changes in glucose levels may influence the regulation strategies used by the executive control.

Efficiency, in terms of the input to output ratio, will influence behaviour depending on the regulation strategy chosen by the individual. One could decide to be less efficient by performing with a low accuracy and high speed or *vice versa*. Alternatively, one could equally compromise speed and accuracy, making the effort required for task execution more efficient. The amount of effort invested in the task will alter the efficiency strategy used to complete the task (Hockey, 1997). Gaillard and Wientjes (1994) found that highly demanding tasks requiring high effort investment will result in large energy costs, making it an inefficient task that is not worth continuing. An increase in workload will cause a decrease in efficiency, unless increased effort is invested in the task (Hockey, 1997).

---

[1] The Stroop task (Stroop, 1935) involves naming the colour of the ink in which an incongruent word is printed. For example, the word blue is printed in the colour red and therefore the answer is red.

Effort investment is a control option in regulating behaviour; therefore it is important to monitor effort levels according to the performance output. Van der Linden *et al* (2003) found that with time on task, the stress applied to the cognitive system accumulates, leading to greater effort needed to sustain a given performance level. Hockey (1997) proposed that an individual is continually required to adjust the effort invested in a task to maintain the desired level of performance over time. This effort level may be increased or decreased depending on whether or not the individual deems it worth maintaining performance to reach a desired goal.

The amount of effort invested in a task fluctuates according to the regulation strategy used, which is based on feedback received in terms of reaching the task goal (Hockey, 1997). When a mismatch between performance level and goal state exists, individuals can decide to either increase effort investment or accept a performance output below the set goal (Singh *et al.,* 2010). Lundberg and Frankenhaeuser (1978) found that when individuals conducted an arithmetic task under noise stress there were two options to regulate performance: either performance decreased and no changes in adrenaline and subjective effort were observed, or performance was sustained and increased adrenaline and effort were recorded. However, if maximum effort has been invested and performance output is low, this strategy cannot be adopted and this results in increased strain (Singh *et al.,* 2010). Disengagement occurs when further energy expenditure is not effective to maintain performance (Hockey, 1997). Individuals either increase effort to maintain the task goal or reduce effort by compromising task performance or switching to another task (Hockey, 1997).

### 2.4.2 Resource use

It is suggested that self-regulation strategies are influenced by resource use and availability. Hockey (1997, p. 75) defines a resource as “one or more pools of general purpose processing units, capable of performing elementary operations across a range of tasks and drawing upon common energy sources”. A resource is finite and depletion will occur if demands on the resource are heavy (Kaplan and Berman, 2010). Wickens (1984) argues that multiple resource pools exist where different resources are used for different types of processing, therefore the more resources that are shared among tasks the greater the task interference. Wickens (1984) found that if two tasks use separate resources, time-sharing is more efficient, changes in task difficulty will have little effect on performance of the other task, and lastly, resources withdrawn from one task cannot be used by another task. Resources are thought to be limited in capacity, meaning that processing units will be competed for if two tasks requiring the same resources are conducted simultaneously (Hockey, 1997). Wickens (1984) further showed that a tracking task using motor response resources was interrupted by another concurrent tracking task, but was not affected by a mental task that required central processing. This confirms that a mental task requires a separate resource pool from a perceptual and motor task. Similarly, Birch (2012) found that performance improved when concurrently completing a tracking task and memory recall task. However, when doing a tracking task and a choice reaction task simultaneously, performance was unaffected.

An increase in task difficulty, or the required performance level, results in fewer resources being available for completing secondary tasks, leading to an overall decreased performance (Wickens, 1984). With increased time on task, there is an increased demand on resource utilization; consequently to maintain the primary goal under conditions of stress, the remaining resources must either be reconfigured or additional resources recruited (Hockey, 1997). The mobilization of more resources costs energy and has been associated with increased activation of certain physiological systems such as sympathetic responses (Hockey, 1997). To prevent exhaustion of the available resources, performance regulation strategies, where speed and accuracy are balanced, must occur (Fairclough and Mulder, 2011). Chaplin and Goebel (2011) found evidence to support this when reading performance decreased significantly over time (speed decreased and errors increased), but physiological measures remained constant. This suggests that performance was regulated to protect the visual system from further additional strain.

In contrast to the study by Chaplin and Goebel (2011), Baddeley and Weiskrantz (1995) found that performance impairments of 10% or more during information-processing tasks are rare; however, this may be due to the experimental design used. Individuals therefore have an ability to maintain a consistent performance level, despite being exposed to external stressors. Kahneman (1971) describes this process as the protection strategy. Performance is protected from disruptions due to the effectiveness of attention control in maintaining priority of goals. However, this performance stability occurs at the cost of decreasing stability in other systems that at the time are less relevant to performance output. These costs incurred in other systems are said to be within acceptable limits, provided conditions are normal, and thus do not cause health implications (Kahneman, 1973). Health implications may be more evident if this protection mechanism occurred for prolonged periods. This protection strategy was found to be more effective in real world situations when the value placed on the goal was greater than in laboratory conditions (Baddeley and Weiskrantz, 1995). This can lead to an under-estimation of the negative health implications caused by the protection strategy. Individuals may compromise their work goals to prevent the occurrence of the performance protection strategy, so as to maintain an acceptable level of well-being (Baddeley and Weiskrantz, 1995). The performance protection strategy makes it challenging to observe performance decrements in primary task performance. However, one can identify the process of self-regulation occurring by monitoring indirect performance degradation such as compensatory costs, strategic adjustments and fatigue after effects (Baddeley and Weiskrantz, 1995).

### 2.4.3 Perceived boredom

Boredom is caused by a “lack of stimulation from the task at hand or from the environment” (Brown, 1982, pg. 12). Monotony refers to the type, amount and degree of sensory stimulation in any situation (Thiffault and Bergeron, 2003). If the stimuli remain the same, are repetitive or tend to be predictable, the situation is considered monotonous (Thiffault and Bergeron, 2003). Vigilance refers to the underlying processes that contribute to the ability of an individual to maintain sustained attention. Decrements in vigilance are one of the most pronounced effects resulting from down regulation due to monotony (Thiffault and Bergeron, 2003).

Desmond and Matthews (1996) conducted a driving simulator study where they discovered increased performance decrements on a straight road compared to a curved road. Monotony causes decreased vigilance and alertness which may result in an accident due to human error (Grandjean and Kogi, 1975, Thiffault and Bergeron, 2003). Monotony results in physiological and psychological changes where physiological changes refer to tonic variations and an increase in parasympathetic activity, which in turn causes a drop in activation (Thiffault and Bergeron, 2003). Psychological changes associated with monotony include feelings of boredom, drowsiness and reduced motivation to perform the task (Grandjean and Kogi, 1975). Monotony can be explained as the process of habituation due to the repetitive appearance of stimuli (Thiffault and Bergeron, 2003). When a stimulus is first presented, it leads to increased attention and arousal. However, repetitions of these stimuli will reduce the response until it disappears (Thiffault and Bergeron, 2003). If a change occurs in the stimulus, the response will reappear and arousal and attention will increase again (Thiffault and Bergeron, 2003). Parasuraman *et al* (1993) found that tasks such as monitoring an automated system are said to have a low workload which results in boredom being experienced by the worker. Monotonous tasks result in individuals wanting to avoid or leave a task which is known as task aversion (Matthews *et al*., 2010). Behaviour regulation is therefore proposed to be driven by monotony or boredom. At the beginning of a task the degree of boredom is low but this increases with the passing of time, until a threshold is reached and the individual cannot continue further. Tasks that are highly repetitive, automatic and unchallenging are said to be more monotonous than others (Parasuraman *et al*., 1993).

### 2.4.4 Fatigue

It is well established that prolonged mental activity leads to fatigue (Desmond and Matthews, 2002); however, many types of fatigue can be experienced. Fatigue can be described as an increase in resistance to carry on with the task (Bridger, 2003). Therefore greater effort is required to continue performing the task and overcome this resistance (Bridger, 2003).

Task-specific fatigue occurs when the individual is tired of performing the task but by switching to another task this fatigue will disappear, provided there is a change in resource usage (Matthews *et al*., 2010). On the other hand, the individual may be generally fatigued from lack of sleep for example, and therefore a switch to another task will not alleviate the fatigue (Matthews *et al*., 2010). Monotony is said to contribute to the onset of fatigue, however, fatigue does not contribute to monotony (Brown, 1982). Fatigue can also cause problems in recruiting sufficient effort to maintain performance. Hence a change in the task goal is necessary (Matthews and Desmond, 2002). Regulation strategies may involve a reduction in performance level or the adoption of strategies that require less effort such as task-switching or attentional narrowing (Matthews and Desmond, 2002). Fatigue weakens the individual's capacity to achieve a balance between effort and task demands, which is why fatigue is often synonymous with performance decrements (Thiffault and Bergeron, 2003).

Self-regulatory strength is likened to muscle strength. The more effort one expends, the greater the resultant muscle fatigue and consequently, less strength is available for further efforts (Segerstrom and Solberg Nes, 2007). This can result in self-regulation failure, but unlike muscle fatigue, people are unaware of self-regulatory fatigue (Segerstrom and Solberg Nes, 2007). If a task is conducted for a prolonged duration, the onset of fatigue or down regulation will influence performance. Fatigue causes a depletion of available resources and reduced energetical resources, both of which result in cognitive processes becoming less efficient (Lorist *et al.,* 2000).

### 2.4.5 Motivation

Self-regulation is largely influenced by motivation to achieve the task objective. Motivation affects effort invested in a task, which in turn influences regulation strategies and performance (Cnossen *et al*., 2000). Lord *et al*. (2010) state that stable attributes of an individual can directly or indirectly influence self-regulation. Furthermore, an individual's level of motivation may be affected by mood, the perception of the value or importance in reaching the goal, and the attitude of the individual (Karoly, 1993). The individual incentive must therefore be strong enough to drive self-regulation strategies to guide performance so as to reach the final goal of the task.

The task satisfaction and perception of performance experienced by the individual during the task will affect regulation behaviour. For example Keller and Bless

(2006) found that cognitive (arithmetic) task performance increased with task enjoyment which suggested that increased intrinsic motivation may be the underlying mechanism driving self-regulation. In addition, it is assumed that if one perceives oneself to be performing well in a task, motivation levels will increase, improving performance.

Mental fatigue causes a decrease in motivation, resulting in less drive to reach the desired goal and a potentially compromised performance (Steinborn *et al*., 2009). Lorist *et al*. (2000) found that performance deteriorated (reaction time increased) with time on task. Participants stated that as aversion to the task performance increased, less effort was invested, which resulted in both speed and accuracy being compromised (Lorist *et al*., 2000). In some industries (for example forestry) it is common practice to pay the workers according to the worker output, which causes an increased work rate. This can lead to more errors and can negatively affect workers' health and safety (Christie, 2006). On the other hand, being paid per shift decreases motivation of workers to produce maximum output and may result in a seemingly 'lazy workforce' despite lower error rates and enhanced worker safety.

External conscious feedback refers to that which is given from the environment, an example being a computer screen telling the user whether the task was completed correctly or not. This type of feedback tends to improve the individuals' focus on task engagement and motivation to reach the desired goal (Lord *et al*., 2010). However, feedback can be positive or negative, and depending on the individual, negative feedback can elicit one of two responses. Firstly, the individual could give up on the task and switch to another task, and secondly the individual could persist by increasing effort investment to improve performance. Tucker *et al***.** (1997) found that feedback lowered the error rate of tasks relying on controlled processing; however, feedback had no effect on tasks that required automatic processing. Positive external feedback contributes to task satisfaction and can encourage the individual to spend more time on a task. Additionally, the amount and type of feedback, and how immediate the feedback is, will affect task-switching behaviour.

### 2.4.6 Activation level

Alertness refers to selective attention, vigilance, and attentional control (Van Dongen and Dinges, 2000). The inverted U-shape theory states that an increase in arousal causes improved performance up to a point, beyond which a further increase will lead to performance degradation (Martens and Landers, 1970). Therefore an optimum arousal level, which falls between low and high arousal levels, will result in best performance (Martens and Landers, 1970). Matthews and Desmond (2002) found that during a driving simulator task, performance increased with increasing task demands and a loss of effort was apparent when task demands were low. It was suggested that during low task demand conditions, the individual underestimates the need to maintain task-directed effort (Matthews and Desmond, 2002). In situations of low task demands, the effects of down regulation, fatigue and boredom will adversely affect performance (Matthews and Desmond, 2002). Conversely, according to Roscoe (1992) a high activation level will result in quicker information processing and thus faster reaction time to a stimulus in the environment, but this will cost greater energy and effort. Self-regulation controls the changes in activation levels according to the task demands to achieve an optimal state of task engagement (Loren and Parasuraman, 2003). Oken *et al* (2006) stated that when conducting a task with a high financial incentive, activation and persistence to continue with the task increased.

Greater self-focused attention activates the comparator component of the feedback mechanism (see section 2.2.3). An increased effort to reduce any discrepancies between the desired and actual performance takes place by the regulation of performance (Carver and Scheier, 1998). It was suggested that a higher activation level will result in less task-switching as individuals can withstand the effects of boredom for longer durations. In contrast, decreased activation levels will cause more frequent task switches. However, Demanet *et al***.** (2011) found that the level of arousal did not have an effect on whether individuals repeated or switched tasks.

## 2.5 MEASUREMENT AND TESTING OF SELF REGULATION

Despite the increased need for self-regulation in modern workplaces, (in order to reach goals, targets and deadlines with optimal performance) there has been little research in terms of what factors are responsible for behaviour regulation. This is probably due to the methodological problems associated with testing self-regulation due to the lack of validated measures to indicate the changes in self-regulation strategies (Schmidt *et al.,* 2007). Firstly, self-regulation can be measured by comparing performance and psycho-physiological measures during self-paced and externally-paced conditions. Secondly, self-regulation can be measured by allowing task switches in an attempt to determine the effect on performance and psycho-physiological measures.

### 2.5.1 Self-paced and externally-paced conditions

Self-paced tasks involve individuals working at their own pace to complete a task. Alternatively, externally paced tasks involve individuals having no control over the speed at which a task is completed, and timing is controlled by equipment and machinery (Knight and Salvendy, 1981). Karoly (1993) states that when routinized activity becomes hindered or restricted, self-regulation processes are activated as individuals are required to manage their actions according to the final goal and available resources. Self-paced performance allows for sufficient time to co-ordinate the mobilization of resources with the rate of carrying out the task, which results in an "optimal adjustment to the workload" (Renaud and Blondin, 1997). Self-paced work allows the worker to freely regulate performance and devise strategies to effectively divide the given time between various tasks. In contrast, externally-paced work inhibits the use of self-regulation strategies. Industrial tasks fall along a continuum where on one end, tasks are externally-paced, examples of which are conveyor-line operations, and on the other end tasks are self-paced, such as bench operations (Knight and Salvendy, 1981).

According to Knight and Salvendy (1981), task pacing affects production performance, physiological responses and emotional and psychological responses to the job. Rabbitt (1969) states that self-paced studies over prolonged periods result in very small increases in error rate over time compared to externally-paced studies. A study conducted by Renaud and Blondin (1997) assessed performance differences between self-paced and externally-paced conditions when executing a stroop task. The self-paced condition elicited longer response times but very low error rate whereas the externally-paced condition elicited shorter response time but high error rate. This indicates that more time was spent on accuracy in the self-paced condition which was not possible during the externally-paced condition. Parkes *et al.* (1990) found that during a self-paced mechanized letter-sorting task, subjects worked at significantly faster speeds with a higher level of accuracy. Knight and Salvendy (1981) found the following disadvantages when investigating externally-paced work: firstly subjects did not complete the work in the allocated time. Secondly, subjects were unable to achieve an even work rate, which resulted in physiological costs, and lastly, variable cycle times interfered with preferred work rhythms.

Job strain in the working environment is associated with high demands and low control over how the work is conducted (Steptoe *et al.,* 1997). Steptoe (1993) showed that high demands and low control over work may lead to stress. Externally-paced work was found to elicit higher autonomic activity, greater psychological discomfort and performance disruptions in comparison to self-paced work (Bohlin *et al.,* 1986). The effects of work pace on human performance and physiological responses are crucial in achieving worker productivity (Steptoe *et al*., 1997). More errors were produced during the externally-paced condition and participants added they felt pressurised by the time constraints (Steptoe *et al.,* 1997). According to Renaud and Blondin (1997), this increased job strain may be attributed to less available time processing information. Therefore greater effort is required to manage the increased workload. If available resources are exceeded, a stress response may be induced. In contrast to this, Salvendy and Humphreys (1979) found that a self-paced task elicited a higher cognitive workload than an externally-paced task, suggesting that self-paced work would not be beneficial to tasks involving extensive information-handling. Knight and Salvendy (1981) explained that self-paced tasks require additional responsibilities in the form of performance regulation. These include deciding on a work pace, reaching the required target and how much time remains to complete the task. These additional processes will increase the memory and cognitive workload. During externally-paced work the individual has no control over the above demands, which reduces the overall workload. Renaud and Blondin (1997) found that the type of pacing affected only performance and resulted in no significant differences in physiological measures.

Indirectly, paced work manipulates self-regulation by either limiting the process through externally paced work or allowing the process to occur freely through self-paced work. Research suggests that externally paced work results in performance decrements, increased job strain and in some instances increased physiological strain. These observations highlight the importance of self-regulation during human performance in the workplace.

### 2.5.2 Task-switching

In reality, individuals are faced with multiple tasks to complete on a daily basis. The logical way to approach this situation would be to work on one task at a time and start a new task following completion of the current task. However this is seldom the case, because humans tend to switch between multiple cognitive tasks based on the regulation strategy chosen by the executive control (Kaplan and Berman, 2010). Payne *et al* (2007) conducted a study which found that participants switched between cognitive tasks about seven times in ten minutes, therefore concluding that when individuals are allowed to freely divide their time among multiple tasks, frequent switches are made. In everyday life, individuals are faced with a number of independent goals, hence the individual must decide when and what task must be completed, and how the total time allocation will be divided among these goals (Payne *et al.,* 2007). A study showed that task difficulty influences the time spent on a task because significantly more time was spent on the easier task rather than the difficult one (Payne *et al.,* 2007). Van der Linden *et al***.** (2003) found that by instructing individuals when to switch between tasks, less effort was needed to develop regulation strategies and employ complex problem solving.

A change from one cognitive task to another requires a reconfiguration of the mental resources recruited (Lorist *et al.,* 2000, Payne *et al*., 2007,). This reconfiguration process takes time and is known as a task-switching cost (Payne *et al*., 2007). The more task switches that occur, the greater the physiological cost, and as a result it would be more efficient to finish the task before switching to a new one. Waszak *et al*. (2003) describe a study where increased reaction times and error rates occurred when a task shift took place, as opposed to when the same task was repeated consecutively. Studies by Rogers and Monsell, (1995), Wylie and Allport, (2000), Rubinstein *et al*., (2001) and Monsell, (2003) compared performance between subjects switching tasks on successive trials as opposed to performing the same task on successive trials. The observed performance differences found during these studies indicated that task-switching resulted in additional costs due to the change in control processes during the switch.

The executive control is largely responsible for selecting and implementing the correct combination of task-sets to achieve the goal at hand rather than other goals (Monsell, 2003). Task-sets can be described as the cognitive processes required for the human to respond in a certain manner and complete the task (Lorist *et al*., 2000). Previously-used task-sets are kept in the memory to be executed when the individual needs to react in the same way and with practice these reactions become automatic (Monsell, 2003). Novel tasks require new or adapted task-sets to be configured, whereas already stored task-sets are used for familiar tasks (van der Linden *et al*., 2003). Based on the above explanation, one would assume that individuals should start a task, create the required task-set and repeat it until it is an automatic process and the task is completed (Monsell, 2003). However, during task-switching the task-set is created and then stored as the individual shifts to another task where either a new task set will be created or a previously stored task set will be used (Lorist *et al***.,** 2000). With time, a shift back to the original task will occur and the task set will need to be re-accessed. This continual process of creating, storing, re-accessing and modifying task sets is time-consuming and costs the executive control more effort (Lorist *et al*., 2000). This suggests that task-switching is influenced by other factors, such as boredom, that override the cost factor and cause individuals to switch between tasks despite the cost incurred.

Based on Wickens theory of multiple resource pools, it can be speculated that switching frequently among tasks requiring different resources prevents prolonged resource use and thus the onset of fatigue. On the other hand, a low task-switching frequency will cause greater strain on the resource pool and allow less available time for replenishment. Therefore a slow task-switching frequency represents a higher workload in terms of resource use. Monsell (2003) found that subject’s responses are initially slower and prone to errors immediately after a task switch and based on these findings, the higher the frequency of task-switching the higher the costs. Monsell (2003) added that switching from one task to another results in a rapid recovery of performance. However, initially responses remain slower than if one task was performed throughout.

Payne *et al*. (2007) proposed reasons as to why individuals make switches between tasks. Firstly, task switches took place to allocate time preferentially between tasks according to performance output. The individual identified the degree of reward or gain in completing the task, and this determined which task the most time was allocated to. Initially, it took a number of frequent switches to determine which task had the highest reward, and this was followed by longer periods devoted to a single task. Payne *et al.* (2007) stated that *Green's rule* (Green, 1984) is a credible explanation to explain task-switching. This rule states that subjects decide on the duration that they are willing to spend doing a task and this time allocation will increase as the subject experiences success during the task. This is supported by evidence that individuals allocate more time to simpler tasks than complex ones. Payne *et al*. (2007) then concluded from their findings that the probability of making a task switch was increased when a sub-goal was completed during the task.

Gonzalez and Mark (2005) conducted a field study on the workers of two companies carrying out tasks during a normal day's work. Through observations of the individuals' behaviour Gonzalez and Mark (2005) found that three fundamental processes are responsible for managing task transitions. Firstly, the continual renewal of overviews, which refers to maintaining a state of preparedness by having the required knowledge about the task, its purpose and actions required. Secondly, maintaining a flexible window of focus, which refers to being able to easily shift attention and focus between multiple tasks. Thirdly, the management of transitions, which involves the strategies used to re-orientate oneself when switching to a new task (Gonzalez and Mark, 2005). These processes directly influence whether one should switch to another task or continue with the current task, and therefore play a prominent role in behaviour regulation.

## 2.6 MEASURE OF MENTAL EFFORT

Mental effort is described by Hockey (1997) as a compensatory process where mental task demands are controlled by cognitive-energetical mechanisms. A number of measures have been shown to reflect changes in mental effort; however, because of their high sensitivity to other factors (other than workload) they can produce conflicting results. In addition, Bridger (2005) recognizes that human thought processes are not directly observable when measuring mental workload. Despite this, physiological measures of mental effort can be helpful when used with psychological measures (Bridger, 2005).

It has been proposed that cardiovascular responses (heart rate and energy expenditure) during information-processing tasks are metabolically exaggerated, meaning that the responses are higher than what would be expected from the somatic needs (Backs and Seljos, 1994). However, this exaggerated measure is said to include the somatic and the psychological task demands. Therefore the metabolic activity of the body refers to the somatic needs, whereas mental effort refers to the exaggerated metabolic measure which includes the psychological demands (Backs and Seljos, 1994). However, if physical activity is reduced to a minimum or kept constant among tasks, changes in cardiovascular activity can be attributed to changes in mental effort. Backs and Seljos (1994) found that mental workload will be underestimated if the heart rate measurements reflect only the psychological demands of the task and not the metabolic cost of the central processing unit.

### 2.6.1 Heart rate frequency and heart rate variability

Both heart rate (HR) and heart rate variability (HRV) measures are used as an indication of the effort needed to conduct the task at hand (Segerstrom and Solberg Nes, 2007). HR is defined as the number of times the heart beats (contracts) within one minute (Tortora and Derrickson, 2006). It is a measure of the amount of oxygen required by the body and the amount of carbon dioxide to be excreted. In terms of this study, HR is a measure of the psycho-emotional state of the individual and thus will change according to stress and anxiety (Tortora and Derrickson, 2006). HR is controlled by the sympathetic and parasympathetic nervous systems (Tortora and Derrickson, 2006). Therefore, an increase in the sympathetic nervous system activation causes an increase in HR (Mehler *et al*., 2009). Roscoe (1993) and Ohsuga *et al*. (2001) have found HR to increase during mentally demanding tasks or situations of stress and decrease during times of monotony or reduced arousal.

HRV refers to the beat-to-beat variation in HR (Segerstrom and Solberg Nes, 2007). It is caused by constant changes in parasympathetic and sympathetic balance which results in the sinus rhythm producing fluctuations about the mean HR (Karim *et al.,* 2011). An increased parasympathetic input causes greater acceleration and deceleration of the heart which results in greater variability between heart beats (Segerstrom and Solberg Nes, 2007). Mulder (1988), describes HRV as a frequent measure of physiological arousal mechanisms used to regulate mental effort. An increase in HRV is driven by the parasympathetic nervous system and indicates low cognitive resource utilization (Ohsuga *et al*., 2001; Backs and Seljos, 2007; Segerstrom and Solberg Nes, 2007, and Karim *et al*., 2011). Conversely, a decreased HRV is driven by the sympathetic nervous system which is said to represent increased task difficulty, workload and mental effort (Ohsuga *et al*., 2001 and Karim *et al.,* 2011). An increase in mental effort results in increased HR and more regular HRV (decreased HRV) (Fairclough and Mulder, 2011). HRV decreases with increased stress, which can be emotional or physical, while HRV will increase during rest (Karim *et al*., 2011). However, because this measure is sensitive to a range of other factors, not all studies have found significant changes in HRV with increased cognitive workload thus it was concluded that HRV must be used in conjunction with other measures (Jorna, 1992; Garde *et al*., 2002; Nickel, and Nachreiner, 2003; Chaplin & Goebel, 2011).

Meijman (1997) conducted a study which found that after 7 hours of work, HRV values had considerably increased and drivers did not react to 31% of the signals. This led the authors to conclude that individuals strategically decided to invest less attention and effort into the task due to the onset of mental fatigue. A study which involved participants completing an air traffic control radar task for one hour found that greater boredom ratings were associated with significantly higher HRV and response times (Thackray *et al*., 1975). Fairclough and Houston (2004) reported an increase in HRV and a decrease in HR and blood glucose with time during a cognitive task. Based on these findings, it was proposed that decreases in mental effort with time on task may be due to task aversion, boredom and the learning effect as performance becomes more efficient over time.

*2.6.1.1 Time-domain Analysis*

Time domain methods are the simplest to determine HRV, and involve measuring the intervals between successive normal heart beats (Karim *et al*., 2011). Many types of time domain indices are measured in this manner, however, this study will only use the *rMSSD* and the *pNN50* indices. The *rMSSD* is the square root of the mean of all the differences calculated between successive intervals (Karim *et al***.,** 2011). The *pNN50* measures the percentage of differences between successive intervals that exceed 50ms. *rMSSD* and *pNN50* are based on differences between successive beats and therefore measure short-term variability in the normal cardiac cycle (Karim *et al*., 2011).

*2.6.1.2 Frequency Domain Analysis*

HRV is comprised of multiple spectral components; however, the very low frequency, low frequency and the high frequency will be used in this study. These components are calculated from short term recordings of roughly 2 to 5 minutes. The high frequency components (0.15-0.40 Hz) are regulated by efferent vagal activity, which also influences the respiration rate (Jorna, 1992; Elsenbruch *et al***.,** 1999, Garde *et al***.,** 2002). The power in the high frequency band is said to decrease with increased task demand (Backs *et al*., 1991). The low frequency components (0.02-0.06 Hz) reflect the activity of the sympathetic branch. An increase in low frequency power causes an increase in activation. However it has also been suggested that vagal activity plays a role in regulating the low frequency band (Garde *et al***.,** 2002). Houle and Billman (1999), found the low-frequency component of the heart rate power spectrum to not accurately reflect changes in the sympathetic activity. It was concluded that the low frequency power may result from the interaction between the sympathetic and parasympathetic nervous systems (Houle and Billman, 1999). Both the low frequency and high frequency power and centre frequency are measured and are influenced by the autonomic regulation of the heart beat (Elsenburch *et al*., 1999).

### 2.6.2 Energy Expenditure and Breathing Frequency

The brain requires energy for information processing but because it cannot store energy, it relies on a constant supply of oxygen and glucose from the bloodstream (Fairclough and Mulder, 2011). Cognitive activity depends on the mobilisation of energy and therefore energy expenditure can be used as a measure of mental effort (Fairclough and Houston, 2004). Despite this argument, there has been controversy over whether energy expenditure can be used to determine the degree of mental effort invested in the task. Past research indicates that an increase in energy expenditure from resting to task performance cannot be interpreted as information processing having an independent metabolic cost, but rather is due to the somatomotor demands of the task (Carroll *et al.,* 1986). However, a mental task where somatomotor activity was reduced produced a conflicting argument. Backs and Ryan (1992) conducted a study where participants only responded verbally to memory tasks of differing complexity. An increase in task difficulty resulted in increased HR and greater energy consumption, which provided evidence that mental effort affects metabolic activity. A more recent study supports this finding, as energy expenditure was found to increase with task complexity and therefore mental effort (Backs and Seljos, 1994). Caroll *et al***.** (1986) found no change in the exchange of oxygen and carbon dioxide volumes during tasks of differing complexities. Despite there being a difference between male and female metabolism rates, energy expenditure was not significantly different (Backs and Seljos, 1994). Backs and Seljos (1994) found that good performers expended less energy than poor performers, which led the authors to the conclusion that poor performers had less efficient cognitive processes.

The amount of oxygen needed by the body depends on the level of activity, where increased task demands result in greater respiration rate (Roscoe, 1992). Increases in cardiovascular activity during information-processing tasks have been attributed to the metabolic costs accumulated by the central processing unit as it is limited in capacity (Backs and Ryan, 1992). Breathing frequency is considered a useful but underutilized measure of mental workload (Roscoe, 1992). An increase in breathing frequency and shallower respiration is said to represent effortful information processing (Backs and Seljos, 1994). A slow respiration rate (less than 8 breaths.min$^{-1}$) is associated with rest and faster respiration rate (greater than 9 breaths.min$^{-1}$) is associated with task execution (Fairclough and Mulder, 2011). Hyperventilation was found to occur during times of stress and high mental demand (Roscoe, 1992).

The high frequency (HF) band, which is a component of HRV, is influenced by respiration rate (Jorna, 1992). The HF band is an indicator of parasympathetic activity, therefore an inverse relationship exists between the HF band and breathing rate.

### 2.6.3 Body temperature

Body temperature is a useful measure of arousal and tends to increase with increasing task demands (Mehler *et al*., 2009). A study by Wright *et al.* (2002) found improved performance measures (working memory, subjective alertness, and visual attention) when body temperature was elevated. Body temperature fluctuates according to the amount of peripheral blood flow, which gives an indication of brain activity and heart rate (Cherbuin and Brinkman, 2004). An increase in cerebral activation requires greater energy, therefore cerebral blood flow increases which causes a rise in the forehead temperature (Cherbuin and Brinkman, 2004). Skin temperature is known to measure peripheral sympathetic activity in response to mental strain. However, a problem with this measure is that it is also sensitive to environmental temperature (Ohsuga *et al.,* 2001). According to Genno *et al.* (1997) forehead temperature is the most stable body surface and remains constant during cognitive tasks, despite an increase in mental workload. Calvin and Vincent (2007) found no significant changes in forehead skin temperature during a driving simulator task.

Tympanic temperature refers to the measurement of ear temperature. Studies have shown that an increase in tympanic temperature indicates decreased cerebral activation and *vice versa* (Helton *et al.,* 2009, Calvin and Vincent, 2007, Cherbuin and Brinkman, 2004). The head comprises 5% of total body mass but uses 30% of total energy stores, thus producing large amounts of heat which is dissipated by radiation and heat exchange during blood circulation (Cherbuin and

Brinkman, 2004). Tympanic temperature is influenced by carotid blood flow such that as carotid blood flow increases, there is more rapid heat exchange with the rest of the body resulting in a decrease in ear temperature (Helton *et al*., 2009). A study revealed findings where tympanic temperature increased during a tracking task representing cerebral deactivation, which may be due to task disengagement and monotony (Helton *et al*., 2009). A study (Cherbuin and Brinkman, 2004) involved participants switching from a task where the left hemisphere was activated to a task where the right hemisphere was activated. This resulted in the left ear temperature increasing and the right ear temperature decreasing. Therefore ear temperature can be used to determine whether tasks elicit activation in the left or right hemisphere.

## 2.7 SUMMARY AND RATIONALE BEHIND THE CURRENT STUDY

As can be seen from this chapter, there is little research that has tested or measured self-regulation during information-processing tasks. Furthermore, there is no available evidence to support the assumption that certain factors are responsible for driving task-switching. As a result, this study attempts to establish links between task-switching behaviour and psycho-physiological measures. The literature in this chapter shows inconsistent findings with regard to measures of mental effort such as heart rate variability. It is advisable to utilize a number of physiological measures to assess the mental effort induced during the testing. Performance and subjective measures are also used to support the findings from the physiological measures. The objective of this study was to determine the primary factors that influence task-switching behaviour, by allowing individuals the freedom to alter self-regulation strategies where necessary. The findings from this study can then be used to redesign job rotation systems by allowing workers to switch tasks before adverse effects prevail. This may include resource exhaustion or task disengagement due to monotony.

# CHAPTER 3

# METHODOLOGY

## 3.1 INTRODUCTION

This study aimed to identify the factors causing individuals to regulate performance by switching between information-processing tasks, rather than continuing with the current task. More specifically, it focused on understanding the interaction between task-switching and physiological and psycho-physiological responses. Participants were given the control to switch between given tasks as desired which facilitated the self-regulation of performance. The objective was to identify what factors underlying the decision to regulate behaviour by switching to another task. It has been hypothesized that resource usage, monotony and effort regulation are primary drivers in behaviour regulation.

## 3.2 RESEARCH CONCEPT

Self-regulation is known to operate through a closed-loop feedback system which makes isolating and manipulating the process of self-regulation impossible (Bahill and Hamm, 1989). It is challenging to determine what factors are causing the change in the output, and therefore to identify the involvement of each element, the loop needs to be opened (Bahill and Hamm, 1989). In this study, self-regulation is monitored by analysing the output (behaviour) of the closed-loop system and how this fluctuates over time in relation to the effort invested. Because human behaviour fluctuates with changes in available resources, learning effects and fatigue, it is vital to adopt a holistic approach when investigating this phenomenon. In addition to this already complex concept, numerous extraneous variables confound performance influence the factors that contribute to performance fluctuations. Some of these include monotony, providing short rest breaks to break up the monotony, sleep and activities prior to the task, the type of task (skill-based or rule-based), the level of motivation and proactive self-regulation (Lord *et al.*, 2010). The relationship between effort and performance is measured as this analyses both the input and output of the closed loop of the information processing system and how changes in input affect the output differently over time.

### 3.2.1 Amount of control over actions

It was originally hypothesized that to analyze behaviour and performance regulation, the level of control individuals have over their work and actions could be manipulated. The greater the level of control, the greater the degree of self-regulation that can occur, whereas the less control, the less self-regulation can take place (Bohlin *et al.,* 1986). A continuum exists, where self-paced work correlates with high levels of control and externally-paced work correlates with low levels of control (Knight and Salvendy, 1981). Two conditions namely self-paced (high self-regulation) and externally-paced work (low self-regulation) could be used to determine the effect on physiological responses and performance. It was assumed that individuals would approach each task with two aims; one being to complete the task as quickly as possible and the other being to conserve as much energy (be efficient) as possible.

This method did pose limitations and was reconsidered. This was because during self-paced work, the individual may not be motivated to complete the task efficiently. Individuals may choose more rest breaks than needed by the body, which is possible because there are no time constraints. During the externally-paced condition, the participant may choose to complete the task quickly and rest during the remaining allocated time or use all the time available to complete the task. This would result in different work-to-rest ratio profiles for each individual. In conclusion, this method could not be used to measure the effects of self-regulation as it does not control how much time is spent working and resting.

Another limitation with this method is trying to analyse the closed-loop system. For example, strategic adjustments will be made to ensure actions executed do not require a resource that is low in availability. Due to the closed loop feedback system, the reason for behaviour being regulated cannot be determined.

### 3.2.2 Task-switching

The method of testing self-paced and externally-paced work was then discarded and a new method involving task-switching was proposed. Self-regulation can be analyzed through task-switching by allowing the participant to choose freely when to change from one task to another. Initially it was proposed that a control condition, where task-switching was prescribed, could be used to compare the effect of self-regulation on behaviour and physiological responses. However, this was not feasible because self-regulation may not be the only factor influencing behaviour. It was decided that individuals would have maximum control over their actions, and the option to regulate behaviour by switching tasks was available when necessary. This method proposes that subjective and physiological responses could be used to explain changes in behaviour.

### 3.2.3 Task experience

When performing exactly the same task for a second time, a change in performance was observed between the first and the repeat trials (Steinborn *et al.,* 2009). During the first trial, the participant was said to be naïve to the task and possess no experience. However, after the first trial or habituation period, the participant became experienced and had expectations of the task experience prior to the start of the repeat trial. Steinborn *et al* (2009) found that during the first trial of a mental addition task, reaction time decreased with time indicating that learning occurred. In addition learning was greater during the first trial compared to the repeat trial. However, if the participant experienced discomfort during trial one, performance and effort level may have potentially decreased as the participant anticipated the onset of discomfort and would therefore try to avoid it. Once the participant was habituated to the task, the self-regulation strategy employed changed, based on the experience and knowledge gained from previous experience with the task (Lord *et al.,* 2010). Experts require fewer resources to execute the task, therefore more resources can be devoted to strategizing efficient self-regulation processes (Lord *et al.,* 2010).

During pilot studies conducted by the author, the effect of experience on behaviour was clearly observed. Two of the participants from the second pilot study had extensive exposure to three of the tasks prior to the study. This resulted in considerably different task-switching behaviour as the participant’s perceptions towards the tasks either caused task avoidance or task attractiveness. Both of the participants that had been previously exposed to the tasks avoided even attempting one of the tasks (Appendix C). It was concluded that all participants recruited for this study must have no prior experience in any of the tasks used.

### 3.2.4 The Learning effect

It was decided that the type of tasks selected for this study should not result in a significant learning effect as this would influence the self-regulation strategy used to execute the task. This was overcome by choosing a skill-based task which involved very little strain as the motor program required for the action was automatic and pre-programmed (such as the target response task) (Rasmussen, 1983). However, skill-based tasks require little effort and can be sustained for long periods without any observable decrements in task performance (Van der Linden *et al.,* 2003). Monotony accumulates more quickly during skill-based tasks than rule-based tasks (Rasmussen, 1983). A rule-based task involves creating a new motor program or adapting an existing one to the situation (Rasmussen, 1983, Lehto, 2006). These tasks require more effortful processing due to greater resource use (Van der Linden *et al.,* 2003). However, rule-based tasks tend to become easier with practice as the motor program does not need to be created but rather modified, which may cause performance to increase with time due to the learning effect (Rasmussen, 1983, Lehto, 2006). It is therefore important that if a rule-based task is selected, all participants have the same degree of experience with the task and are habituated to the task to reduce the learning effect as much as possible.

### 3.2.5 Selection of the type of tasks

After deciding that the task-switching method would be used to determine which factors underlie behaviour regulation, the next challenge was to develop tasks with specific characteristics that would directly determine which factor (energy, resource usage or boredom) was the causative factor driving behaviour regulation.

The following criteria were set prior to deciding on the final tasks to be used in this protocol. They were as follows:

- Individual had the option to regulate performance during each task
- All tasks were information-processing tasks.

- Tasks were resource specific, meaning they required either motor, cognitive or perceptual resources, or all three resources.
- Tasks differed in required resources (visual, cognitive or motor) needed for the task.
- Tasks differed in the degree of mental effort required, which influenced required resources for the task.
- Tasks required resources from either one system (cognitive) or two systems (visual and motor), or equal resources from all three systems.
- Tasks induced differing degrees of perceived boredom.
- Task cycles differed in frequency and therefore some tasks were more repetitive than others.

### 3.3 PILOT TESTING

Pilot studies were conducted prior to finalizing the experimental design for this study. The aim of the first pilot study was to determine the effect of mental workload and task difficulty on physiological responses. Energy expenditure (EE), breathing frequency (BF), heart rate (HR) and heart rate variability (HRV) were measured while three participants conducted three different information-processing tasks, each with varying degrees of difficulty.

It was found that EE differed between information-processing tasks. More importantly, EE differed between tasks of low (target response task) and high (memory task) cognitive workload. It was concluded that the greater the cognitive workload and mental effort, the higher the energy expenditure and slower the breathing frequency (Appendix C). The HRV measures were in accordance with the above findings as the greater the cognitive workload, the lower the HRV. (See Appendix C for more detailed results)

The second pilot study (Appendix C) was aimed at investigating task-switching behaviour during information-processing tasks. The five participants were given the freedom to switch between five different tasks as desired for a total of 45 minutes. Participants were allowed to switch as often as they pleased, go back to a previous task and finally, they did not have to complete all the tasks. From this pilot study, the frequency of task-switching and the percentage of time spent on different tasks were recorded. A questionnaire was administered following testing to determine each individual's attitudes, perceptions and feelings towards the various tasks. No physiological measures were recorded during this pilot task.

The results showed that the participants switched frequently between tasks. Participants made on average over 10 transitions between tasks over 45 minutes. The average time spent on a task before switching to another task was 4.1 minutes. According to (Monsell, 2003), a task switch results in a physiological cost being incurred as the motor processes have to be reconfigured for the new task, resulting in a time delay. Therefore, it was unexpected that individuals would prefer to incur the switch cost rather than continue with the task and not incur the cost. This may be explained by the assumption that it was more beneficial to change tasks, despite the switch cost, rather than to continue with the task.

### 3.4 EXPERIMENTAL DESIGN

This study examined the factors underlying performance and behaviour regulation during information-processing tasks. The independent variable was the type of information-processing task. The type of task each participant performed is affected by the task-switching behaviour, which in turn affects performance measures, subjective ratings and physiological responses. Each task was designed to influence task-switching behaviour according to the various characteristics of the task, such as the resources required, the monotony of the task and the amount of effort required to maintain a given level of performance. The dependent variables included performance measures during each task (accuracy and response time), physiological measures (heart rate, heart rate variability, energy expenditure, breathing frequency and forehead and tympanic temperature) and subjective measures (rating of perceived boredom for each task, perception of time passing for each task and overall rating of tasks according to various categories).

The participants of this study were given the option to choose between five different tasks for the duration of 45 minutes. A task switch could be made at any point and could occur between any of the five tasks. The tasks were setup on a rotating circular table. Therefore the participant remained on the fixed chair, while the researcher rotated the table to the desired task. This ensured that large physical movements (such as applying physical force to turn the table or shifting postures) were limited as this may interfere with the physiological measures.

Figure 2: Experimental setup of the five different tasks on a rotating table to reduce physical movement of the participant and allow for fast and flexible task-switching.

**3.5 PARTICIPANTS**

Thirty four healthy male (n=17) and female (n=17) participants from Rhodes University volunteered for this study. As, this research did not use a repeated study design, there was no need for permutation of conditions. Hence, technically any number of participants would be applicable. The study did not compare different conditions and therefore there was no need for an odd or even sample size. The sample size of 30 to 35 was considered sufficient enough to allow for achieving statistical significance as all measures were analyzed as a function of time and before and after task transitions. The participants ranged in age from 18 to 22 years. Participants were excluded from the study if they had prior experience with any of the tasks, as this would influence the task-switching behaviour and performance output. However, this criterion excluded the spelling task as participants would have had prior experience to spelling tests. Participants were excluded from the study if they were computer illiterate, suffered from dyslexia or any form of learning or attention disorder.

## 3.6 ETHICAL CONSIDERATIONS

The study was approved by the ethics committee of the Human Kinetics and Ergonomics Department of Rhodes University, prior to any testing taking place. Prior to testing, participants were informed about the aims of the study, the procedures involved and what was required of them both verbally and in writing. After asking any possible questions, the participants voluntarily signed consent forms, in order to agree to voluntarily participating in the study. Each participant was identified using a participant code, rather than first names, in order to keep data confidential. Participants were reminded before and throughout the testing that they were free to leave the testing at any point and there would be no negative consequences for them if this decision was made.

## 3.7 INDEPENDENT VARIABLES

Five information-processing tasks were developed or modified for the purpose the study. Each task had specific characteristics which would influence switching behaviour and therefore allow the researcher to either accept or reject the research hypotheses. The tasks differed from one another in terms of the type of resources recruited, the amount of mental effort required and the repetition rate of each task cycle.

### 3.7.1 Simple Target Response Task

*NOTE: This task will be referred to as **target response** task from here onwards

The target response task was developed by Goebel (2010) and modified by the author. This was a perceptual-motor task with micro rest breaks between cycles. The task had no cognitive component and required primarily the perceptual and motor systems to complete the task. Pilot studies proved that the task had low cognitive workload requirements and low mental effort (energy expenditure) compared to memory and reading tasks (Appendix C). The task began with the presentation of a stimulus: a green circle with a diameter of 1mm, on a black background. The participant was required to click the mouse button as soon as the stimulus appeared on the screen and the stimulus then disappeared as soon as the mouse button was clicked. The position of the stimulus on the screen changed each time the stimulus appeared.  The participant aimed to respond to the stimulus as quickly as possible and thus response time was measured. A new stimulus appeared every 0.25 to 1.5 seconds following the previous mouse click response and this time delay was determined through pilot testing (Appendix C). This created a delay period between each stimulus, which was referred to as a micro rest break. Reaction time (time from presentation of stimulus to clicking the mouse) was measured. (See Appendix B4 for the experimental setup).

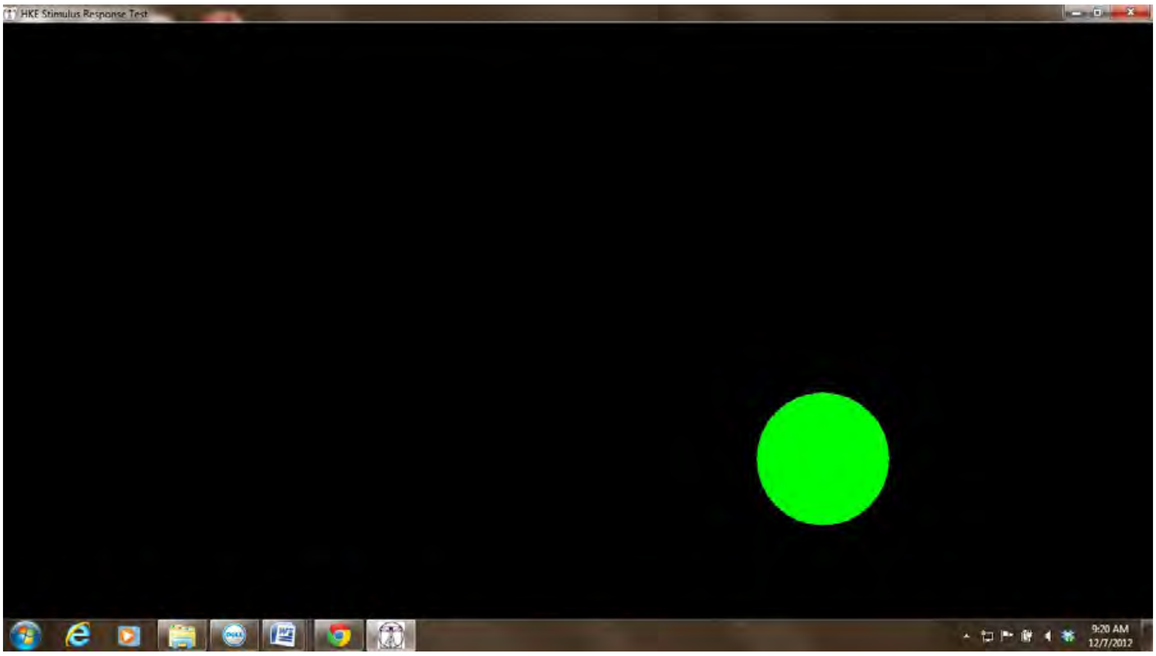

Figure 3: Target response task

### 3.7.2 Continuous Tracking Task

*NOTE: This task will be referred to as **tracking** task from here onwards

The continuous tracking task was developed by Goebel (2010). This was a perceptual-motor task which required continuous attention throughout the task. The tracking task relied on feedback mechanisms in order to perceive changes in road curvature and to respond using the motor system. Birch (2012) found that performance was not impaired when conducting a cognitive task while simultaneously conducting the continuous tracking task, however, performance was impaired when conducting a simple reaction time task and tracking task simultaneously. This suggested that the tracking task was not cognitively demanding and rather placed strain on the perceptual and motor systems. The participant was required to use the mouse to keep the yellow triangle on the middle line with as little deviation as possible. This task therefore measures fine proprioceptive control. The travelling speed remained constant throughout the testing. (See Appendix B4 for task settings).

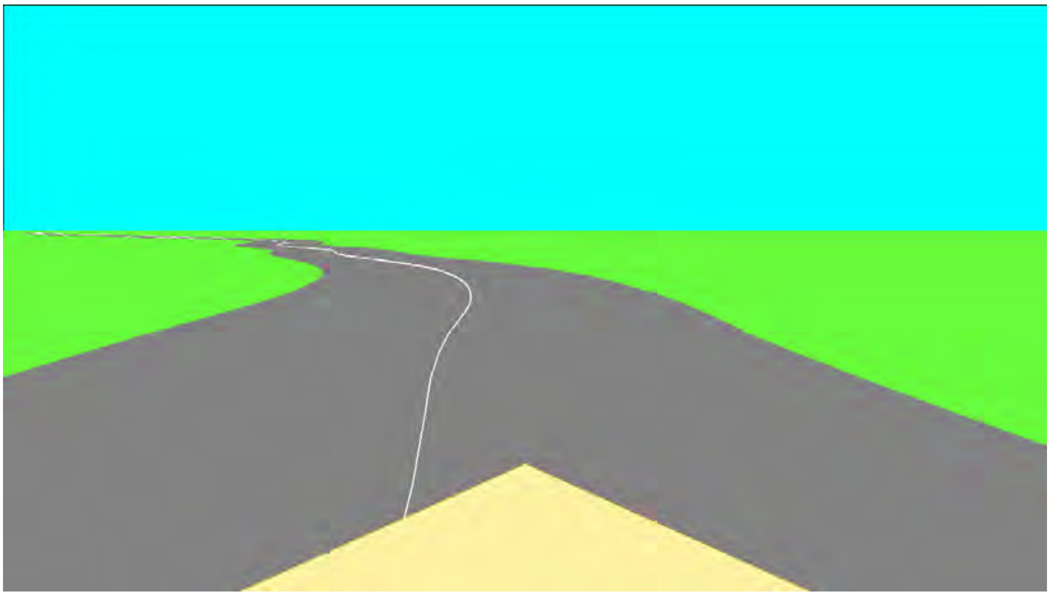

Figure 4: Tracking Task

### 3.7.3 Spelling Task

*NOTE: This task will be referred to as **spelling** task from here onwards

A Verbal Ability Spelling Task developed by Newton & Bristoll from *Psychometric Success* was used in this study. Additional spelling questions were developed by Chaplin (2012) based on the format used by Newton & Bristoll (Appendix D). This was a cognitive task and therefore mainly cognitive resources were recruited and less perceptual and motor resources were needed. Participants were presented with four versions of the same word and told to identify the correctly spelt version of the word by circling the letter corresponding to it. Both the number of completed questions per unit of time and the number of accurately completed questions were measured. This task was done on paper using a pen to circle the correct option.

### 3.7.4 Choice Reaction Task

*NOTE: This task will be referred to as **Choice** task from here onwards

The choice reaction task was developed by Goebel (2010) and modified by Chaplin (2012). This task was a perceptual-cognitive-motor task with a short cycle time and was therefore highly repetitive. Participants were required to respond to certain stimuli appearing on the screen, based on an assigned rule made known to the participant prior to the task. In this particular task, the participant was told that when the presented stimulus was a blue circle, the right mouse button was to be pressed, and when the presented stimulus was a red square, the left mouse button was to be pressed. This task tested the participant's logical reasoning. The task was modified following pilot studies (Appendix C) as participants avoided the task due to it being too complex. Therefore instead of responding to type of shape and colour, it was made easier by responding only to type of shape. The participant was encouraged to respond to the stimulus as quickly and accurately as possible. This task required the same amount of resources as the target response task in terms of perceptual and motor requirements; however, it differed in that it had an added cognitive component, as a decision had to be made before the response was made. Response time and correct and incorrect mouse responses were measured. Resources from all three systems in the information processing system were required for this task, resulting in the resource usage being more balanced between the three information processing systems. (See Appendix B4 for task settings).

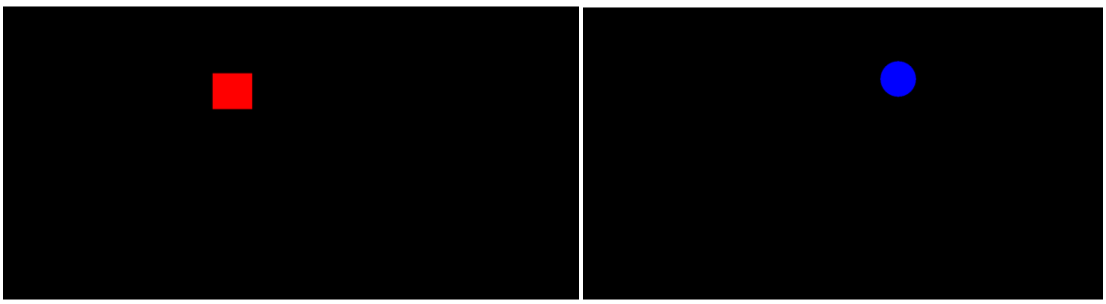

Figure 5: Choice reaction task

### 3.7.5 Berg's Card Sorting Task

*NOTE: This task will be referred to as **Card Sort** task from here onwards

The Berg's Card Sorting Task (Berg and Grant, 1948) was taken from the PEBL Psychological Task Battery. However, Goebel (2012) modified the original task taken from the PEBL Psychological Task Battery to suit the needs of this study. This is a neuropsychological task which investigated the ability to shift from one task set to another (Berg and Grant, 1948). In this study it was used to test the perceptual-cognitive-motor systems along with the choice reaction task. However, this task had a longer cycle time and therefore was not as repetitive. It involved categorizing cards based on the pictures appearing on them. Four piles were presented on a screen, each of which contained a different shape, colour and number of items. A series of cards appeared below the four piles with a specific shape, colour and number of items on the card. The participant was required to determine which pile each card belonged to, according to a rule that was unknown to the participant. The rule used to categorize the cards was based on the shape, colour or number of items on the card. The participant clicked on the pile that the card belonged to and immediate external feedback as to whether the decision was correct or incorrect appeared on the screen. However, the rule changed after a certain number of cards had passed (this was not a constant number) and therefore the participant was required to identify this and determine the new rule as quickly as possible. Both the number of correct and incorrect responses and response time was recorded.

This task involved problem solving consisting of rule search, where individuals had to determine the rule based on task feedback. Rule application was also required, where once the rule was determined the individual had to remember the rule and sort cards accordingly (Somsen *et al.,* 2000). Van der Linden *et al.* (2003) found that significantly longer response times occurred during rule search than rule application. This indicated that greater demands on the executive control occurred during rule search compared to rule application.

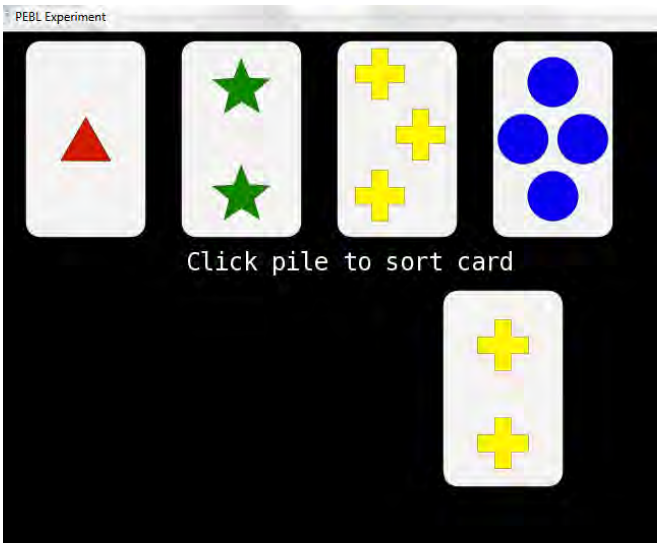


Figure 6: Berg's Card Sorting Task

Table I shows the options the participants had to self-regulate performance when needed during the different tasks. The table also includes the options for external regulation. However, these were set by the researcher and remained standard throughout the testing.

Table I: Types of task and options to regulate internally and externally

| Task | Performance regulation | External regulation |
|---|---|---|
| Tracking Task | Deviation from middle lane | Set the speed |
| Card Sorting Task | Response time (RT) and response accuracy | How often the rule changes. |
| Target Response Task | RT | Degree of precision |
| Choice Reaction | RT and error rate | Criteria for response to stimulus |
| Spelling task | Speed of completed questions and error rate | Complexity of words chosen |

Table II illustrated the type of resources required by each task. Some tasks posed a greater demand on the resource type than others. The cycle time is also included and this influenced the strain placed on the various resource types.

Table II: The type of resources required by each task, and the mean cycle time for each task.

| | Target response | Tracking | Choice | Card Sort | Spelling |
|---|---|---|---|---|---|
| **Perceptual resources** | X | X | X | X | X |
| **Motor resources** | X | X | X | X | X |
| **Cognitive resources** | | | X | X | X |
| **Predicted cycle time (pilot studies)** | Fastest | Continuous | Medium to fast | Medium to slow | Slowest |

## 3.8 MEASUREMENT OF DEPENDENT VARIABLES

### 3.8.1 Physiological measures

An Ergospirometer (Cosmed Quarkb[2]) was used to measure oxygen uptake by the participant during the different tasks. The amount of oxygen consumed and the amount of carbon dioxide expelled was then used to determine energy expenditure (EE) relative to the participant's body mass. The breathing frequency (BF) of the participants was also recorded. The Ergospirometer was calibrated prior to the testing of each participant. The data were analysed separately for each task to determine if energy expenditure showed any changes before and after a task switch. To attach the Ergospirometer to the participant, a mask was placed over the nose and the mouth region and a hairnet was used to keep the mask fixed and in place. The flow meter mouth-piece was then attached to the mask over the gap where the mouth was situated. The participant was encouraged to breathe as normally as possible. A breath by breath analysis took place and these values appeared on the Ergospirometer software.

A Heart Rate monitor (Polar) was used to measure heart rate variability (HRV) and heart rate (HR) throughout the testing. HR and HRV were recorded continuously to determine effort levels, cognitive workload and level of concentration over the entire protocol. The HR belt, containing electrode gel, was fitted to the participant around the chest in line with the sternum, and monitored the activity of the heart. These data were transferred immediately to the laptop via Bluetooth, which was connected to the data logger.

Skin (forehead) temperature and tympanic temperature were measured using sensors placed in the required region (Figure 6). An ear plug was inserted into the participant's ear to measure tympanic temperature, and a sensor was placed on the forehead. These sensors were plugged into the data logger and continuous measurement of temperature took place. Forehead temperature was measured to determine the blood flow to the forehead which gives an indication of the brain activity taking place. These sensors were calibrated prior to testing.

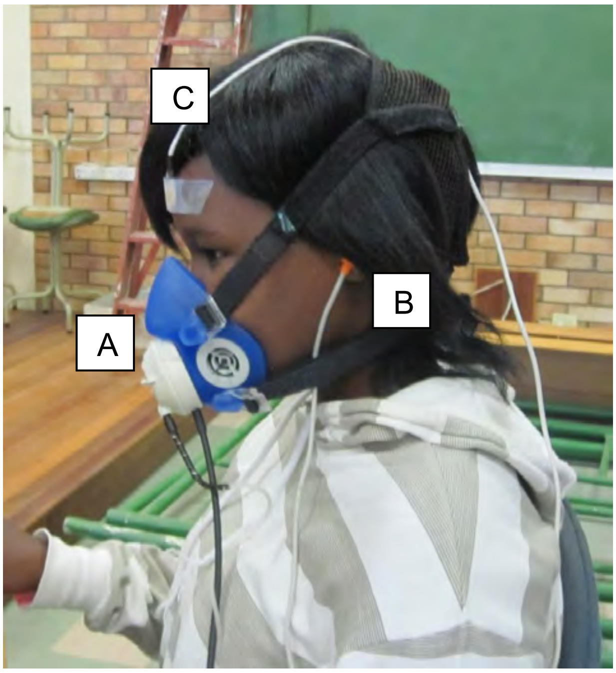


Figure 7: Participant with the Ergospirometer (A) fitted and the tympanic (B) and forehead (C) temperature nodes.

### 3.8.2 Behaviour and Performance measures

The researcher recorded the time of each task switch, which task the participant switched to and the total amount of time spent on each task. The performance output of each participant during each task was recorded. Response time and accuracy of response was collected for four tasks (target response task, tracking task, choice task and card sorting task). The speed (number of words per task trial) and accuracy of executing the spelling task was recorded. The tasks differed in resources recruited, effort needed to complete the task, and cycle time (how often the task was repeated). These observations can be therefore used to establish links between the physiological measures and task-switching behaviour.

### 3.8.3 Subjective measures

A self-report boredom scale developed by the author was used to measure the degree of boredom experienced by the participant for each task (Appendix B2). This scale ranged from 1 to 4, where 1 represented no boredom and 4 represented a great deal of boredom. The participant rated the perceived boredom of each task, following 90 seconds of exposure to the task. This value was used as a baseline boredom measure. During the protocol, the same process occurred at each task transition using the same scale. Lastly, at the end of the experiment, participants rated the boredom of each task. The researcher asked the participant, verbally, how much time was perceived to have been spent on each task when switching. Watt (1991) found that individuals who experienced greater boredom perceived time to pass more slowly than individuals who experienced lower levels of boredom. The perception of time passing was used to understand the degree of boredom experienced during each task, how this changed over time, and between tasks. A ratio was calculated by dividing the perceived time by the actual time passed. Therefore if the ratio exceeded 1 then time was overestimated.

A self-report scale (Appendix B1) was administered to participants following the testing. This consisted of four different categories rated according to four levels of experience of the particular category.

- The mental effort experienced during each task was rated according to there being none, some, much or too much mental effort.

- Performance was rated according to task performance being the worst, fine, good or the best.
- Monotony was rated according to tasks inducing boredom: not at all, occasional, much or extreme monotony.
- Task satisfaction was rated according to the task being very frustrating, frustrating at times, satisfying at times or very satisfying.

### 3.9 EXPERIMENTAL PROCEDURE

Each participant was required to report to the Human Kinetics and Ergonomics Department for the testing session. Participants were emailed a detailed letter about the study and what would be required of them, prior to agreeing to participate in the study (Appendix A1). On arrival, participants were informed of the procedure, read and signed consent forms and were free to ask any questions. The five different information-processing tasks were demonstrated and explained. The participants were introduced to and familiarized with the Ergospirometer, HR monitor and the temperature sensors, which were then fitted to the participant (see measurement of dependent variables for more detail). The participant was required to sit quietly and relax prior to beginning the testing to ensure physiological variables were at rest. The participant was considered at rest once heart rate was at or below 75bt.min$^{-1}$.

Participants trialed each task for 90 seconds in a prescribed sequence. The sequence of tasks was randomized among participants to prevent order effects. This allowed participants to become familiar with the tasks and feel comfortable with the skills needed without inducing much boredom. During pilot testing, participants were given as much time as needed to practice the tasks until they felt comfortable. None of the five participants tested in the pilot study required longer than 90 seconds. Following the warm-up of each task, participants rated the perceived level of boredom, using the provided boredom scale.

Once the participants had executed each task for 90 seconds, one of the five tasks were selected to begin the experimental procedure. The participant then had the freedom to switch from the current task to any of the four other tasks at their discretion. Participants were not required to complete all five tasks and were permitted to switch back to a task that had already been conducted. Participants conducted the various tasks for 45 minutes.

At each task transition, participants were asked to rate the perceived level of boredom, using the provided scale, of the task that was switched away from. In addition, participants were asked to verbally estimate the length of time that was spent on the previous task. After the 45 minute protocol ended, participants completed a questionnaire based on the personal experience of the task (Appendix B). The entire testing lasted 1 hour 30 minutes, which included the equipment setup, the warm-up session and the experimental protocol. Following this, the equipment was removed from the participant after which they were debriefed and permitted to ask any further questions, if desired.

### 3.10 STATISTICAL HYPOTHESES

This study hypothesized that boredom, effort regulation and resource use are motivating factors driving the need to switch from one task to another as a means of self-regulation. The following statistical hypotheses are developed to identify whether this research hypothesis can be accepted or rejected.

***Hypothesis 1:*** The null hypothesis proposed that there will be no significant difference in task-switching behavior among the five tasks

$H_o$: $\mu B_{Target\ response} = \mu B_{Card\ sort} = \mu B_{Choice} = \mu B_{Tracking} = \mu B_{Spelling}$

$H_A$: $\mu B_{Target\ response} \neq \mu B_{Card\ sort} \neq \mu B_{Choice} \neq \mu B_{Tracking} \neq \mu B_{Spelling}$

Where: B = {task duration, frequency of task chosen, task switch combinations}

***Hypothesis 2*****:** The null hypothesis proposed that there will be no significant difference in measures of perceived boredom pre-and post-the experimental protocol.

$H_o$: $\mu PB_{(Pre)} = \mu PB_{(Post)}$

$H_A$: $\mu PB_{(Pre)} \neq \mu PB_{(Post)}$

Where: PB = Perceived boredom, Pre = after the 90 second practice and before the experimental protocol, Post = after the experimental protocol.

***Hypothesis 3:*** The null hypothesis proposed that there will be no significant difference in the subjective ratings between the tasks.

***3a:***

$H_o$: $\mu ME_{Target\ response} = \mu ME_{Card\ sort} = \mu ME_{Choice} = \mu ME_{Tracking} = \mu ME_{Spelling}$

$H_A$: $\mu ME_{Target\ response} \neq \mu ME_{Card\ sort} \neq \mu ME_{Choice} \neq \mu ME_{Tracking} \neq \mu ME_{Spelling}$

Where: ME = mental effort

***3b:***

$H_o$: $\mu F_{Target\ response} = \mu F_{Card\ sort} = \mu F_{Choice} = \mu F_{Tracking} = \mu F_{Spelling}$

$H_A$: $\mu F_{Target\ response} \neq \mu F_{Card\ sort} \neq \mu F_{Choice} \neq \mu F_{Tracking} \neq \mu F_{Spelling}$

Where: F = frustration

***3c:***

$H_o$: $\mu P_{Target\ response} = \mu P_{Card\ sort} = \mu P_{Choice} = \mu P_{Tracking} = \mu P_{Spelling}$

$H_A$: $\mu P_{Target\ response} \neq \mu P_{Card\ sort} \neq \mu P_{Choice} \neq \mu P_{Tracking} \neq \mu P_{Spelling}$

Where: P = perceived performance

***3d:***

$H_o$: $\mu B_{Target\ response} = \mu B_{Card\ sort} = \mu B_{Choice} = \mu B_{Tracking} = \mu B_{Spelling}$

$H_A$: $\mu B_{Target\ response} \neq \mu B_{Card\ sort} \neq \mu B_{Choice} \neq \mu B_{Tracking} \neq \mu B_{Spelling}$

Where: B = boredom

***Hypothesis 4:*** The null hypothesis proposed that there will be no significant difference in physiological measures as a function of time.

$H_o$: $\mu PR_{(time)} = \mu PR_{(time)}$

$H_A$: $\mu PR_{(time)} \neq \mu PR_{(time)}$

Where: PR = {energy expenditure, breathing frequency, heart rate frequency, heart rate variability (refer to chapter 3 for detail on type of parameters) and tympanic and forehead temperature}, Time = over 5 minute time intervals.

***Hypothesis 5:*** The null hypothesis proposed that there will be no significant difference in physiological measures between the tasks.

$H_o$: $\mu PR_{Target\ response} = \mu PR_{Card\ sort} = \mu PR_{Choice} = \mu PR_{Tracking} = \mu PR_{Spelling}$

$H_A$: $\mu PR_{Target\ response} \neq \mu PR_{Card\ sort} \neq \mu PR_{Choice} \neq \mu PR_{Tracking} \neq \mu PR_{Spelling}$

Where: PR = {energy expenditure, breathing frequency, heart rate frequency, heart rate variability (refer to chapter 3 for detail on type of parameters) and tympanic and forehead temperature}

***Hypothesis 6:*** The null hypothesis proposed that there will be no significant difference in physiological measures between the beginning and end of the task.

$H_o$: $\mu PR_{(beginning)} = \mu PR_{(end)}$

$H_A$: $\mu PR_{(beginning)} \neq \mu PR_{(end)}$

Where: PR = {energy expenditure, breathing frequency, heart rate frequency, heart rate variability (refer to chapter 3 for detail on type of parameters) and tympanic and forehead temperature}, beginning = a) the first minute of the task and b) the second minute of the task, end = the last minute of the task.

***Hypothesis 7:*** The null hypothesis proposed that there will be no significant difference in physiological measures between the first and second minute of the task.

$H_o$: $\mu PR_{(first\ minute)} = \mu PR_{(second\ minute)}$

$H_A$: $\mu PR_{(first\ minute)} \neq \mu PR_{(second\ minute)}$

Where: {energy expenditure, breathing frequency, heart rate frequency, heart rate variability (refer to chapter 3 for detail on type of parameters) and tympanic and forehead temperature}

***Hypothesis 8:*** The null hypothesis proposed that there will be no significant difference in performance, between the first and last minute of the task.

$H_o$: $\mu P_{(first\ minute)} = \mu P_{(last\ minute)}$

$H_A$: $\mu P_{(first\ minute)} \neq \mu P_{(last\ minute)}$

Where: P = {response time and accuracy}

***Hypothesis 9****:* The null hypothesis proposed that there will be no significant difference in physiological measures pre and post the task transition.

$H_o$: $\mu PR_{(pre)} = \mu PR_{(post)}$

$H_A$: $\mu PR_{(pre)} \neq \mu PR_{(post)}$

Where: PR = {energy expenditure, breathing frequency, heart rate frequency, heart rate variability (refer to chapter 3 for detail on type of parameters) and tympanic and forehead temperature}, Pre = the minute before task transition, Post = a) the minute after the task transition and b) the second minute after task transition.

### 3.11 DATA REDUCTION AND ANALYSIS

Measures of task-switching behaviour were collected throughout testing. These included the time the participant spent on each task (duration) as a percentage of the total duration of the experimental procedure, and the type of task switched to (frequency) during the protocol. A task matrix was compiled which illustrated the probability of one task being chosen over another, and the probability of a specific task being chosen in succession from another task. This study posed a challenging statistical analysis due to the unpredictable durations and frequencies spent on different tasks. The independent variable in this study is the task performed. However, the type of task performed is dependent on the task-switching behaviour of the individual.

The raw performance data for the target response task (response time); choice reaction task (response time and correct response) and tracking task (reaction time and target deviation) were analyzed using the Human Kinetics and Ergonomics reduction tool developed by Goebel (2012). The raw performance data for the card sorting task were reduced using the PEBL software. The number of correct spelling questions and overall speed was recorded by the investigator per trial. Performance measures were however analysed in time intervals within each trial and therefore it was not possible to analyze spelling performance.

Physiological data were collected by the data logger (HR, HRV and body temperature) and the Ergospirometer (EE and BF). These data were reduced using the Human Kinetics and Ergonomics data reduction tool developed by Goebel (2010).

All statistical analyses were conducted using STATISTICA (version 10) software package to determine significant differences, and graphically display the information. All physiological data were normalised by dividing the values by the mean of each interval. The purpose of this was to reduce the variance among the participants. Additionally, by normalizing the data, comparisons could be made between different task types because the type of task elicited varying physiological responses. Analyses were conducted by averaging across individuals rather than analyzing each individual's data in isolation. The variability in responses among individuals would be too vast to make it possible to identify exactly which factors cause task switching. Each task trial differed in duration within and between participants. Data were therefore analysed in one minute intervals during the beginning and end of the trial. An interval greater than one minute would exclude any trials less than two minutes (first and last minute) from the analysis. Each trial, even if it was completed by the same participant, was regarded as a separate case in Statistica. This was due to the fact that each participant conducted differing numbers of trials of either the same task or different tasks.

A one factorial analysis of variance was used to determine significant differences in the following factors:

- Duration and frequency between the five task types.
- Subjective measures between the five different tasks.
- Boredom before and after the testing procedures.
- Physiological variables per task type and over time, without task type being considered.
- Physiological variables before and after the task transition.
- Physiological and performance measures during the beginning and end of each task trial.

In some cases, gender was used as a covariate to determine significant differences between male and female. A confidence level of $p<0.05$ was used to determine significance for all statistical analyses and Scheffe *post-hoc* analyses were conducted where appropriate.

# CHAPTER 4

# RESULTS

## 4.1 INTRODUCTION

The present study analysed task-switching behaviour over a 45 minute period and attempted to match observable behavioural changes (task-switching decisions and time spent on tasks) to the internal responses of the body. The objective of the study was to identify how physiological, performance and subjective measures fluctuated when individuals were given the control to self-regulate behaviour by switching between five tasks.

Participants selected one of the five tasks to perform and worked on this task for a desired duration. Not all tasks were performed, and some were repeated by participants. All tasks were executed for differing durations by the participants.

The independent variable was the type of task conducted. The five different tasks were selected and modified with the purpose of investigating resource usage and relative cycle time to determine how these factors affect task-switching behaviour. The tasks had the following properties: Target response task required perceptual and motor resources with micro breaks separating repetitions; tracking task required perceptual and motor resources with continuous attention needed throughout; choice task required perceptual, cognitive and motor resources with a fast cycle time; card sorting task required perceptual, cognitive and motor resources with a slower cycle time; spelling required perceptual, cognitive and motor resources and was a self-paced task. The following average cycle times were determined to distinguish between the repetition rates of each task:

- The tracking task = continuous (no cycle)
- The target response task = 0.34s
- The choice reaction task = 1.15s
- The card sorting task = 1.31s
- The spelling task = 8.00s

The dependent variables included physiological, performance and subjective measures. Physiological measures were recorded as an indication of effort and task demands. These included energy expenditure, respiration rate, heart rate, heart rate variability and body temperature. Performance measures included reaction time and accuracy. Subjective measures included ratings of boredom, mental effort, frustration, perceived performance and time perception. Behavioural measures were recorded which involved the task alternation profile and the duration spent on each task.

The method used in this investigation resulted in each participant selecting a unique task alternation profile. Firstly, task-switching behaviour was analysed by determining the frequency of choosing one task more often than another and the duration spent on each task. Secondly, subjective measures were analysed for each task type. Thirdly, the physiological responses for the different tasks were averaged and compared. Fourthly, the physiological responses were analysed over five-minute intervals, regardless of the task type. Fifthly, performance and physiological responses during the beginning of the task were compared to the end of the task. Lastly, physiological responses were analysed before and after the transitions between tasks.

### 4.2 TASK-SWITCHING BEHAVIOUR

Task-switching behaviour was analysed by determining the frequency of each task being selected, the total time spent on each task and the mean time spent on each task trial.

In Figure 8, the total number of times (frequency) each task was chosen by all participants is displayed. Task frequency for each task type was expressed as a percentage of the total number of task selections. The higher the task frequency, the more often the task was selected.

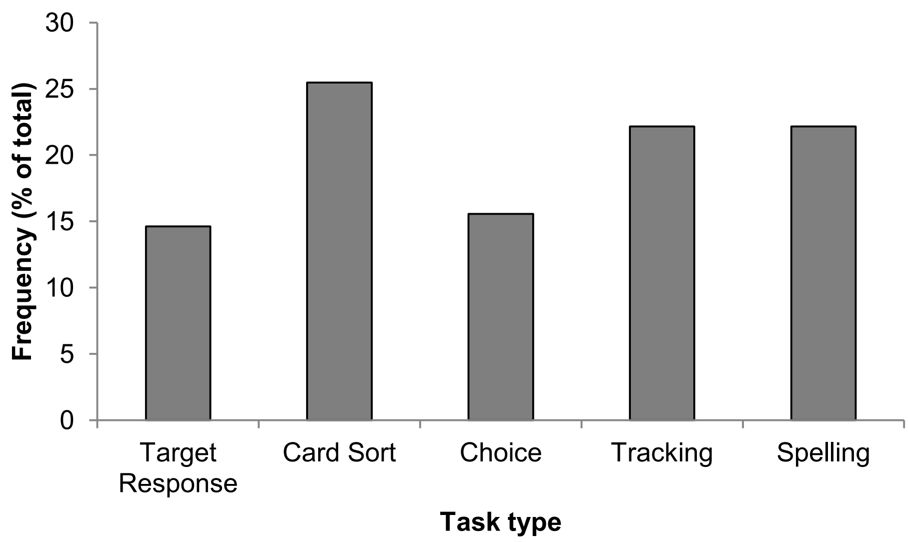


Figure 8: The frequency (% of total) that each task type was conducted.

The card sorting task was selected the most frequently (26%), whereas the target response and choice tasks were the least frequently chosen, respectively. The frequencies of conducting the target response and choice tasks were similar (only differed by 1%). However, Figure 10 shows a considerable difference in mean duration between the target response (4 minutes) and choice task (5.5 minutes). Similarly, the frequency of the tracking and the spelling task being performed were similar (only differed by 1%); yet, the mean duration of the tracking task (6.7 minutes) was considerably less than the spelling task (7.7 minutes) (Figure 10).

In Figure 9, the total amount of time spent on each task collectively among the participants is shown.

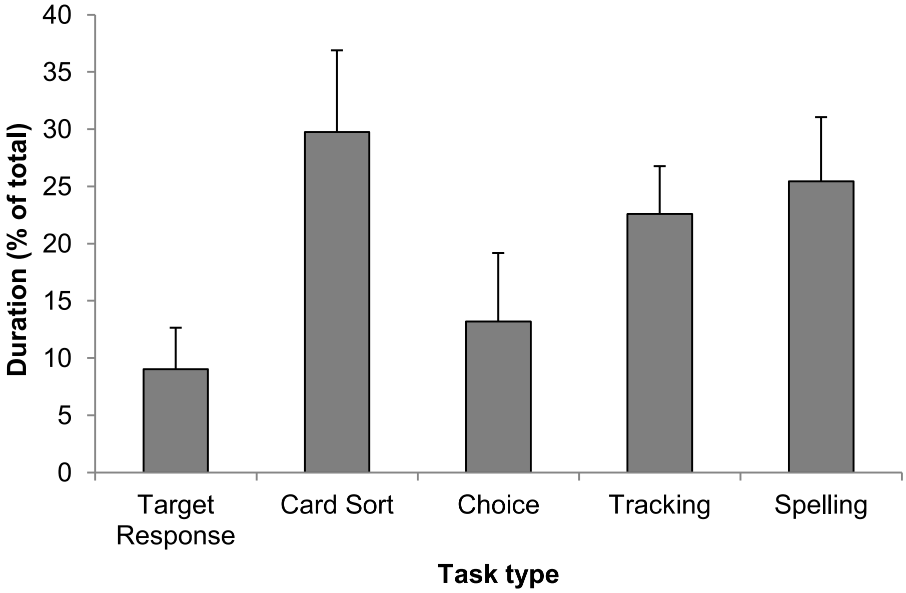


Figure 9: The total duration (% of total time) spent on each task. (error bar indicates 95% confidence interval)

In Figure 9, participants chose to spend the majority of the time on the card sorting task (30%), which was closely followed by the spelling test (25%). The least amount of time was spent on the target response task (9%), followed by the choice task (13%).

Figure 10 shows the mean time participants chose to spend on each task trial.

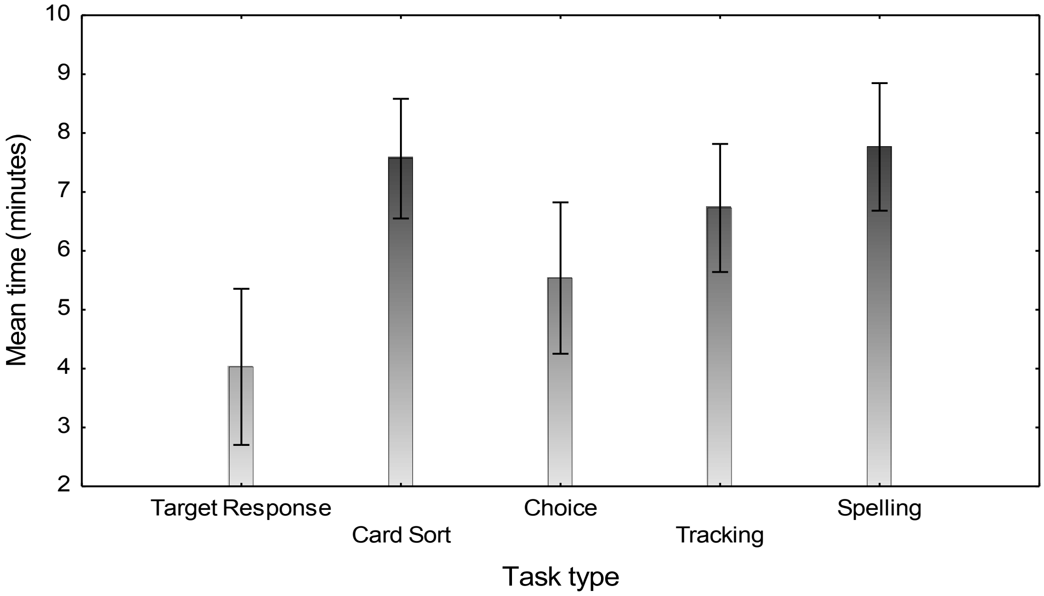


Figure 10: The mean duration spent on each task before deciding to switch to another task (error bar indicates 95% confidence interval).

The amount of time spent on each task was significantly ($F(4,201) = 6.335$, $p<.001$) different among the five tasks. A *post-hoc* analysis revealed that the time spent on the target response task was significantly ($p<0.01$) less than the card sorting, tracking and spelling task. In contrast, participants chose to spend longer on the spelling and card sorting tasks. Figure 9 showed that 5% more total time was spent on card sorting than spelling, however, Figure 10 showed that the mean duration spent on spelling (7.7 minutes) and card sorting (7.5 minutes) tasks was very similar. The card sorting task was repeated more often than the spelling task (Figure 8), but conducted for shorter durations.

Table III: The relative frequency (% of total) of each task type being conducting during the specified time markers over the testing time. The shaded blocks in Table III highlight the tasks that were conducted most often during the specific time marker.

| Task | Min 1 | Min 5 | Min 10 | Min 15 | Min 20 | Min 25 | Min 30 | Min 35 | Min 40 |
|---|---|---|---|---|---|---|---|---|---|
| **Target Response** | 21% | 18% | 12% | 6% | 9% | 6% | 6% | 6% | 18% |
| **Card Sort** | 36% | 18% | 32% | 24% | 18% | 30% | 35% | 41% | 18% |
| **Choice** | 3% | 9% | 18% | 18% | 18% | 9% | 21% | 9% | 15% |
| **Tracking** | 15% | 35% | 15% | 15% | 26% | 39% | 18% | 18% | 18% |
| **Spelling** | 24% | 21% | 24% | 38% | 29% | 15% | 21% | 26% | 32% |

**Note: Tasks may have overlapped into more than one time interval depending on the duration of the task. Tasks that were conducted for longer durations (spelling task) will be more frequent than those conducted for short durations (target response task).**

The frequency of one task being selected over another as a function of time was significantly different ($F(4,140) = 6.014$, $p<.001$). The target response task was conducted most frequently in the 1$^{st}$, 5$^{th}$ and 40$^{th}$ minute, whereas from the 10$^{th}$ to the 35$^{th}$ the target response task was conducted very seldom. The spelling task was the most frequently conducted during the 15$^{th}$, 20$^{th}$ and 40$^{th}$ minutes, but this decreased substantially during the 25$^{th}$ and 30$^{th}$ minutes. The tracking task was the most frequently selected task during the 25$^{th}$ minute.

Table IV: The frequency of different transitions from one task to another.

| TASK FROM | FROM \ TO | Target response | Spelling | Tracking | Choice | Card sorting | Total |
|---|---|---|---|---|---|---|---|
| | Target response | | 6 | 9 | 3 | 8 | 26 |
| | Spelling | 10 | | 9 | 7 | 10 | 36 |
| | Tracking | 5 | 8 | | 12 | 14 | 39 |
| | Choice | 4 | 10 | 4 | | 10 | 28 |
| | Card sort | 5 | 14 | 18 | 10 | | 47 |
| Total | | 24 | 38 | 40 | 32 | 42 | |

(Column group "TASK TO" spans Target response through Card sorting.)

**Note: The total for task to and task from are not necessarily equal because a participant may have decided to start or end on a task resulting in only going from a task (start) or to a task (end).**

In Table IV, the shade of the block varies from dark (highest number) to light (lowest number). The most common task switch was from card sorting to tracking (18 times). The second most frequent task switch combination was tracking to card sorting and card sorting to spelling task. The least common task switch was from target response to choice, followed closely by choice to target response. The switch from choice to tracking was rare (4 times), whereas the switch from tracking to choice was relatively common (12 times).

### 4.3 SUBJECTIVE PERCEPTION OF TASKS

Subjective ratings were recorded to understand task-switching behaviour and the influence that boredom and perception of the task had on an individual's performance regulation. Boredom was measured before, during each task transition and after the experiment. Perception error was measured at task transitions and mental effort, frustration and perception of performance were measured after the experiment.

### 4.3.1 Boredom

Boredom ratings were taken at three points during the study. Firstly, the baseline boredom rating was taken after the 90 second warm-up, which was conducted prior to the experimental testing. Participants verbally rated how boring the task was following the warm-up (scale from 1-4). Secondly, the same scale was used to rate all five tasks at the end of the experiment. Thirdly, each time the participant decided to switch to another task, a boredom rating was given for the task that the participant decided to leave. Baseline boredom and post experiment boredom ratings were taken for each task. Therefore there were 170 samples because 34 participants rated each of the five tasks. Transition boredom was taken at each task transition, which resulted in 211 samples. Therefore transition boredom had to be statistically analysed separately.

The baseline and post experiment boredom ratings differed significantly ($F(4,132) = 24.774$, $p<.001$) between the different tasks. In addition, there was a significant difference ($F(1,33) = 37.988$ $p<.001$) between the baseline boredom ratings and those taken at the end of the experiment.

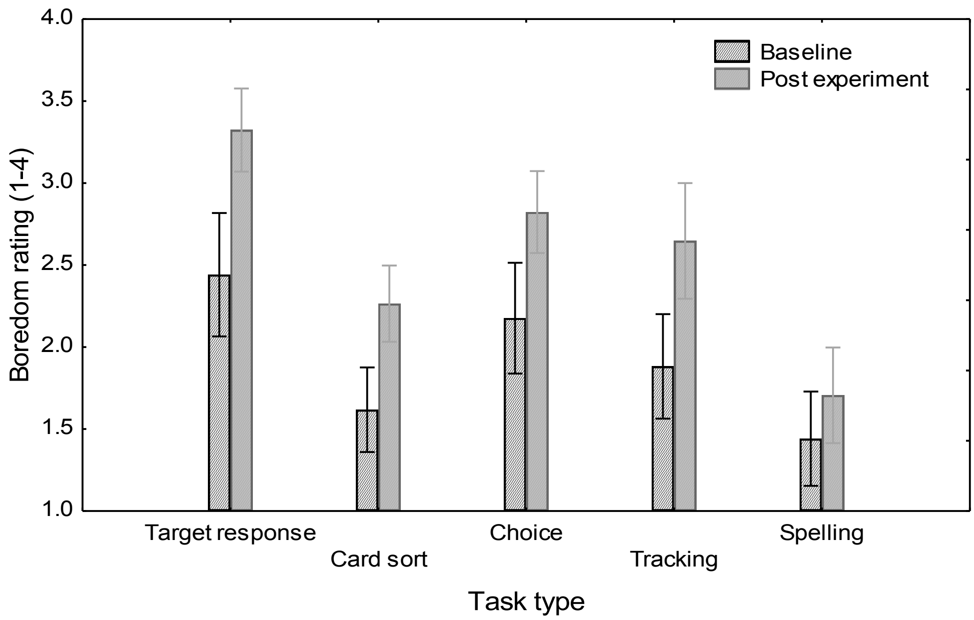


Figure 11: Baseline (taken after each task warm-up) and post-experiment boredom ratings (1=none, 4=a lot) taken for five different tasks (error bar indicates 95% confidence interval).

In Figure 11, the target response task was rated as the most boring, followed by the choice reaction task. The spelling task was rated as the least boring, followed by the card sorting task. This trend in boredom ratings remained the same following the experiment for all five tasks. The boredom ratings increased significantly from after the warm up to the end of the study for all five tasks. The spelling task showed the smallest increase in boredom, whereas the target response task showed the greatest increase in boredom over time. A *post hoc* analysis showed that a significant (p<.01) difference between the baseline and post experiment boredom ratings was evident for all tasks, excluding the spelling task.

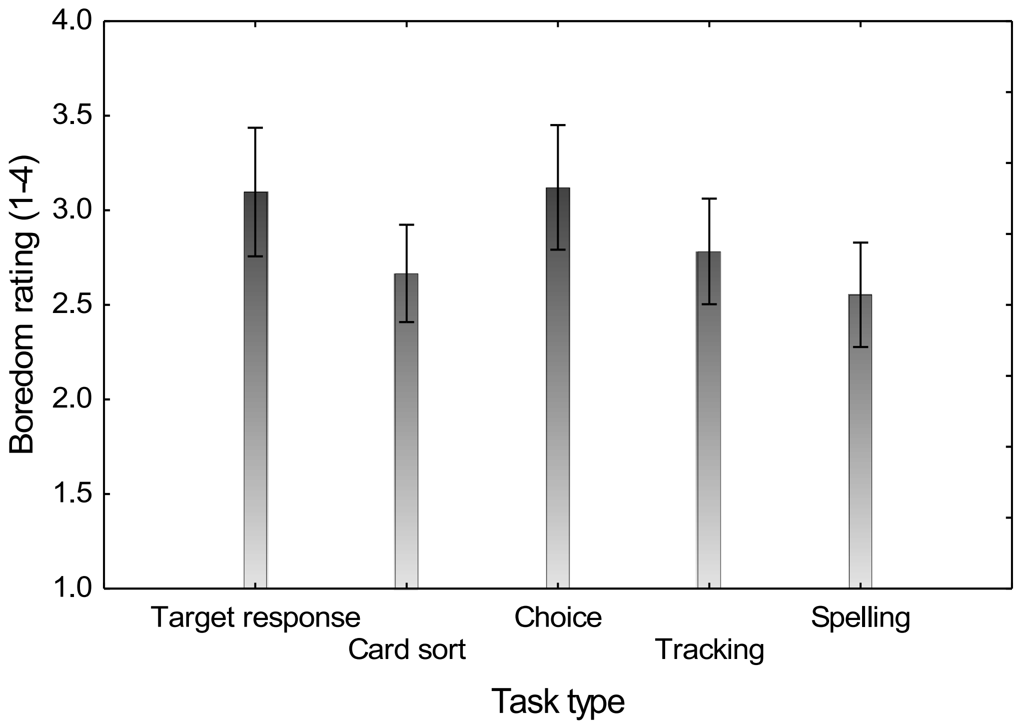


Figure 12: An average of the subjective ratings of boredom (1=none, 4=a lot) recorded at each task transition of the task that was switched away from (error bar indicates 95% confidence interval).

The transition boredom ratings were significantly different ($F(4,206) = 2.708$ $p<.05$) between the tasks. Figure 12 shows the spelling task had the lowest boredom rating, whereas the choice reaction had the highest boredom rating. The target response and tracking tasks were rated as the second most boring tasks. The boredom ratings during task transition were greater than the boredom ratings taken after the experiment for all tasks except the target response task, where post boredom exceeded transition boredom. Figures 11 and 12 show that the spelling task had the greatest increase in transition boredom (2.54 rating) from baseline boredom as opposed to post boredom (1.69 rating). Statistical analyses between transition boredom and boredom before and after the experiment were not possible because the samples were uneven. The degrees of freedom for the transition boredom and boredom before and after the experiment were 206 and 132 respectively.

### 4.3.2 Time perception

At each task transition the participants were asked to determine how much time they perceived to have spent on the task that they decided to switch away from. This perceived time was then divided by the actual time spent on the task to determine the time perception error (ratio of perceived time to actual time). Therefore, if the perception error was greater than 1, perceived time exceeded actual time spent on a task, meaning that the participant perceived time to be passing more slowly than in reality.

There was no significant difference between the five different tasks in the ratio of perceived to actual time spent on the task. For all tasks, participants perceived to have spent more time on the task than the actual time that was spent (ratio>1), except during the choice task (ratio<1).

### 4.3.3 Task frustration

Task frustration was subjectively rated at the end of the testing session. There were no significant differences in frustration ratings between the tasks; however there was a significant interaction ($F(1,120)$, $p<.05$) between task and gender. Males rated all tasks, except for the tracking task, as being more frustrating than the females. Females rated the tracking task as being the most frustrating task.

### 4.3.4 Mental Effort

There was a significant difference ($F(4,120) = 28.181$, $p<.001$) between the subjective ratings of mental effort for each task.

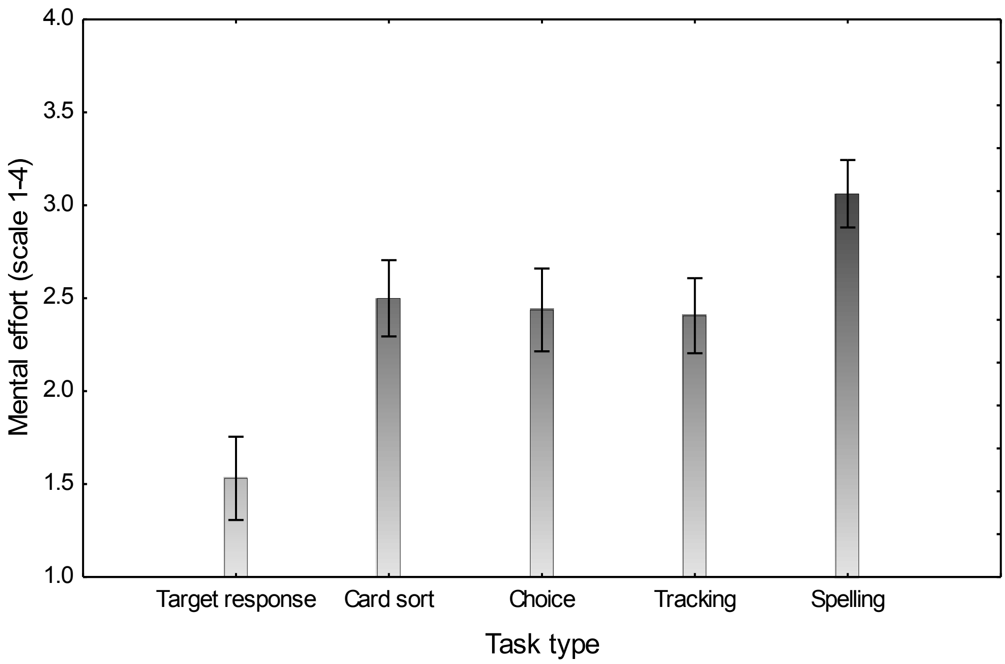


Figure 13: Subjective rating of mental effort (1=none, 4=too much) for five different tasks (error bar indicates 95% confidence interval).

A *post-hoc* analysis showed that the spelling task was rated as having significantly ($p<.01$) higher mental effort than the other four tasks. Conversely, the target response task was rated as having significantly ($p<.01$) lower mental effort than the other tasks. The choice, tracking and card sorting tasks were rated as having roughly the same level of mental effort (Figure 13).

#### 4.3.5 Subjective performance

Participants were asked to rate their level of performance in terms of which tasks they perceived to have performed best, and which worst, on a scale of 1-4, where 1=best and 4=worst.

There was a significant difference ($F(4,120) = 9.781$, $p<.001$) in subjective rating of performance between the five different tasks.

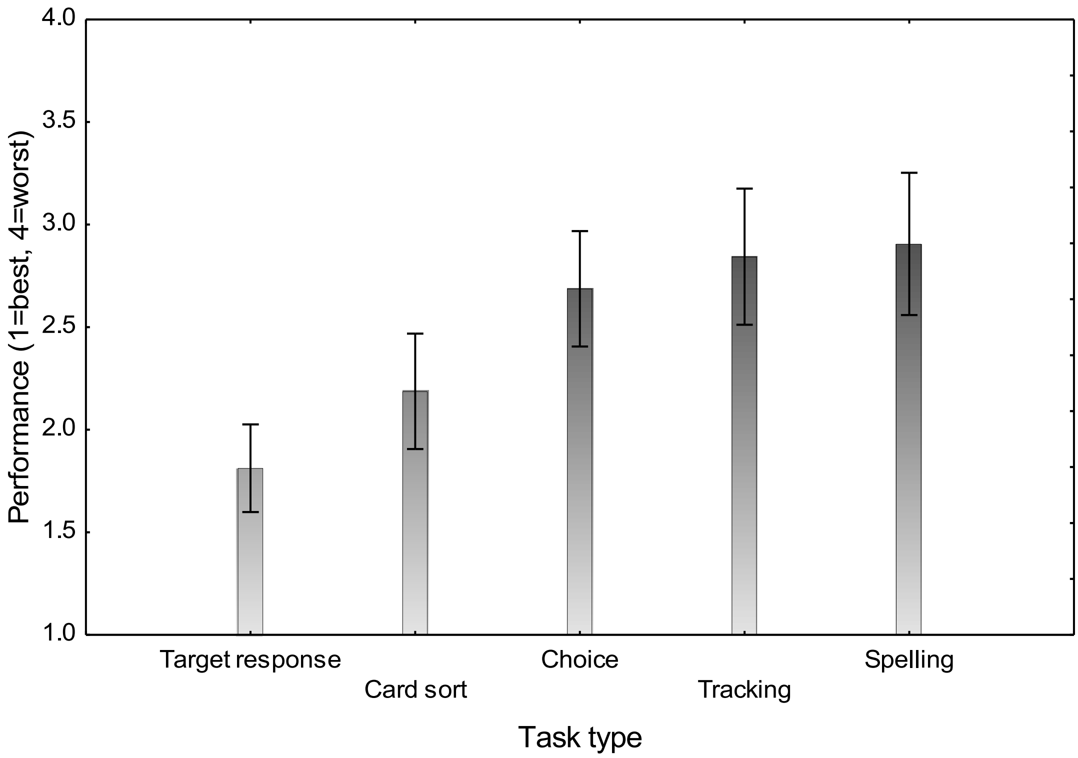


Figure 14: Subjective performance rating (1=best, 4=worst) for five different tasks (error bar indicates 95% confidence interval).

Participants rated performance to be best in the target response task, followed by card sorting. In contrast, performance was rated to be worst in the spelling and tracking task.

Table V: Summary of subjective measures that showed significant difference for each task, where TASK = changes in subjective measures depending on the type of task and TIME = changes in the subjective measures from baseline to post-experiment (X denotes significant difference where $p<.05$).

| SUBJECTIVE MEASURES | TASK | TIME |
|---|---|---|
| Boredom baseline | X | X |
| Boredom post-experiment | X | X |
| Boredom at transition | X | NA |
| Perception error | | NA |
| Task frustration | | NA |
| Mental effort | X | NA |
| Performance | X | NA |

## 4.4 PHYSIOLOGICAL RESPONSES FOR THE DIFFERENT TASKS

The means for all physiological parameters were calculated for each task so as to determine the general effect the task type had on the physiological responses of the body. This assessment of the physiological responses was used to determine the differing degrees of strain induced by each task. The effect of time was not included in this analysis and instead was processed separately (See Section 4.5). This allowed for inferences to be made in terms of understanding human task-switching behaviour. All physiological data used in this study were normalised. For each participant, the mean physiological responses per task were normalised against the mean of all tasks conducted by the participant.

### 4.4.1 Energy expenditure

Energy expenditure (EE) differed significantly ($F(4,201) = 4.537$ , $p<.05$) among the five tasks. *Post-hoc* analysis showed that the spelling task required significantly more energy than the card sorting task. Figure 15 shows that the choice and target response task required the second greatest amount of energy, followed closely by the tracking task.

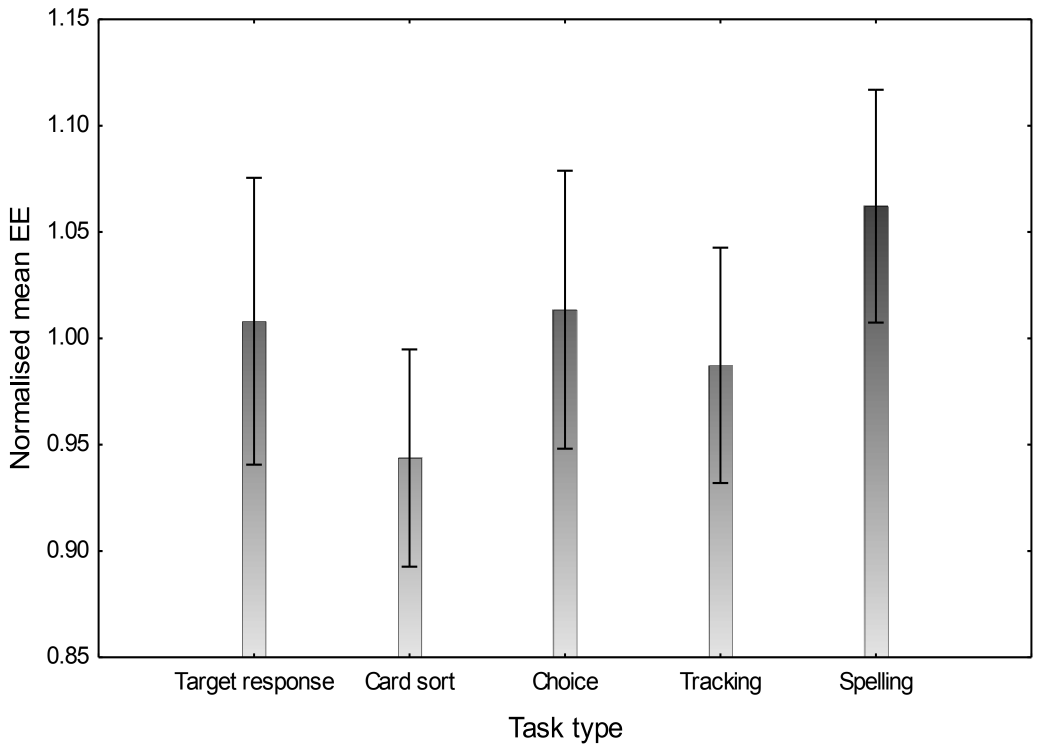


Figure 15: The normalised mean energy expenditure (EE) for five different tasks (error bar indicates 95% confidence interval).

### 4.4.2 Breathing frequency

The spelling task elicited a significantly ($F(4,201) = 9.33$, $p<.001$) lower breathing rate than any of the other four tasks. The tracking task, however, elicited the most rapid breathing frequency (BF), which was closely followed by the card sorting task (Figure 16).

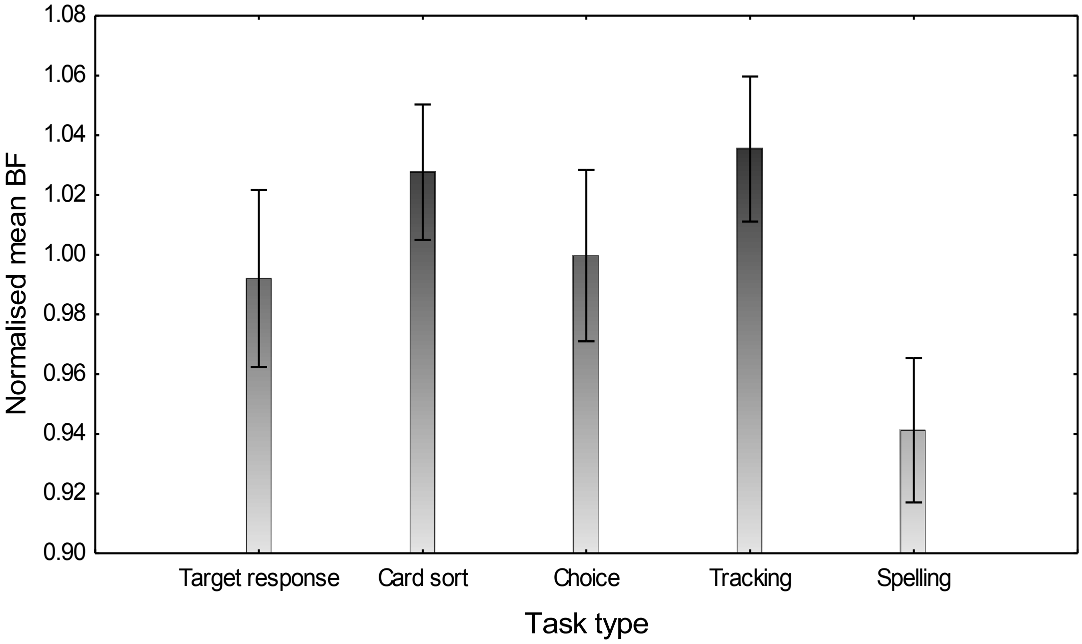


Figure 16: The normalised mean breathing frequency (BF) for five different tasks (error bar indicates 95% confidence interval).

### 4.4.3 Heart rate and heart rate variability measures

No significant differences in heart rate (HR) were found between the tasks. There was a significant difference ($F(4,201) = 5.987$, $p<.001$) in the *rMSSD* measure of heart rate variability (HRV) between the tasks. In Figure 17, HRV (*rMSSD)* was the highest during the spelling and choice tasks and the lowest during the target response and the tracking tasks. The *pNN50* measure of HRV was also analysed and delivered a similar pattern to the *rMSSD* data, however, no significant differences in *pNN50* were found between the tasks. A *post-hoc* analysis showed that there was a significant difference ($p<0.01$) between the spelling and target response tasks and between the spelling and tracking task.

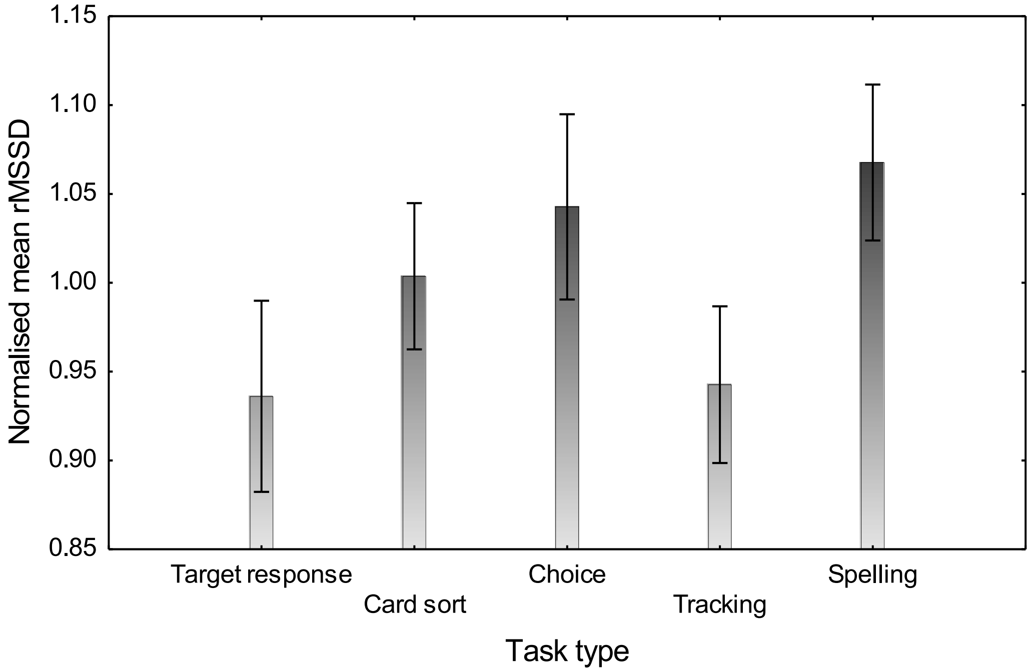


Figure 17: The normalised mean heart rate variability (*rMSSD*) for five different tasks (error bar indicates 95% confidence interval).

The power in the low frequency (LF) and high frequency bands (HF) was analysed as a measure of HRV. There were no significant differences in *HF power* between the tasks. However, a significant difference ($F(4,201) = 4.213$, $p<.01$) in *LF power* was found between the tasks. In Figure 18, the *LF Power* was highest during the spelling task and lowest during the tracking and target response task. The pattern was similar to that delivered by the *HF power band*; however, the choice task elicited lower values than the other tasks. Furthermore, the spelling task showed higher values than the other four tasks. A *post-hoc* analysis showed a significant ($p<.05$) difference between the spelling and target response tasks and the spelling and tracking tasks.

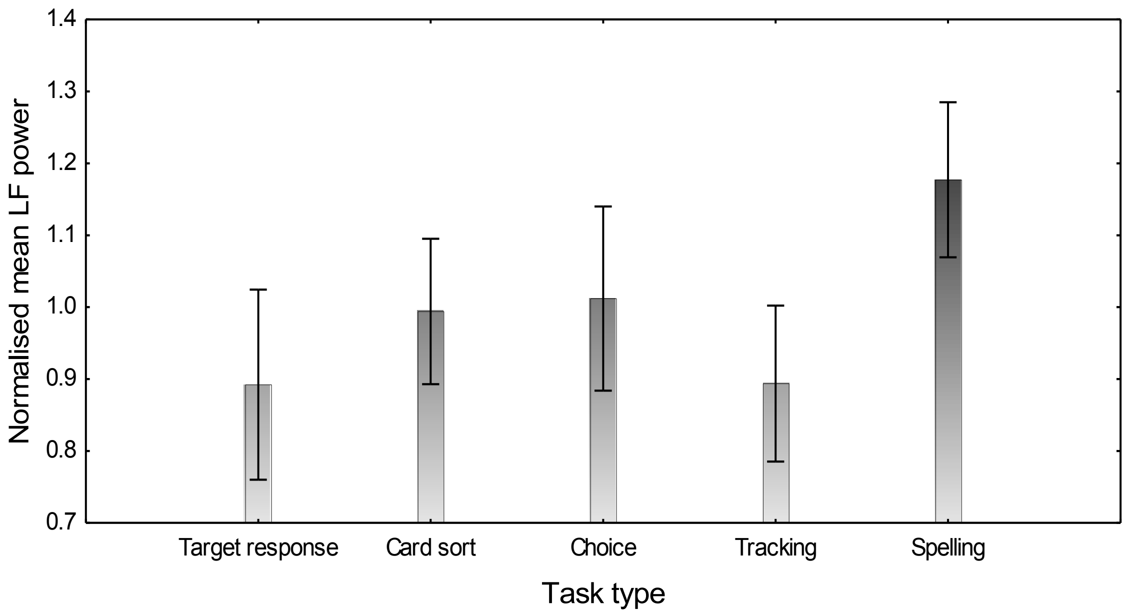


Figure 18: The normalised mean *low frequency (LF) power* for five different tasks (error bar indicates 95% confidence interval).

The *High frequency centre frequency* was analysed as a measure of HRV and was found to differ significantly ($F(4,201) = 6.8$, $p<.001$) between the tasks. Figure 19 shows that the spelling task was significantly lower than the other four tasks. The tracking and target response tasks had the *highest centre frequency* measure, followed closely by the card sorting task (Figure 19). *High frequency centre frequency* followed a similar pattern to breathing frequency, with the exception of the target response task having a lower breathing frequency. A *post-hoc* analysis showed a significant difference ($p<0.05$) between the spelling and target response tasks, and the tracking and card sorting tasks.

The target response and tracking tasks were perceptual-motor tasks requiring very little cognitive effort, but had a short cycle time. On the other hand, the spelling task is a perceptual-cognitive-motor task that was self-paced. This difference in task characteristics may explain the variation in the centre frequencies.

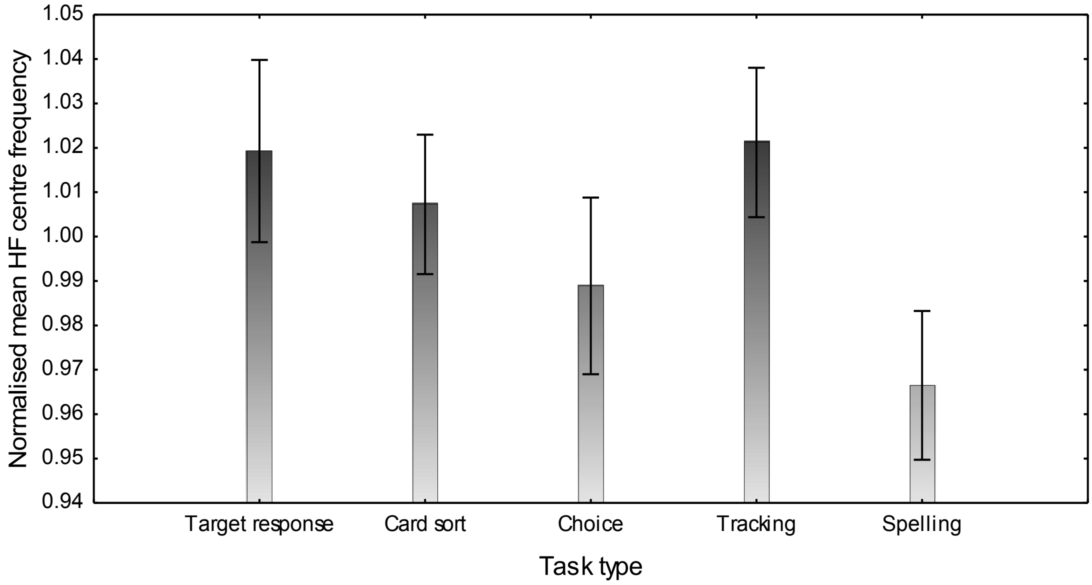


Figure 19: The normalised mean *high frequency (HF) centre frequency* for five different tasks (error bar indicates 95% confidence interval).

The relative strength of the power of the LF and HF bands is known as the *LF/HF ratio.* This ratio differed significantly ($F(4,201) = 3.03$, $p<.05$) between the tasks (Figure 20). This ratio represents the balance between the relative strength of the sympathetic and autonomic branches (see section 2.7.1.1). A *post-hoc* analysis showed the spelling task to have a significantly higher ($p<.05$) LF/HF ratio than the target response task.

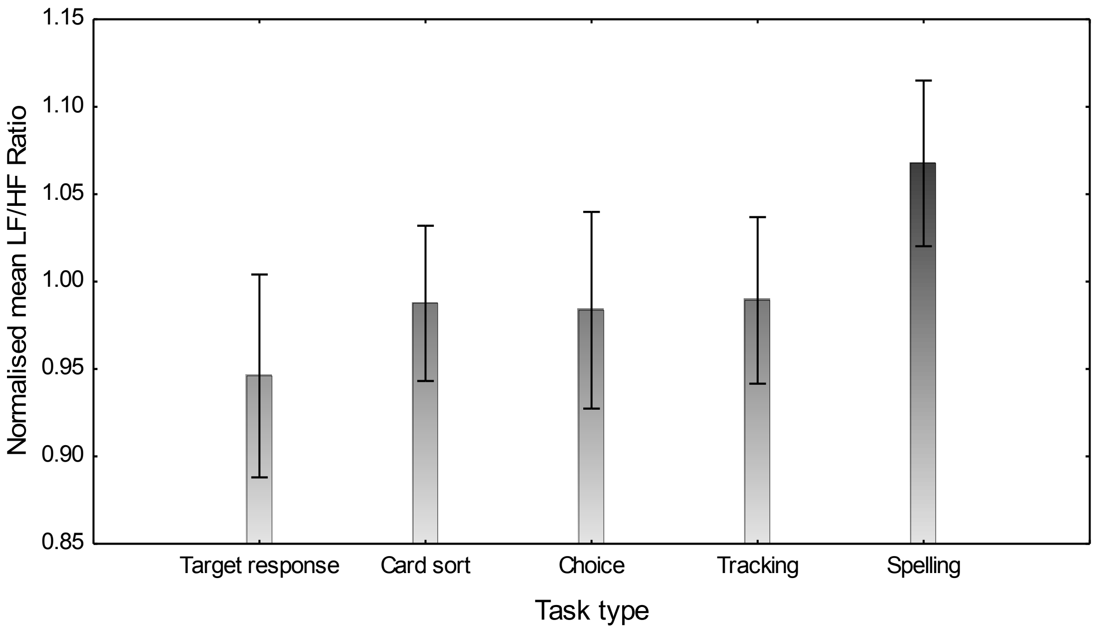


Figure 20: The normalised mean low frequency versus high frequency ratio (LF/HF) for five different tasks (error bar indicates 95% confidence interval).

### 4.4.4 Tympanic and skin temperature

There was a significant difference ($F(4,201) = 3.001$, $p<.05$) in temperature between the tasks. Both the tympanic and skin temperatures were greatest during the choice task, whereas the lowest temperatures were recorded during the spelling task. Figure 21 shows that there was a significant decrease ($p<.05$) in skin temperature during the spelling task compared to the other four tasks. A *post-hoc* analysis showed a significant difference ($p<.05$) between the tympanic and skin temperature during the spelling task.

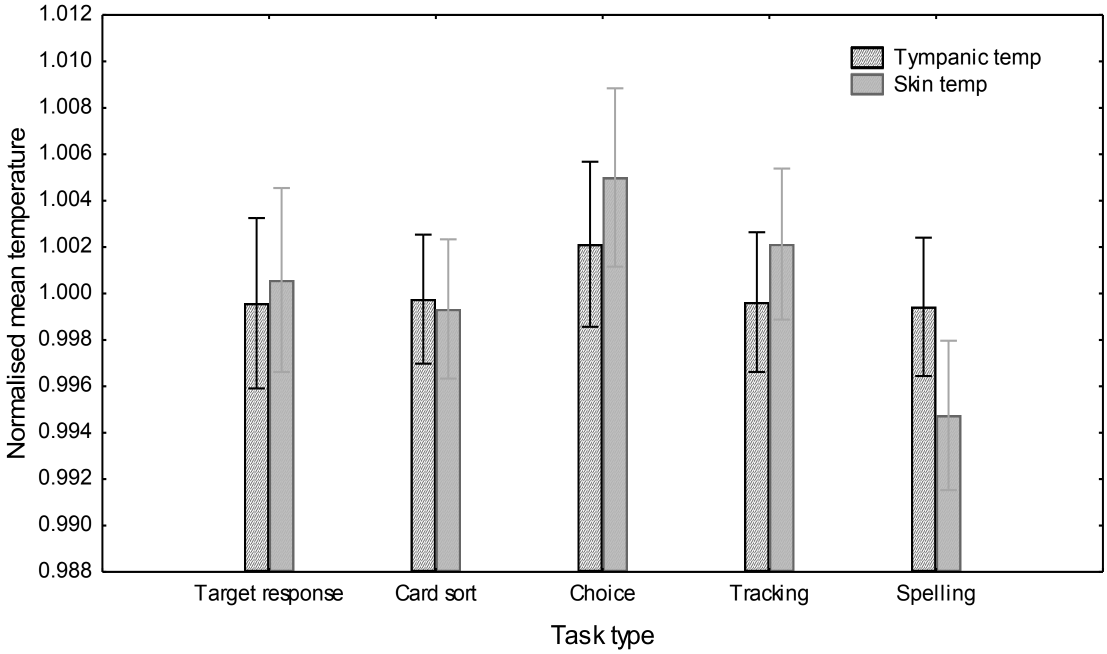


Figure 21: The normalised mean skin and tympanic temperature for five different tasks (error bar indicates 95% confidence interval).

Table VI: Summary of physiological parameters that showed significant differences between the type of task; where TASK = changes in the mean physiological parameters for each task type (X denotes significant difference where p <.05).

| PHYSIOLOGICAL PARAMETERS | TASK TYPE |
|---|---|
| Energy expenditure | X |
| Breathing frequency | X |
| Heart rate | |
| HRV: rMSSD | X |
| HRV: High frequency Power | |
| HRV: Low frequency Power | X |
| HRV: High frequency centre frequency | X |
| HRV: Low frequency centre frequency | |
| HRV: Low frequency high frequency Ratio | X |
| Tympanic temperature | X |
| Skin temperature | X |

## 4.5 PHYSIOLOGICAL RESPONSES OVER TIME

The physiological variables were analysed over time intervals of five minutes, irrespective of the type of task conducted and duration of time spent on the task. This was to gain a general understanding of how the physiological responses change over time. This is important to highlight the coping strategy of the human body from the start of a task and with time on task. Physiological variables were normalised against the individual mean for each five minute time interval.

### 4.5.1 Energy Expenditure

There was a significant increase ($F(7,224) = 2.714$, $p<.05$) in energy expenditure (EE) between the second and third time intervals. EE then remained consistent till the end of the experiment, despite the significant decrease in EE between the 20-25 and 25-30 minute intervals (Figure 22).

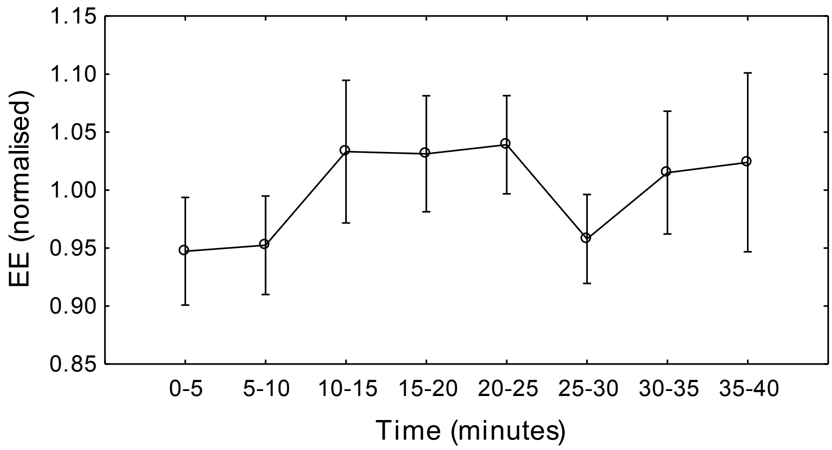


Figure 22: Energy Expenditure (EE) normalised over time intervals of five minutes (error bar indicates 95% confidence interval).

### 4.5.2 Breathing frequency

Breathing frequency changed significantly ($F(7,224) = 3.023$, $p<.01$) over time. A decrease was observed over time from the first to the 15-20 minute interval. Breathing frequency increased from the 15-20 to the 20-25 minute interval, after which a consistent decrease in breathing frequency was observed (Figure 23).

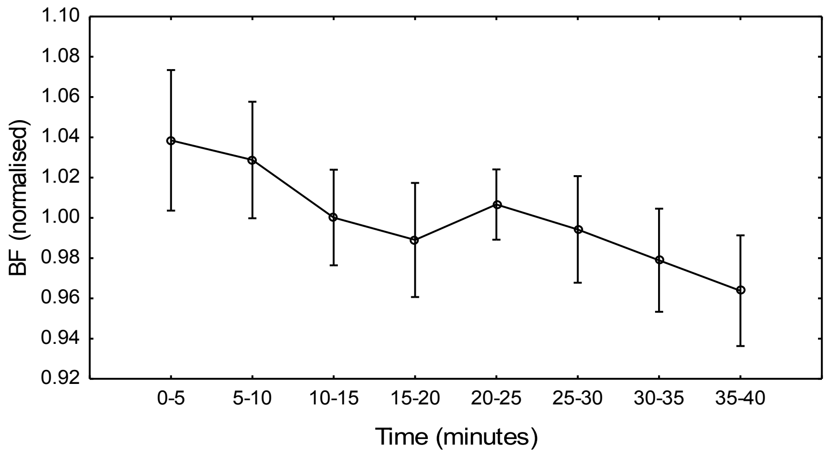


Figure 23: Breathing frequency (BF) normalised over time intervals of five minutes (error bar indicates 95% confidence interval).

### 4.5.3 Heart rate

Heart rate (HR) decreased significantly ($F(7,224) = 5.606$, $p<.001$) over time from the beginning to the end of the experiment.

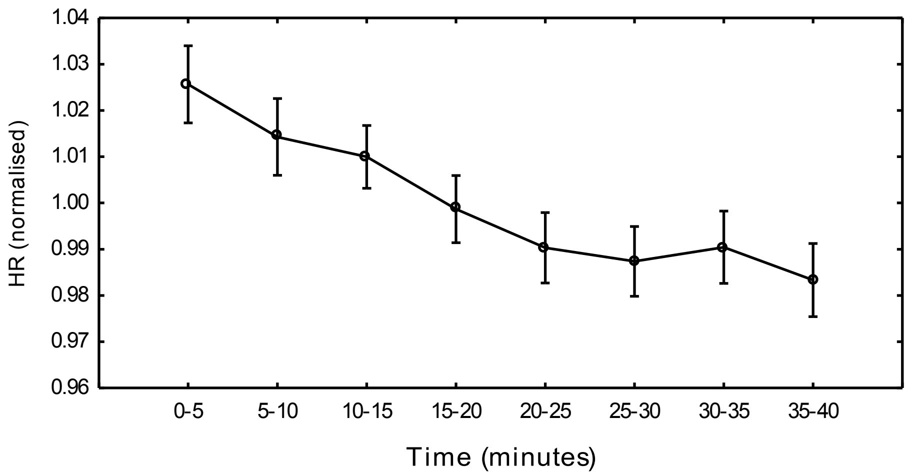


Figure 24: Heart rate (HR) normalised over time intervals of five minutes (error bar indicates 95% confidence interval).

### 4.5.4 Heart rate variability

HRV (rMSSD) increased significantly ($F(7,224) = 1.384$, $p<.001$) from the first to the last interval. Figure 25 shows a substantial increase in HRV (rMSSD) during the first three intervals. However, this reached a plateau which continued to the 20-25 minute interval. The HRV (rMSSD) increased until the last interval, where a reduction was observed.

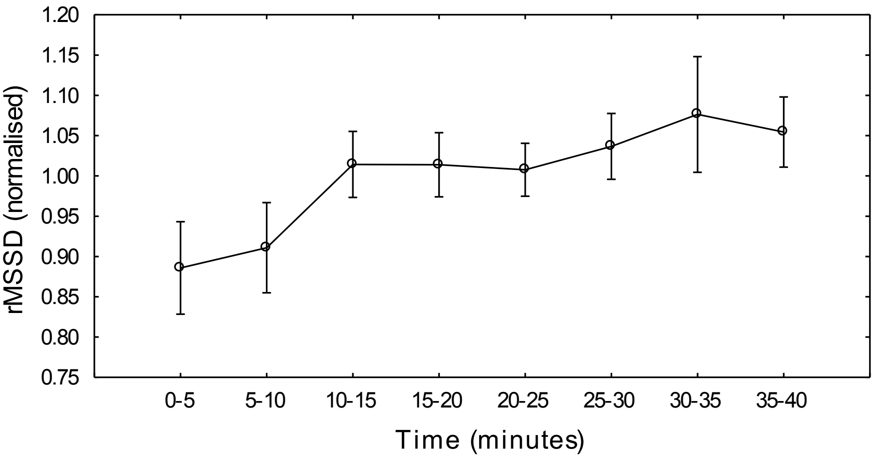


Figure 25: Heart rate variability (*rMSSD)* normalised over time intervals of five minutes (error bar indicates 95% confidence interval).

A significant (F(7,224) = 6.720, p<.001) increase in HRV (*pNN50)* was observed during the first 20 minutes of conducting the experiment. This trend then reached a plateau and decreased slightly from the 20-25 minute interval.

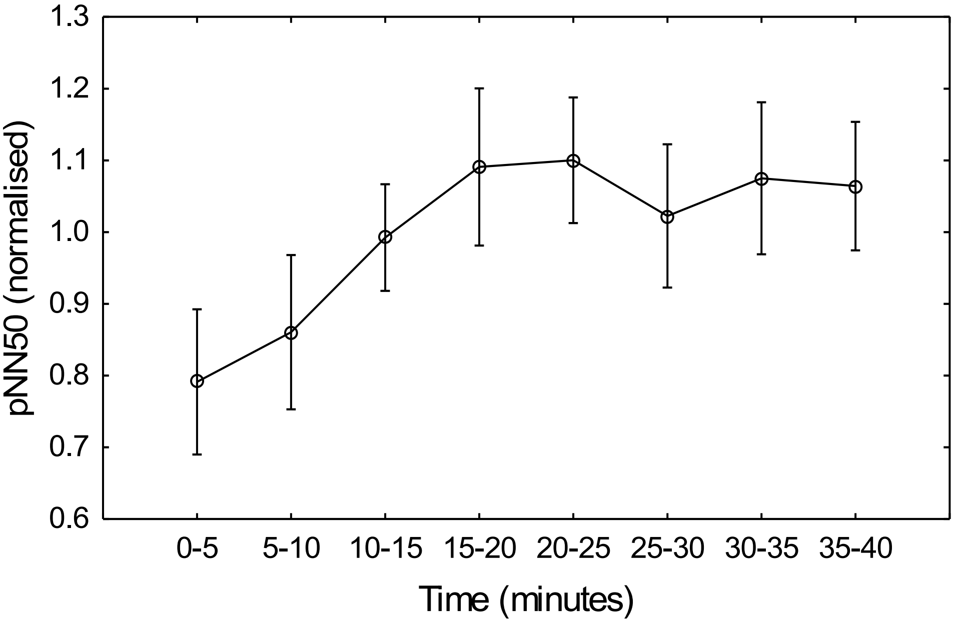


Figure 26: Heart rate variability (*pNN50)* normalised over time intervals of five minutes (error bar indicates 95% confidence interval).

The power in the HF band increased significantly (F(7,224) = 5.058, p<.001) from the beginning of the experiment to the 15-20 minute interval. In Figure 27, a plateau was reached from the 20th minute and continued until the end of the experiment.

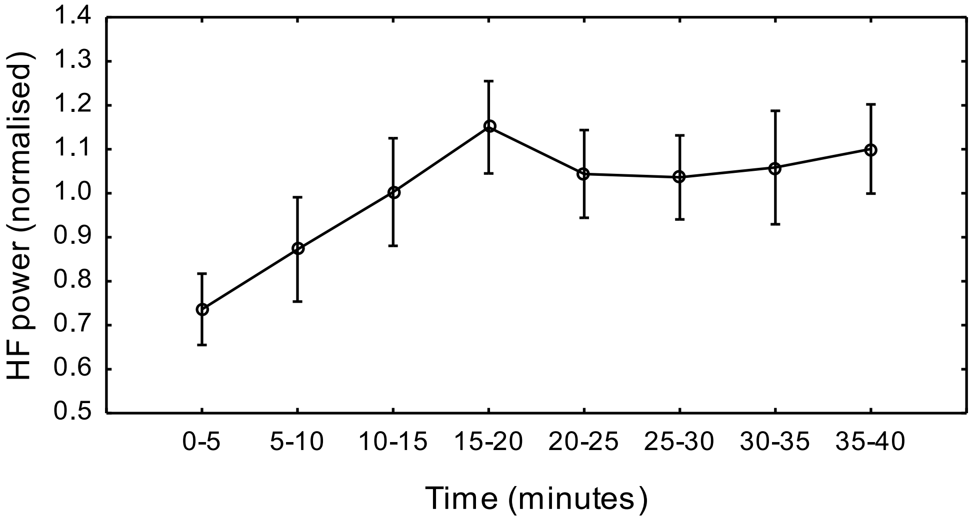


Figure 27: *High frequency (HF) power* normalised over time intervals of five minutes (error bar indicates 95% confidence interval).

There was a significant increase ($F(7,224) = 3.250$, $p < .01$) in the power of the LF band from the beginning to the end of the experiment.

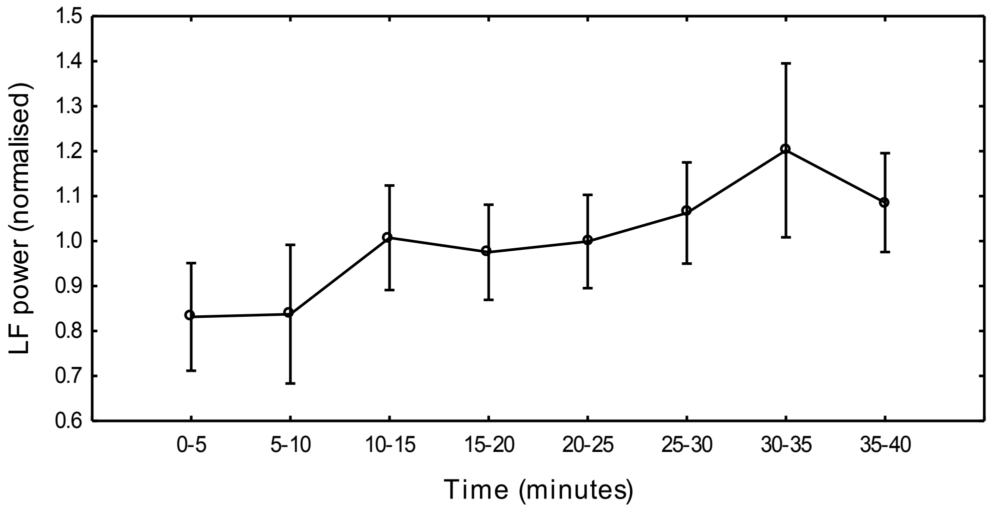


Figure 28: *Low frequency (LF) power* normalised over time intervals of five minutes (error bar indicates 95% confidence interval).

### 4.5.5 Tympanic and skin temperature

No significant ($p=0.77$) change in skin temperature was observed. Tympanic temperature (TT) increased significantly ($F(7,224) = 2.213$, $p<.05$) for the duration of the experiment. The first three intervals showed a gradual increase as this was considered the warm-up phase of the experiment (Figure 30). There was an increase in temperature from the 10-15 minute interval to the 20-25 minute interval.

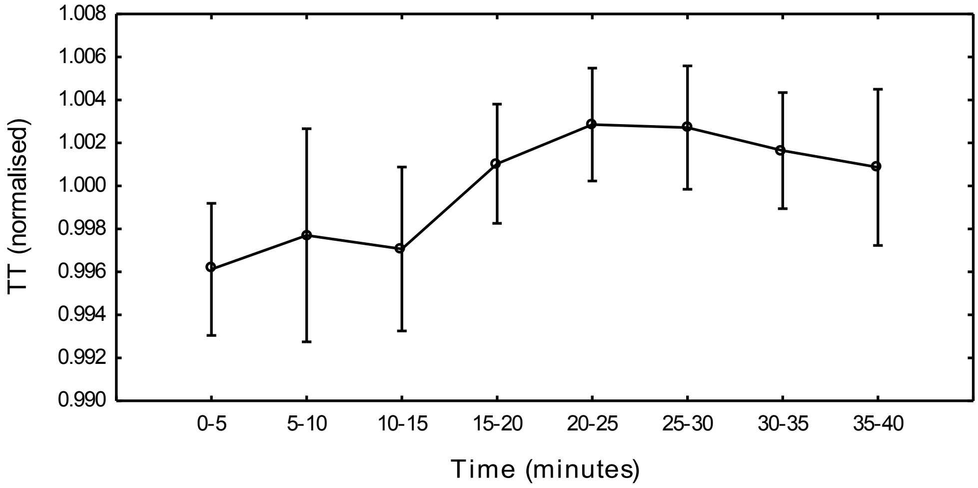


Figure 29: Tympanic temperature (TT) over 5 minute time intervals (error bar indicates 95% confidence interval).

Table VII: Summary of physiological parameters that showed significant difference over time in 5 minute intervals, where TIME = changes in the mean physiological parameters over time on task (X denotes significant effects where p<.05).

| **PHYSIOLOGICAL PARAMETERS** | **TIME** |
|---|---|
| Energy expenditure | X |
| Breathing frequency | X |
| Heart rate | X |
| HRV: rMSSD | X |
| HRV: pNN50 | X |
| HRV: High frequency Power | X |
| HRV: Low frequency Power | X |
| HRV: Low frequency high frequency ratio | |
| Tympanic temperature | X |
| Skin temperature | |

## 4.6 RESPONSE CHANGES WITHIN EACH TASK TRIAL

The beginning and end of each task trial were compared to determine whether there was a significant change in performance or physiological responses that may explain the decision to switch to another task. It was hypothesized that a significant decrease in performance or increase in the physiological responses before the task switch, as opposed to the start of the task, would confirm these as factors motivating task-switching.

### 4.6.1 Performance measures

The first and last minute of each task was analysed to determine the change in performance from starting the task, to the point where the participant decided to make a task switch. Response time (ms) and accuracy (deviation and number of correct responses) were analysed for all tasks except the target response task, as this task had no measure of accuracy. The performance indicators for the spelling task were not measured, because the speed of completing questions and the number of correct answers were calculated over the whole duration of the task, rather than in one minute intervals. Therefore analyses for the first and last minute were not possible.

There was no significant difference in response time (ms) between the first and last minute of the task for the target response task, the tracking task and the choice task. The choice task produced no significant changes in accuracy. The tracking task elicited a significant increase ($F(1,43) = 4.45$, $p<.05$) in target deviation from the first to the last minute of the task. During the card sorting task, a significant ($F(1,55) = 12.853$, $p<.01$) increase in response time and significant ($F(1,55) = 3.877$, $p<.001$) decrease in accuracy was found, and thus performance decreased significantly.

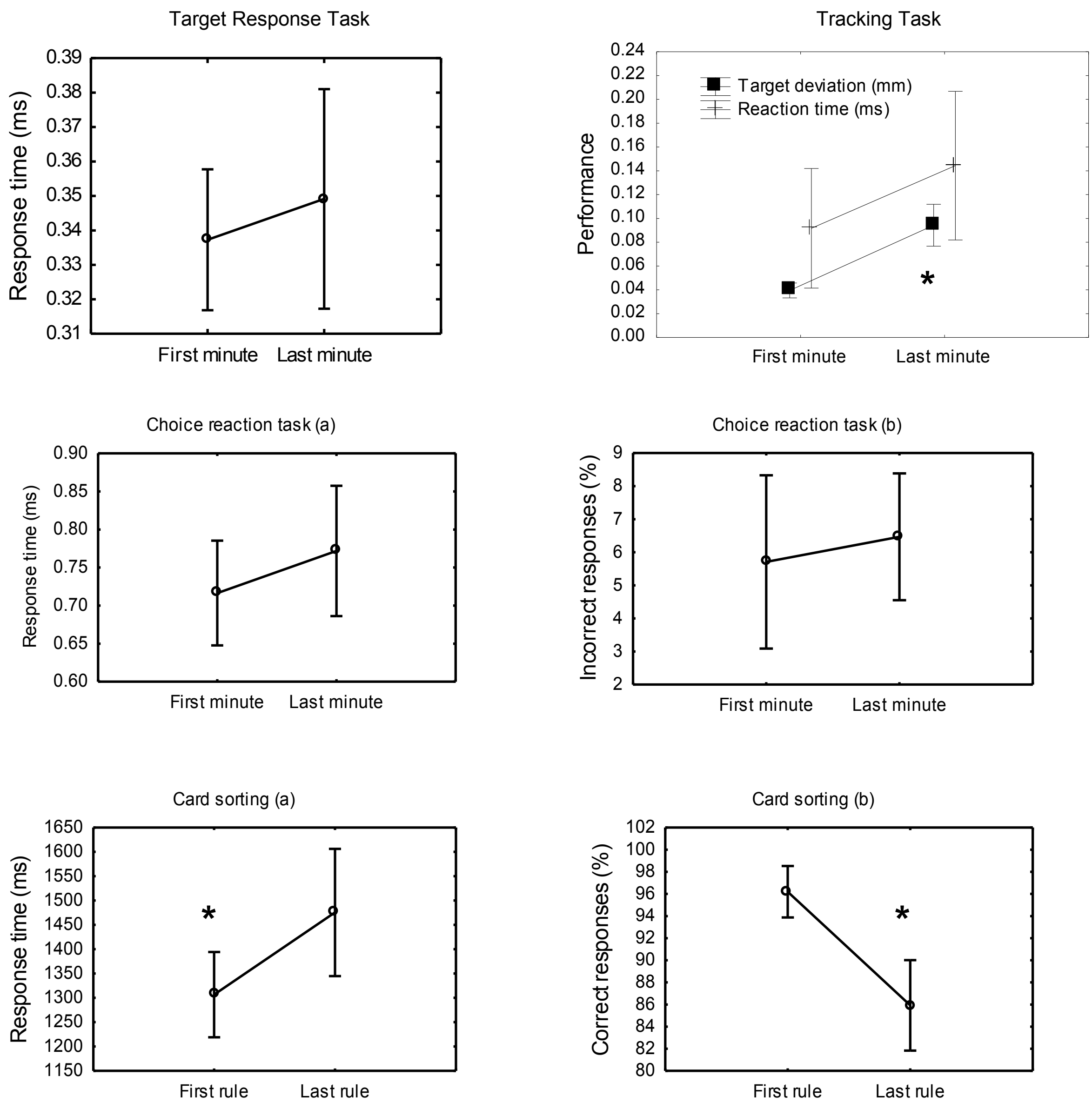


Figure 30: The change in performance for the target response task (response time), the tracking task (target deviation and reaction time), the choice reaction task (a: response time and b: accuracy) and the card sorting task (a: response time and b: accuracy) from the beginning of the task to the end, before the task switch was made. Note: * denotes significance (p<.05).

### 4.6.2 Physiological measures

It was hypothesized that a significant change in physiological parameters would exist between the start and end of each task trial. This significant change was thought to motivate the need for a task switch. The hypothesis was first tested by comparing the first and last minute of each task trial. The statistical analyses were processed regardless of the type of task conducted to determine the general effect of time. No significant changes in physiological responses were found between the beginning and the end of the task trial. The data were then re-processed according to the type of task conducted. However, no significant changes in physiological responses were found.

Further analyses were processed, where the second minute of each task trial was compared to the last minute before a task switch was made. The first minute of the task may have involved additional physiological effort due to reconfiguration of motor processes and a shift in attention and focus due to the task switch. Therefore, the second minute was analysed to gain a more valid reflection of task effort. There was a significant decrease in skin temperature from the second to the last minute of the spelling task. All other physiological variables showed no significant change from the second to the last minute. The first and second minute of each task was compared to determine whether any physiological costs were incurred by the task switch. However, HR was the only physiological measure to significantly ($F(1,175) = 20.573$, $p<0.01$) differ between the first and second minute of the task trial (Figure 32).

## 4.7 TASK TRANSITION EFFECT

It was hypothesized that parameter X would significantly differ between the end of one task (pre transition) and the beginning of a new task (post-transition). The first and second minute of doing the new task after the task switch was compared to the final minute of the old task before the switch took place.

It was also hypothesized that parameter X would be significantly different between the first and second minute of the new task, post transition. This was explained by the physiological costs associated with a task switch (see section 2.6.2).

The following time intervals were statistically compared to one another:

- The last minute of the task pre-transition and the first minute of the new task post-transition.
- The last minute of the task pre-transition and the second minute of the new task post-transition.

These analyses assessed the effect of time on the physiological responses with and without the consideration of the task type performed. Statistical analyses were conducted individually between the abovementioned time intervals; however, the data for all three time intervals were graphically presented together.

### 4.7.1 Energy expenditure and Breathing frequency

There were no significant differences in energy expenditure and breathing frequency between the last minute and the first minute after the task switch, the last minute and the second minute after the task switch and lastly, the first and second minute of the new task. Energy expenditure showed a numerical decrease from the last minute before the task switch to the first minute of the new task, which then increased from the first to the second minute of the new task. There were no significant changes in breathing frequency or energy expenditure before and after the task transition during any of the five tasks.

### 4.7.2 Heart rate

HR significantly decreased ($F(1,175) = 9.625$, $p<.01$) from the last minute before the transition to the second minute after the transition. There was a significant ($F(1,175) = 20.573$, $p<.001$) decrease from the first to the second minute of the new task.

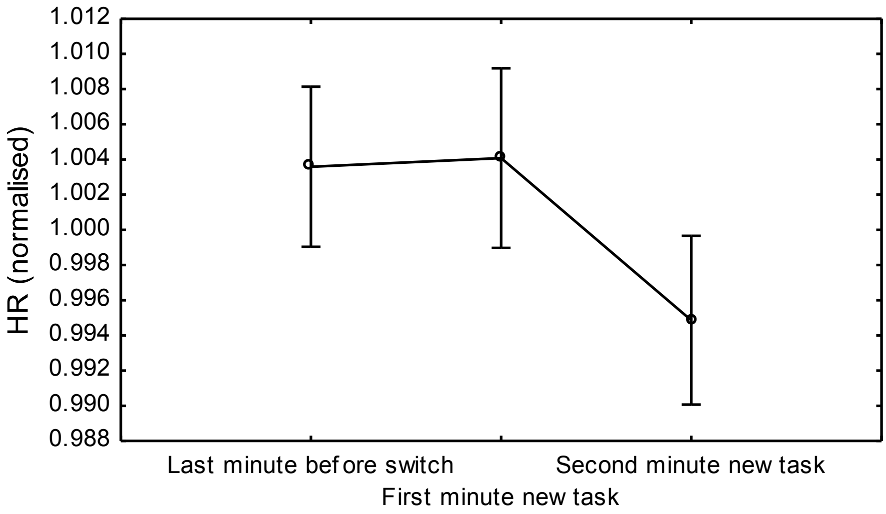


Figure 31: Heart rate (HR) during the last minute before the task switch, and the first and second minute during the new task (error bar indicates 95% confidence interval).

In Figure 32, the x-axis label represents the type of task that was switched away from. Therefore the last minute of this task type was analysed. The second minute after the switch refers to any of the four remaining tasks. A significant ($F(1,172) = 7.524$ $p<0.01$) difference was observed before and after the task transition according to the task type. It was found that HR decreased after the transition for all tasks except the target response task.

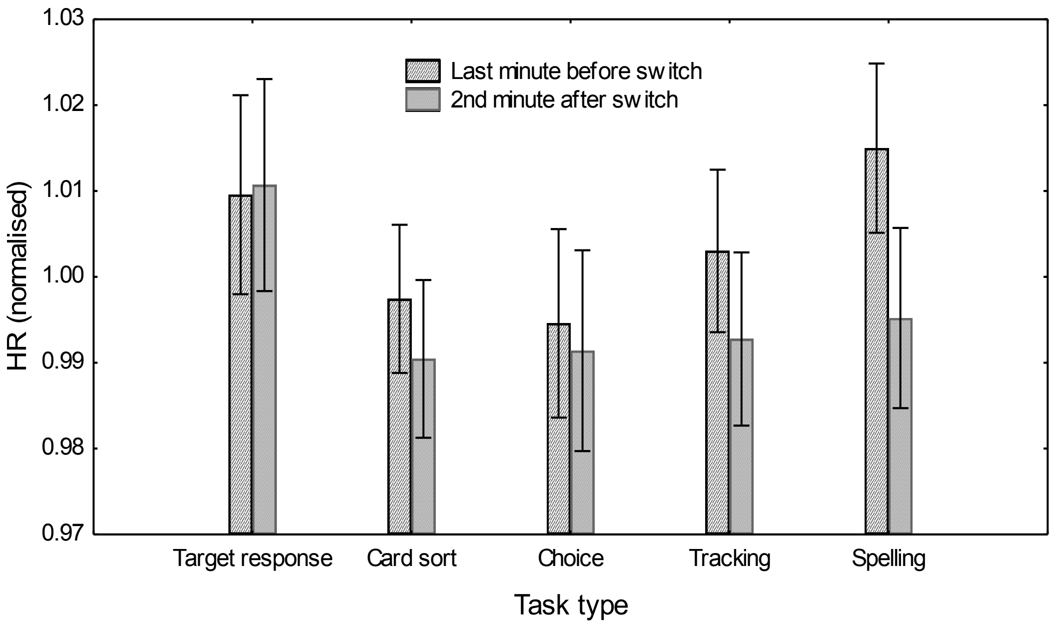


Figure 32: Heart rate (HR) during the last minute before the task switch, and the second minute during the new task for five different tasks (error bar indicates 95% confidence interval).

Note: The x-axis label refers to the task that was performed during the last minute before the switch.

### 4.7.3 Heart rate variability

The general pattern in HRV measures (*rMSSD*, *pNN50*, *HF power* and *LF power*) showed an increase from before the task transition, to the first minute following the transition and then a further increase to the second minute of the task.

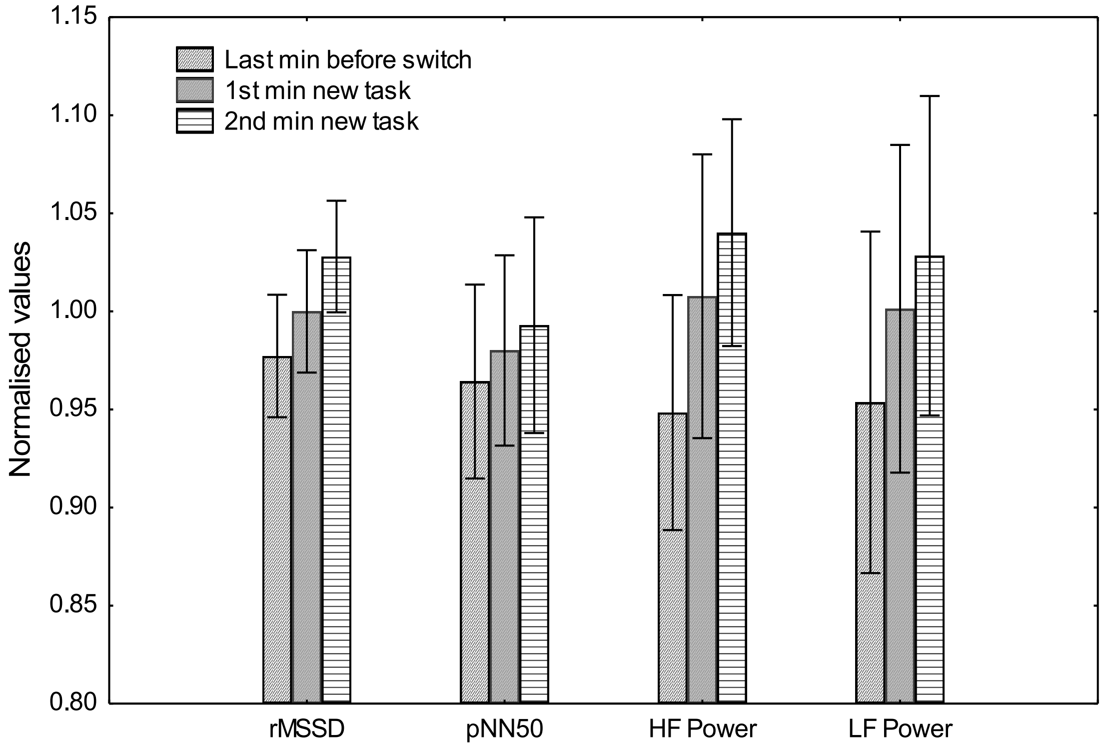


Figure 33: Heart rate variability measures (*rMSSD*, *pNN50*, *HF power* and *LF power)* during the last minute before the task switch, and the first and second minute during the new task (error bar indicates 95% confidence interval).

A significant increase ($F(1,175) = 6.468$, $p<.05$) in HRV (r*MSSD)* was observed before (last minute) and after ($2^{nd}$ minute) the task transition (Figure 33). There was a steady increase in HRV (*rMSSD)* from the last minute before the transition, to the first minute of the new task and a further increase to the second minute. A similar pattern was observed in the HRV (*pNN50*) in Figure 33, however it was less pronounced and therefore not significant.

No significant differences were found in the *LF power* before and after the transition or between the first and second minute of the new task. However, a linear increase in *LF power* was observed before and after the transition (Figure 33).

A significant ($F(1,175) = 4.405$, $p<.05$) increase in *HF power* occurred from the last minute before the transition to the second minute of conducting the new task. The power of the band increased from the last minute before the transition to the first minute of the task and a further increase occurred from the first to the second minute of the new task (Figure 33).

There was a significant ($F(1,172) = 3.982$, $p<.05$) change in HRV (*rMSSD)* before and after the transition according to the task type. In Figure 34, HRV (*rMSSD)* increased for all tasks after the task transition except for the spelling task. A *post-hoc* analysis showed a significant increase in HRV (*rMSSD)* when switching from the tracking task to another task.

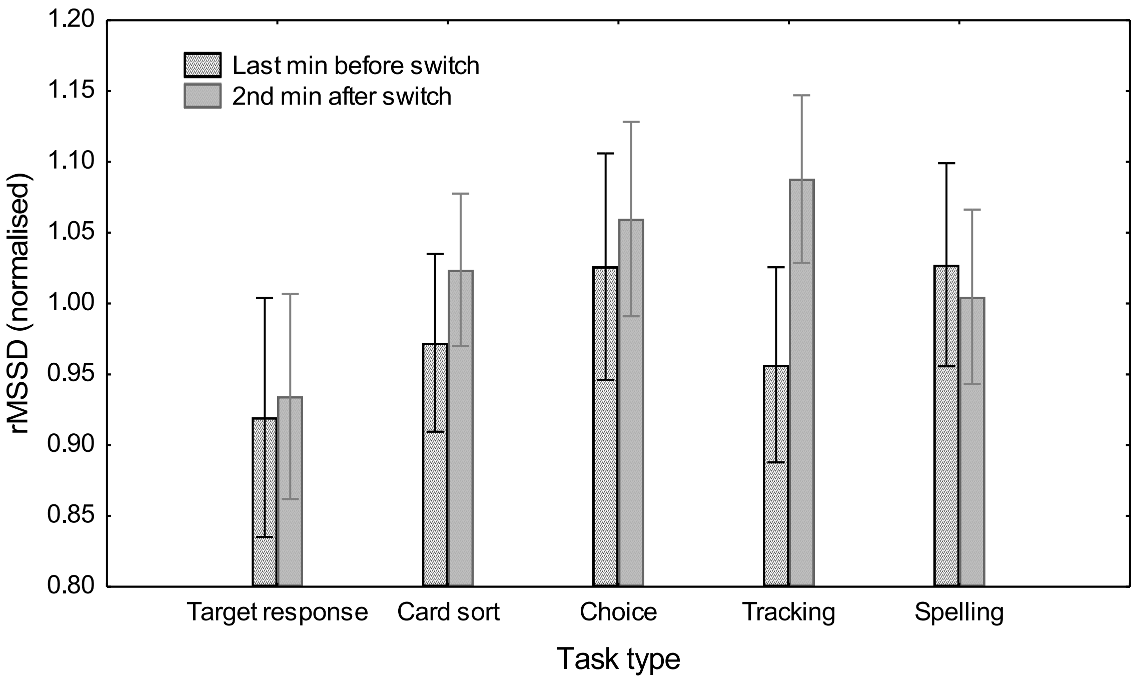


Figure 34: Heart rate variability (*rMSSD*) during the last minute before the task switch, and the second minute during the new task for five different tasks (error bar indicates 95% confidence interval).

Note: The x-axis label refers to the task that was performed during the last minute before the switch.

There was a significant ($F(1,172) = 3.94$, $p<.05$) difference in *HF power* before and after the task transition according to the task type performed. A numerical increase in *HF power* is revealed in Figure 35 for all five tasks. A *post-hoc* analysis showed a significant ($p<.05$) increase when switching away from the tracking task to another task.

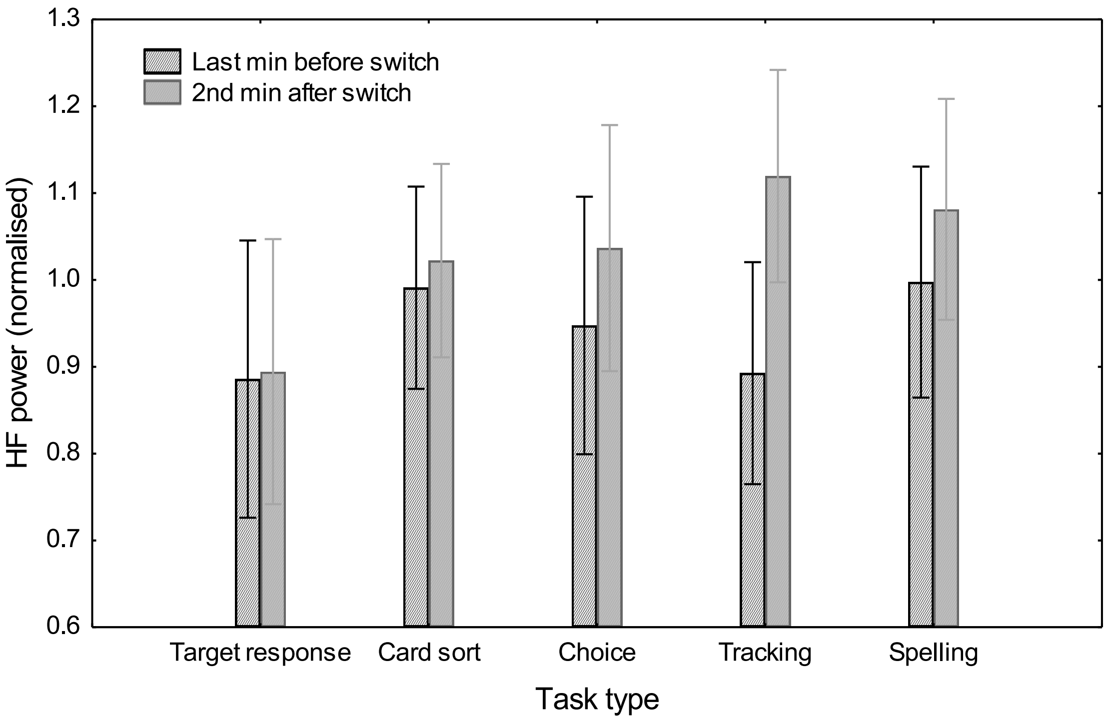


Figure 35: *High frequency (HF) power* during the last minute before the task switch, and the second minute during the new task for five different tasks (error bar indicates 95% confidence interval).

Note: The x-axis label refers to the task that was performed during the last minute before the switch.

The *centre frequency* for the HF band produced a significant interaction ($F(4,171) = 3.43$, $p<.01$) before and after the transition according to the type of task performed. In Figure 36, the *centre frequency* for the HF band increased after the transition for all tasks, excluding the target response task. A *post-hoc* analysis confirmed a significant ($p<.05$) decrease when switching away from the target response task to another task.

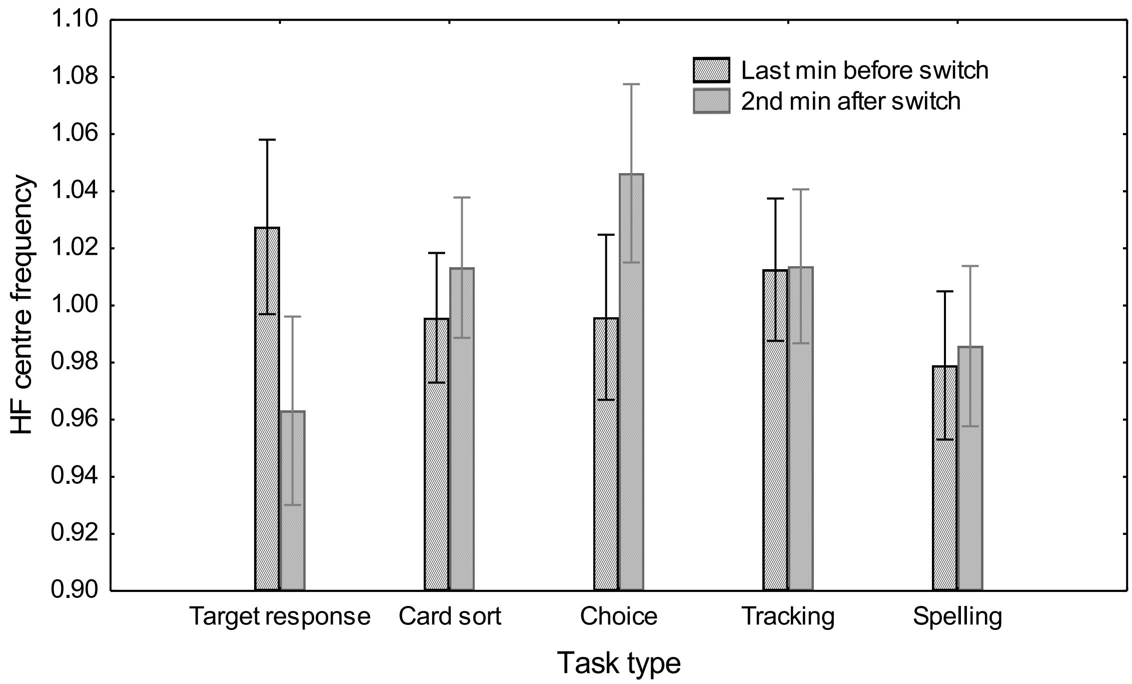


Figure 36: *High frequency (HF) centre frequency* during the last minute before the task switch, and the second minute during the new task for five different tasks (error bar indicates 95% confidence interval).

Note: The x-axis label refers to the task that was performed during the last minute before the switch.

#### 4.7.4 Skin temperature

There was a significant interaction ($F(4,172) = 6.746$, $p<.05$) in skin temperature difference between before and after the transition, according to the type of task performed. A *post-hoc* analysis showed a significant difference ($p<.01$) in skin temperature during the spelling task before and after the task switch, as well as between the spelling task and the other four tasks (Figure 37).

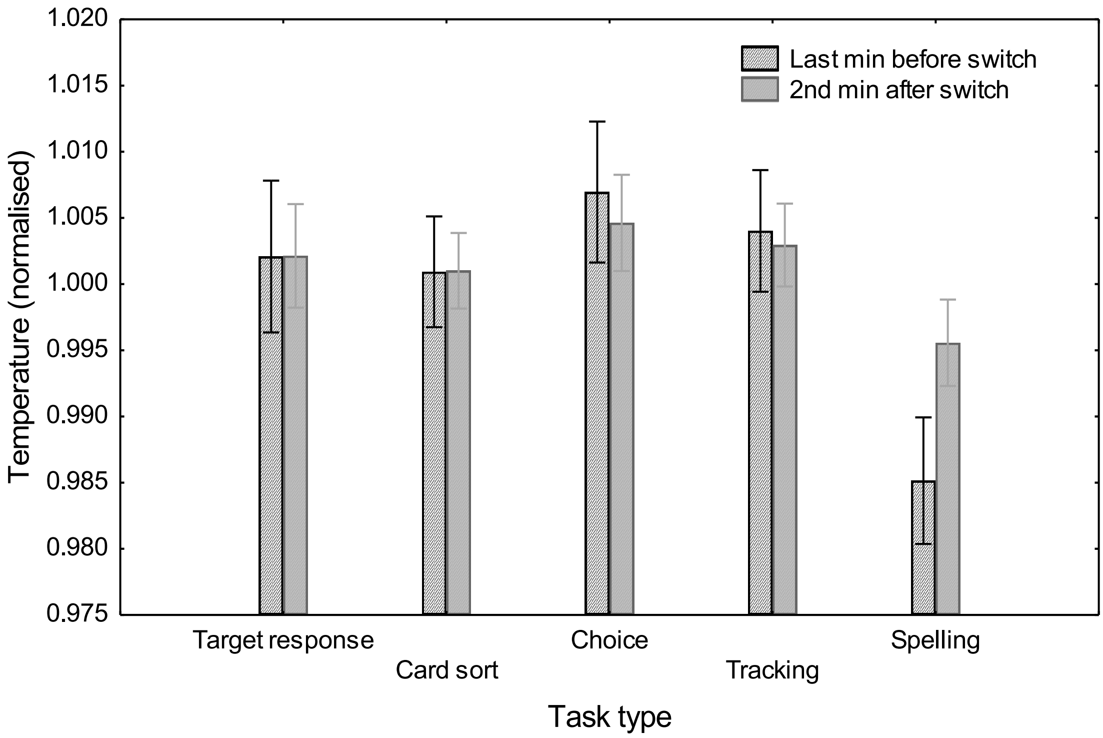


Figure 37: Skin temperature during the last minute before the task switch, and the second minute during the new task for five different tasks (error bar indicates 95% confidence interval).

Note: The x-axis label refers to the task that was performed during the last minute before the switch.

Table VIII: Summary of physiological parameters that showed significant difference before and after the task transition, where TRANSITION = changes in the mean physiological parameters between the last minute before switching and the first and the second minute after the task switch. TRANSITION PER TASK = changes in the mean physiological parameters between the last minute before switching and the second minute after the task switch, per task and TRANSITION*TASK = changes in the mean physiological parameters before and after the transition depending on the task type (X denotes significant difference where p <.05).

| **PHYSIOLOGICAL PARAMETERS** | **TRANSITION (last min to min 1)** | **WARM UP (min 1 to min 2)** | **TRANSITION (last min to min 2)** | **TRANSITION PER TASK** | **TRANSITION *TASK** |
|---|---|---|---|---|---|
| Energy expenditure | | | | | |
| Breathing frequency | | | | | |
| Heart rate | | X | X | X | |
| rMSSD | | | X | X | |
| pNN50 | | | | | |
| High frequency power | | | X | X | |
| Low frequency power | | | | | |
| Low frequency high frequency ratio | | | | | |
| High frequency centre frequency | | | | | X |
| Low frequency centre frequency | | | | | |
| Tympanic temperature | | | | | |
| Skin temperature | | | | | X |

## 4.8 CORRELATIONS BETWEEN VARIABLES

A Pearson-product moment correlation was processed using STATISTICA. Physiological and subjective measures and the mean duration spent on tasks were correlated with one another. This was conducted to determine if any significant relationships existed between the physiological and subjective measures, in order to assist in the understanding of why task-switching takes place.

If a participant repeated the same task, a weighted average, depending on the time spent on the task, was calculated for all the physiological measures. This ensured that for each physiological measure, participants had one value for each task type, which results in 170 cases (34 subjects multiplied by 5 tasks). However, not all five tasks were performed by each participant, therefore only 147 cases were used in the correlation.

Subjective measures and the mean duration spent on the task were included only for the tasks that were performed by the participants. All data were averaged and then normalised against the individual mean of each participant.

Table IX: Pearson-product moment correlation between physiological, perceptual and time measures.

Note: Marked correlations are significant at p<.01 (N=147). The significance level was corrected from p<.05 to account for the larger sample size (N=147) used in the correlations.

| | Energy Expenditure | Breathing Frequency | Heart rate | rMSSD | pNN50 | HF power | LF power | HF centre frequency | LF centre frequency | LF:HF ratio | Tympanic temperature | Skin Temperature | Boredom Transition |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Energy expenditure | | | | | | | | | | | | | |
| Breathing frequency | | | | | | | | | | | | | |
| Heart rate | | 0.58 | | | | | | | | | | | |
| rMSSD | 0.36 | -0.31 | | | | | | | | | | | |
| pNN50 | | | -0.21 | 0.46 | | | | | | | | | |
| HF power | | -0.36 | -0.36 | 0.62 | 0.65 | | | | | | | | |
| LF power | 0.34 | -0.47 | -0.25 | 0.66 | | 0.31 | | | | | | | |
| HF centre frequency | | 0.75 | 0.67 | -0.33 | | -0.31 | -0.44 | | | | | | |
| LF centre frequency | | 0.4 | 0.68 | | | | -0.3 | 0.43 | | | | | |
| LF:HF ratio | 0.25 | | 0.36 | | -0.3 | -0.48 | 0.45 | | | | | | |
| Tympanic temp | | 0.62 | 0.91 | | | -0.21 | | 0.73 | 0.65 | 0.35 | | | |
| Skin temp | | 0.61 | 0.9 | | | -0.24 | | 0.72 | 0.64 | 0.33 | 0.97 | | |
| Boredom Transition | | | | | | | | | | | | | |
| Mean duration | | | | | | | | | | | | | -0.25 |
| Perception error | | 0.24 | | | | | | 0.25 | | | | | |
| Boredom pre | | | | | | | | | | | | | |
| Boredom post | | | | | | | | | -0.23 | | | | |
| Frustration | | | | | | | | | | | | | |
| Mental effort | | | | | | | | | | | | | |
| Performance | | | | | | | | | | | | | |

| | Mean duration | Perception error | Boredom pre | Boredom post | Frustration | Mental effort | Performance |
|---|---|---|---|---|---|---|---|
| Energy expenditure | | | | | | | |
| Breathing frequency | | | | | | | |
| Heart rate | | | | | | | |
| *rMSSD* | | | | | | | |
| pNN50 | | | | | | | |
| HF power | | | | | | | |
| LF power | | | | | | | |
| HF centre frequency | | | | | | | |
| LF centre frequency | | | | | | | |
| LF:HF ratio | | | | | | | |
| Tympanic temp | | | | | | | |
| Skin temp | | | | | | | |
| Boredom Transition | | | | | | | |
| Mean duration | | | | | | | |
| Perception error | | | | | | | |
| Boredom pre | -0.33 | | | | | | |
| Boredom post | -0.35 | | 0.44 | | | | |
| Frustration | -0.35 | | | | | | |
| Mental effort | 0.35 | | -0.32 | -0.47 | | | |
| Performance | | | | | | | |

Mean duration of time spent on a task was negatively correlated with boredom ratings taken before the experiment, at task transitions and after the experiment. Therefore the greater the perceived boredom, the shorter the time spent on a task. In addition, the greater the level of frustration experienced during a task, the less time spent on the task. In contrast to this, mental effort was positively correlated to mean duration on task, therefore the greater the mental effort required by the task the more time spent on the task. Boredom before and after the experiment was negatively correlated with mental effort. It can be said that tasks with little mental effort were more boring and the more boring and frustrating the task, the less time spent on the task. Lastly, the negative correlation between *low frequency centre frequency* and boredom after the experiment suggests that as boredom increased there was a down-regulation and decreased arousal level.

Temperature increased with HR and breathing frequency, indicating increased effort invested in the task. Accompanied by this increase in temperature was a decrease in *HF power*, as the parasympathetic branch weakened in strength to prevent down regulation. Both the *HF and LF centre frequency* increased with increasing temperature. Lastly, the low *LF/HF ratio* showed a positive correlation with temperature, suggesting an increase in sympathetic activity.

The *LF/HF ratio* correlates positively with the *LF power* and negatively with *HF power*. An increase in the *LF/HF ratio* corresponds to a decrease in HRV *(pNN50)*, suggesting that as the activity of the sympathetic branch increased, the HRV decreased as greater effort and concentration were invested in the task. Both heart rate and energy expenditure correlated positively with the *LF/HF ratio* as it represented increased sympathetic activity, which involves increased arousal and effort.

*HF and LF centre frequency* had a positive correlation with both HR and breathing frequency. All correlations exceeded r=0.67 except the correlation between *LF centre frequency* and breathing frequency (r=0.4). The *HF centre frequency* had a negative correlation with HRV (*rMSSD)*, *HF power and LF power*, suggesting that a decrease in power of both *HF and LF power* and increased mental effort was accompanied by an increase in *HF centre frequency*.

HRV *(rMSSD)* correlated positively with energy expenditure. HRV *(rMSSD)* also correlated negatively with breathing frequency, which indicated an increase in breathing frequency with increased task demands and stress.

Both *HF and LF power* had a positive correlation with HRV *(rMSSD)*, therefore an increase in both the sympathetic and parasympathetic activity caused a decrease in mental effort and coping with task demands. However, this may be explained as a coping strategy; that as both branches increased in strength, the sympatho-vagal balance reached an optimum and less effort was required to fulfill the task needs.

*HF and LF power* correlated negatively with breathing frequency and heart rate. This was in line with decreased effort and task stress as the optimum balance was achieved by the autonomic system.

### 4.9 SUMMARY OF RESULTS

There was a significant difference in time spent and frequency among the five tasks. Task-switching behavior was highly variable among participants and no generally preferred pattern of task transitions was evident.

The subjective perception of tasks resulted in boredom significantly differing between the tasks and before and after the experiment. Transition boredom exceeded a rating of 2.5 out of a maximum rating of 4, for all tasks. Perceived mental effort and performance significantly differed between the tasks. The target response task was subjectively rated as the most boring task that required the least mental effort, and performance was perceived to be the highest during this task. On the other hand, the spelling task was subjectively rated as the least boring task, required the most mental effort, and performance was perceived to be the worst compared to the other tasks.

The tasks produced significant differences in physiological responses, namely energy expenditure, breathing frequency, HRV (*rMSSD)*, *LF power*, *HF centre frequency*, *LF to HF ratio* and body temperature. More specifically, energy expenditure and breathing frequency differed significantly between the card sorting and spelling tasks. HRV (*rMSSD*), BF, *LF power* and *HF centre frequency* differed significantly when comparing the spelling task to the target response and the tracking task.

The physiological responses differed significantly over time, irrespective of the type of task. A significant increase in energy expenditure occurred over the first 15 minutes, after which a plateau was reached. Breathing frequency and HR decreased over time, whereas HRV in all frequency bands (low, mid-range and high) increased over time. This trend over time illustrated an elevated physiological response at the start of the experiment, after which, over time, the physiological responses started returning towards resting values.

The performance measures decreased from the beginning to the end of the task. However, significant decrements were found only during the tracking task (increased target deviation) and the card sorting task (increased response time and reduced accuracy). No significant differences in physiological responses were found between the first or the second minute and the last minute of the task, irrespective of the task type. The target response task produced a significant decrease in breathing frequency in the last minute of the task compared to that produced during the task. The spelling task showed a significant decrease in skin (forehead) temperature from the second to the final minute of the task.

Physiological variables showed a significant difference before and after the task transition. HR, HRV (*rMSSD)* and *HF Power* changed significantly from after the task transition, both according to the task type and irrespective of the task type. The change in these three parameters represented a decrease in effort investment, following the task transition. The transition away from the spelling task to any other task caused a significant decrease in HR and increase in skin temperature. The transition away from the tracking task to another task resulted in a significant increase in HRV (*rMSSD* and *HF Power*).

Significant correlations were found between physiological, subjective and behavioural measures. Boredom was found to negatively correlate with duration and subjective mental effort, whereas mental effort and duration correlated positively.

# CHAPTER 5

# DISCUSSION

## 5.1 INTRODUCTION

This study aimed to gain an understanding of self-regulation in terms of analyzing behaviour, performance, physiological and subjective responses during voluntary switching between information-processing tasks. The study attempted to support the proposed factors causing task-switching with changes in physiological, subjective and performance measures before and after a switch. The degree of boredom caused by the task was hypothesized to influence the time spent on a task and the type of tasks performed. The physiological effort required to continue with the task was hypothesized to fluctuate according to factors such as the task requirements, activation level and resource supply. Different amounts and types of resources were required to perform each of the five tasks. Therefore it was hypothesized that resource usage would motivate the need to switch between tasks.

## 5.2 BOREDOM

The main findings supported the hypothesis that boredom motivated the need to switch to another task. Ratings of boredom during task transitions exceeded a score of 2.5 out of a possible 4 for all tasks (Figure 12). This suggested that humans persisted on a task until a boredom threshold was exceeded, after which a task switch occurred. Boredom ratings taken at each task transition, showed minor differences among the tasks, however, before and after the experimental procedure, significant differences occurred (Figure 11). With time on task, boredom accumulated rapidly but also disappeared quickly after the task. This was shown by the decrease in boredom ratings taken after the experiment as opposed to those taken during the experiment for each task. All tasks were rated as being frustrating rather than satisfying, suggesting that task aversion occurred. Table IX confirmed that task frustration resulted in less time being spent on the task.

Boredom influenced the type of task chosen and the duration spent on the task. The target response task was rated the most monotonous throughout the study

(Figure 11). It was conducted least frequently and sustained for the shortest duration (Figure 8 and 10). Conversely, the spelling and card sorting tasks were rated the least monotonous, and were conducted most frequently and for the longest durations. The study found that individuals avoided monotonous tasks by choosing them less frequently. Additionally, a significant correlation (Table IX) was found where the average time spent on a task decreased as the perceived boredom increased.

The degree of monotony experienced by the task may be attributed to the cycle time of the task. In this study, participants were found to respond to the stimulus during the target response task on average every 0.34 seconds as opposed to making a response roughly every 8 seconds during the spelling task. Thiffault and Bergeron (2003) found that attention, arousal and response time decreased with increased repetitions of the same stimulus. This is in line with the findings from this study, where the task with the fastest (target response task) and slowest repetition cycle (spelling task) were the most and least boring tasks respectively. The type of stimuli may have also affected the monotony experienced by each task. The only change in the stimulus during the target response task was the position of the green dot on the screen, whereas during the spelling task each stimulus was a new word. According to Oken *et al* (2006) novel stimuli enhanced sustained attention compared to repetitive stimuli. This may explain why individuals chose to spend longer on the spelling task.

The spelling task was rated less boring than the card sorting task, although the card sorting task was performed more frequently, resulting in more total time spent on this task (Figure 8 and 10). This may be attributed to the fact that the performance was perceived to be worse during the spelling task compared to the card sorting task (Figure 14), therefore individuals avoided the spelling task.

The observed boredom level during the target response task was also expressed through a significantly higher parasympathetic activation, relative to the spelling task (Figure 18, 19 and 20). In addition, a significant decrease in the *centre frequency of the HF band* occurred when a switch was made from the target response task to any of the other four tasks (Figure 36). The boredom induced by the target response task may have resulted in a predominance of parasympathetic activation, and this may have prompted a change to another task. In the context of this research, the target response task was one such task that may have resulted in mental underload due to its monotonous nature, which resulted in a decreased level of activation and less interest in continuing with the task. This was supported by Young and Stanton's (2002) findings that during conditions of mental underload, individuals tended to allocate insufficient attention to the task. An inverse relationship was found between perceived boredom and subjective mental effort where those tasks with low mental effort were rated the most monotonous (Table IX). The findings of this study support the inverted-U hypothesis (Martens and Landers, 1970) in that the simple tasks requiring little mental effort were rated as monotonous and this may have lowered the activation level. The monotony induced by the task affected activation levels and motivated the need for a task switch.

## 5.3 EFFORT REGULATION

The fluctuation in the physiological effort during a task was hypothesized to motivate task-switching as a means of self-regulation. The results from this study showed no significant change in the physiological measures (energy expenditure (EE), breathing frequency (BF), heart rate (HR), heart rate variability (HRV) and temperature) between the beginning and end of each task trial, regardless of the task performed. This may suggest that the self-regulation strategy employed by the individuals, aimed to maintain consistent effort levels during each task trial. The central executive received feedback from receptors about the system state and based on this information, a decision to switch tasks was made to avoid the adverse effects of sustained task performance such as fatigue. These findings are in line with Wickens (1986) where it was stated that performing a task at a higher effort level was recognized to be uncomfortable and should be avoided.

On the other hand, there was a significant change in physiological measures (*HR, rMSSD and HF power*) before (last minute) and after (second minute) the task transition, regardless of the task type (Figure 31 and 33). HR was found to decrease (Figure 31), and HRV (*rMSSD* and *HF power*) increase following the task transition (Figure 33). This suggested that the effort required to perform the task decreased with the switch to a new task. In addition, the increased power of the

HF band suggested an attempt to return measures to resting values as the activity of the parasympathetic system increased. (Birch, 2012) proposed that with sustained time on task, resources became limited and down regulation accelerated. To continue with this task, the mobilization of more energy was required (Hockey, 1997). However, in the case of this study, when given the freedom to regulate behaviour, individuals would rather switch tasks to protect the information processing system from further strain than continue with the current task. This was supported by Hockey's (1997) proposed self-regulation strategy of passive control, where individuals interrupt an activity and will only return to it once they are regarded as being in a 'suitable' state. Task-switching can be seen as an example of this strategy in that one can escape the effects of sustained performance on a task requiring increased effort mobilization. It may be concluded that task-switching occurred when the level of effort could not be sustained any longer and therefore behaviour was regulated to reduce the demands on the information processing system.

*HF power* and *rMSSD* significantly increased when a switch was made away from the tracking task (Figure 34 and 35). This suggested that the task was switched away from due to the high level of effort needed to perform the task. The tracking task required uninterrupted attention and therefore continuous demand on the perceptual and motor processes. This may explain the effortful information processing needed for this task compared to the other four tasks. These findings provide evidence that task-switching was influenced by effort and a switch away from an effortful task, such as the tracking task, allows for a reduction in required effort.

No significant changes were found in physiological variables between the last minute before the transition and the first minute of the new task. This may be explained by the initial elevated effort required to reconfigure the neural pathways and refocus the attention following the task switch (Payne *et al.,* 2007, Lorist *et al.,* 2000). HR was found to significantly decrease between the first and second minute of the new task (Figure 31). In addition, numerical increases that were not statistically supported were observed in HRV measures (*rMSSD*, *pNN50 HF power and LF power)* between the first and second minute of the new task (Figure 33).

This suggested that there was an initial increase in the sympathetic response of the body to cope with the demands of the new task. The amount of effort required was regulated as the body adapted to the task demands. Moreover, processes become more automatic with time; consequently less effort was needed to execute the task. This study therefore supports the findings of Monsell (2003), in that switching to a new task initially required increased physiological effort to refocus attention and configuration of mental resources. This study compared only the first and second minute of physiological responses to the last minute before the task switch. This may explain why there was no significant change in physiological responses before the task switch. The first minute showed an elevated response compared to the second minute, which may have still been elevated as the individual regulated effort according to adaptation to the task demands. The final minute before the task switch may have been compared to an elevated response. If this was the case, then a significant change in effort may have been found if the third minute was measured.

Table X: Simplified comparison between different tasks for physiological parameters and time spent on task, only showing significant differences obtained from *post-hoc* tests.

| **Measure** | **Card Sorting** | **Spelling** | **Target response** | **Tracking** | **Choice** |
|---|---|---|---|---|---|
| **Mean duration** | 7.5 minutes | 8.1 minutes | 4 minutes | 7 minutes | 5.5 minutes |
| **EE** | Low | High | | | |
| **BF** | High | Low | | High | |
| **rMSSD** | | High | Low | Low | |
| **LF Power** | | High | Low | Low | |
| **HF-CF** | High | Low | High | High | |
| **LF/HF Ratio** | | High | Low | | |
| **Skin temperature** | | Low | | High | High |

Table X shows the significant differences in the physiological measures that occurred among the five tasks. Energy consumption differed significantly depending on the type of task conducted. It was observed that the spelling task had the highest energy consumption (Figure 15) and was subjectively the most mentally demanding (Figure 13). This result supported the findings of Backs and Seljos (1994) who found that EE increased with task difficulty and the associated increase in mental effort. Contradictory to this, the card sorting task required the least energy (Figure 15), despite its being subjectively more mentally demanding than the other three tasks (Figure 13). The differences in energy consumption may be attributed to the different type and frequency of the motor response. Firstly, the card sorting task required a slower motor response than the other three tasks. Secondly, the card sorting task required a response involving a click of the mouse button, whereas the spelling task required a written response. The study showed that longer durations were spent on the card sorting task, suggesting that the low energy requirements of the task prolonged the interval before a task switch. This is in line with Lorist *et al* (2000) who state that humans choose tasks requiring the least energy. However, the longest mean time was spent on the spelling task, despite the greater energy consumption. It can be suggested that if EE were the only factor underlying task-switching behaviour, then the task requiring the least energy would be selected. However, other factors such as boredom and the type of resources used may influence this decision and therefore this may explain why more time was spent on a task requiring more energy.

During the card sorting task, BF was significantly higher and EE significantly lower, than during the spelling task (Table X). This was in contrast to findings by Backs and Ryan (1992), where increased task demands required mobilisation of more energy, consequently respiration rate increased. No inverse relationship was found between EE and BF in this study (Table IX) to support this finding. This indicated that this response was specific to these two task types. A possible explanation for this inverse relationship may be that respiration volume increased with a decrease in BF in order to satisfy the demands of increased EE and sympathetic activity. The spelling task showed a significantly higher HRV (an explanation for this finding will be discussed later) (Figure 17). This was in line with Sroufe's (1971) finding that deeper breathing increased HRV (*rMSSD*). Breathing volume was not measured during this study and so it was unknown as to whether the volume changed with increased respiration rate.

The interplay between the LF and HF bands is known as the sympathovagal balance (Fairclough and Mulder, 2011). In the context of self-regulation, this might be helpful in explaining task switching behaviour based on the following findings. This study found a significant correlation between the power in the LF and HF bands (Table IX), meaning that as the power in one band increased, so did the other. This was supported by Davydov and Shapiro (1999) who discovered a decrease in vagal withdrawal and increased sympathetic activity during a mental arithmetic task, therefore an increase in both autonomic branches can occur concurrently (Porges, 1992). In contrast to this, Karim *et al.* (2011) established that an increase in sympathetic activity was associated with a decrease in parasympathetic activity. The increase in the power of both the HF and LF bands may be explained by the regulation of the autonomic branches to achieve an optimal state of functioning during unfavourable conditions associated with boredom.

The present study found that a significant change in autonomic activation occurred during the different task types, seen in Table X. When looking specifically at the *LF* *power, high frequency centre frequency* and the *LF/HF ratio* measures, one sees that an increase in activation occurred during the spelling task in comparison to the target response and tracking task (Figure 18,19 and20 ), which indicated increased parasympathetic activity. This suggested that the lack of mental effort during the target response task caused decreased arousal and down regulation which could account for why significantly less time was spent on the task. On the other hand, the spelling task was more cognitively demanding which increased the level of activation during the task and may explain why significantly more time was spent on it. However, significantly more time was spent on the tracking task than the target response task, despite the lack of mental effort and subsequent increased parasympathetic response. The individual may have been more tolerant in sustaining the tracking task due to the lower rating of boredom compared to the target response task.

The target response and tracking tasks produced significantly lower HRV (*rMSSD*) values than the spelling task (Table X). The target response and tracking tasks placed demands mainly on the perceptual and motor resources, whereas the spelling task placed demands mainly on the cognitive resources. This finding was inconsistent with literature where it was found that a lower HRV indicated greater cognitive workload (Roscoe, 1993; Ohsuga *et al.,* 2001). On the other hand, Nickel and Nachreiner (2003) conducted a study in which a grammatical reasoning task produced HRV measures comparable to resting values. This finding therefore was in line with the HRV produced by the spelling task during the present study.

Nickel and Nachreiner (2003) concluded that task pacing and time pressure may have an influence HRV. This may explain the unexpected higher HRV measure, found in this study, during a task requiring greater cognitive resources than another task. The spelling task was the only self-paced task, in which participants were encouraged to work quickly, however, there was no enforced time pressure. All other tasks were externally paced, where the tracking task required continuous attention and the target response task had the fastest repetition rate (0.34s). One would expect the frequency of the motor response to influence the HRV but Kamphuis and Frowein (1985) found that time pressure caused HRV to decrease even though muscle activity increased with increasing responses. Past studies had found that HRV was more sensitive to task-related effort (Fairclough and Houston, 2004) and represented activation, arousal and emotional strain rather than cognitive strain (Nickel and Nachreiner, 2003). One may conclude that this study found HRV to decrease with fast externally paced tasks and increase with self-paced tasks. The target response and tracking task allowed for little or no rest breaks. It could be proposed that a lower HRV therefore represented attentional demands required by the tasks. Task-switching behaviour may have been influenced by the HRV response as significantly less time was spent on the target response task, which produced lower HRV and significantly more time was spent on the spelling task, which produced higher HRV.

A decrease in HR and increase in skin temperature was found when switching from the spelling task to any other task (Figure 32 and 37). Additionally, skin temperature was significantly lower during the last minute than the second minute of the spelling task. The spelling task was rated as requiring the most mental effort; this could explain the drop in HR when switching to another task. However, the low skin temperature recorded during the spelling task was not supported by the findings of Mehler *et al.* (2009) where temperature increased with increased mental effort. This finding may be attributed to the body regulating the core temperature during the other tasks. An increased skin temperature may have occurred due to a decreased core temperature, through dissipation of heat through the skin (Oken *et al.,* 2006). Therefore the low skin temperature observed during the spelling task (Table X) may represent an increased alertness and activation as no heat was lost and the core temperature remained constant. This increased activation during the spelling task may explain the increased time spent on the task.

### 5.4 RESOURCE USE

Kaplan and Berman (2010) state that resources are finite and heavy demands on these resources will cause depletion. Based on this, it was expected that a task switch occurred when the availability of a resource, used during the execution of a specific task, became limited. Furthermore, a switch would be made to a task requiring the least of the resource type in limited supply. As illustrated in Table IV, the most popular task transitions included: from card sorting to the tracking task

(18 times); from tracking to card sorting, and card sorting to spelling task, (14 times), and lastly from tracking to choice task (12 times). The tasks used in this study were designed such that specific resources were taxed more than others. Therefore the card sorting to the tracking task transition represented a switch from a task requiring intense cognitive resources to a task requiring minimal cognitive resources. Based on the resource usage hypothesis, the cognitive resources may have become limited in availability with time on task (Hockey, 1997), resulting in a switch to the tracking task where only minimal cognitive resources were required. This theory was supported by the tracking to card sorting task combination and the tracking to choice combination (Table II).

The card sorting to spelling task transition cannot be explained by this theory because both tasks utilized all three resources. One must consider that these two tasks were the most frequently chosen tasks during the experiment (Figure 8). This should have resulted in this being a popular task switch combination. Other task characteristics may influence behaviour such as the repetition rate determined by the cycle time and the perceived boredom induced by the task. However, the card sorting and spelling tasks were both rated as the least boring with the lowest repetition rate. An alternative explanation for this popular task switch combination may have been related to the physiological responses produced by the tasks. A switch from the card sorting to the spelling task resulted in a shift in the relative strengths of the HF and LF bands and therefore the sympatho-vagal balance was altered (Figure 18, 19 and 20). It could therefore be proposed that this task switch was motivated by the need to increase the activation level which may have counteracted the effects of down regulation and monotony. The significant difference in EE and BF between the card sorting and spelling tasks may also explain this frequent task-switching combination. The individual may have regulated behaviour by switching from a task of high energy and slow BF to one of low energy and rapid BF.

The least popular task transitions (Table IV) included the target response to choice task, which occurred 3 times, the choice to target response task, which occurred 4 times and the choice to tracking task, which also occurred 4 times. The target response and choice task have an almost identical task set up (see chapter 3) where the only difference was an added decision-making component in the choice task. Therefore, even after a task switch was made, the same perceptual and motor resources would be strained, which may have prevented replenishment of these resources. In addition, due to the similar task characteristics, the level of perceived boredom would remain high when a transition was made between the target response and choice tasks due to the lack of change in task set-up. It was unexpected that the choice to tracking task transition was unpopular because the choice task required a cognitive component that was not required by the tracking task. This made it a viable regulation option to allow for the replenishment of the cognitive resources. On the other hand, the choice and tracking tasks were rated as being the most frustrating tasks therefore this factor may have caused the low occurrence of this task transition combination, rather than resource usage. In addition, these two tasks produced no significant differences in physiological measures. This means that a task switch from the one task to the other could not be used as a means of regulating physiological responses and the sympatho-vagal balance.

## 5.5 OTHER FACTORS AFFECTING TASK-SWITCHING

This study, hypothesized boredom, effort and resource use to motivate the need for a task switch. However, other factors which may have had an influence on task switching behaviour are discussed below.

### 5.5.1 Performance

Perceived performance was rated to be best during the target response task and worst during the spelling task (Figure 14). This suggested that perceived performance may have had no effect on task-switching behaviour because more time was spent on the spelling task, where performance was perceived to be the worst and conversely for the target response task (Figure 9 and 10). However, the target response task was simple and so it would be expected that performance was perceived to be the best. Similarly, the spelling task was complex, resulting in a rating of low perceived boredom. However, Matthews and Desmond (2002) found that during low task demand conditions, the individual underestimated the need to maintain task-directed effort and effects of boredom and down regulation adversely affected performance. This may explain why less time was spent on the target response task. In this study, performance could not be compared between the spelling and target response task therefore it was unknown whether the objective performance measures were in line with perceived performance. It can be proposed that performance did not drive task-switching because significant decrements in objective performance were found only during the card sorting and tracking tasks (Figure 30), and a considerable proportion of time was spent on these two tasks.

### 5.5.2 Cognitive control

The target response and tracking tasks were designed to involve only a minimal cognitive component; however, because it was impossible to completely control the amount of mental activity occurring during a task, this may not always be the case. By manipulating the task characteristics, one can only attempt to increase or decrease the required cognitive resources and mental effort. In this particular study, the target response and tracking tasks were designed to require only perceptual and motor resources. Nonetheless, there is no control of the participant's brain activity, and despite there being no cognitive component required by the task, the mind may have still been active. This degree of brain activity would depend on the emotional state of the individual among other factors. This may have influenced task-switching behaviour with regard to time spent on the tracking and target response tasks.

### 5.5.3 The change in physiological measures with time on task.

The results from this study showed that initially heart rate (Figure 24) and breathing frequency were elevated (Figure 23), but decreased with time on task and where an initially low HRV (*rMSSD* and *pNN50*) increased with time (Figure 25 and 26). These findings are supported by other studies (Jorna, 1992, Birch, 2012, Fairclough and Mulder, 2011) where as one began a cognitive task, the body's response was marked by an increase in EE, HR, BF and decreased HRV in order to cope with the task demands. This change in physiological variables over time may be due to one of two regulation strategies; the human body adapted and learnt to cope with the task demands which resulted in less effort being needed for task execution. Related to this, the learning effect may have occurred and thus less effort was required to complete the task. Alternatively, the body adopted a regulation strategy in which effort; motivation and activation levels were reduced and down regulation occurred to preserve energy and resources. However, this strategy could also occur as a result of the learning effect. This process of down regulation became evident during the execution of both the card sorting and tracking tasks in that, over time, performance significantly decreased.

The power in both the LF and HF bands increased with time (Figure 27 and 28), which was contradictory to Karim *et al* (2011) finding that an increase in the parasympathetic activation caused a decrease in the sympathetic activation. Instead during the present study, a simultaneous increase in the sympathetic and parasympathetic branches of the autonomic system occurred. This relative increase of both bands may have been an attempt to achieve an optimal balance between the sympathetic and parasympathetic branches. The increased sympathetic activity may have also reflected an attempt to counteract the adverse effects associated with down regulation and monotony (Lombard, 2009).

Tympanic temperature increased with time on task due to an initially elevated arousal and activation level from rest (Helton *et al.,* 2009), until a plateau was reached (Figure 29). The changes in the physiological measures over time, suggested that task-switching behaviour may be affected differently during the course of the experiment. Table I showed that specific tasks were selected more frequently during different time intervals during the study. The target response task was more frequently chosen during the first 5 minutes than at any other time during the experiment. This may be because during the first five minutes, the activation level was the highest and therefore the less monotonous tasks such as card sorting and spelling tasks were most frequently performed towards the end of the experiment when activation levels were low.

### 5.6 CONCLUDING DISCUSSION

This study aimed to determine whether physiological, subjective and behavioural measures could be linked together to support the proposed factors hypothesized to influence task-switching behaviour.

The findings showed that perceived boredom can be used to explain task-switching behaviour. Individuals spent less time on the more monotonous tasks, which required little mental effort such as the target response task. This suggested that tasks of low mental demand are more monotonous and therefore cause a withdrawal of attention and arousal. This may have resulted in self-regulation causing a task switch to another task to avoid these conditions associated with boredom. However, this withdrawal of attention from the task due to monotony may have caused a decrease in the effort required by the task. Therefore the boredom experienced during the task may have had an effect on effort regulation.

The physiological effort required during an information processing task was found to influence task-switching behaviour and therefore self-regulation. The findings from this study, led the author to conclude that a task switch occurred firstly before any further increase in effort was required, and secondly to a new task that required less physiological effort. The effect of effort regulation in causing task-switching was also observed during performance of specific task types and therefore influenced the time spent on certain tasks. The lowest energy was expended during the card sorting task which may explain why most of the time was spent on this task. However, the spelling task required the most energy, yet a comparable amount of time to the card sorting task was spent on the spelling task. This led to the conclusion that other factors such as monotony play a role in task-switching, and therefore individuals were willing to expend the additional energy on the spelling task because it was the least monotonous.

The changes in task-specific effort can be related to the relative resource use required by each task. The self-paced spelling task produced a lower HRV than the externally-paced target response task, which may have resulted in more time being spent on the spelling rather than the target response task. Therefore depending on the task type, individuals may have adopted different self-regulation strategies. More time was spent on the spelling task than on the target response and tracking tasks. The spelling task was designed to tax the cognitive resources compared to the target response and tracking tasks, which were designed to tax only the perceptual and motor resources. The findings from this study, suggested that tasks requiring a high usage of cognitive resources may have increased sympathetic activation and energy consumption. On the other hand, tasks requiring mainly perceptual and motor resources (and minimal cognitive resources) may have increased parasympathetic activation. Therefore, during these specific tasks individuals may have used a self-regulation strategy where more time was spent on stimulating tasks that increased activation levels. This suggested that a task switch occurred to avoid tasks where there was a decrease in alertness and possible task aversion.

Task-switching behaviour was found to be influenced by task monotony, the regulation of physiological effort and resource use. The three factors were interlinked in that a task switch may have occurred due to the high monotony rating, which in turn could have decreased the activation level. The task switch could be explained by the need to avoid monotony and to increase activation levels by regulating the effort invested in the task. The type of resources were found to influence the monotony of the task because the simpler tasks that required little cognitive resources were rated as being more boring. Therefore, either the resource type or boredom may have influenced the task-switching behaviour. These three factors together play a role in deciding on self-regulation strategies and therefore together should be considered in the design of tasks in the work place.

# CHAPTER 6

# SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

## 6.1 INTRODUCTION

Various self-regulation strategies are used to alter task behavior and performance. This is often an unconscious and automatic process that occurs in response to feedback regarding the state of the system. For the purposes of this study, self-regulation was measured by allowing individuals the freedom to switch between tasks as desired. Task-switching behavior was hypothesized to be influenced by three main factors: firstly, the resource usage required by the task, secondly, the degree of perceived boredom induced by the task and lastly, the regulation of effort invested in the task. This research incorporated a range of measures (physiological and subjective) which were used in an attempt to explain task-switching behavior, and therefore identify self-regulation strategies.

## 6.2 SUMMARY OF PROCEDURES

Self-regulation was measured indirectly, through task-switching, by allowing individuals to switch freely between five information-processing tasks. These tasks had different repetition rates and were designed to place demands on specific resources. The method placed no restrictions on self-regulation of task performance, as each participant was provided with maximum control over their behavior.

At each task transition, the time of switch and the type of task switched to was recorded. The participant was asked to rate the level of perceived boredom, using a provided scale (where 1 represented no boredom and 4 represented a great deal of boredom), caused by the task that was switched away from, and was also asked how much time was perceived to have passed during the previous task.

Physiological measures were recorded throughout the testing. These included energy expenditure, breathing frequency, heart rate, heart rate variability, skin temperature and tympanic temperature.

After the test period, a self-report scale was completed. This included subjective measures of boredom, mental effort, frustration and the perceived level of performance achieved in each task.

### 6.3 SUMMARY OF RESULTS

Task-switching behaviour was highly variable among participants. There was a significant difference in task frequency and time spent among the tasks. No uniform or preferred task-switching pattern was found in the study.

Ratings of boredom at each task transition were greater than the baseline and post- experiment ratings, excluding the target response task. There was a significant increase in boredom from before to after the experiment. Significantly less time was spent on the target response task which may be because it was subjectively rated as the most boring task, requiring the least mental effort. On the other hand, significantly more time was spent on the spelling task, possibly because it was subjectively rated as the least boring, and required the most mental effort. A negative correlation was found between task duration and the rating of boredom caused by the task.

Performance was subjectively perceived to be highest during the target response task and lowest during the spelling task, despite more time being spent on the latter. However, the objective performance could not be compared between these two tasks to determine whether performance actually differed or whether it was only perceived to differ.

The most common task-switching combinations involved the card sorting to the tracking task, and the card sorting to the spelling task. The least common task-switching combination included the target response to the choice task. These task-switching combinations were used to support the hypothesis that resource use influenced task-switching behaviour.

The physiological responses differed significantly during the experiment, irrespective of the type of task. This change over time illustrated an elevated physiological response at the start of the experiment, after which the physiological responses moved towards a resting state. This may have affected the frequency of the type of task chosen during the course of the experiment. The target response task was most frequently selected during the beginning of the protocol, when activation levels were higher. Conversely, the spelling and card sorting tasks were selected towards the end of the experiment, when the activation levels had decreased.

There were no significant differences in physiological measures between the beginning and end of each task trial, irrespective of the task type. However, there was a significant decrease in HR and increase in HRV (*HF power* and *rMSSD*) after a task transition. Significant differences were found only between the second minute after a transition and the final minute before the next transition, suggesting that physiological responses increased when starting a new task.

A number of physiological responses significantly differed according to the type of task performed. Skin temperature significantly decreased from the beginning to the end of the spelling task. The switch away from the spelling task produced a significant decrease in HR and increase in skin temperature.

Sympathetic activity was significantly higher during the spelling task than the target response task. The tracking and target response tasks, which were both externally-paced, perceptual-motor tasks, differed significantly from the spelling task, which was a self-paced cognitive task, in that *rMSSD* and *LF power* were lower and the *HF centre frequency* was higher in the target response and tracking tasks.

The card sorting task significantly differed from the spelling task in that EE was lower, BF higher and *HF centre frequency* higher. There was a significant increase in HRV (*HF power and rMSSD*) when switching away from the tracking task.

## 6.4 CONCLUSIONS

It can be concluded from the findings of this study that task-switching behaviour was influenced by boredom, effort regulation and resource use.

Boredom influenced the time spent on the different tasks, where the least and most time was spent on the tasks rated as the most and least boring respectively. These subjective ratings were supported by increased sympathetic activity during tasks of low boredom and increased parasympathetic activity during tasks of high boredom. A boredom threshold was established that triggered the individual to switch to another task when exceeded. Tasks requiring little mental effort, such as the target response task, were found to be more boring, and consequently less time was spent on these tasks. Individuals were found to switch to another task to escape the negative effects, such as fatigue, associated with monotony.

There was no change in physiological responses between the beginning and the end of a task trial, suggesting that a task switch was made before additional energy or effort was required to continue the task. Because effort decreased after the task transition, it was concluded that task switches were made in an attempt to decrease effort and the activation required by the task. Therefore a switch in tasks was used as an option to regulate the amount of effort expended by the individual. It was found that with time on task, irrespective of the task type, there was a general decrease in effort, suggesting that the body adapted to the task demands and down regulation occurred as a means of self-regulation over time.

The most common task switch combinations involved switching from a task of high cognitive demand to a task of low cognitive demand. This allowed for the recuperation of resources that may be limited in supply. These two tasks differed significantly in activation and energy consumption, therefore a task switch may have occurred to regulate the effort required by the tasks. The least popular task-switch combination involved switching from a task of low cognitive demand to one of high cognitive demand. However, the similarity in the task characteristics suggested that this task switch taxed the same perceptual and motor resources and prevented the alleviation of monotony. In addition, these two tasks produced no significant differences in physiological responses, suggesting that a switch between the tasks did not allow for a change in effort. The resources required by the different tasks were therefore found to either promote or discourage switching between specific task types.

The findings from this study provided some support for all three hypotheses. Not all the evidence supported the factor hypothesized to cause task-switching behaviour. For example, it was suggested that a task transition was made in an attempt to decrease the effort investment by a reduction in sympathetic activation.

However, the spelling task was sustained for the longest duration, even though it produced a significant increase in sympathetic activation and EE. This behaviour may be explained by the low monotony experienced during the spelling task and therefore individuals' self-regulation strategy was based on perceived boredom rather than effort. This showed that it was impossible to completely isolate the effects of one factor from another. This study did, however, find evidence to support the notion that the executive control regulated behaviour through task-switching based on the effort, resource usage and boredom experienced by the tasks.

These findings can be applied to improving the effectiveness of job rotation systems in the workplace. An understanding of the type of tasks to be alternated and the duration spent on different tasks can be used to prevent the onset of fatigue and down regulation. This study emphasized the need for workers to be given more responsibility over their work so they can regulate their behaviour to avoid monotony, resource depletion or operating at an uncomfortable effort level. However, too much autonomy can also cause problems and may initially reduce productivity. Self-regulation strategies can and should be employed to manage multiple goals efficiently. This research expands the understanding of human behaviour which can be used to improve productivity and well-being of the worker.

## 6.5 RECOMMENDATIONS AND CONSIDERATIONS FOR FUTURE RESEARCH

This study has highlighted a number of findings in terms of understanding behaviour regulation through task-switching. The following recommendations should be considered in the design of future methodologies:

1. It is recommended that the experimental procedure is repeated, where the first execution of the procedure acts as the habituation phase. This will also allow for participants to improve on regulation strategies during the repeat condition as they have gained experience and knowledge of the tasks.

2. The five tasks used in the study were designed to test the effect of boredom, resource use and effort regulation on task-switching. The choice task produced very little significance in terms of physiological measures and

subjective measures. Therefore, future research should consider omitting this task and having four tasks to choose from. The choice task also had an almost identical task setup to the target response task, and this may have discouraged individuals from selecting this task.

3. Physiological baseline measures were collected during the first 30 seconds of performing the task. However, this did not allow enough time for these measures to settle. The baseline measures should therefore be recorded only once the participant has been habituated to the task.

4. These methods resulted in ‘unusual’ statistics because each participant chose a different order of tasks, for differing durations and frequencies. This resulted in having to treat each task trial, regardless of whether it was from the same participant or not, as a new case. There is no recommendation to avoid this without causing restrictions to the task-switching behaviour. Therefore it may be considered as a challenge in future task-switching behaviour research.

5. Future research should consider the statistical analysis of more time intervals (every minute) during each task trial, especially for objective performance and physiological measures. For example an analysis of the physiological measures during the third minute may have indicated whether or not the measures were still elevated two minutes after starting a new task. The change in objective performance over time may have helped in interpreting whether effort regulation occurred to maintain performance or due to task disengagement. However, these analyses could only be conducted on task trials that were sustained for long enough to allow for more than just the first and last minute to be analysed.

6. The type of motor response and the working speed of each task should be carefully considered. For example, the target response task required a motor response every 0.34 seconds, whereas the card sorting task required a response every 1.31 seconds. Both tasks required the same physical

response (clicking the mouse) however, this faster response may have influenced the physiological responses. On the other hand, the spelling task required a response involving circling a letter, and this may have influenced the muscle activity and energy requirements of the body.

# REFERENCES

**Note: Asterisked citations * are secondary sources. These were not directly consulted and are referenced fully as primary sources.**

*Backs, R.W., Ryan, A.M., Wilson, G.F., 1991. Cardiorespiratory measures of workload during continuous manual performance. Paper Presented at the *Proceedings of the 35th Annual Meeting of the Human Factors Society*, San Francisco.

Backs, R.W. and Ryan, A.M. (1992). Multimodal measures of mental workload during dual-task performance: energetic demands of cognitive processes. *Memory, Human Factors Society,* 36:1413-1417.

Backs, R.W. and Seljos, K.A. (1994). Metabolic and cardiorespiratory measures of mental effort: the effects of level of difficulty in a working memory task. *International Journal of Psychophysiology*, 16:57-68.

Baddeley, A.D. and Weiskrantz, L. (1995). Attention: Selection, awareness and control: A tribute to Donald Broadbent. Oxford University Press, Oxford. 346-373pp

Bahill, T.A. and Hamm, T.M. (1989). Using open-loop experiments to study physiological systems, with examples from the human eye-movement systems. *International Union Physiology of Science*, 4:104-109.

Behncke, L. (2011). Self-Regulation: A brief review. *Athletics Insight, the online journal of sport psychology.*

Berg, E. and Grant, D. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card-sorting problem. *Journal of Experimental Psychology*, 38(4):404-411

Birch, C (2012). The effects of sustained attention, workload and task-related fatigue on physiological measures and performance during a tracking task. Unpublished Master's thesis, Rhodes University, Grahamstown, South Africa.

Boekaerts, M., Pintrich, P. R., & Zeidner, M. (Eds) (2000). *Handbook of self-regulation.* San Diego: Academic Press.

*Bohlin, G., Eliasson, K., Hjemdahl, P., Klein, K. and Frankenhaeuser, M. (1986). Pace variation and control of work pace as related to cardiovascular, neuroendocrine and subjective responses. *Biology of Psychology*, 23:247-263.

Bridger, R.S. (2003). *Introduction to Ergonomics*. 2nd edition. New York: McGrawHill

Brookhuis, K.A., De Vries, G. and De Waard, D. (1991). The effects of mobile telephoning on driving performance. *Accident Analysis and Prevention*, 23:309-316.

Brown, I.D. (1982). Driving Fatigue. *Endeavour, New Series*. 6(2): 83-90.

Calvin, K.L. and Vincent, G.D. (2007). Development of a facial skin temperature-based methodology for non-invasive mental workload measurement. *Occupational Ergonomics,* 7:83-94.

Carroll, D., Turner, J.R. and Prasad, R. (1986). The effects of level of difficulty of mental arithmetic challenge on heart rate and oxygen consumption. *International Journal of Psychophysiology,* 4:167-173.

Carver, C.S. and Scheier, M.F. (1998). *On the Self-Regulation of Behaviour.* Cambridge University Press, United States of America, pp. 22-26.

Chaplin, C., and Goebel, M. (2011). The effects of sustained visual workload on performance and on psycho-physiological responses. *Proceedings: Tenth International Symposium on Human Factors in Organizational Design and Management. Grahamstown, Eastern Cape, South Africa, April 4-6, 2011.*

Cherbuin, N. and Brinkman, C. (2004). Cognition is cool: Can hemisphere activation be assessed by tympanic membrane thermometry. *Brain and Cognition*, 54:228-231.

Christie, C.J. (2006).A Field investigation of physical workloads imposed on harvesters in South African forestry. Ph.D, Rhodes University, Grahamstown.

Cnossen, F., Rothengatter, T. and Meijman, T. (2000). Strategic changes in task performance in simulated car driving as an adaptive response to task demands. *Transportation Research,* 3:123-140.

Davydov, D.M., & Shapiro, D. (1999). Single and combined effects of sympathetic and parasympathetic activity on perceptual sensitivity and attention. *Journal of Russian and East European Psychology*, 37, 68-90.

Demanet, J., Liefooghe, B. and Verbruggen, F. (2011). Valence, arousal and cognitive control: a voluntary task-switching study. *Frontiers in Psychology*, 336(2): 1-9.

DeShon, R.P., Brown, K.G. and Greenis, J.L. (1996). Does self-regulation require cognitive resources? Evaluation of resource allocation models of goal setting. *Journal of Applied Physiology*, 81(5): 595-608

*Desmond, P.A., and Matthews, G. (1996). Task-induced fatigue effects on simulated driving performance. In: Gale, A.G. (Ed.), *Vision in Vehicles* VI. North-Holland, Amsterdam.

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

Dunbar, R.I.M. (1998). The social brain hypothesis. *Evolutionary Anthropology*, 6(5):178-190.

Elsenbruch, S., Harnish, M.J. and Williams, C. (1999). Heart rate variability during waking and sleeping in healthy males and females. *Sleep,* 22(8):1067-1071.

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

Fairclough, S.H. and Mulder, L.J.M. (2011). Psychophysiological processes of mental effort investment. In R, Wright and G.H.E., Gendolla (Eds.). How motivation affects the cardiovascular response mechanisms and applications. 44:1-25.

Flynn, N. and James, J.E. (2009). Relative effects of demand and control on task-related cardiovascular reactivity, task perceptions, performance and accuracy and mood. *International Journal of Psychophysiology*, 72:217-227.

Gaillard, A.W.K. and Wientjes, C.J.E. (1994). Mental load and work stress as two types of energy mobilization. *Work and Stress*, 8:141-152.

Gailliot, M.T., Baumeister, R.P., DeWall, C.N., Maner, J.K., Plant, A., Tice, D.M., Schmeichel, B.J. and Brewer,L.E. (2007). Self-Control relies on glucose as a limited energy source: Willpower is more than a metaphor. *Journal of Personality and Social Psychology*, 92(2):325-336.

Garde, L.H., Laursen, B., Jorgensen, A.H. and Jensen, B.R. (2002). Effects of mental and physical demands on heart rate variability during computer work. *European Journal of Applied Physiology*, 87:456-461.

*Genno, H., Ishikawa, K., Kanbara, O. and Kikumoto, M. (1997). Using facial skin temperature to objectively evaluate sensations. *International Journal of Industrial Ergonomics,* 19(2): 161-171.

Goebel, M. (2010). Development of the software for the target response task, the driving simulator task and the HKE data reduction tool. Department of Human Kinetics and Ergonomics, Rhodes University, Grahamstown.

Gonzalez, V.M. and Mark, G. (2005). Managing currents of work: Multi-tasking among multiple collaborations. In proceedings of the 8th European Conference of Computer-supported Cooperative Work, Paris, France.

Grandjean, E. and Kogi, K. (1975). *Fatigue in Daily Life*. In: Methodology in human fatigue assessment. Taylor and Francis Ltd, London.

Green, R.F. (1984). Stopping rules for optimal foragers. *American Naturalist*, 123: 30-43.

Gregory, H.B., Beck, J.W. and Carr, A.E. (2011). Goals, feedback, and self-regulation: Control theory as a natural framework for executive coaching. *Consulting Psychology Journal: Practice and Research,* 63(1):26-38.

Helton, W.S., Hayrynen, L. and Schoeffer, D. (2009). Sustained attention to local and global target features is different: Performance and tympanic membrane temperatures. *Brain and Cognition*, 71: 9-13.

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

Houle, M.S., and Billman, G.E. (1999). Low-frequency component of the heart rate variability spectrum: a poor marker of sympathetic activity. *Heart and Circulatory Physiology,* 276(1); 215-223.

Jahandideh, S. (2012). Job Scheduling considering both mental fatigue and boredom. Unpublished Master's Thesis. University of Ottawa, Canada.

Jermier, J.M., and Michaels, C.E. (2001). Autonomy at work. *Social and Behavioural Sciences*, 1006-1009.

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

Karim, N., Hasan, J.A. and Ali, S.S. (2011). Heart rate variability – A review. *Journal of Basic and Applied Sciences,* 7(1):71-77.

Kahneman, D. (1971). Remarks on attentional control. In A.F. Sanders (Eds.), *Attention and Performance* III. Amsterdam: North Holland.

Kahneman, D. (1973). *Attention and Effort*. Englewood Cliffs, NJ: Prentice Hall.

*Kamphuis, A., and Frowein, H.W. (1985). Assessment of mental effort by means of heart rate spectral analysis. *In* J.F. Orlebeke, G. Mulder, & L.J.P. van Doornen *(Eds.), Psychophysiology of cardiovascular control: Models, methods, and data (pp.* 841–853*).* New York: Plenum

Kaplan, S. and Berman, M.G. (2010). Directed attention as a common resource for executive functioning and self-regulation. *Perspectives on Psychological Science*, 5(1): 43-57.

Karoly, P. (1993). Mechanisms of self-regulation: a systems view. *Annual Review of Psychology*, 44:23-52.

Keller, J. and Bless, H. (2006). Regulatory fit and cognitive performance: The interactive effect of chronic and situationally induced self-regulatory mechanisms on test performance. *European Journal of Social Psychology,* 36:393-405.

Kennedy, D.O and Scholey, A.B. (2000). Glucose administration, heart rate and cognitive performance: effects of increasing mental effort. *Psychopharmacology*, 149:63-79.

Knight, J.L. and Salvendy, G. (1981). Effects of task feedback and stringency of external pacing on mental load and work performance. *Ergonomics*, 24(10):757-764.

Lehto, M.R. (2006). Human Factors Models. In Wogalter, M.S. (eds): *Handbook of warnings*. New Jersey: Lawrence Erlbaum Associates Publishers, Pp. 78-81.

Lombard, W.R. (2009). The effects of booster breaks during a sedentary night shift on physiological and cognitive performance over a 3 night shift habituation phase. Unpublished Master's thesis, Rhodes University, Grahamstown, South Africa.

Lord, R.G., Diefendorff, J.M., Schmidt, A.M. and Hall, R.J. (2010). Self-Regulation at Work. *Annual Review of Psychology*, 61:543-568.

Loren, B. and Parasuraman, R. (2003). Human operator functional state in automated system. In: Hockey, G.R.J., Gaillard, A.W.K., Burov, O. (Eds), Operator Functional State. The Assessment and Prediction of Human Performance Degradation in Complex Tasks. NATO Science Series. IOS Press, Amsterdam, pp. 2223-233.

Lorist, M.M., Klein, M., Nieuwenhuis, S., De Jong, R., Mulder, G. and Meijman, T. (2000). Mental fatigue and task control: Planning and preparation. *Psychophysiology*, 37:614-625.

Lundberg, J. (2007). More work and less control over pace of work, Oxford Research Institute.

Lundberg, U. and Frankenhaeuser, M. (1978). Psychophysiological reactions to noise as modified by personal control over noise intensity, *Biological Psychology*, 6:55-59.

Luszczynska, A., Diehl, M., Gutierrez-Dona, B., Kuusinen, P. and Schwarzer, R. (2004). Measuring one component of dispositional self-regulation: Attention control in goal pursuit. *Personality and Individual Differences*, 37:555-566.

Martens, R. and Landers, D.M. (1970). Motor performance under stress: a test of the inverted-U hypothesis. *Journal of Personality and Social Psychology*, 1(1):29-37.

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

Matthews, G., Warm, J., Reinerman, L., Langheim, L. and Saxby, D. (2010). Task engagement, attention and executive control. In A. Gruszka et al (eds): *Handbook of individual differences in cognition: Attention, memory and executive control.* The Springer Series on Human Exceptionality. Springer Science and Business Media, chapter 13.

Maume, D.J and Purcell, D.A (2007). The ‘Over-Paced’ American: Recent Trends in the Intensification of Work. *Research in the Sociology of Work*, 17: 251-283.

Mehler, B., Reimer, B., Coughlin, J.F. and Dusek, J.A. (2009). Impact of incremental increases in cognitive workload on physiological arousal and performance in young adult drivers. *Journal of the Transportation Research Board*, 2138: 6-12.

Meijman, T.F. (1997). Mental fatigue and the efficiency of information processing in relation to work times. *International Journal of Industrial Ergonomics*, 20:31-38.

Monsell, S. (2003). Task-switching. *Trends in Cognitive Sciences*. 7(3): 134-141.

*Mulder, L.J.M. (1988). Assessment of cardiovascular reactivity by means of spectral analysis. Ph.D. thesis, University of Groningen, Groningen.

Nickel, P. and Nachreiner, F. (2003). Sensitivity and diagnosticity of the 0.1-Hz component of heart rate variability and an indicator of mental workload. *The Journal of Human factors and Ergonomics Society*, 45(4): 575-590.

Oken, B.S., Salinsky, M.C., and Elsas, S.M. (2006). Vigilance, alertness or sustained attention: physiological basis and measurement. *International Federation of Clinical Neurophysiology*, 117(9): 1885-1901.

Ohsuga, M., Shimano, F. and Genno, H. (2001). Assessment of phasic work stress using autonomic indices. *International Journal of Psychophysiology*, 40:211-220.

Owens, D.S. and Benton, D. (1994). The impact of raising blood glucose on reaction times. *Neuropsychobiology*, 30:106-113.

Parasuraman, R., Molloy, R. and Singh, I. L. (1993). Performance consequences of automation-induced complacency. *International Journal of Aviation Psychology*, 3 (1), 1-23.

Parkes, K.R., Styles, E.A. and Broadbent, D.E. (1990). Work preferences as moderators of the effects of paced and unpaced work on mood and cognitive performance: A laboratory simulation of mechanized letter sorting. *Human factors*, 32(2):197-216.

Payne, S.J., Duggan, G.B and Neth, H. (2007). Discretionary task interleaving: heuristics for time allocation in cognitive foraging. *Journal of Experimental Psychology: General.* 136(3):370-388.

Pintrich, P.R., Smith, D.A.F, Garcia, T. and McKeachie, W.J. (1993). Reliability and predictive validity of the motivated strategies for learning questionnaire. *Educational and Psychological measurement*, 53:801-803.

Porges, S.W. (1992). Chapter 8: Automatic regulation and attention. In: *Attention and information processing in infants and adults*. (Eds), Campbell, B.A., Hayne, H. and Richardson, R. Lawrence Erlbaum Associates, Inc, New Jersey.

Rabbitt, P.M.A. (1969). Psychological refractory delay and response-stimulus interval duration in serial-choice response tasks. *Acta Psychological*, 30:195-219.

Rasmussen, J. (1983). Skills, Rules and Knowledge; signals, signs and symbols and other distinctions in human performance models*. IEEE Transactions on Systems, man and Cybernetics*, 13(3):257-266.

Renaud, P. and Blondin, J.P. (1997). The stress of Stroop performance: physiological and emotional responses to color-word interference, task-pacing and pacing speed. *International Journal of psychophysiology*, 27(2): 87-97.

Rogers, R.D. and Monsell, S. (1995). The costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology General*, 124: 207-231.

Roscoe, A.H. (1992). Assessing pilot workload. Why measure heart rate, HRV and respiration? *Biological Psychology* 34: 259-287.

Roscoe, A.H. (1993). Heart rate as a psychophysiological measure for in-flight workload assessment. *Ergonomics*, 36(9): 1055-1062.

Rubinstein, J. S., Meyer, D. E. & Evans, J. E. (2001). Executive control of cognitive processes in task-switching. *Journal of Experimental Psychology: Human Perception and Performance*, 27: 763-797.

Salvendy, G. and Humphreys, A.P. (1979). Effects of personality, perceptual difficulty and pacing of a task on productivity, job satisfaction and psychological stress. *Perceptual and Motor Skills*, 49: 219-222.

Segerstrom, S.C. and Solberg Nes, L. (2007). Heart rate variability reflects self-regulatory strength, effort and fatigue. *Psychological Science*. 18(3): 275-281.

Schmidt, K.H., Neubach, B. and Heuer, H. (2007). Self-control demands, cognitive control deficits, and burnout. *Work and Stress,* 21(2): 142-154.

Singh, A.L., Tiwari, T. and Singh, I.L. (2010). Performance feedback, mental workload and monitoring efficiency. *Journal of the Indian Academy of Applied Psychology*, 36(1):151-158.

Somsen, R.J.M., van der Molen, M.W., Jennings, JR. and van Beek, B. (2000). Wisconsin Card Sorting in adolescents: analysis of performance, response time and heart rate. *Acta Psychologica*, 104:27-257.

Sroufe, L. (1971). Effects of depth and rate of breathing on heart rate and heart rate variability. *Psychophysiology*, 8(5): 648-655.

Steinborn, M.B., Flehmig, H.C., Westhoff, K. and Langner, R. (2009). Differential effects of prolonged work on performance measures in self-paced speed tests. *Advances in Cognitive Psychology,* 5:105-113.

Steptoe, A., Evans, O. and Fieldman, G. (1997). Perceptions of control over work: Psychophysiological responses to self-paced and externally-paced tasks in an adult population sample. *International Journal of Psychophysiology,* 25(3):211-220.

*Steptoe, A. (1993). Stress and the cardiovascular system: a psychosocial perspective. In: C.E. Stanford and P. Salmon (Eds.), *Stress: From Synapse to Syndrome*. Academic Press, London, pp. 120-141.

Stroop, J.R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology,* 18, 643-622.

Tanner, H. and Jones, S. (2003). Self-efficacy in mathematics and students use of self-regulated learning strategies during assessment events. International Group for psychology of Mathematics Education. Paper presented at the 27th International Group for the psychology of Mathematics Education Conference (vol. 4, pp. 275-282). Honolulu, USA: PME

Thackray, R. I., Bailey, J.P., Touchstone, R.M. (1975). Physiological, Subjective, and Performance Correlates of Reported Boredom and Monotony while Performing a Simulated Radar Control Task. *Federal Aviation Administration, office of Aviation Medicine. Washington DC.*

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

Tortora, G. and Derrickson, B. (2006). *Principles of Anatomy and Physiology*. 11th Edition. John Wiley and Sons, USA.

Tucker, P., Macdonald, I. Sytnik, N.I. Owens, D.S. and Folkard, S. (1997). Levels of control in the extended performance of a monotonous task. In S,A. Robertson (ed.) Contemporary Ergonomics (pp.357-362). London: Taylor and Francis.

Van der Linden, D., Frese, M. and Meijman, T.F. (2003). Mental fatigue and the control of cognitive processes: effects on reservation and planning. *Acta Psychologica*, 113:45-65.

Van Dongen, H.P.A and Dinges, D.F. (2000). Circadian Rhythms in Fatigue, Alertness and Performance, In: Kryger, M.H., *et al*. (Eds), *Principles and Practice of Sleep medicine.* 3rd Edition. W.B. Saunders, Philadelphia, Pennsylvania.

Waszak, F., Hommel, B. and Allport, A (2003). Task-switching and long-term priming: Role of episodic stimulus-task bindings in task-shift costs. Cognitive Psychology, 46:361-413.

Watt, J.D. (1991). Effect of boredom proneness on time perception. *Psychological Reports,* 69(1):323-327.

Wickens, C.D. (1984). *Engineering Psychology and Human Performance*. Scott, Foresman and Company, USA. 291-306pp

*Wickens, C.D. (1986). Gain and energetic in information processing theory. In G.R.J. Hockey, A.W.K. Gaillard and M.G.H. Coles (Eds.), *Energetics and Information Processing*. Dordrecht: Martinus Nijhoff.

Wright, K.P., Hull, J.T. and Czeisler, C.A. (2002). Relationship between alertness, performance, and body temperature in humans. *American Journal of Physiology*, 283(6): 1370-1377.

Wylie, G. and Allport, A. (2000). Task-switching and the measurement of 'switch costs'. *Psychological Research*, 63:212-233.

Young, M.S. and Stanton, N.A. (2002). Malleable attentional resources theory: A new explanation for the effects of mental underload on performance. *Human Factors*, 44(3): 365-375.

# APPENDICES

## APPENDIX A: GENERAL INFORMATION

### A1: Letter to the Participant

Dear Participant

Thank you for offering to participate in my Masters Study entitled:

**"FACTORS DRIVING INDIVIDUALS TO CHANGE BEHAVIOUR DURING HUMAN INFORMATION-PROCESSING TASKS AND THEREFORE REGULATE PERFORMANCE"**

AIM OF THE STUDY

This study aims to determine what factors cause individuals to regulate their performance by switching between information-processing tasks. In everyday life, it has been observed that humans switch back and forth between tasks rather than finishing one task before moving to the next task. It is speculated that this behaviour is driven by certain factors and once the threshold is reached then the brain instructs the body to switch to another task. This study speculates that monotony, efficiency and resource usage drives behaviour regulation. This study measures the physiological responses, the subjective responses and performance output and behaviour in task-switching in order to determine if the speculated factors are indeed the underlying factors causing this performance regulation. The findings from this study will assist in determining more efficient ways to complete various information-processing tasks with minimal error and high levels of accuracy and therefore enhance human performance and job satisfaction in the workplace.

TASKS

You will be presented with five different information-processing tasks in which you can select from to conduct during the study. These tasks are explained below.

Firstly there is the target response test which is a stimulus-response test. You are required to respond to the stimulus, which is a green circle with a diameter of 3mm on a black background, which appears on the computer screen by clicking the mouse pointer as quickly as possible. The stimulus will appear every 0.25 to 1.5 seconds therefore preventing you from anticipating the appearance of the stimulus and responding in a rhythmic manner which would be the case if the time delay was always the same. Your response time (time from presentation of stimulus to clicking the mouse) will be measured.

Secondly, there is a tracking task which is conducted on a computer. This requires you to use the mouse to keep the bonnet of the car on the middle line. Deviation away from this centre line will be measured. If you go too far off the road press esc and you will automatically be positioned back onto the road. The travelling speed will remain constant at 9 $km.h^{-1}$ throughout the testing. Please note that this speed cannot be compared to the speed reached when driving on the road in reality.

Thirdly, there is an English spelling test. You will be given four versions of the same word and must identify which option is the correct spelling of the word by circling the corresponding letter. The number of completed questions in the time spent on the task and percentage of questions correct will be measured. This test will be completed on paper using a pen.

Fourthly, there is a choice reaction test which is similar to the target response task in that it is also a stimulus-response test. In this particular task, when the presented stimulus is a blue circle the right mouse button must be pressed and when the presented stimulus is a red square the left mouse button must be pressed. Once again you are encouraged to respond by clicking the correct mouse button as quickly as possible. Your response time and correct mouse responses will be measured.

Lastly, there is Berg's Card Sorting Test. You are presented with four piles of cards each containing a different shape, colour and number of items. You are then given a card with a specific shape, colour and number of items and are required to click on one of the four piles based on a rule. The rule can either be that cards must be sorted according to the colour, the shape or the number of items on the card. After making your response you will be given immediate feedback as to whether the decision was correct or incorrect and therefore you can determine what the rule is based on the feedback. However, the rule does change after a certain amount of cards have passed and you must then pick this up as quickly as possible. Both accuracy in your responses and response time (time taken from when card is presented to when the corresponding pile is clicked on) will be measured.

PROCEDURE

This study will involve one testing session at the Human Kinetics and Ergonomics Department, Rhodes University. In total, the testing will take 1 hour and 30 minutes. Upon arrival, you will be informed of the procedure and reminded that participating in this study is voluntarily and you can withdraw from this study at any point. Consent forms will be signed voluntarily once you agree to take part in the study.

Firstly, I will explain and familiarize you with equipment which is fitted onto you during the testing. A Polar heart rate belt will be fitted around your chest and adjusted until a heartbeat is picked up. The Ergospirometer is used to measure oxygen inhaled and carbon dioxide expelled thus a mask is placed over the nose and mouth region, which contains a turbine that covers the mouth and measures gas exchange and a hairnet is used to keep the mask in place. Because the Ergospirometer covers the mouth and nose regions it can make you feel restricted and claustrophobic however, you are able to breathe normally and are encouraged to do so. Two temperature sensors will be used, where one involves an ear plug being placed into the ear which can be invasive however, the plug will be cleaned with ethanol and you are free to adjust it until it feels comfortable and the other involves a sensor being positioned onto the forehead. There is no danger involved in having this equipment fitted onto you however; it can feel uncomfortable and invasive. You are therefore reminded that you have the freedom to leave the study at any moment.

Once equipment is fitted, I will explain and demonstrate the five different tasks to you. You will sit and relax until you are at rest and then have the opportunity to practice each task for duration of 90 seconds. Baseline values will be obtained during the last minute of each practice test. After each task you will relax until you at rest before starting the next task. You will use the provided boredom scale to rate the perceived level of boredom experienced during each task.

You will then have the freedom to select one out of the five tests to start the protocol with. You are entitled to switch between the tests whenever you feel necessary and this process will continue for 45 minutes. You can switch back and forth between tasks and are not required to attempt all the tasks available. No feedback will be given about the amount of time passed during the 45 minute protocol. At each task transition you will be asked to indicate verbally, how much time you think you have spent on the previous task and give a rating of boredom of the previous task. After 45 minutes, the test will end and the equipment will be removed from you as soon as possible. Finally you will be asked to rate the various tasks according to different categories after which you will be free to leave, provided you have no questions to ask.

REQUIREMENTS OF PARTICIPANTS

Prior to testing, please adhere to the following:

- Do not consume alcohol 24 hours before
- Do not participate in vigorous physical activity 24 hours before
- Do not eat one hour before testing
- Do not consume caffeine 8 hours prior to testing
- Ensure you have had sufficient sleep (at least 8 hours) prior to testing

RISKS AND BENEFITS

The risks associated with this study are minimal. You are not required to exert yourself physically as all tasks require use of the information processing system only. Each of the tasks, if continued for prolonged durations, may induce a level of discomfort, but you have the freedom to alleviate this discomfort at any point by switching to another task. Four out of the five tests involve working on a computer and therefore you may experience symptoms associated with computer use such as drowsiness, watering eyes or visual discomfort but if this is the case you can switch to the spelling test which is conducted on paper. The tests require concentration and mental effort and this may cause the occurrence of a headache however these symptoms are brief, reversible and easily eradicated once the protocol has been completed. It must be noted that during pilot testing there were no complaints of the above symptoms mentioned or any side effects of fatigue occurring. However, to be cautious you will be required to rest in the Department until these side effects subside. Please remember that if, at any stage during the procedure, you wish to withdraw from the protocol, please inform me immediately and there will be no negative consequences against you for doing this. In addition if you feel any signs of nausea or excessive discomfort please inform me of this.

Please be aware that your anonymity is maintained during this testing. All information will be coded according to participant number to ensure your data is kept confidential. Furthermore, data will be stored on the primary researcher’s laptop only and on one of the researchers flash stick, until statistical analysis has been completed, after which the data will be deleted and only remain on the researchers laptop for maximum 5 years. If you would like to receive feedback on the outcome of the study, please feel free to contact the primary researcher, however, feedback can only be provided after all data is collected and analyzed.

By participating in this study, you will benefit in terms of acquiring knowledge about the information processing system and the role of self-regulation on performance. You will be exposed to interesting equipment such as the Ergospirometer, heart rate monitor and five different information processing tests. You will also contribute to finding more information about human behaviour in terms of switching between tasks which is vital in working environments especially with the change in work character where you are often faced with a number of tasks to complete by set deadlines and thus decisions must be made as to how to tackle these tasks the most efficient and effective way. It must be noted that you are free to withdraw from your participation as a participant in this study at any time and are under no obligation to continue with the study against your will. Thank you for showing an interest in this study and I hope you will learn from this experience. Please do not hesitate to contact me with any queries.

Yours sincerely,

Caley Chaplin

(Masters student Department of Human Kinetics and Ergonomics)

caleychaplin@gmail.com

Mathias Goebel

(Supervisor)

m.goebel@ru.ac.za

**A2: Participant Consent Form**

I,______________________, do hereby consent to participate in this study entitled: **"THE FACTORS DRIVING INDIVIDUALS TO CHANGE BEHAVIOUR DURING HUMAN INFORMATION-PROCESSING TASKS AND THEREFORE REGULATE PERFORMANCE"** I have been fully informed about the nature of the research, the procedures of the study and the potential risks that might occur during testing. This has been explained to me by the primary researcher both verbally and in writing.

I am aware that by voluntarily consenting to participate in this study, I waive any legal recourse against the researcher, The Human Kinetics and Ergonomics Department or Rhodes University in the event of any injury occurring during testing whereby I will take full responsibility of the costs involved. In addition, I am aware that the Human Kinetics and Ergonomics Department will take no responsibility if the injury is self-inflicted or as a result of negligence by the participant. I will inform the researcher immediately if I experience any abnormality or distress. Furthermore, I am aware that I can withdraw from participation in the study at any time and am under no obligation to continue with the testing against my will.

I realize that my anonymity will be protected at all times, and agree to allowing the information collected in the study to be used and published for scientific purposes. I am willing to have photographs taken of me during testing to be used in the final copy of this study. I am willing to have the various measurements (stated in information to participants) recorded during the testing and for them to be used in statistical analyses. I have read and understood the information above and the accompanying information about the study and all questions have been answered to my satisfaction.

Signed at the Human Kinetics and Ergonomics Department, Rhodes University, on ________ (Date)

**PARTICIPANT:** ________________ (Name) ________________ (Signed)

**RESEARCHER:** ________________ (Name) ________________ (Signed)

**WITNESS 1:**__________________ (Name) __________________ (Signed)

**WITNESS 2:**__________________ (Name) __________________ (Signed)

## APPENDIX B

### B1: Self-report task scale

Rate the following tasks according to the specific category by crossing the appropriate box.

| Category | Tasks | None | Some | Much | Too much |
|---|---|---|---|---|---|
| Mental Effort | Target response task | | | | |
| | Tracking task | | | | |
| | Spelling task | | | | |
| | Choice reaction | | | | |
| | Card sorting | | | | |
| Category | Tasks | Worst | Fine | Good | Best |
| Performance | Target response task | | | | |
| | Tracking task | | | | |
| | Spelling task | | | | |
| | Choice reaction | | | | |
| | Card rorting | | | | |
| Category | Tasks | Not at all | At times | Much | Extremely |
| Monotonous | Target response task | | | | |
| | Tracking task | | | | |
| | Spelling task | | | | |
| | Choice reaction | | | | |
| | Card sorting | | | | |
| Category | Tasks | Very frustrating | Frustrating at times | Satisfying at times | Very satisfying |
| Satisfaction | Target response task | | | | |
| | Tracking task | | | | |
| | Spelling task | | | | |
| | Choice reaction | | | | |
| | Card sorting | | | | |

**B2: Self-report Boredom Scale**

Rate each task according to the degree of boredom experienced during the task.

I felt ________ boredom during the task

1: No

2: Some/occasional

3: Much

4: A great deal of

### B3: Spelling Task

| A | B | C | D |
|---|---|---|---|
| acomodate | accomodate | acommodate | accommodate |

| A | B | C | D |
|---|---|---|---|
| acknowledgment | acknowledgement | acknowlegment | acknowlegement |

| A | B | C | D |
|---|---|---|---|
| arguement | argument | arguemant | arguemint |

| A | B | C | D |
|---|---|---|---|
| comitment | comitmment | commitment | comitmant |

| A | B | C | D |
|---|---|---|---|
| consensus | concensus | consencus | consenssus |

| A | B | C | D |
|---|---|---|---|
| deductible | deductable | deductuble | deductabel |

| A | B | C | D |
|---|---|---|---|
| embarras | embaras | embarass | embarrass |

| A | B | C | D |
|---|---|---|---|
| existance | existence | existanse | existanc |

## B4: Task settings

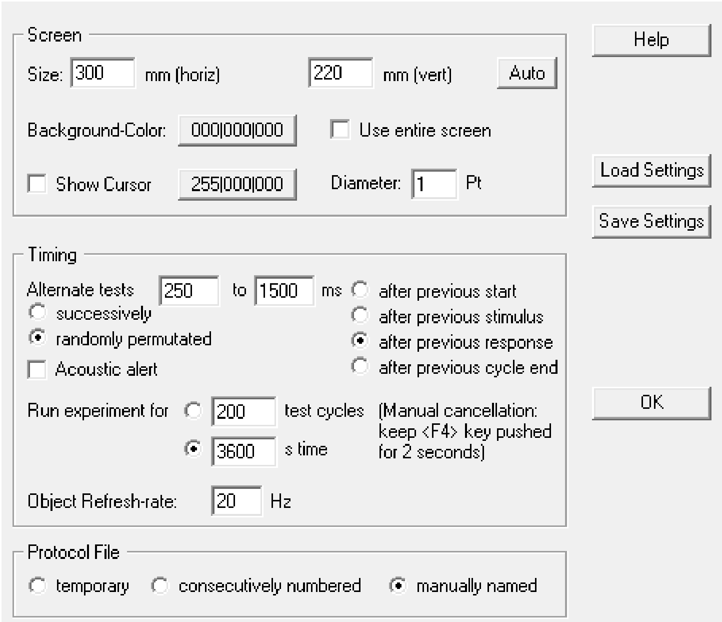


Figure 38: The settings used for the target response task


Figure 39: The settings used for the tracking task.

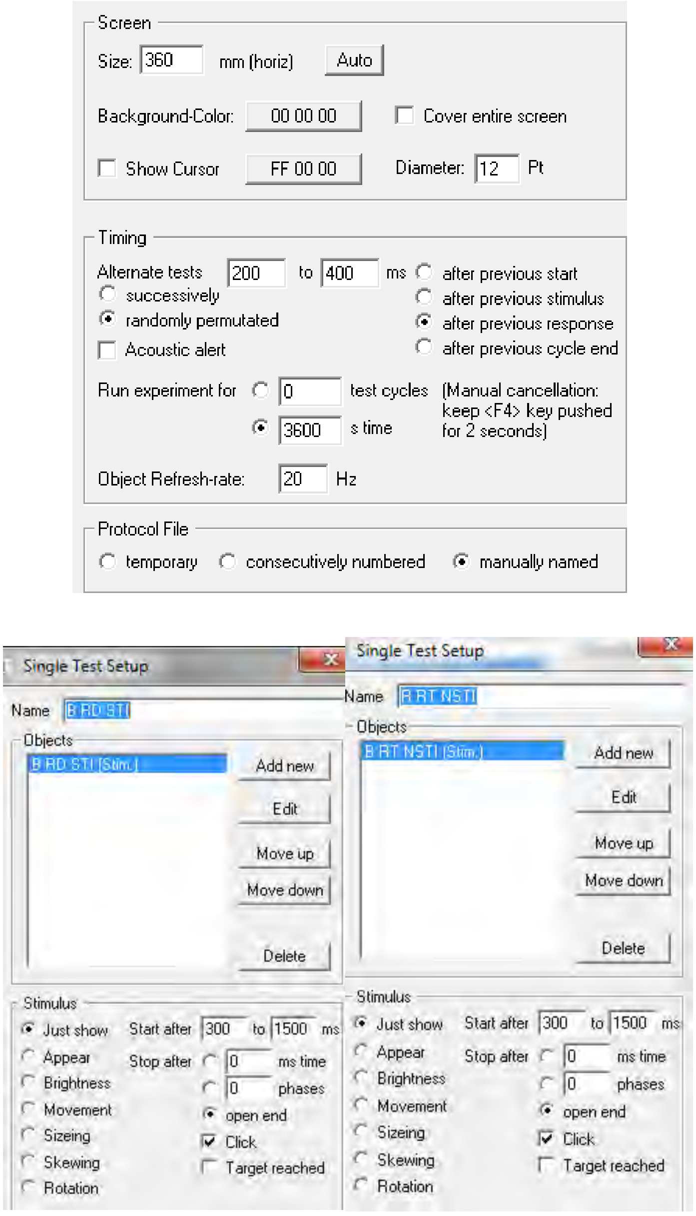


Figure 40: The settings used for the choice reaction task

## APPENDIX C: PILOT TESTS

### C1: Pilot Task 1

This pilot study aimed to determine the effect of information-processing tasks differing in workload and mental effort on physiological responses (heart rate, heart rate variability, breathing frequency and energy expenditure) and performance (reaction time and accuracy).

The tasks were as follows:

*The Reading task with typing errors* required the participant to read the given text silently as fast as possible, while verbally identifying any typing errors (bookk) in the text. This was a scanning task. *Reading task with content errors* required participants to do as above but verbally identify content errors (wrong use of word) in the text. This version required increased cognitive effort and reasoning.

*A memory task* involved numbers appearing on the screen for a limited duration, before disappearing. Participants were required to recall the numbers by typing them on the screen after the beep. There were two versions of the memory task, where one only had *6 numbers* to memorize and the other had *7 numbers* to remember. The two versions differed in difficulty and workload.

*The target response task* involved responding to a stimulus (circle) that appeared on the screen by clicking the mouse button as quickly as possible. This measured the response time. Three variations of this task were used; *low, medium* and *high* workload. The tasks differed in the amount of time that elapsed before the next stimulus was presented on the screen. The low, medium and high workload had an average delay of 2s, 1s and 250ms respectively.

*Data Collection*

The Ergospirometer was used to measure the rate of oxygen uptake and from this energy expenditure was calculated. A Suunto Heart Rate Monitor was used to measure HR and HRV throughout the testing. Three participants (n=2 females and n=1 male) from Rhodes University were used for this pilot. Participants completed each task for five minutes.

*Results*

The response time (s) increased as the delay between the stimuli increased. It was concluded from these findings that a delay time of 250ms to 1500ms will be used during the target response task in the final protocol. The increased range in time delay was to prevent the participants from getting into a rhythm of responding to the stimuli.

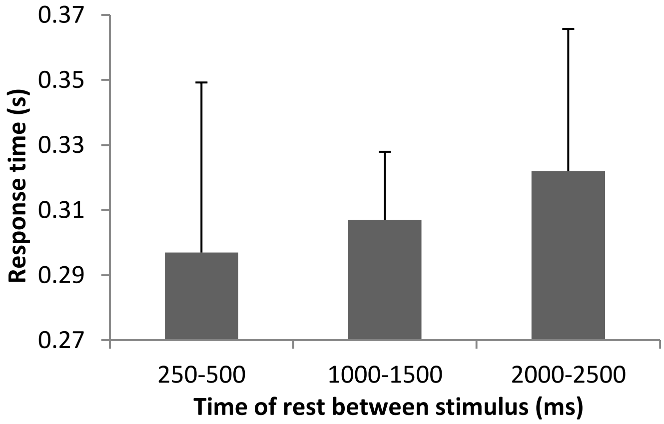


Figure 41: Response time during three different time delays between stimuli appearing

Energy expenditure (EE) was measured to determine how breathing frequency and EE were influenced by the type of task. The tasks had minimal physical component therefore changes in these values were attributed to changes in the level of effort, concentration and cognitive workload.

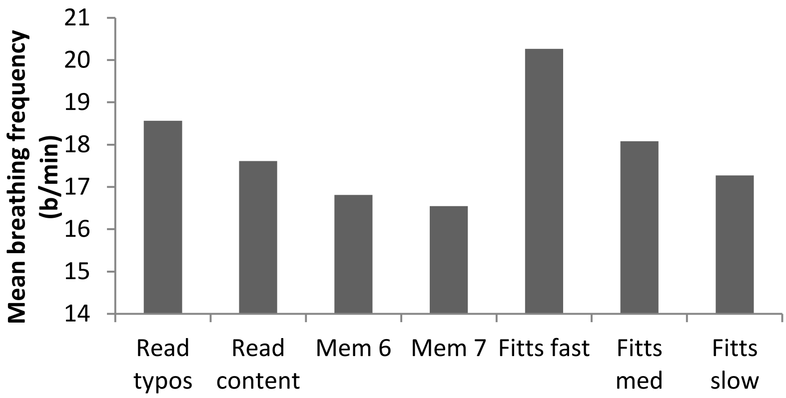


Figure 42: Mean breathing frequency for the different task types during the pilot study.

The target response task (labeled Fitts fast, med and slow on Figure 42) showed high values for breathing frequency whereas the memory task showed lower values. One could speculate that the greater the concentration on the task at hand, the greater the cognitive workload and thus the slower the breathing frequency. Therefore, the target response task required less concentration and had a lower cognitive workload than reading and memory.

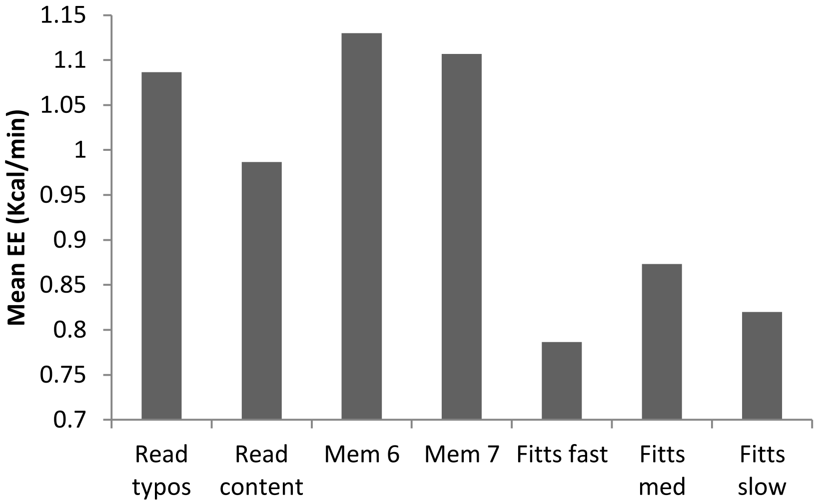


Figure 43: Mean energy expenditure during different task types

Memory task was found to have the highest EE whereas the target response task (Labeled Fitts on Figure 43) had the lowest EE. This correlated with the assumption that the greater the cognitive workload and concentration on the task at hand, the greater the EE. This would mean that the memory task was the most demanding in terms of effort and the target response the least demanding. When looking at degrees of difficulty of the task type, the easier memory task was found to use slightly more energy than the more difficult. This may be due to the learning effect as the easier memory task was administered before the difficult memory task for all 3 participants. The fast target response task (Fitts) had the lowest EE and this correlated with previous findings as it was the least mentally taxing and required less effort than other tasks.

From these findings, it was concluded that using the Ergospirometer to determine EE, was an appropriate measure of the amount of mental effort and degree of cognitive workload needed to conduct the task.

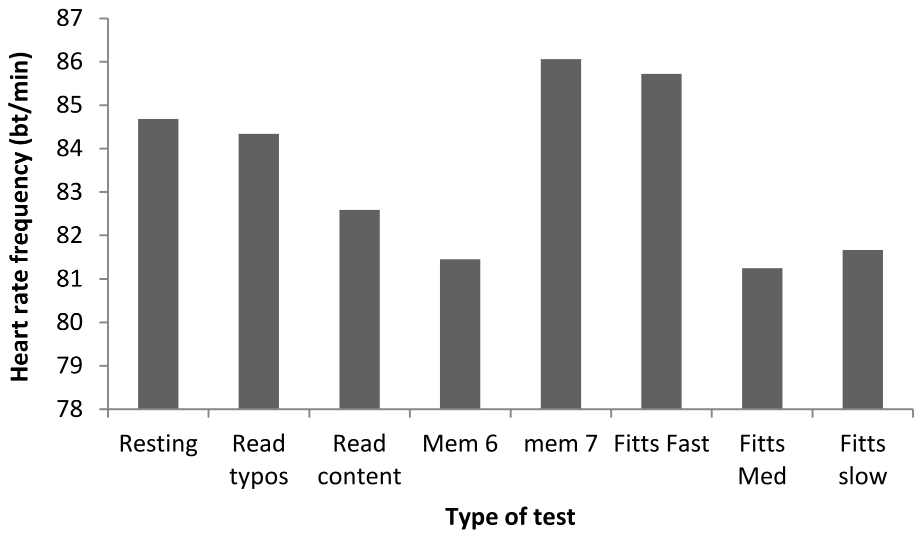


Figure 44: Heart rate frequency during different information-processing tasks

Heart rate was considerably high for the difficult memory task and this may be due to the increase in difficulty. However, participants may have also panicked as they attempted to recall 7 numbers leading to increased HR values. The easier reading task and easier target response task elicited higher HR values which may be due to faster reading speed and faster target response task cycle rate respectively.

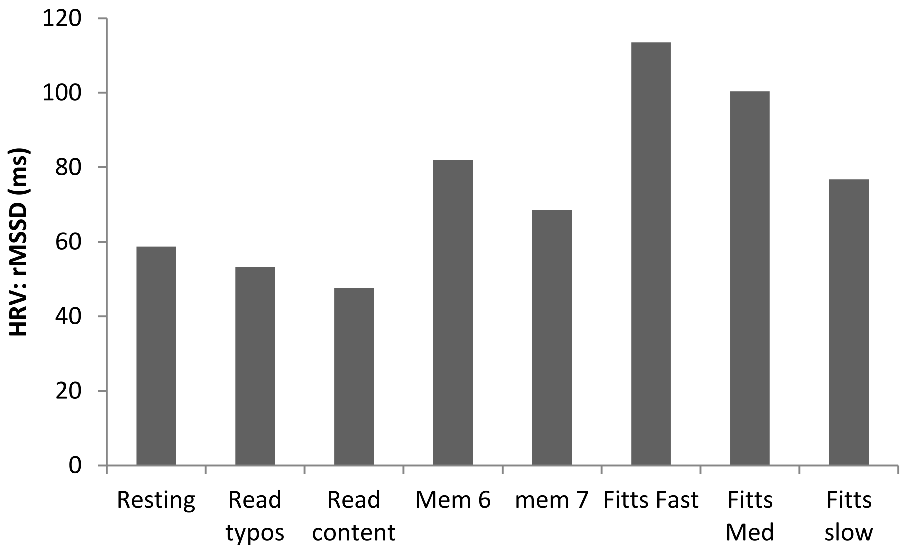


Figure 45: HRV: *rMSSD* during the different tasks

The lower the *rMSSD* HRV value correlated to a higher cognitive workload. Figure 46 showed that the target response task (Fitts) had the highest HRV suggesting the lowest cognitive workload. The reading task showed a higher cognitive workload than the memory task which was unexpected as memory task was assumed to have a higher cognitive workload. The difficult memory task had a higher cognitive workload than the easier memory task. It can be concluded that *rMSSD* can be used as an appropriate measure of cognitive workload

## C2: Pilot Task 2

This pilot study aimed to determine human behaviour in response to switching between five different information-processing tasks over one hour.

The five different information-processing tasks were as follows:

- Perceptual-motor task with micro rest breaks: Target response task
- Perceptual-motor task which is continuous: Continuous tracking task
- Cognitive: Verbal comprehension/spelling task
- Perceptual-cognitive-motor task (fast repetition): Choice reaction task
- Perceptual-cognitive-motor task (slow repetition): Berg's card sorting task

### *Protocol*

The participant was assigned a task to begin the protocol. The participant was then free to switch between the tasks as desired. Participants were allowed to switch back to a previous conducted task and did not have to complete all available tasks. The protocol continued for 45 minutes.

### *Data Collection*

Every task switch was noted in terms of what task was switched to and what task was currently being performed and the percentage of time spent on each task. A matrix displaying the total percentage of time spent on each task was constructed to determine probability of participants choosing one task over another.

Individuals' perception of time passing was recorded at each transition between tasks as an indicator of the level of monotony experienced by asking the participant how much time they perceive to have passed. A questionnaire about the reasons for task-switching was conducted after the experiment.

*Results*

Table XI: Results of task-switching behaviour from one participant

| Switch number | Task switch | Time of switch | Time on task | Perceived time on task |
|---|---|---|---|---|
| 1 | Spelling Task | 2.33 | 2.33 | 3.00 |
| 2 | Target Response Task | 3.22 | 0.50 | 1.00 |
| 3 | Tracking Task | 7.16 | 3.54 | 5.00 |
| 4 | Card Sorting | 10.33 | 3.17 | 5.00 |
| 5 | Choice Reaction | 12.06 | 2.34 | 4.00 |
| 6 | Spelling Task | 21.42 | 8.36 | 8.00 |
| 7 | Tracking Task | 29.02 | 7.20 | 7.00 |
| 8 | Target Response Task | 33.25 | 4.23 | 5.00 |
| 9 | Spelling Task | 36.00 | 2.35 | 2.00 |
| 10 | Card Sorting | 41.35 | 5.35 | 5.00 |
| 11 | Choice Reaction | 45.00 | 3.25 | 5.00 |

It is shown that humans switch frequently between tasks. Participants made over 10 transitions between tasks over a period of 45 minutes. The longest and shortest time spent on a task was 8 minutes 36 seconds and 50 seconds respectively. The average time spent on a task before switching to another task was roughly four minutes.

The choice reaction task was rated as the most boring task and time on task was overestimated. The spelling task was rated as the least monotonous task and time on task was underestimated. One could conclude that the more boring the task, the greater the overestimation of time spent on the task. It can be suggested that during the first 15 minutes time was perceived to pass more slowly than during the last half an hour.

Table XII: The subjective perception of the amount of time passed.

| Actual time (minutes) | Perceived time (minutes) | |
|---|---|---|
| | Subject 3 | Subject 4 |
| 8 | 7 | 10 |
| 15 | 15 | 15 |
| 30 | 25 | 25 |
| 42 | 35 | 35 |

Figure 47 showed the mean percentage of the total 45 minutes spent on each task. The majority of the time was spent on the spelling task, whereas the least amount of time was spent on the choice reaction time. The choice reaction task involved resources from the visual, cognitive and motor systems however; it required intense concentration and participants stated that it was frustrating with a low level of satisfaction. The simple target response and tracking task had no cognitive component and therefore participants found these tasks monotonous.

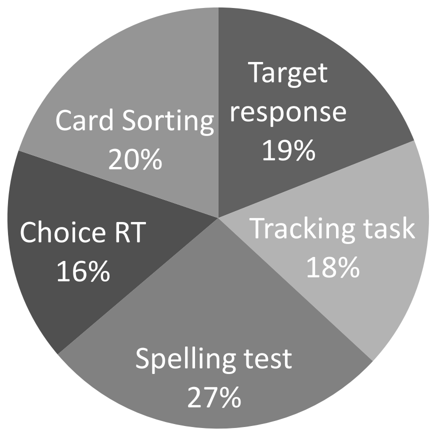


Figure 46: The mean percentage of time spent on the five different information-processing tasks.

## APPENDIX D: TABLES OF STATISTICAL ANALYSES

### D1: Task-switching Behaviour

Table XIII: Statistical analysis for mean time spent (minutes) on five different tasks with gender as a covariate.

| Effect | Degr. of Freedom | F | p |
|---|---|---|---|
| **Task** | **4, 201** | **6.335** | **0.000** |
| **Gender** | **1, 201** | **6.280** | **0.013** |
| **Task*Gender** | 4, 201 | 1.168 | 0.326 |

Table XIV: Statistical analysis of the task frequency at different time intervals.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Task** | **4, 140** | **6.014** | **0.000** |
| **Time*Task** | **32, 1120** | **1.676** | **0.011** |

### D2: Subjective perception of tasks

Table XV: Statistical analysis of boredom ratings for five different tasks taken after the warm-up and at the end of the experiment.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Task** | **4, 132** | **24.774** | **0.000** |
| **Time** | **1, 33** | **37.988** | **0.000** |
| **Task*Time** | 4, 132 | 1.598 | 0.179 |

Table XVI: Statistical analysis of the boredom rating for five different tasks taken at each task transition away from the specified task.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Task** | **4, 206** | **2.708** | **0.031** |

Table XVII: Statistical analysis of subjective rating of mental effort for five different tasks following the experiment, with gender as a covariate.

| Effect | Degr. of Freedom | F | p |
|---|---|---|---|
| **Gender** | **1, 30** | **4.401** | **0.0444** |
| **Task type** | **4, 120** | **28.181** | **0.000** |
| **Task type*Gender** | 4, 120 | 0.612 | 0.654 |

Table XVIII: Statistical analysis of subjective rating of performance in the five different tasks, with gender as a covariate.

| Effect | Degr. of Freedom | F | p |
|---|---|---|---|
| **Task type** | **4, 120** | **9.781** | **0.000** |

**D3: Physiological response to different tasks**

Table XIX: Statistical analysis of energy expenditure for five different tasks.

| Effect | Degr. of Freedom | F | p |
|---|---|---|---|
| **Task** | **4, 201** | **2.537** | **0.041** |

Table XX: Statistical analysis of breathing frequency for five different tasks.

| Effect | Degr. of Freedom | F | p |
|---|---|---|---|
| **Task** | **4, 201** | **9.33** | **0.000** |

Table XXI: Statistical analysis of rMSSD for five different tasks.

| Effect | Degr. of Freedom | F | p |
|---|---|---|---|
| **Task** | **4, 201** | **5.987** | **0.000** |

Table XXII: Statistical analysis of low frequency power for five different tasks.

| Effect | Degr. of Freedom | F | p |
|---|---|---|---|
| **Task** | **4, 201** | **4.213** | **0.003** |

Table XXIII: Statistical analysis of high frequency centre frequency for five different tasks.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Task** | **4, 201** | **6.80** | **0.000** |

Table XXIV: Statistical analysis of low frequency high frequency ratio for five different tasks.

| | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Task** | **4, 201** | **3.028** | **0.019** |

Table XXV: Statistical analysis of tympanic and skin temperature for five different tasks.

| Effect | Degr. of Freedom | F | p |
|---|---|---|---|
| **Task** | **4, 201** | **3.001** | **0.019** |
| **Temp type** | 1, 201 | 0.694 | 0.787 |
| **Temp type*Task** | 4, 201 | 2.035 | 0.061 |

## D4: Physiological responses over time

Table XXVI: Statistical analysis of energy expenditure over 5 minute time intervals

| Effect | Degr. of Freedom | F | p |
|---|---|---|---|
| Time | 7, 224 | 2.714 | 0.032 |

Table XXVII: Statistical analysis of breathing frequency over 5 minute intervals.

| Effect | Degr. of Freedom | F | p |
|---|---|---|---|
| Time | 7, 224 | 3.023 | 0.005 |

Table XXVIII: Statistical analysis of heart rate frequency over 5 minute time intervals.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| Time | 7, 224 | 5.606 | 0.000 |

Table XXIX: Statistical analysis of heart rate variability (rMSSD) over 5 minute time intervals.

| Effect | Degr. of Freedom | F | p |
|---|---|---|---|
| Time | 7, 224 | 1.384 | 0.000 |

Table XXX: Statistical analysis of heart rate variability (*pNN50*) over 5 minute time intervals.

| Effect | Degr. of Freedom | F | p |
|---|---|---|---|
| Time | 7, 224 | 6.720 | 0.000 |

Table XXXI: Statistical analysis of high frequency power over 5 minute time intervals.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Time** | **7, 224** | **5.058** | **0.000** |

Table XXXII: Statistical analysis of low frequency power over 5 minute time intervals

| Effect | Degr. of Freedom | F | p |
|---|---|---|---|
| **Gender** | **1, 32** | **1.245** | **0.000** |
| **Time** | **7, 224** | **3.250** | **0.003** |
| **Time*Gender** | 7, 224 | 7.398 | 0.638 |

Table XXXIII: Statistical analysis of tympanic temperature over 5 minute time intervals.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Gender** | **1, 32** | 4.958 | 1.000 |
| **Time** | **7, 224** | **2.213** | **0.034** |
| **Time*Gender** | 7, 224 | **2.737** | **0.010** |

### D5: Response change within each trial

Table XXXIV: Statistical analysis of performance (target deviation) over time during the tracking task.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Time** | **1, 43** | **4.450** | **0.041** |

Table XXXV: Statistical analysis of performance (response time) over time during the card sorting.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Time** | **1, 55** | **12.853** | **0.001** |

Table XXXVI: Statistical analysis of performance (% correct responses) over time during the card sorting.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Time** | **1,55** | **33.877** | **0.000** |

Table XXXVII: Statistical analysis of breathing frequency comparing the second minute to the last minute for each task.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Task type** | **4,206** | **6.182** | **0.000** |
| **Time** | 1,206 | 0.190 | 0.662 |
| **Time*task type** | **4,206** | **2.941** | **0.022** |

Table XXXVIII: Statistical analysis of skin temperature comparing the second minute to the last minute for each task.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Task type** | **4,206** | **3.214** | **0.015** |
| **Time** | **1,206** | **118.801** | **0.000** |
| **Time*Task type** | **4,206** | **2.720** | **0.033** |

Table XXXIX: Statistical analysis of breathing frequency comparing the task trend to the last minute of the task trend for each task.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Task type (from)** | **4,206** | **3.512** | **0.008** |
| **Time** | 1,206 | 2.944 | 0.088 |
| **Time*Task type (from)** | **4,206** | **2.827** | **0.026** |

**D6: Task transition effect**

Table XL: Statistical analysis of heart rate comparing the last minute before the switch to the second minute after the switch.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Time** | **1,175** | **9.625** | **0.002** |

Table XLI: Statistical analysis of heart rate comparing the first and second minute of the task

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Time** | **1,175** | **20.573** | **0.000** |

Table XLII: Statistical analysis of heart rate comparing the last minute before the switch to the second minute after the switch, with task as a covariate.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Task type (from)** | **4,172** | **2.810** | **0.028** |
| **Time** | **1,172** | **7.524** | **0.007** |
| **Time*Task type (from)** | 4,172 | 1.525 | 0.219 |

Table XLIII: Statistical analysis of rMSSD comparing the last minute before the switch to the second minute after the switch.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Time** | **1,175** | **6.468** | **0.012** |

Table XLIV: Statistical analysis of rMSSD comparing the last minute before the switch to the second minute after the switch, with task as a covariate.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Task type (from)** | 4,172 | 2.389 | 0.053 |
| **Time** | **1,172** | **3.982** | **0.047** |
| **Time*Task type (from)** | 4,172 | 1.638 | 0.167 |

Table XLV: Statistical analysis of high frequency power comparing the last minute before the switch to the second minute after the switch.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Time** | **1,175** | **4.405** | **0.037** |

Table XLVI: Statistical analysis of high frequency power comparing the last minute before the switch to the second minute after the switch, with task as a covariate.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Task type (from)** | 4,172 | 1.241 | 0.295 |
| **Time** | **1,172** | **3.940** | **0.049** |
| **Time*Task type (from)** | 4,172 | 0.787 | 0.535 |

Table XLVII: Statistical analysis of high frequency centre frequency comparing the last minute before the switch to the second minute after the switch, with task as a covariate.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Task type (from)** | 4,172 | 2.16 | 0.075 |
| **Time** | 1,172 | 0.09 | 0.768 |
| **Time*Task type (from)** | **4,172** | **3.43** | **0.010** |

Table XLVIII: Statistical analysis of skin temperature comparing the last minute before the switch to the second minute after the switch, with task as a covariate.

| Effect | Degr. of - Freedom | F | p |
|---|---|---|---|
| **Task type (from)** | 4,172 | 1.371 | 0.455 |
| **Time** | 1,172 | 1.206 | 0.346 |
| **Time*Task type (from)** | **4,172** | **6.746** | **0.000** |