THE ACUTE IMPACT OF EXTENDED AEROBIC EXERCISE ON COGNITIVE PERFORMANCE

BY

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THESIS

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ABSTRACT

Previous research has established a relationship between exercise and cognition, with more emphasis on this ascertained link, being made on the effects of long term and endurance exercise on cognition. However, enhanced worker effectiveness relies on a strong acute collaboration of physical and cognitive performance during task execution. As a result, the purpose of this study was to examine the acute effects of extended aerobic exercise on visual perception, working memory and motor responses, and to achieve this 24 participants (12 males and 12 females) aged between 18 and 24 participated in a 2 bout cycling exercise. The experimental condition had cycling resistance set at 60% of each individual's maximum aerobic output and the control condition had zero cycling resistance, where three cognitive tasks were performed at 10 minute intervals during the cycling exercise. The results showed that exercise did not affect any significant changes on the cognitive performance measures over the entire cycling duration, as well as during the exercise phase (cycling with resistance). However, visual perception improved significantly ($p<0.05$) immediately after exercise. This led to the conclusion that moderate to high intensity exercise when performed for an extended duration, has selective effects on certain cognitive performance measures, with the time at which the performance is measured during the exercise being a relevant factor to be considered for maximum activation effects of the exercise.

Key Words: cognitive performance, aerobic exercise, visual perception, motor responses, working memory, information processing, extended duration

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CHAPTER 1

INTRODUCTION

1.1 Background to the Study

Various occupations require their respective personnel to have a strong combination of physical endurance as well as cognitive proficiency as they perform their various work related tasks. Examples that spring readily to mind are soldiers, fire-fighters, and miners. In addition, performance in sport and exercise activities has been observed to be strongly dependent on the ability to simultaneously carry out cognitive and physical demands (Davranche and Morris, 2009). As a result, the relationship between physical activity and cognition becomes a crucial factor to study in order to increase efficiency in the tasks involved.

Previous studies have established that long term, regular physical exercise is well associated with better cognitive function, especially in the elderly (Weuve *et al.*, 2004). Acute exercise in particular, has been found to improve cognitive performance (Brisswatter *et al*., 2002; Echols, 2006; and Pontifex *et al*., 2009). Brisswatter *et al*. (2002) pointed out that in order to properly ascertain the relationship between exercise and cognitive performance, the methodological factors which need to be considered are the nature of the psychological task and the intensity and duration of the physical activity.

In a study by Lo Bue-Estes *et al. (*2008), cognitive performance decreased during exercise and increased after aerobic exercise. A number of studies where cycling was the form of aerobic activity, have shown cognition to improve during exercise (Adam *et al.*, 1997; Arcelin *et al.*, 1998; Pesce *et al.*, 2003; Serwah and Marino, 2006; Audiffren *et al.*, 2008), though in some studies cycling exercise had no effect on cognitive performance (Travlos and Marisi, 1995; Cote *et al.*, 1992; McMorris and Graydon, 1996). However, cognitive function was observed to improve immediately following aerobic exercise (cycling bouts) ranging from 40-60 minutes in duration at about 60-

85% of exercise intensity (Coles and Tomporowski, 2008; Davranche and Pichon, 2005; Hogervorst *et al.*, 1996; Tomporowski *et al.*, 2005).

1.2 Problem Statement

Numerous studies have attempted to respond to the question of how exercise affects cognition. However, the uniqueness of this study is that it not only seeks to understand the basic relationship between exercise and cognition, but how the effects of the former on the later change over time. Thus, one of the main areas of interest in this current study was observing the changes in cognitive performance in an extended duration protocol, in particular changes in responses before, during and after physical exertion. The findings from this study can as a result assist in reinforcing and encouraging physical activities in the workplace, seeing that enhanced cognitive performance strengthens the imperative for interventions through physical activity that serve to promote health and productivity (Ratey and Loehr, 2011).

1.3 Aims and Objectives

The aim of this study to explore the limits and scope of the relationship between physical exercise and cognitive performance.

As a result, the objectives of the study were the following:

(1.) To compare the cognitive responses given during a moderate-to-high intensity exercise against those given during a low-to-nil intensity exercise.

(2.) To observe how cognitive performance changes over time during the same-intensity exercise bouts for an extended duration.

(3.) To ultimately have a better understand of the relationship existing between physical activity and cognition.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter seeks to introduce the two focuses of this research; cognition and physical exertion, and give in sufficient detail the basic principles behind each of these two concepts. The primary understanding of each of them, i.e. cognition and physical exertion, will pave a path to comprehending the interaction between the two, more especially how physical exertion impacts cognition. Thus, this chapter will open with an introduction into cognitive functionality, followed by an overview on physical activities. Thereafter, a review on studies that have dealt with exercise and the various facets of cognitive performance will follow. This will then lead to the gap in existing knowledge and angle at which this study comes in to respond to the same general question on how exercise affects cognitive performance.

2.2 Cognition

According to Li (1999), cognition refers to the mental processes involved in information processing such as perception, learning, remembering and thinking/reasoning which relate largely to decision-making and problem-solving. Decision-making has been identified to be influenced by internal and external factors to the decision maker (Jacobs and Gaver, 1998).

The internal factors that influence decision making include; limited information processing and memory capabilities (Hogarth, 1987). However, training and experience can minimize the effects of limited information processing and memory capabilities, making work more efficient (Cohen, 1993 and Cohen *et al.,* 1996). In contrast, the external factors on decision-making include the environmental context, in which the decision is made (Adelman *et al.,* 1997), whose interaction with the individual's experiences can alter the nature of the ultimate choice. Experience has been shown to assist in building confidence when making decisions and more especially when executing the subsequent action or task (Cohen *et al.,* 1996)

Other influences of consideration when it comes to decision-making and problem-solving include physical fatigue which causes cognitive skills to degrade (Halbert, 1998); sleep deprivation which limits the ability to process information and make decisions (Bradshaw, 1995); extreme heat and dehydration which lead to a degeneration of cognitive skills and performance (Halbert, 1998). Task complexity has also been described as another factor to consider in decision making where more individuals will opt for simplifying decision heuristics (Payne *et al.*, 1992).

However, human information processing, from which the operations of decision-making and problem-solving arise, involves the reception of stimulus or multiple stimuli and the appropriate selection of a response (Wickens, 1984).

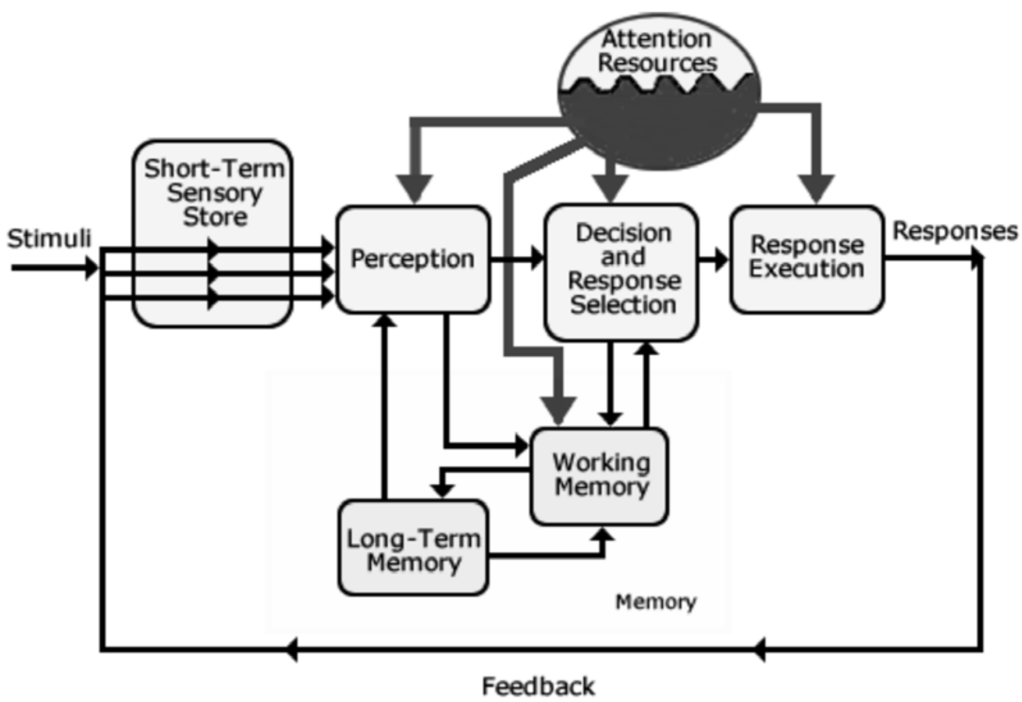

Figure 1. Wickens' Model of human information processing (taken from Wickens, 1984, page 12)

In this human information processing theory (see Figure 1), attention is regarded as a filtering process which selectively processes stimuli as they are received according to their importance (Jerome, 2007). Once processed, the information is matched with pre-existing information within memory, stored as either short or long-term memory or used to eventually select an appropriate response to the stimuli received (Wickens and Carswell, 1997).

In summary, cognition can be described as an integrated system of events involving internal information processing stages, leading to decision making and the execution of an appropriate response, but these processes are vulnerable to external environmental and non-personality factors. This study seeks to understand how exercise, as one of the external factors, impacts on cognitive performance over an extended duration.

2.3 Physical Exertion

Physical activity, exercise, and physical fitness are terms that describe different concepts in the same domain of physical exertion. Physical activity has been defined as any bodily movement produced by the contraction of skeletal muscles that increases energy expenditure above a basal level and enhances health. (Bouchard *et al.,* 1994; Nieman, 2010). Exercise, however, is a subcategory of physical activity that is planned, structured, repetitive, and purposive, in the sense that improvement or maintenance of physical fitness is an objective (Caspersen *et al.,* 1985). Lastly, fitness is the ability to perform moderate to vigorous levels of physical activity without undue fatigue and the capability of maintaining such ability throughout life, (ACSM, 1990).

Exercise falls into two general categories which are aerobic and anaerobic (Wayne, 2013). Aerobic exercise (also called cardiovascular exercise) is muscle movement that utilizes oxygen to burn carbohydrates and fats to produce energy, and examples of such activities are running, cycling and swimming where there’s a temporal increase in heart rate and respiration. Anaerobic exercise (also called resistance training) on the other hand, is muscle movement that does not require oxygen and only burns carbohydrates to produce energy, where typical examples are weightlifting and yoga, which build muscle and physical strength through short bursts of strenuous activity (Wayne, 2013).

Even though most exercise involves both dynamic and static contraction as well as aerobic and anaerobic metabolisms, current exercise testing procedures manifest a predominant dynamic-aerobic component (Fletcher, 2013). This is because aerobic exercise easily allows for evaluation of physical capacity, endurance and effort tolerance (Fletcher, 2013). Therefore, aerobic exercise was the preferred category of physical exertion chosen for this study seeing that the focus of the study was on the responses made during extended exercise duration, implying that endurance played a huge role in the exercise bouts.

Bushman (2011) recommended that aerobic exercise or workout should follow a consistent pattern to optimize safety as well as enjoyment. Thus, a three phase outline was given to guide aerobic exercise protocols. These stages are warm-up, endurance conditioning and the cool-down phase, as illustrated in Figure 2. The warm-up is the initial phase of the session which serves the purpose increasing the temperature of the muscles, thus preparing the body for the demands of the endurance conditioning phase which is the focal point of the workout (Bushman, 2011).

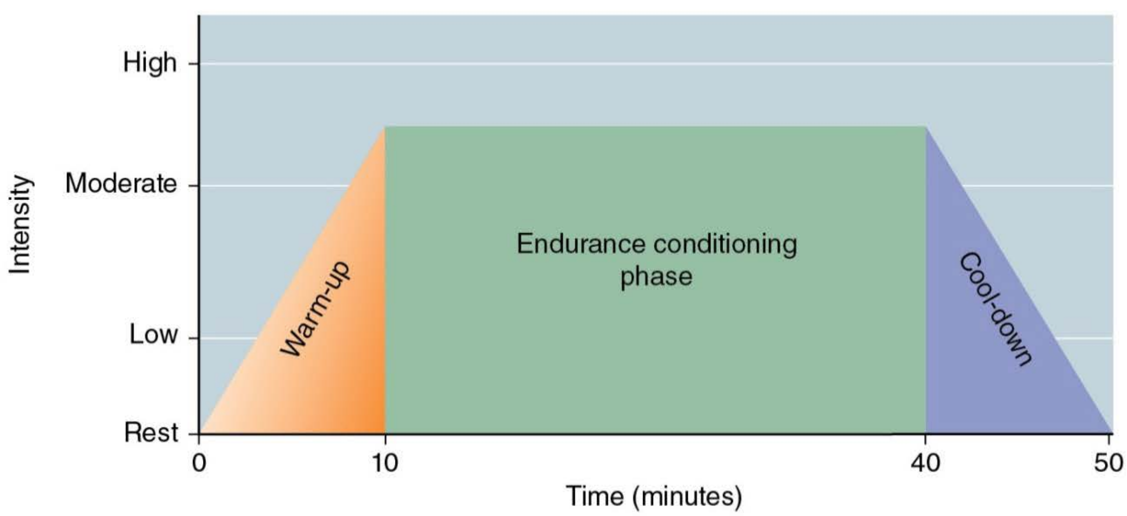

Figure 2. An outline of an aerobic exercise workout processing (taken from Bushman and Young, 2005, page 35)

The endurance conditioning phase for aerobic exercise is guided or defined by the FITT principle which is an acronym for frequency, intensity, time, and type (Bushman, 2011). Frequency refers to the number of times a week that exercise is conducted. Intensity reflects on how hard or how much effort is put into the exercise. Time is simply the duration of the exercise. And lastly, type or exercise mode focuses on the nature of the activities performed, i.e. those that involve large-muscle groups to improve cardiorespiratory fitness (Bushman, 2011).

The cooling down phase, also known as the recovery phase, serves the main purpose of normalization of physiological functions (e.g., blood pressure, cardiac cycle, heart rate and respiration rate), returning the body to homeostasis (resting cell environment, including body temperature), restoration of energy stores (blood glucose and muscle glycogen as well as clearing off of lactic acid which would accumulated in the muscles), and replenishment of cellular energy enzyme (Bishop *et al.,* 2008 and Jeffrey, 2005).

2.4 The Impact of Physical Exertion on Cognitive Performance

This section of the review of literature chapter looks at the research that has been done that is related to the scope of this study. Thus, the subtitles in this section serve the purpose of expounding on the studies that have linked exercise to response time, working memory, visual perception and processing speed; which are the main measures of performance in the current study.

There is a general perspective that has been established over the years from the various research conducted around the area of exercise and cognition. A review by Tomporowski and Ellis (1986) on several studies suggests that exercise has short term facilitation effects on mental tasks, but this relationship is indefinite. Long term regular physical activity has been associated with significantly better cognitive function and less cognition decline in the elderly (Weuve *et al.,* 2004).

However, a recent meta-analysis suggested that acute bouts of aerobic exercise in particular, are associated with a small but reliable positive effect on cognitive performance (Lambourne and Tomporowski, 2010). Hogervorst *et al. (*1996) also confirmed that exercise-related enhanced activation was responsible for better performance in psychomotor and cognitive tasks.

On the contrary, Themanson and Hillman (2006) looked at the effects of cardiorespiratory fitness and acute aerobic exercise on cognitive function as measured by the Eriksen flanker test (for response time and accuracy) using 28 higher- and lower-fit adults. Their protocol involved three phases: a post-rest (pre-exercise) cognitive assessment, a 30 minute treadmill exercise at 80% maximal heart rate (approximately 16 RPE) and a post-exercise cognitive assessment. The results showed that cardiorespiratory fitness, but not acute aerobic exercise, may be beneficial in cognitive processing and function (Themanson and Hillman, 2006).

Nevertheless, the exercise-induced arousal effects of cognitive performance are dependent on the following factors; the type of cognitive task being performed (memory or processing speed), the temporal sequencing of cognitive assessment in relation to exercise (following bout or during bout), and the mode of exercise performed (cycling or running), (Lambourne and Tomporowski, 2010). It is because of this that this study's protocol was specific to aerobic cycling exercise comparing the performance in working memory, processing speed and response time before, during and after the exercise bout. This was because acute moderate exercise differently affects some specific aspects of cognitive functions (Davranche and McMorris, 2009).

Cycling was thus, taken as an exceptional choice for this exercise testing procedure because it was associated with enhanced cognitive performance during and after exercise, whereas treadmill running caused impaired performance during exercise and a small improvement in cognitive performance post-exercise. (Lambourne & Tomporowski, 2010).

2.4.1 Effect of Aerobic Exercise Duration on Cognitive Performance

Pontifex *et al. (*2009) conducted a study that utilized both aerobic exercise and resistance exercise as the modes of physical exertion, with the objective of investigation how physical exertion impacts cognitive performance which was measured by the reaction time and accuracy of the participants. They observed from the results of their study that there were shorter reaction times soon after and 30mins after aerobic exercise (Pontifex *et al.,* 2009).

This ameliorating effect that exercise has on cognition however has a time limit. Even though sub-maximal aerobic exercise for up to 60 minutes in duration was associated with increasing information processing capabilities, bouts that extended more than 60 minutes resulted in dehydration, decrease in information processing and memory function of the subjects (Tomporowski, 2003).

2.4.2 Effect of Exercise on Specific Cognitive Performance Measures

Reaction Time and Visual Perception:

In studies looking at reaction time and exercise, reaction time results confirmed that performance is better and faster without change in accuracy when the cognitive task is performed simultaneously with exercise (Davranche and McMorris, 2009).

In another study which focused on aerobic exercise on simple reaction time, visual spatial memory, continual processing (attention), performance decreased after short-term maximal exercise but improved after exercise (Lo Bue-Estes *et al*., 2008). The researchers also found that working memory decreased during and increased after exercise (Lo Bue-Estes *et al*., 2008). Echols, (2006) likewise concluded from their studies that reaction time & working memory in males and females improves after aerobic exercise.

Yanagisawa *et al. (*2010) demonstrated that acute aerobic exercise increased cortical activation of the left dorsolateral prefrontal cortex during the Stroop task, a psychological test where the names of colors, for example ‘red’ or ‘black’ are printed in a color that is not denoted by the name itself. This measures processing speed, selective attention and visual search; and Yanagisawa *et al*. (2010) found that the enhanced activation in the prefrontal cortex corresponded with improved performance in the Stroop task. In addition McMorris and Graydon, (1997) showed that with regards to speed of search, speed of decision and accuracy of decision, performance was better during exercise than at rest for soccer players.

Working Memory and Information Processing:

Working memory was one of the measures of performance that was considered in this study, and it is interesting to note that when Ratey and Loehr, (2011) looked at the effects of exercise on cognition, they specifically found that physical activity beneficially influences mental organization (planning scheduling) and working memory.

Martins *et al. (*2013), in a study with 24 male athletes who performed PASAT (paced auditory serial addition task) while cycling at varying cadences, observed that cycling was associated with improved performance compared to rest when the stimuli were presented every two to three seconds whereas this effect was absent when stimuli were presented at a slower rate. They thus concluded that working memory can be improved by aerobic exercise performed at moderate intensities (Martins *et al.*, 2013).

Findings from Lambourne's published PhD thesis show that exercise-induced arousal improves cognitive performance on rapid decision making tasks by impacting basic sensorimotor processing during and soon after exercise, and in addition the residual arousal during the post-exercise phase also facilitates memory processes (Lambourne and Tomporowski, 2010).

2.5 Physiological mechanisms behind the effects of exercise on cognition

The theoretical perspectives and views on the acute exercise-cognition interaction explanation are based in cognitive psychology, cognitive neuroscience and psychophysiology (Audiffren, 2009). Research has revealed that exercise is associated with a reduction in physiological measures of stress and psychological measures such as anxiety and depression as well as with elevations in mood states and psychological well-being (Tomporowski, 2003). This has been confirmed by the psychological improvements observed in mentally challenged patients following physical fitness training (Folkins and Sine, 1981)

However, aerobic exercise does not only stop neuronal decline, but it incites a plethora of physiologically effects that facilitate improved cognition (Gligoroska and Manchevska, 2012). These effects include an increase cerebral fluid formation; increased neurotransmitter production; increases in angiogenesis (formation of new blood vessels from existing ones), synaptogenesis (formation of synapses between neurons in the nervous system) and neurogenesis (generation of new neurons from neural stem cells); increased heart rate which in turn increases oxygen uptake and availability to neural tissue; and increased production of the brain-derived neurotropic factor in the hippocampus which facilitates learning (Gligoroska and Manchevska, 2012; Davranche *et al.*, 2005; Jones, 1970; Ferris *et al.*, 2007; Bullock and Giesbrecht, 2014).

McMorris (2011) suggested that exercise is a stressor which increases in arousal levels as intensity increases. This leads to an inverted-U effect of exercise on cognitive performance (see Figure 3 below) which would be demonstrated by rest or low intensity exercise (low arousal) inducing poor cognitive performance, intermediate intensity exercise (optimal arousal) resulting in maximal performance and heavy exercise (high arousal) inducing poor cognitive functioning (McMorris *et. al,* 2011).

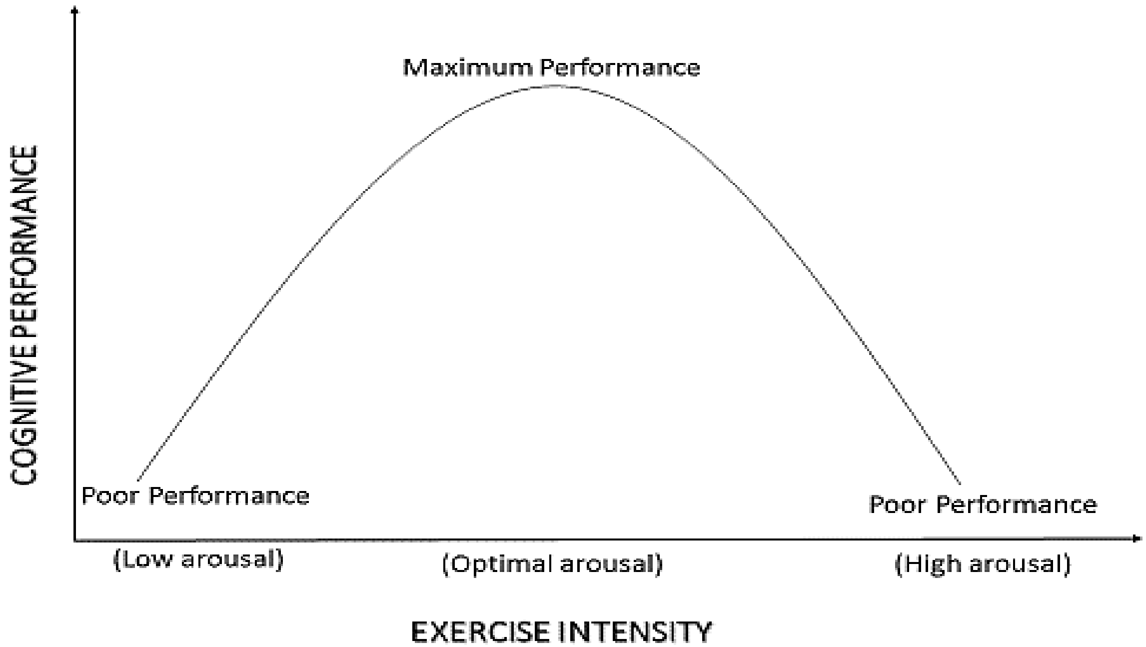

Figure 3. The inverted-U effect of exercise on cognition (as described by McMorris, 2011)

In this inverted-U theory, the arousing effects of exercise would be with intermediate intensity exercise causing increased sympatho-adrenal system and hypothalamic-pituitary-adrenal axis activity resulting in the increased brain concentrations of norepinephrine, dopamine, adrenocorticotropin hormone and cortisol (McMorris *et. al,* 2011 and Brisswatter *et al.*, 2002). This would result in optimal performance, while further increases during heavy or high intensity exercise would cause neural noise and hence poor performance (McMorris *et al.,* 2011).

CHAPTER 3

METHODOLOGY

3.1 General Experimental Concept

In order to investigate the nature of the relationship between aerobic exercise and cognitive performance, a repeated measures experimental design was adopted, where the same sample of participants came to the Ergonomics laboratory for three visits where they participated in an initial habituation session, followed by two separate sessions where they exercised at different intensities while attempting a set of cognitive tasks. Thus, their cognitive performance was compared between the instances when they exerted physically while exercising at moderate to high intensity as compared to when they were exercising at nil to minimal physical exertion. This protocol was guided by a recommendation made by Brisswatter *et al. (*2002) that the main methodological factors to control in exploring physical exertion and cognitive performance should be the nature of the psychological task and the intensity and duration of the exercise. It was through this that a response to the research question was made, as to the nature and extent of the impact that physical exertion has on cognitive performance.

3.2 Research Hypotheses

The hypothesis proposed for this study was that cognitive performance will be better during the aerobic exercise bout at moderate to high intensity than when exercise was at nil to minimal intensity, as a result of acute aerobic exercise playing a role in improving cognition.

As such, three hypotheses were derived from this, which are;

Hypothesis 1: Cognitive performance and physiological responses will be different for the moderate to high intensity exercise condition and the nil to minimal intensity exercise condition.

Alternative Hypothesis	H_1: $\mu AE_1 = \Delta\mu CP$; $\mu AE_2 \neq \Delta\mu CP$
Null Hypothesis	H_0: $\mu AE1 = \mu CP$; $\mu AE2 = \mu CP$

Where:

AE_1 – moderate to high intensity aerobic exercise;

AE_2 – nil to minimal intensity aerobic exercise,

ΔCP – change in cognitive performance.

CP – cognitive performance

Hypothesis 2: Cognitive performance and physiological responses will change over time between the pre-exercise and post-exercise phases; and during the exercise phase.

Alternative Hypothesis H_1: $\mu PE = \mu \Delta CP$ (Pre-Post) $= \mu \Delta CP$ (During)

Null Hypothesis H_0: $\mu PE = \mu CP$ (Pre-Post) $= \mu CP$ (During)

Where:

PE – physical exertion;

ΔCP – change in cognitive performance;

CP – cognitive performance;

Pre-Post – comparison of responses between the pre- and post-exercise phases; During – responses from during the exercise phase.

Hypothesis 3: The change in cognitive and physiological responses over the course of exercise will be different for the moderate to high intensity exercise condition and the nil to minimal intensity exercise condition.

Alternative Hypothesis H_1: $\mu PE = \mu \Delta CP_t$,

Null Hypothesis $H_{0:}$ $\mu PE = \mu CP_t$.

Where:

PE – physical exertion;

ΔCP_t – change in cognitive performance over the course of exercise.

CP – cognitive performance.

3.3 Conditions

The independent variables that were considered include the two experimental conditions used in the study which are the cycling with load and the cycling with no load conditions.

Cycling was used for testing as it is the safer and more convenient of the two recommended protocols of cardiopulmonary exercise testing i.e. treadmill and cycle ergometer (Weisman and Zeballos, 2002). Both articles by Weisman and Zeballos (2002) and Casaburi *et al. (*2003) recognize the cycle ergometer and the treadmill as the two modes of exercise commonly employed in cardiopulmonary exercise tests. However, the cycle ergometer was selected for this study over the treadmill because it is much safer for the participants and allows for easier data collection seeing that participants were multitasking between cognitive tasks and the cycling exercise, hence a seated posture with minimal head movement during the exercise bouts was the most preferred posture. The cycle ergometer also has less instrumental noise to limit auditory stimuli that could have affected the participants' concentration and cognitive responses, and it requires less space to enable a simpler setup with the incorporation of the platform for the cognitive testing instrumentation (Weisman and Zeballos, 2002; Casaburi *et al.*, 2003 and Nieman, 2010).

Furthermore, the cycle ergometer enabled the participants to multitask the cycling and the cognitive tasks while they were in the same position for subjective and physiological measures to be recorded easily, as opposed to the challenges that would be anticipated in an actual work environment setup. These challenges would include mobility of the participants in the work environment that would interfere with them performing the cognitive task; the time it would take them to be physically exhausted in that environment; among others.

The cycling load that was used was 60% of the pre-determined Maximum Aerobic Power for each participant (Lepers *et al.,* 2001). This load was relative to each participant according to their physical capabilities as determined by the Maximum

Aerobic Power test. It was also confirmed through pilot testing that at 60% of this pre-determined MAP, participants will be experiencing psychophysiological signs of early onset of physical fatigue in approximately 50 minutes but not extreme exhaustion at that stage.

Due to a lack of literature available to support the exercise intensity (cycling load and cadence) and duration required for this type of submaximal test, a pilot study was conducted. In this pilot study (conducted on the researcher himself as well as on a class mate), different intensities of cycling loads were used at different cadences to determine an intensity where participants are able to cycle for a duration that allows for sufficient cognitive test cycles. This intensity also allowed the participants to adequately exert themselves physically so that, if physical exertion affects cognitive performance, the change in cognitive performance could thus be measured. See Appendix A5 for the pilot test results.

The intensity consisting of a cadence range of 80 to 90rpm and cycling load of 60% of MAP was eventually chosen due its 50 minute duration that allows for up to 5 cognitive test batteries (each lasting 8 minutes) to be conducted and used for determining the progressive changes in cognitive performance during the exercise session.

The second experimental condition used in the study was the unloaded cycling one which was regarded as the control condition to compare and verify whether the changes in cognitive performance, if any, were entirely because of the participants' physical exertion and not a learning effect with time. Unloaded cycling implies to cycling with no load on the cycle ergometer (Weisman and Zeballos, 2002 and Weisman, 2003).

3.4 Dependent Variables

3.4.1 Cognitive Performance

The measures of cognitive performance that were considered in this study are visual perceptual, working memory and sensory-motor responses. These measures were specifically selected due to their link with the resources required for proper task execution as illustrated in Figure 4 below (Ngcamu and Göbel, 2011). The model of human information processing by Wickens (1984) gives off a conceptualization that after stimuli is received by the human body, a series of processes and stages then follow before a response can be given. These processes include perception of the stimulus linked to long term memory for the identification of the stimuli, then decision and response selection also linked to working memory which then processes the information and aids in the correct selection of a response which is the final stage in the processing chain (Wickens, 1984).

This model of information processing by Wickens (1984) forms the basis for the three measures of cognitive performance in this study, as they address the three main processing stages involved in task execution, namely 1) sensory perception, 2) cognitive processing, and 3) motor programing.

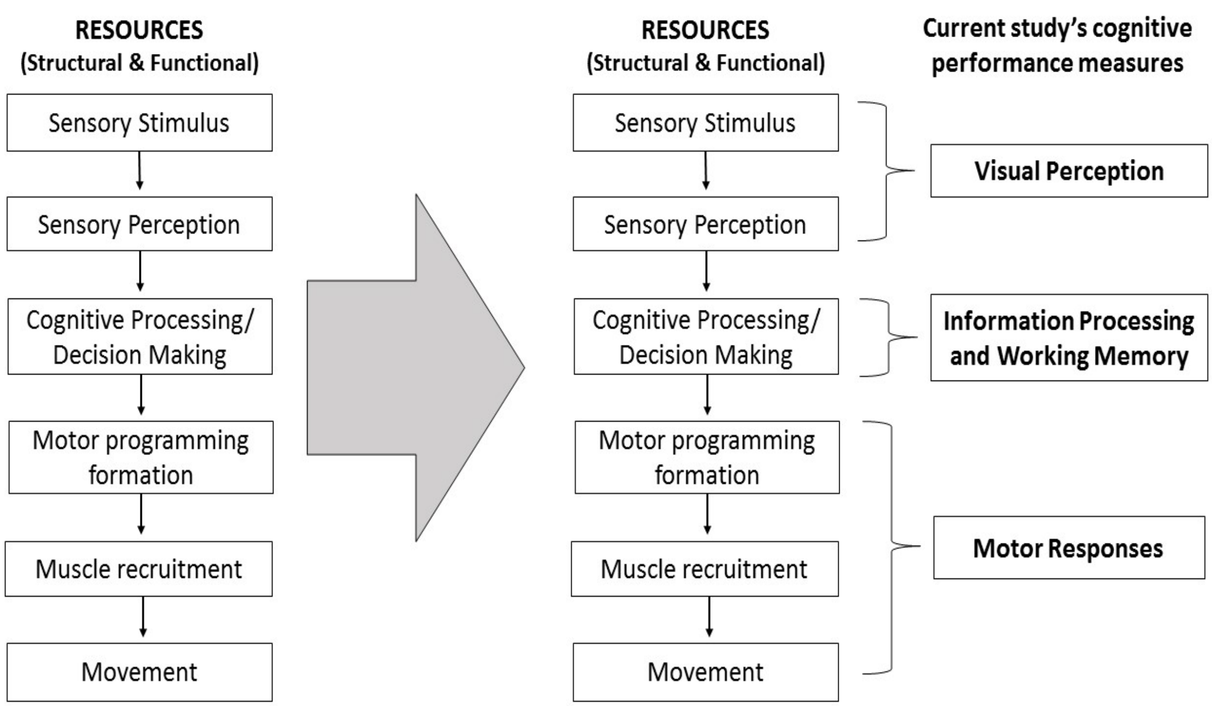

Figure 4. Left: The outline of resource contribution to specific task execution, Right: The link between cognitive task performance components and the cognitive performance measures (Ngcamu and Göbel, 2011, page I-299)

The performance of these cognitive parameters (i.e. visual perception, working memory and motor responses) were measured separately, and this was done differentially in order to assess the individual changes in each parameter.

However, decision making as a cognitive performance measure was not included in this approach because it is very dependent on the participants' prior knowledge, thus making it hard to control. Also success in decision making tasks is difficult to measure and compare across the participants.

1. Visual Perception Responses

For the visual perception parameter, a proof reading task was used as this task has been stated to be a representative of object recognition with cognitive processing (Goble, 2012). In addition, it exclusively utilizes the vision sense with no auditory stimulation required, thus increasing the chances of effectively obtaining an accurate visual perception performance measure. High and low resolutions readings were considered as the two levels of complexity (see Figure 5). In this task, the reading speed (words/minute) and the error detection rate (number of errors identified/total errors present in the read section) were used as measures of performance (Goble, 2012). The errors in the passages were in form misspellings with double-letters for words that do not have double letters (see Figure 5 below).

A. HIGH RESOLUTION PASSAGE EXTRACT:

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

B. LOW RESOLUTION PASSAGE EXTRACT:

Pistorius reacheed the semifinals of the 400 metres at the Olympics, but the effect he had on the crowd and the future of organised sport was out of all proopportion to that relatively modest achievement. As Pistorius, drraped in the South African flag, thanked the crowd, few among them would have been aware of how much bureaucracy he had waded through to represennt his country at the London Games.

Figure 5. An illustration of high and low resolution passages that were used in the proof reading task (the red circles indicate the location of the double-lettered words)

2. Working (Short-term) Memory Responses

A memory recall or digital span task was used to explore the working memory parameter. The task which is presented by the PEBL software (see Figure 6 below), utilizes a memory recall (digital span) with two levels of difficulty presented by number sets with 5 digits and others with 7 digits to evaluate the cognition capacity during physical activity. The measure of performance that was considered was the recall success rate (% correct) (Goble, 2012).

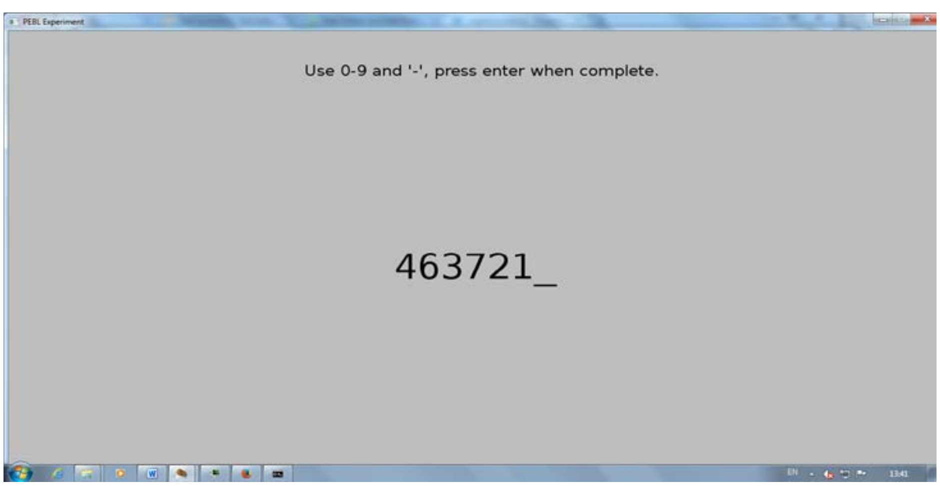

Figure 6. An image exemplifying the PEBL (Psychology Experiment Building Language) software interface that generated the 5 and 7 digits in the memory recall tasks

3. Motor Responses

Under motor responses, a modified Fitts' test (Fitts, 1954) was used to analyze motor pattern recruitment and precision of movement (Goble, 2012). This task was chosen mainly for its ability to provide measures for many motor output parameters (Goble, 2012), while participants perform physical activity (see Figure **7**). Response time (milliseconds) and target deviation (millimeters) were the measures of performance in this task.

Figure 7. An image showing a participant performing the modified Fitts' task while cycling on an ergometer

3.4.2 Physiological responses

Physiologically parameters were the second set of dependent variables where heart rate was measured and analyzed all throughout the experimental sessions, as an indicator of physical exertion during the testing sessions. Polar heart rate monitors (see

Figure 8 below**Error! Reference source not found.**) were used to measure heart rate mainly because they enable minute by minute heart rate measurements all throughout the experimental sessions.

Figure 8. An illustration of the heart rate monitor that was used in this study. (Left: heart rate belt or chest strap with a wireless transmitter; Right: wrist watch receiver with a digital display)

3.4.3 Subjective Performance

The third set of dependent variables that was considered was subjective measures i.e. the Rating of Perceived Exertion (RPE) Scale (See Appendix A4). The RPE scale ranges from 6 to 20 with increasing intensity of the perception of exhaustion, 6 being the lowest and 20 being the highest (Borg, 1998).

3.5 Controlled Variables

1. Exercise Intensity

Exercise intensity was controlled by having the participants cycle at a cadence range of 80 to 90 rpm and cycling resistance of 60% of each individual's Maximum Aerobic Power (Englund *et al.,* 1985). This cycling protocol has been confirmed, through pilot testing (see subheading 3.2.1 on Independent Variables), to exert participants physically after attempting at least 5 cognitive tests in the cycling session that took an average of 50 minutes. In addition, a constant load of 60% of each individual's subjective maximum aerobic power was most preferred seeing that Martins *et al. (*2013) found that varying exercise intensity while participants were cycling was a limitation in their study where this feature in the experimental design may have distracted participants from the cognitive task performance.

2. Exercise Duration

The sessions or exercise durations were controlled. Through pilot testing it was confirmed that in approximately 50 minutes at least 5 cognitive tests could be conducted during the experimental session, with a 10minute interval between the commencements of each test. In addition, more positive effects of aerobic exercise have been observed for exercise bouts that are longer than 20 minutes (Chang *et al.,* 2012).

3. Fitness Levels

Average body fitness was controlled by utilizing participants who engage in regular moderate intensity aerobic exercise, i.e. those who cycle (spinning) 3-5 days a week and those who satisfy the requirements of the Physical Activity Readiness Questionnaire (PAR-Q+) (Warburton *et. al*., 2011), see Appendix A3. Thus, this ensured that the individuals who participated in the study were of relatively the same fitness level. This is because a negative effect has been observed in participants with lower fitness as they need more resources when conducting exercise and fewer resources available for cognitive performance (Chang *et al.,* 2012). Aerobic exercise is thus recorded to be beneficial to cognitive performance more for the participants who are physically fit (Tomporowski and Ellis, 1986; Cbang *et al.,* 2012).

4. Time of Day

Time of day effect was reduced by ensuring that all testing was done during the day, between 12pm and 5pm. Both papers by Dalton *et al. (*1997) and Atkinson and Bardis (2008) confirm that although body temperature does increase between a morning and an afternoon session, total work done and average power output changes remain insignificant during a cycling exercise. However, the changes in body temperature have hypothalamic influence on cognition, hence testing in this study was limited to the daytime period during which there are insignificant changes in body temperature (Blatter and Cajochen, 2007).

3.6 Sample Selection Criteria

A convenience sampling method was used to obtain participants from the Rhodes University Health suite population group, largely constituting of students.

3.6.1 Inclusion

Bulletin posters and email were used to advertise the study and attract the attention of volunteers. 12 males and 12 females, aged between 18 and 24 years, were then selected for the study. These were individuals who participate in the Health Suite spinning class on a regular basis (3-5 days a week). Sex was considered as co-variant in the data analysis.

The age range of 18-24 was chosen because according to Pase *et al. (*2010) different age groups (young, middle-aged, and elderly adults) have different responses to physical activity on cognitive performance. In addition, age is classified as one of the potentially influencing factors on physiological responses to exercise, were a decrease in maximal heart rate with increasing age has been observed (Arena *et al.*, 2008). Therefore, for this study, the young adults age group of 18-24 years (Asamoah *et al.,* 2013) was chosen due to the nature of the exercise testing. Furthermore, a low risk of complications has been associated with young age (Arena *et al.*, 2008).

The Physical Activity Readiness Questionnaire for Everyone (Warburton *et al.*, 2011) was used to assess if it was safe for each participant to go through the study which mainly consists of moderate physical exercise. The questionnaire is composed of seven yes or no questions, where a positive response (yes) to any of the questions will cause the exclusion of that participant from the study (Warburton *et al.*, 2011).

3.6.2 Exclusion

Individuals who were not physically active, chain or frequent smokers, and those who ingested alcohol or any caffeinated drink 24 hours prior to the testing were excluded from the study. Also part of the exclusion list were those who gave a positive response to any of the questions in the Physical Activity Readiness Questionnaire for Everyone, seeing that an positive response indicates high risk from that participant as they would most likely have a serious cardiopulmonary, metabolic or musculoskeletal condition. Likewise individuals with any musculoskeletal injuries or deformities were excluded, to limit the study sample to only able bodied individuals.

3.7 Testing Setup

1. Cycle ergometer:

A cycle ergometer (see Figure 9) was used as it was the most preferable and appropriate testing equipment of choice for this type of cardiopulmonary exercise testing (refer to section 3.3 on Condition for the literature justification for the use of the cycle ergometer over other cardiopulmonary testing equipment).

Figure 9. The cycle ergometer that was used in this study

2. Test Platform Setup:

Part of the equipment included a platform (see **Figure 10**) which hosted the test equipment for measuring cognitive performance. This platform consisted of a touch screen monitor which acted as both an input and output device for the participants as they performed the cognitive tasks and an elevated platform upon which the touch screen monitor was placed. The monitor was connected to a laptop computer from which the software for the cognitive tasks was run, as well as the collected data saved. The software included: PEBL Launcher for PEBL Version 0.13 for the Memory Recall task, the Stimulus-Response Test Version 2.3 for the Modified Fitts' test and the Foxit PDF Reader Version 6.06 for the proof reading task.

Figure 10. An illustration of the testing setup showing a participant on a cycle ergometer, with the touch screen monitor presenting the cognitive tasks in front of her, and the researcher on the right operating the laptop with the software tests and overall overseeing the entire experimental protocol

3.8 Experimental Procedure

Testing was conducted in three sessions; habituation, cycling with load and cycling with no load. As such, the participants were required to come to the HKE department thrice.

3.8.1 Habituation Session

All testing session was conducted in the HKE Ergonomics laboratory where a testing station was set up for all data collection procedures. During the habituation session, the researcher fully explained the purpose of the study plus the entire procedure to the participant who was allowed to ask any questions to clarify their role in the study. Thereafter the participant was asked to fill out a questionnaire (See Appendix A3) to confirm that they satisfied the selection criteria. They also signed a consent form (See Appendix A2) to show that they fully understood their participation and also to give permission for the use of their data and personal information in the study.

While in this session, a heart rate monitor was used to monitor heart rate measures. The transmitter was strapped to the participant's chest just below the xiphoid process and the receiver was held by the experimenter. The cycle ergometer was adjusted for each participant relative to the ideal seat height where the knee angle is between 5 and 15° of flexion when the foot presses the pedal to the bottom of its stroke (Cooper and Storer, 2001). The handle bar was also adjusted relative to the position of the trunk and arms for safety purposes (Pina *et al.,* 1995). Both seat height and bar handle measurements were recorded appropriately for use when the respective participant came later for the testing sessions.

The participant was then requested to pedal at a self-paced speed while they try out each of the cognitive tasks to familiarize themselves with the procedure. This they did till they felt they were well accustomed to the study's procedure as well as what was required of them during the two testing sessions.

A Maximal Aerobic Power (MAP) determination test was then carried out to determine the participants' individual physical capabilities. The test protocol was preceded by 5 minutes of unloaded pedaling as warm up. The load was then increased to 125W for 5 minutes. After this, the resistance was increased by 25W every minute up until volitional exhaustion, i.e. the point at which the participants felt they could not cycle any further (Deakin *et al.,* 2011). The highest power output reached in this test bout was recorded as the MAP for that particular participant (Lepers *et al.,* 2001). To end the test, the participant were allowed 10 minutes of unloaded pedaling to cool down from the exercise and water was also be provided to replenish fluids at this stage (Weisman, 2002).The MAP recorded in this session was later used for determining each participant's level of resistance during the cycling with load session.

At this point, they were allowed to leave the HKE laboratory facilities after scheduling two separate dates for the cycling with load and cycling with no load sessions.

3.8.2 Cycling with load Session

Preparation:

In this session a brief run-down of the procedure was given by the researcher to remind the participant about what to expect, after which the heart rate monitor was attached onto their upper abdominal region and a baseline reading taken down. They then sat on the cycle ergometer which was adjusted to their specific measurements. Thereafter, a pre-exercise cognitive testing was initiated as they started cycling freely with no resistance. A recording of their subjective measures (RPE score) was also made at this stage. A stop-clock was started simultaneously to the commencement of this pre-exercise cognitive testing, which was used to mark 10 minute intervals to determine when the subsequent cognitive tests were then conducted up until the end of the testing session (which was the end of the 10 minute post-exercise phase).

Test:

The participant was given 10 minutes of unloaded pedaling during which a pre-test cognitive test was administered. After which the workload was increased to 60% of their MAP that was pre-determined in the habituation session (Lepers *et al.,* 2001). The participant was also requested to keep their cadence between 80 and 90 rpm (revolutions per minute) all through the exercise session.

At this intensity or workload the participants continued cycling with their cognitive performance and subjective measures assessed every 10 minutes for a set duration of 50 minutes. This duration was to allow for adequate physical exertion of the participants. However, the participants were given the liberty to request for termination of this loaded phase of the cycling with load session due to volitional exhaustion, this being the point when the participant felt they could not proceed any further (Pitcher and Miles, 1997). Alternatively, termination was to be considered after getting a RPE score of 18 and above (Deakin *et al.,* 2011 and Lepers *et al.,* 2001) or a heart rate reading above 90% of the age predictive heart rate maximum (Weisman, 2002; Whitman, 2009; and Bushman, 2011). In the event of any termination occurring, the data recorded was to be assumed void and thus not used in the study.

At the end of 50 minutes the cycling resistance was removed and the participant was requested to continue pedaling with no load during the recovery period. A post-exercise cognitive performance test was then conducted during this 10 minute recovery period at the end of which the session was concluded. The heart rate monitor was then removed from the participant before they left the laboratory.

Criteria for Termination of Exercise Session:

The following was the criteria for termination of the exercise test for the sole purpose of participant safety; chest pain, sudden pallor, loss of coordination, mental confusion, dizziness or faintness and a heart rate of above 90% of the age predicted maximum heart rate (Weisman, 2002; Whitman, 2009; and Bushman, 2011). A request by the participant to stop was also part of this termination criterion, as well as a RPE score of more than 18 (Deakin *et al.*, 2011).

3.8.3 Cycling with no load Session

In this session the participants came to the HKE department and were shown to the Ergonomics laboratory where they had the cycling with no load protocol explained to them before a heart rate monitor was attached to their upper abdominal or lower thoracic region. Thereafter, they were requested to mount the cycle ergometer where they completed a continuous 70 minutes of unloaded cycling bout. This duration was equivalent to the summation of the pre-exercise or warm-up phase (10 minutes), loaded cycling phase (50 minutes) and post-exercise or recovery phase (10 minutes) in the cycling with load condition. Cognitive performance tests were administered every 10 minutes for the duration of the session, after which the participant stopped pedaling and demounted the cycle ergometer to mark the end of the cycling with no load session.

3.9 Data Reduction and Analysis

Cognitive performance data were extracted from the PEBL and Stimulus-Response software, including the notepad records for the proof reading task, and summarized in Microsoft excel spreadsheets as tables and line graph plots. This data, together with the psycho-physiological data, was then be imported into STATISTICA data analysis software where measures of analysis of variance (ANOVAs) were run across each variable to check for statistical significance in the each conditional category that was considered. These categories include the analysis for the entire exercise duration, for during the loaded cycling phase and comparison for the pre-and post-exercise phases.

The outcomes of the aforementioned analyses and summaries were presented in Chapter 4, the results section.

CHAPTER 4

RESULTS

4.1 Results Overview

This chapter presents the data collected from the experimental procedure that aimed to study the impact of acute aerobic exercise on cognitive performance, where 24 volunteers cycled on an ergometer in 2 bouts, one at moderate intensity and the other at very low intensity, while their responses to three cognitive tasks were assessed every 10 minutes. The data is presented in two categories;

- Physiological and subjective response data
- Cognitive performance data.

In each category, the data was further divided into;

- Descriptive Statistics.
- Inferential Statistics.

Descriptive statistics presents all the collected data summarized as means with standard deviation error bars, using the Microsoft Excel software for the psychophysiological responses and the STATISTICA software for the cognitive performance data. Inferential statistics then enabled conclusions to be drawn from the data after statistical analyses using the STATISTICA StaSoft ver10.0 software.

In the inferential statistics category, three analyses were run for each variable namely;

- Analysis over the entire cycling duration
- Before and after the loaded-cycling phase analysis and,
- Loaded-cycling phase analysis.

In the analysis over the entire cycling duration, all the response data for each variable across all time intervals in the cycling conditions were considered. This gave the overview of how responses for each variable changed over time in relation to the changes in conditions from the warm-up through to the cool-down phases.

In the before and after loaded-cycling phase analysis, the aim was to check for changes in performance that could have been a result of the increased resistance or workload in the loaded-cycling phase. Hence the analysis looked at the differences in responses between the two time intervals that corresponded to the warm-up and the cool-down phases.

Lastly the purpose for the loaded-cycling phase analysis was to investigate for changes in each variable's responses during the time lag when the pre-determined resistance was applied to the cycling (this being the same time intervals for the cycling with no load condition though with no resistance to the cycling). This was done to check any significant differences existed in responses (both psychophysiological and cognitive) within this loaded-cycling phase that could then be credited to the constant cycling load (60% of each participant's maximum aerobic power) that contributed as the physical strain in the experiment.

It is of importance to note that the analysis over the entire cycling duration, which considers all the responses given over the entire duration of the two exercise conditions, does not relay much information about the change in psychophysiological responses (heart rate and RPE) due to the fact that these measures map out a steady state where the responses given quickly reach a plateau after the cycling load is introduced, and drop soon after the load is removed. As such, the entire cycling duration analyses for both heart rate and RPE were not included in this chapter, however they were included in the Appendix section (see Appendix B). The summary of the responses given for both heart rate and RPE throughout the exercise bouts was instead presented as descriptive statistics in form of Excel graphs (see the introductory section for each measure, i.e. heart rate and RPE). The analyses considered in the inferential statistics section for heart rate and RPE were the before and after the loaded-cycling phase analysis and the loaded-cycling phase analysis. (See the Appendix B1 and B2 to view the analyses over the entire cycling duration for heart rate and RPE)

All the variables were analyzed with sex as a covariant but no statistical significance was found, hence all data with sex as a covariant were omitted in this chapter (to view this data see Appendix D).

4.2 Physiological and Subjective responses

This subdivision represents the physical responses of the participants as they went through the experimental conditions. As such, it comprises of Heart Rate and RPE (rate of perceived exertion) data.

4.2.1 Heart Rate Data

Heart rate responses were recorded from the polar heart rate monitors that were attached on the participants every 2 minutes for the entire duration of the experimental conditions.

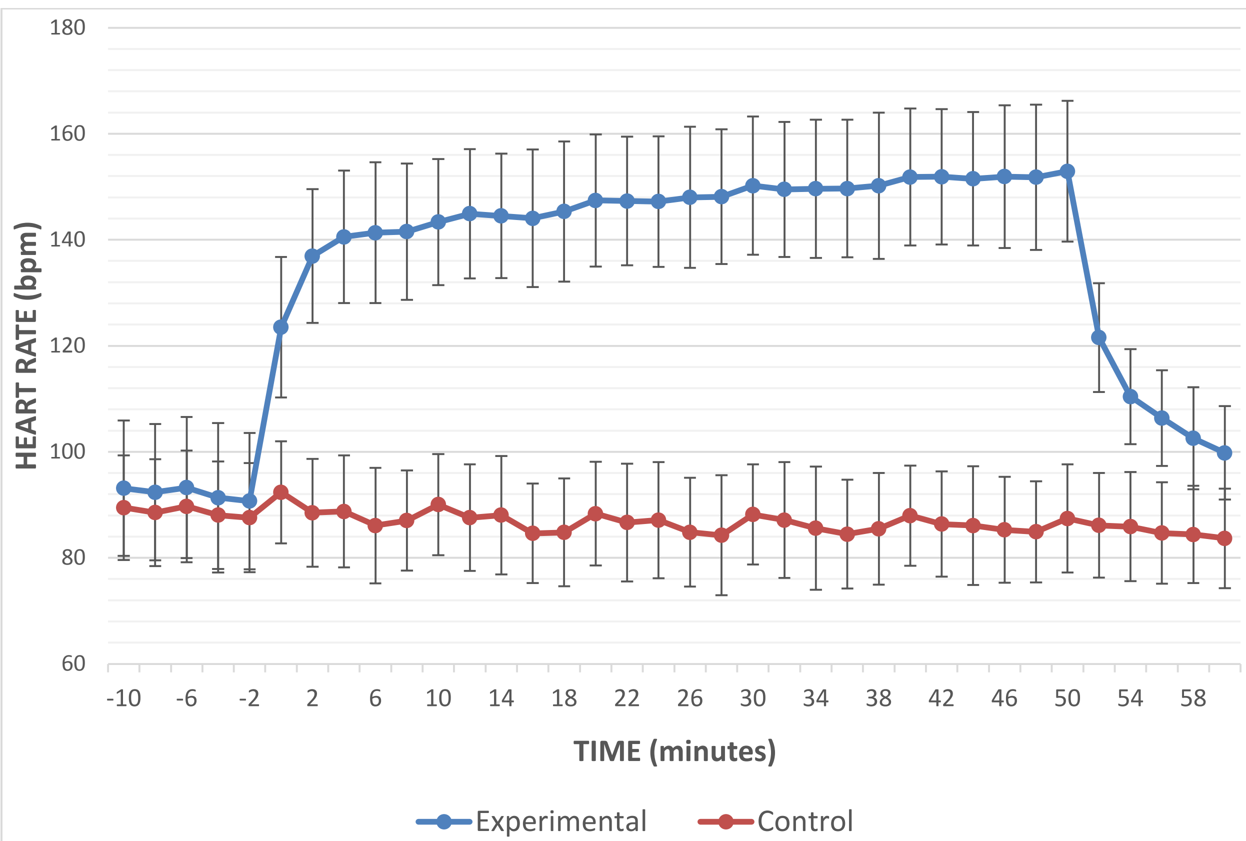

Figure 11. Heart rate responses for both the Cycling with load (experimental) and the Cycling with no load (control) conditions across the time intervals. The period between -10 and 0 minutes represents the warm-up phase, where the 0

minute mark is where the load was introduced. (Error bars depict standard deviations).

Figure 11 lays out the mean heart rate responses of all the participants for the entire duration of both the cycling with load and cycling with no load conditions. The time phase from -10 to 0 minutes was the warm-up period where in both conditions the cycling was with no load. A sharp rise in heart rate can be observed in the cycling with load condition from the 0th minute which marks the point at which the pre-determined resistance (60% of the Maximum Aerobic Output) is added to the cycling. The heart rate, however, plateaus at around 140bpm, with a gradual increase to 152bpm at the 50th minute where the resistance in removed, hence a sharp drop observed in the recovery phase from the 50th to the 60th minute of the cycling with load condition. The cycling with no load (unloaded-cycling) condition exhibits a generally steady and constant heart rate that gradually drops from the initial 89bpm to 83bpm at the end of the condition.

4.2.1.1 Heart rate ANOVA for intervals before and after the loaded-cycling phase.

Table I highlights the analysis of variance results for heart rate responses during both conditions (cycling with load and cycling with no load), for the before and after intervals, representing the warm-up and cool-down phases, respectively. Statistical significance ($p<0.05$) was observed between conditions; between the before and after intervals; and between the conditions and the before and after intervals.

Table I. Repeated measures analysis of variance for heart rate responses (For the intervals before and after the loaded-cycling phase, where the asterisk* highlights statistical significance).

Effect	Degree of Freedom	F	p
CONDITIONS	1, 23	109.608	<0.01*
INTERVALS	1, 23	47.027	<0.01*
CONDITIONS*INTERVALS	1, 23	73.384	<0.01*

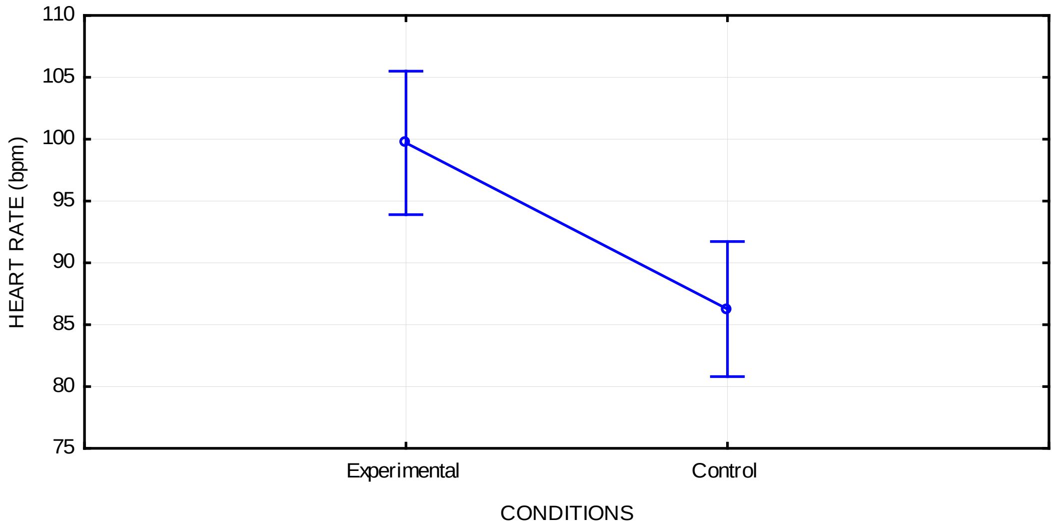

Figure 12. Heart rate ANOVA for the intervals before and after the loaded-cycling phase between the cycling with load (experimental) and cycling with no load conditions (control). (Error bars depict 95% confidence intervals).

Figure 12 illustrates the analysis of variance for the before and after heart rate responses between the cycling with load and cycling with no load conditions, where there is a higher heart rate reading in the cycling with load condition than in the cycling with no load. Statistical significance of ($p<0.01$) was observed between the conditions.

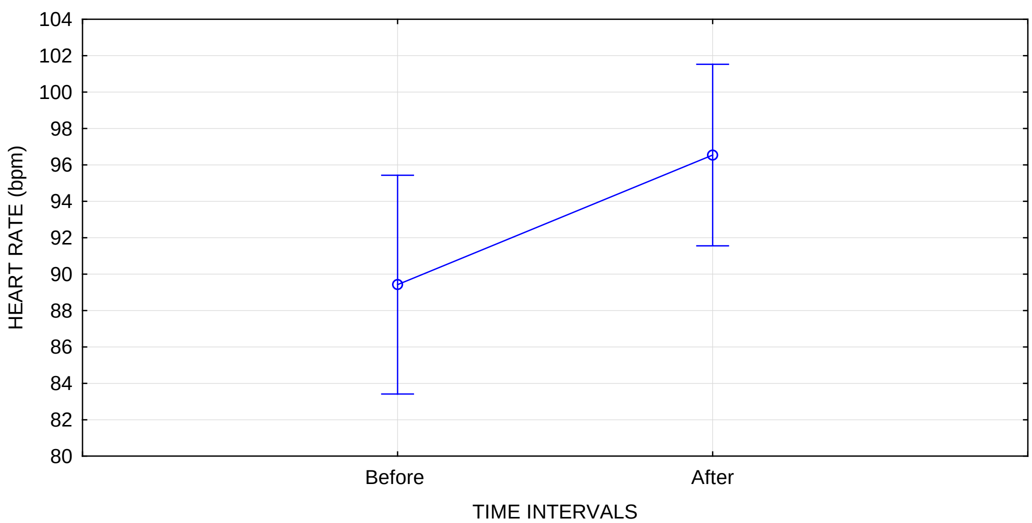

Figure 13. Heart rate ANOVA for the intervals before and after the loaded-cycling phase. (Error bars depict 95% confidence intervals).

Figure 13 shows the analysis of variance for heart rate responses between the before and after intervals, representing the warm-up and cool-down (recovery) phases of the experimental conditions, which shows that the warm-up phase had a lower heart rate reading of 89 rpm than the cool-down phase that had a reading of 97 rpm. Statistical significance was observed at ($p<0.01$).

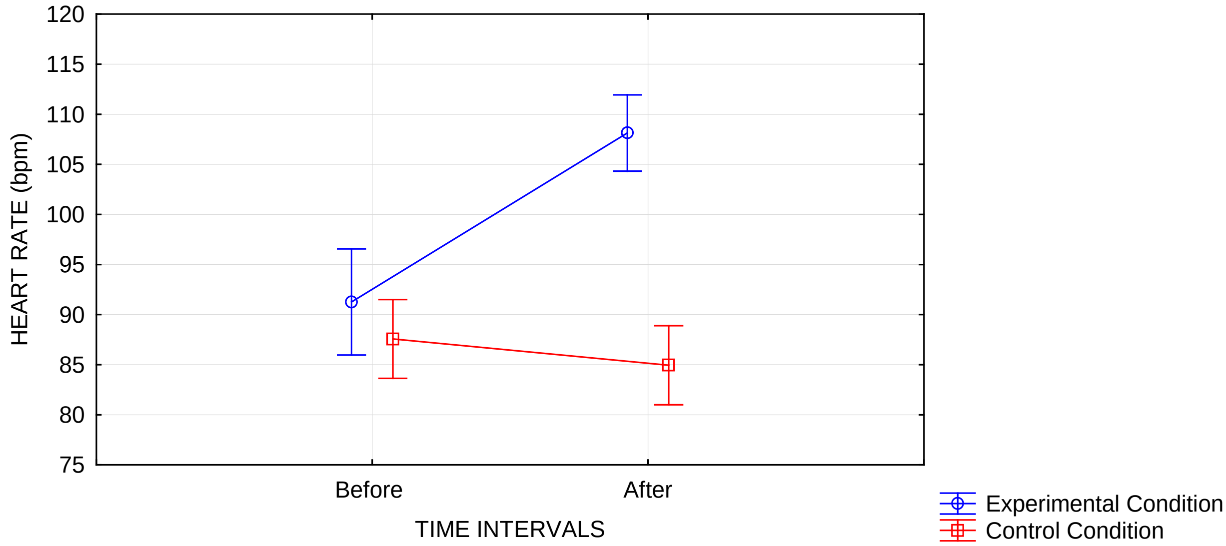

Figure 14. Heart rate ANOVA for the intervals before and after the loaded-cycling phase between conditions and time intervals, where the experimental condition was one with cycling load and control the one with no load. (Error bars depict 95% confidence intervals).

Figure 14 shows the analysis of variance for heart rate responses between conditions (cycling with load and cycling with no load) and the time intervals (before and after). The cycling with no load condition had a drop in heart rate readings between the before and after intervals, and yet there was an increase for the after interval from a lower before interval in the cycling with load condition. Statistical significance was observed ($p<0.01$).

4.2.1.2 Heart rate ANOVA for the period during the loaded cycling phase.

Table II outlines the analysis of variance for heart rate responses for the periods (in both the cycling with load and cycling with no load conditions) analogous to the loaded cycling phase in the cycling with load condition corresponding to the 5 time intervals between the warm-up and the cool-down. Statistical significance ($p<0.05$) was observed between conditions; across intervals; and between the conditions and the before and after intervals.

Table II. Repeated measures analysis of variance for heart rate responses (For the intervals during the loaded-cycling phase, where the asterisk* highlights statistical significance).

Effect	Degree of Freedom	F	p
CONDITIONS	1, 23	696.779	<0.01*
INTERVALS	4, 92	19.061	<0.01*
CONDITIONS*INTERVALS	4, 92	52.045	<0.01*

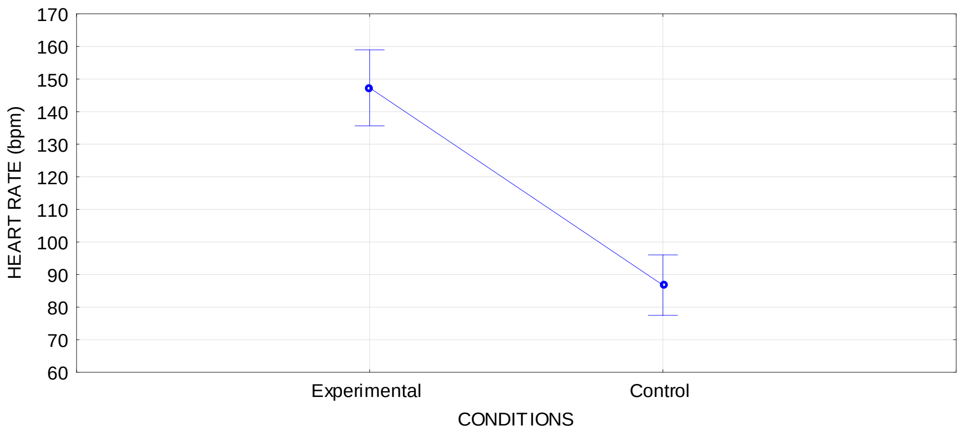

Figure 15. Heart rate ANOVA for the intervals during the loaded-cycling phase between the cycling with load (experimental) and cycling with no load (control) conditions. (Error bars depict 95% confidence intervals).

Figure 15 explicates the analysis of variance for heart rate responses during the loaded-cycling phase between the cycling with load and cycling with no load conditions, where the cycling with no load condition had a lower heart rate than the cycling with load condition. Statistical significance was observed ($p<0.01$) between the conditions.

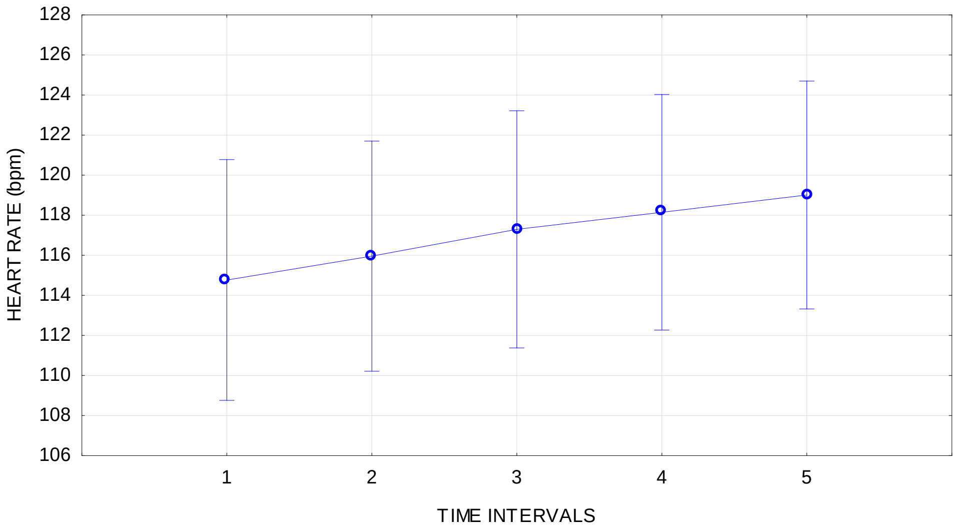

Figure 16. Heart rate ANOVA for the intervals during the loaded-cycling phase across the time intervals. (Error bars depict 95% confidence intervals).

Figure 16 outlines the analysis of variance for heart rate responses during the loaded cycling phase across the 5 time intervals between the warm-up and cool-down. A gradual increase in heart rate is observed from the first to the fifth interval. Statistical significance ($p<0.01$) was observed across the time intervals.

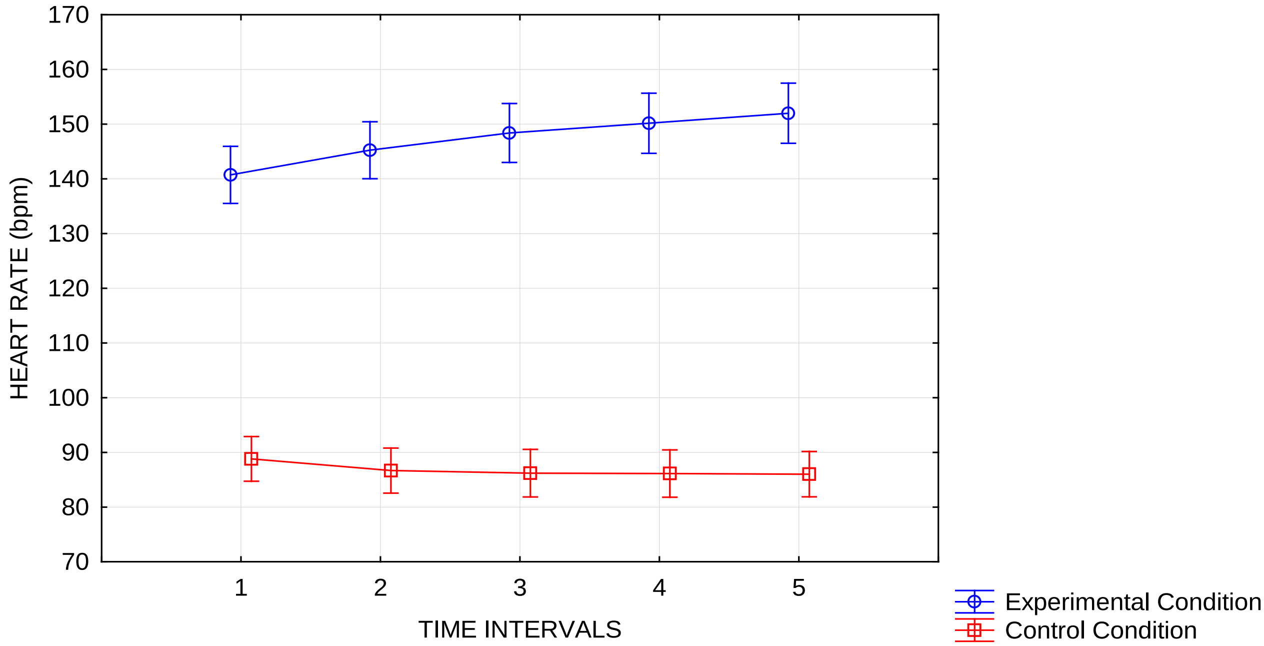

Figure 17. Heart rate ANOVA for the intervals during the loaded-cycling phase between the conditions and time intervals, where the experimental condition was one with cycling load and control the one with no load. (Error bars depict 95% confidence intervals).

Figure 17 illustrates the analysis of variance for the heart rate responses during the loaded cycling phase, between the conditions (cycling with load and cycling with no load) and the 5 time intervals. The cycling with load condition experiences a gradual increase in heart rate readings whilst there is a slight decrease observed in the cycling with no load condition. Statistical significance ($p<0.01$) was observed between the two.

4.2.2 RPE Data

RPE (Rate of Perceived Exertion) responses, which fall under subjective measures, were recorded from each participant every 10 minutes for the duration of each condition (cycling with load and cycling with no load).

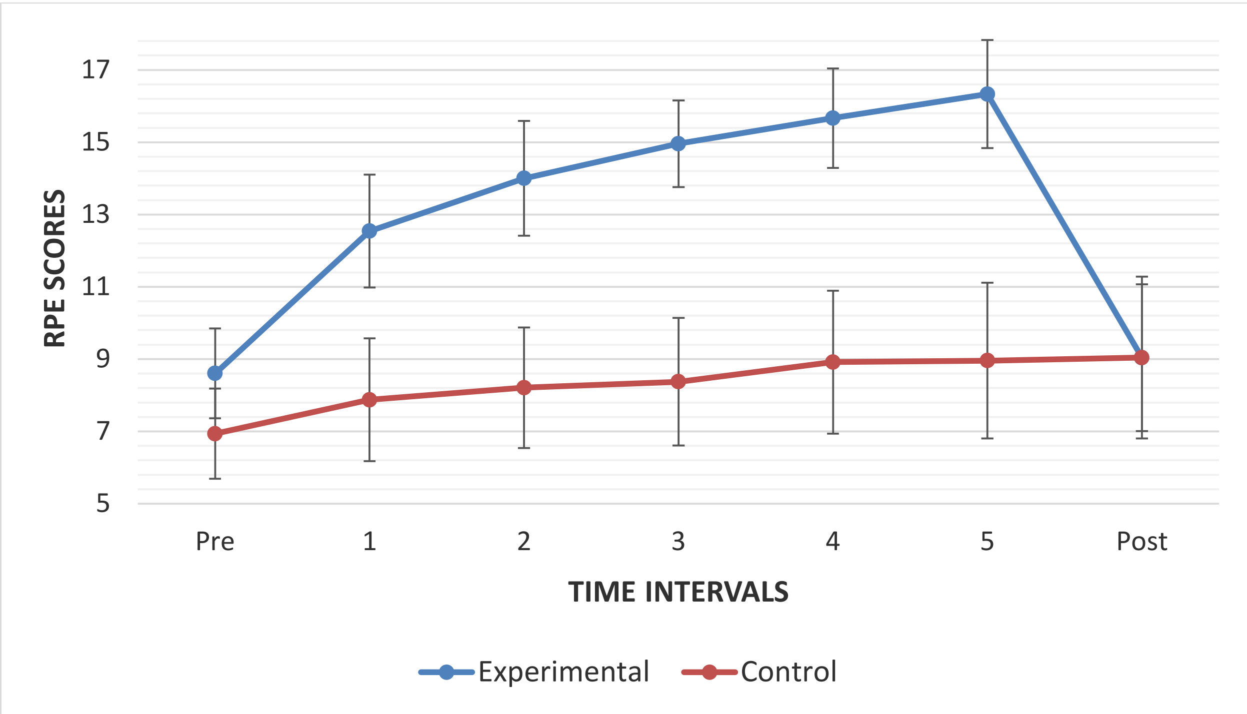

Figure 18. RPE responses for both the cycling with load (experimental) and the cycling with no load (control) conditions across the time intervals. (Error bars depict standard deviations).

Figure 18 serves to illustrate the mean RPE scores for all the participants for both the cycling with load (loaded-cycling) and the cycling with no load (unloaded-cycling) conditions across the 7 seven time intervals of the cycling bouts. Each interval was 10 minutes long, with the first interval being the warm-up phase (before the addition of resistance for the cycling with load condition) and the seventh interval being the cool-down phase. It can be observed that RPE responses remained fairly constant for the cycling with no load condition, starting at an average score of 7 and ending at a score of 9 on the RPE scale. However, for the cycling with load condition, a gradual increase in the RPE responses is observed with an initial average score of 9 to peak at an average score of 16 in the sixth time interval (the last of the interval of the loaded-cycling phase), then drop down to a score of 9 in the seventh and last interval.

4.2.2.1 RPE ANOVA for the intervals before and after the loaded-cycling phase.

Table III outlines the analysis of variance results for the RPE responses during both conditions (cycling with load and cycling with no load), for the before and after intervals, representing the warm-up and cool-down phases (pre and post-loaded cycling phase), respectively. Statistical significance ($p<0.05$) was observed between conditions; between the before and after intervals; and between the conditions and the before and after intervals.

Table III. Repeated measures analysis of variance for RPE responses (For the intervals before and after the loaded-cycling phase, where the asterisk* highlights statistical significance).

Effect	Degree. Of Freedom	F	p
CONDITIONS	1, 23	109.608	<0.01*
INTERVALS	1, 23	47.027	<0.01*
CONDITIONS*INTERVALS	1, 23	73.384	<0.01*

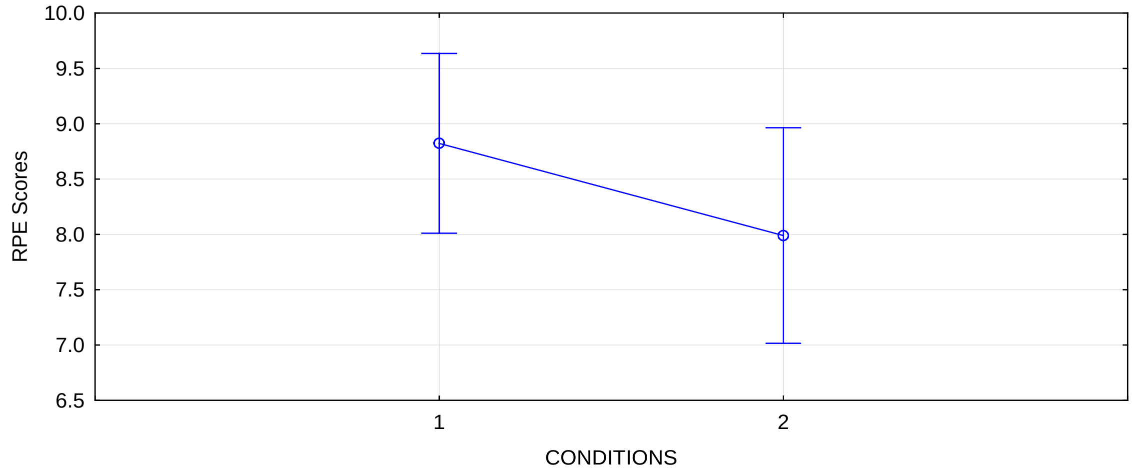

Figure 19. RPE ANOVA for the intervals before and after the loaded-cycling phase between the cycling with load (experimental) and cycling with no load (control) conditions. (Error bars depict 95% confidence intervals).

Figure 19 highlights the analysis of variance for the RPE responses for the before and after the loaded cycling phase, between the cycling with load and cycling with no load conditions. The cycling with load condition had a higher RPE score than the cycling with no load condition. Statistical significance was observed ($p<0.01$) between the conditions.

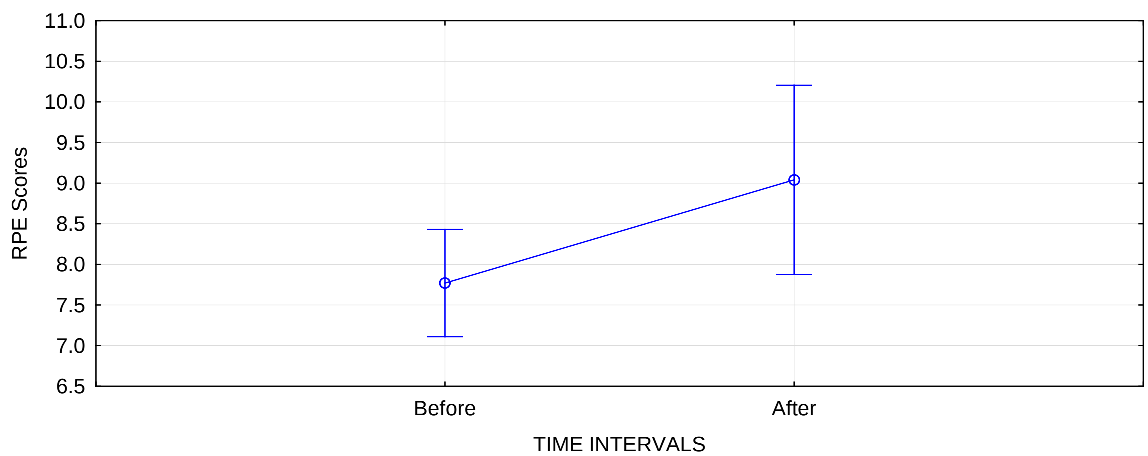

Figure 20. RPE ANOVA for the intervals before and after the loaded-cycling phase. (Error bars depict 95% confidence intervals).

Figure 20 elucidates the analysis of variance for the RPE responses between the before and after the loaded cycling intervals. This is the intervals representing the warm-up and cool-down phases, where the warm-up score is lower than the cool-off score. Statistical significance ($p<0.01$) was observed between the two intervals.

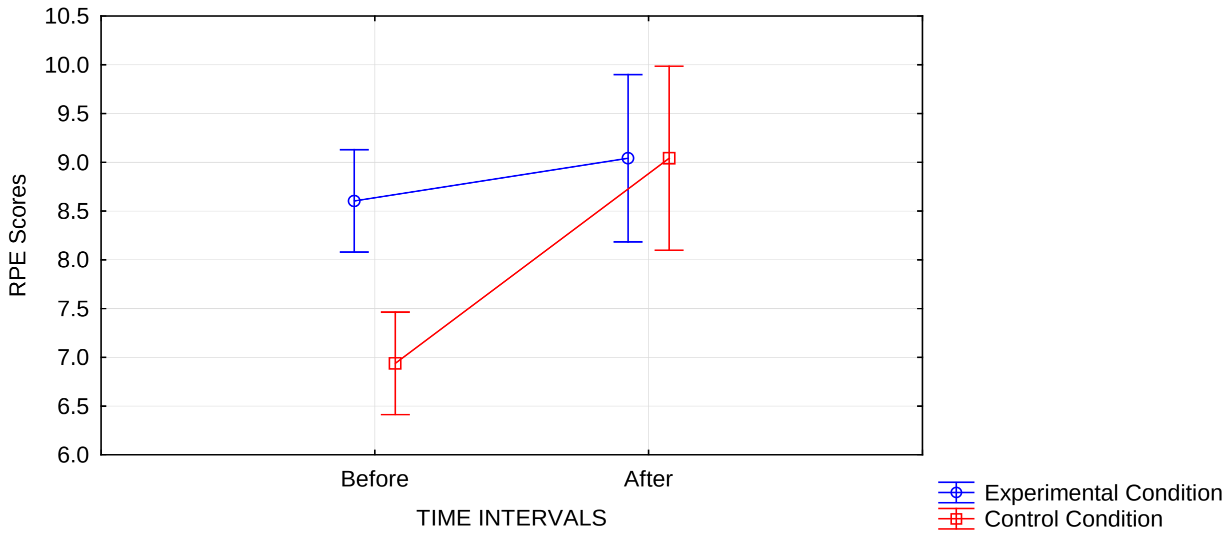

Figure 21. RPE ANOVA for the intervals before and after the loaded-cycling phase between conditions and time intervals, where the experimental condition was one with cycling load and control the one with no load. (Error bars depict 95% confidence intervals).

Figure 21 depicts the analysis of variance for the RPE responses between the two conditions (cycling with load and cycling with no load) and the time intervals (before and after the loaded cycling phase). There is an increase in RPE from the before to the after interval for the cycling with load condition and yet the after interval has a lower score than the before in the cycling with no load condition. Statistical significance ($p<0.01$) was established between the two.

4.2.2.2 RPE ANOVA for the period during the loaded cycling phase.

Table IV shows the analysis of variance results for the RPE responses for the periods (in both the cycling with load and cycling with no load conditions) analogous to the loaded cycling phase in the cycling with load condition corresponding to the 5 time intervals between the warm-up and the cool-down. Statistical significance ($p<0.05$) was observed between conditions; across intervals; and between the conditions and the before and after intervals.

Table IV. Repeated measures analysis of variance for RPE responses (For the intervals during the loaded-cycling phase values, where the asterisk* highlights statistical significance).

Effect	Degree. Of Freedom	F	p
CONDITIONS	1, 23	342.541	<0.01*
INTERVALS	4, 92	68.657	<0.01*
CONDITIONS*INTERVALS	4, 92	20.992	<0.01*

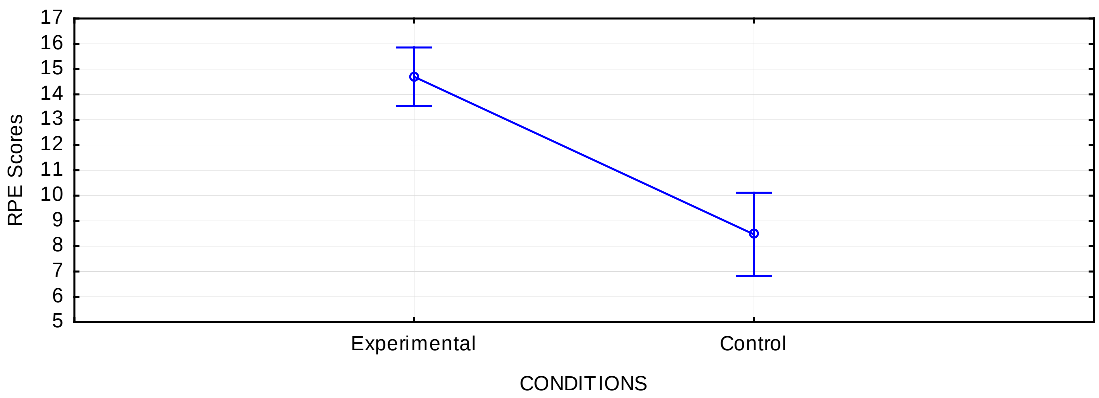

Figure 22. RPE ANOVA for the intervals during the loaded-cycling phase between the cycling with load (experimental) and cycling with no load (control) conditions. (Error bars depict 95% confidence intervals).

Figure 22 outlines the analysis of variance for the RPE responses during the loaded-cycling phase between the cycling with load and cycling with no load conditions, where the cycling with load condition had a higher RPE score than the cycling with no load condition. Statistical significance was noted as $p<0.01$.

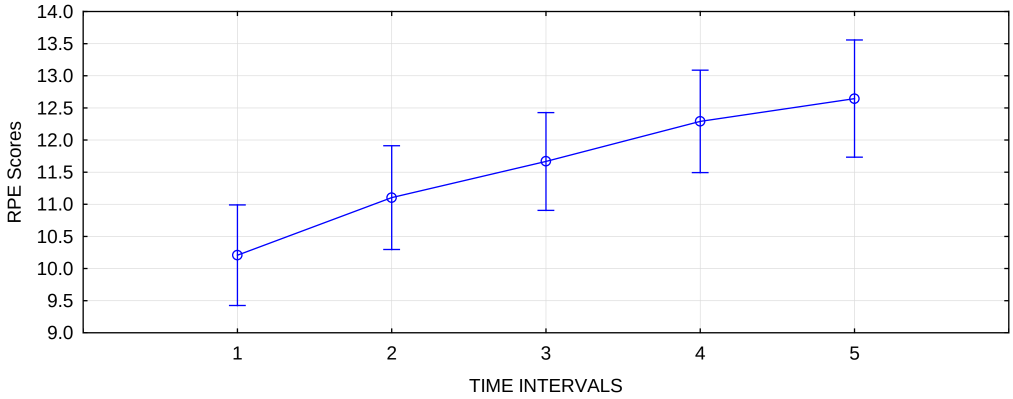

Figure 23. RPE ANOVA for the intervals during the loaded-cycling phase across the time intervals. (Error bars depict 95% confidence intervals).

Figure 23 depicts the analysis of variance for the RPE response across the loaded-cycling phase. Therefore, the time intervals considered were those between the initial warm-up and the final cool-down intervals, where an increase in RPE scores is observed from the first interval to the fifth interval. Statistical significance was confirmed at $p<0.01$.

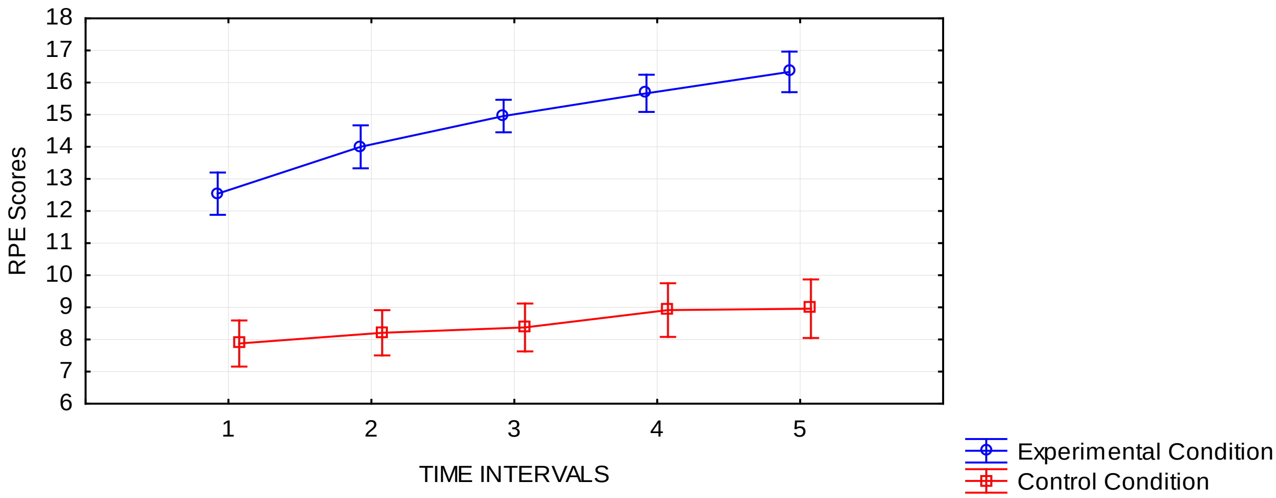

Figure 24. RPE ANOVA for the intervals during the loaded-cycling phase between the conditions and time intervals, where the experimental condition was one with cycling load and control the one with no load. (Error bars depict 95% confidence intervals).

Figure 24 shows the analysis of variance for the RPE responses between the two conditions and the five time intervals within the loaded-cycling phase. A significant increase from an RPE score of 12.5 to 16.5 is observed in the cycling with load condition and yet only a slight increase of 8 to 9 is experienced in the cycling with no load condition. In this instance, statistical significance was observed as $p<0.01$.

4.3 Cognitive Performance

This subdivision is where all the cognitive test results were collectively presented in three factions; memory recall data, proof reading task data and the modified Fitts' test data. All this performance data was recorded every 10 minutes as the participants cycled in each condition.

4.3.1 Memory Recall Task

The memory recall test presented through a PEBL computer software was when each participant was shown a set of numbers (with two levels of difficulty; five and seven digits) then they were required to recall the numbers in the exact order after a short delay lag time. The PEBL software then postulated worksheets from which success rates were calculated for each participant at each interval.

4.3.1.1 Memory recall performance

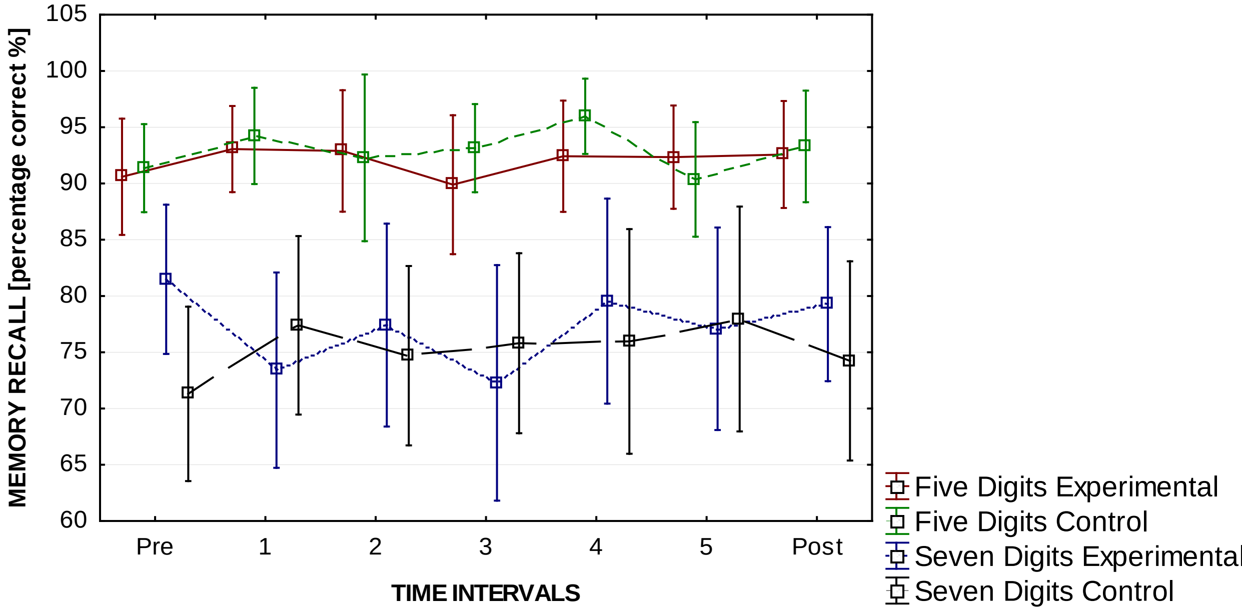

Figure 25. Memory recall responses in the five and seven-digit trials for both the cycling with load (experimental) and the cycling with no load (control) conditions across the time intervals. (Error bars depict 95% confidence intervals).

Figure 25 highlights the trends in the memory recall performance across all the time intervals for both the cycling with load and cycling with no load conditions in all the two levels of complexity. It can be observed that performance was generally high for the five digit trials in both conditions and lower for the seven digit trials, being highest in the 4th interval (five digit trial) of the cycling with no load condition and lowest in the 3rd interval (seventh digit trial) of the cycling with load condition.

4.3.1.2 Memory recall ANOVA for the entire cycling duration

Table V below serves to present the analysis of variance results for memory recall responses from all participants for both complexities and conditions across all intervals. However, statistical significance was only observed between the complexities; five and seven digit trials.

Table V. Repeated measures analysis of variance for memory recall responses (For the entire cycling duration, where the asterisk* highlights statistical significance).

Effect	Degree. Of Freedom	F	p
COMPLEXITIES	1, 23	55.501	<0.01*
CONDITIONS	1, 23	0.093	0.762849
INTERVALS	6, 138	1.054	0.393456
COMPLEXITIES*CONDITIONS	1, 23	2.110	0.159879
COMPLEXITIES*INTERVALS	6, 138	0.605	0.725790
CONDITIONS*INTERVALS	6, 138	1.651	0.137716
COMPLEXITIES*CONDITIONS*INTERVALS	6, 138	1.539	0.169777

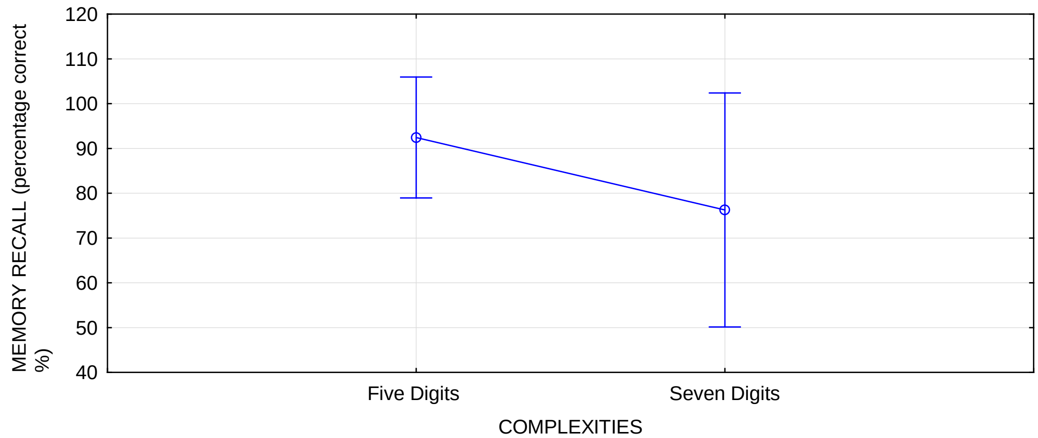

Figure 26. Memory recall ANOVA for the entire cycling duration between the five and seven digit complexities. (Error bars depict 95% confidence intervals).

Figure 26 shows the analysis of variance for memory recall responses between the two levels of complexity; five and seven digits, where the five digit complexity had a higher pass rate than the seven digit complexity. Statistical significance ($p<0.01$) was observed.

4.3.1.3 Memory recall ANOVA for the intervals before and after the loaded-cycling

Table VI lays out the analysis of variance results for the memory recall response data recorded from both the cycling with load and cycling with no load conditions, for the before and after the loaded cycling phase which corresponds to the warm-up and cool-down intervals. Statistical significance was only observed between complexities and between complexities and conditions.

Table VI. Repeated measures analysis of variance for memory recall responses (For the intervals before and after the loaded-cycling phase, where the asterisk* highlights statistical significance).

Effect	Degree. Of Freedom	F	p
COMPLEXITIES	1, 23	63.839	<0.01*
CONDITIONS	1, 23	3.128	0.090227
INTERVALS	1, 23	1.321	0.262296
COMPLEXITIES*CONDITIONS	1, 23	9.085	0.006183*
COMPLEXITIES*INTERVALS	1, 23	1.091	0.307043
CONDITIONS*INTERVALS	1, 23	0.621	0.438708
COMPLEXITIES*CONDITIONS*INTERVALS	1, 23	1.348	0.257568

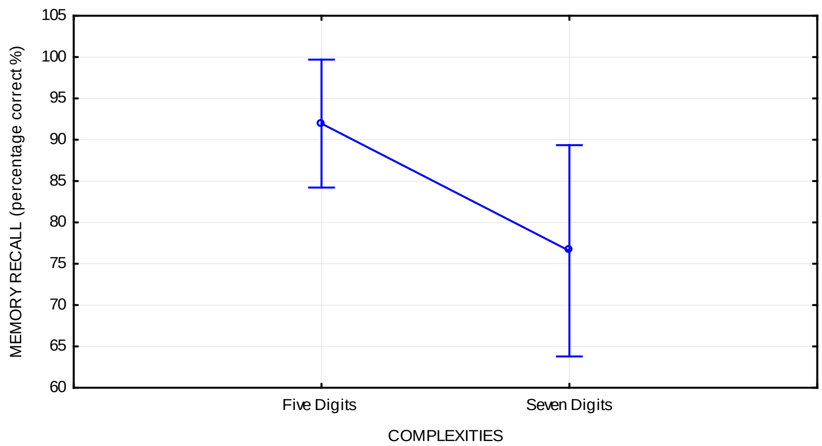

Figure 27. Memory recall ANOVA for the intervals before and after the loaded-cycling phase between the five and seven digit complexities. (Error bars depict 95% confidence intervals).

Figure 27 illustrates the analysis of variance for the memory recall performance data between the five and the seven digit complexities, where five digits represented the simple trial and seven digits the more complex or difficult trial. The five digit complexity had a higher percentage correct response than the seven digit complexity. Statistical significance was observed in this analysis with $p<0.01$.

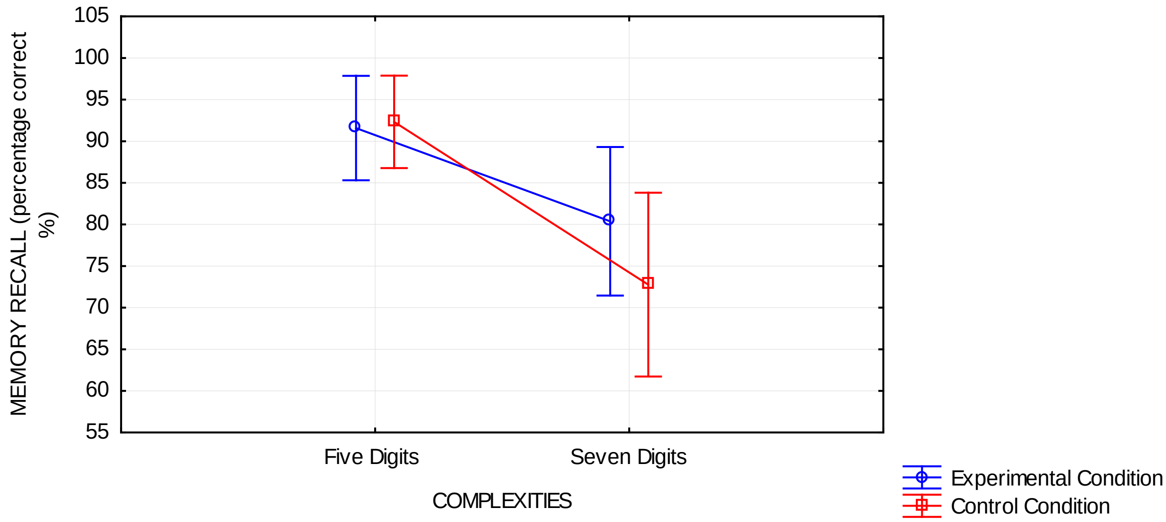

Figure 28. Memory recall ANOVA for the intervals before and after the loaded-cycling phase between complexities and conditions, where the experimental condition was one with cycling load and control the one with no load. (Error bars depict 95% confidence intervals).

Figure 28 expounds the analysis of variance for the memory recall performance data between complexities (five and seven digit trials) and conditions (cycling with load and cycling with no load) for the before and after investigation. A slightly higher percentage was experienced for the five digit complexity in the cycling with no load than the experimental, however, the cycling with load had a marginable higher memory recall percentage for the seven digit than the cycling with no load, even though both values were lower than for the five digit complexity. Statistical significance was confirmed as $p=0.006183$.

4.3.2 Proof Reading Task

The proof reading task was one where the participants read through two pre-determined passages which contained double-letter errors, one of a low resolution and the other of a high resolution, for 90 seconds each. These readings were performed every 10 minutes in both conditions; cycling with load and cycling with no load. Two performance measures were considered namely reading speed and error detection rate. Reading speed was later calculated as words read per minute, as determined by the number of words counted in the passages that the participants were able to read in the 90 second time allocations given per each testing interval. Error detection rate calculated as the number of errors identified out of the total errors in the section read, both measures recorded at each 10 minute interval for the duration of the conditions.

4.3.2.1 Reading speed performance

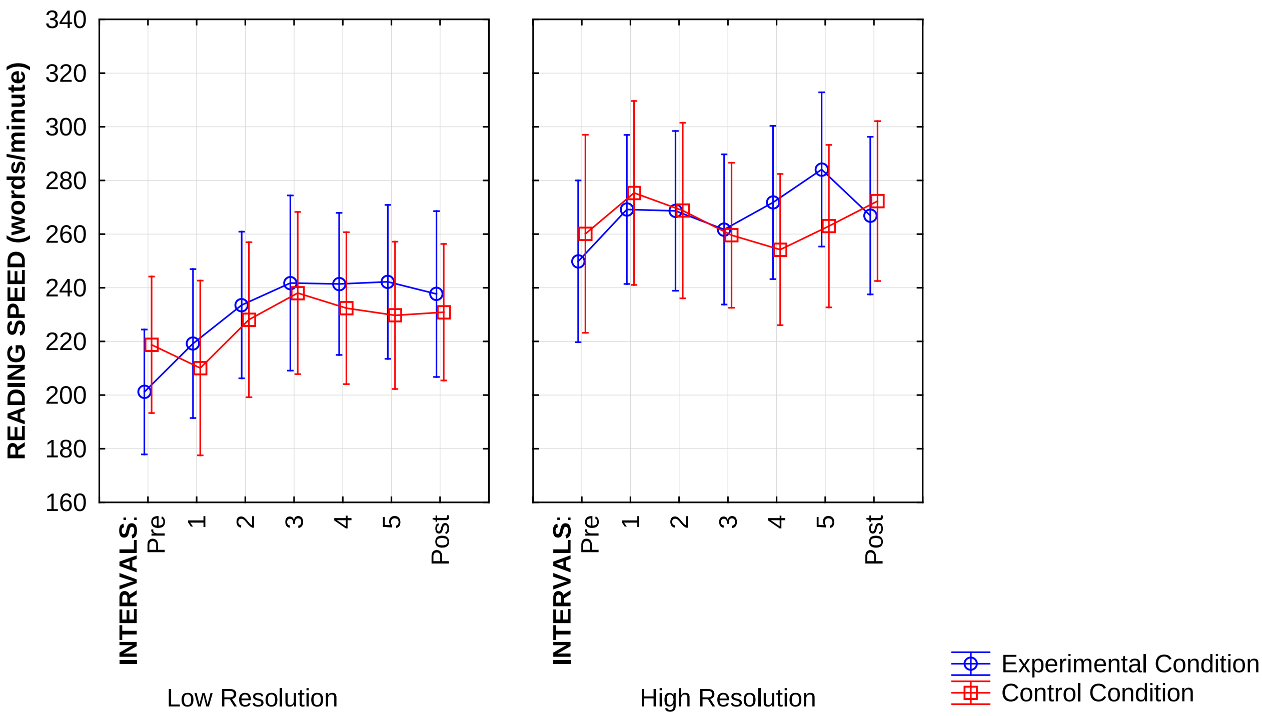

Figure 29. Reading speed responses in high and low resolutions for both the cycling with load (experimental) and the cycling with no load (control) conditions across the time intervals. (Error bars depict 95% confidence intervals).

Figure 29 outlines the progression of the reading speed responses across the time intervals in both the cycling with load and cycling with no load conditions. High resolution responses (for both the cycling with load and the cycling with no load conditions) recorded the highest reading speeds, with the 5th interval in the cycling with load condition having the fastest reading speed of 284 words per minute. The slowest reading speed was recorded in the warm-up phase of the cycling with load condition (low resolution) at 201 words per minute. It's interesting to note that for both the low and high resolution readings, the cycling with load condition started with a slow speed than the cycling with no load then the speed increased to be faster than the cycling with no load condition as time went on.

4.3.2.2 Reading speed ANOVA for the entire cycling duration.

Table VII exhibits the analysis of variance results for the reading speed performance data for both low and high resolution readings in the cycling with load and cycling with no load conditions. Statistical significance ($p<0.05$) was confirmed between resolutions, across time intervals, between resolutions and time intervals, and between conditions and time intervals.

Table VII. Repeated measures analysis of variance for reading speed responses (For the entire cycling duration, where the asterisk* highlights statistical significance).

Effect	Degree. Of Freedom	F	p
RESOLUTIONS	1, 23	257.8294	<0.01*
CONDITIONS	1, 23	0.2320	0.634576
INTERVALS	6, 138	7.1854	<0.01*
RESOLUTI*CONDITIONS	1, 23	0.0667	0.798452
RESOLUTIONS*INTERVALS	6, 138	6.1304	<0.01*
CONDITIONS*INTERVALS	6, 138	2.5346	0.023311*
RESOLUTIONS*CONDITIONS*INTERVALS	6, 138	1.0614	0.388784

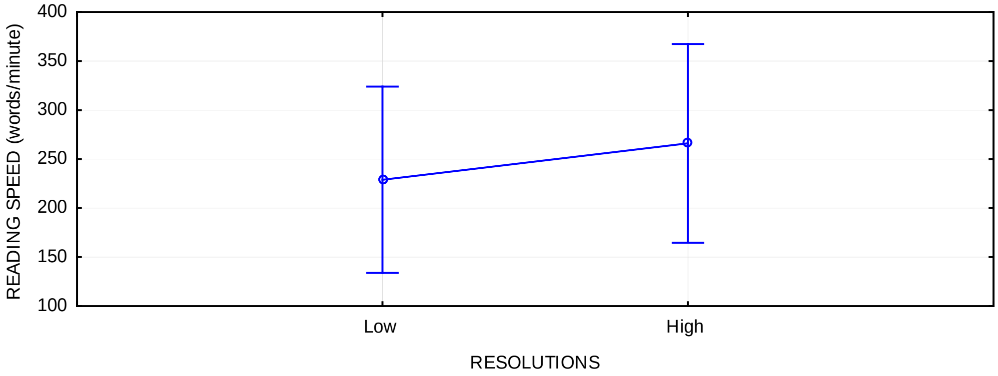

Figure 30. Reading speed ANOVA for the entire cycling duration between the low and high resolution readings. (Error bars depict 95% confidence intervals).

Figure 30 shows the analysis of variance for the reading speed performance data between the low and high resolution readings that were administered every 10 minutes in both the cycling with load and cycling with no load conditions, with a faster average reading speed being observed in the high resolution than the low resolution reading. Statistical significance was confirmed at $p<0.01$.

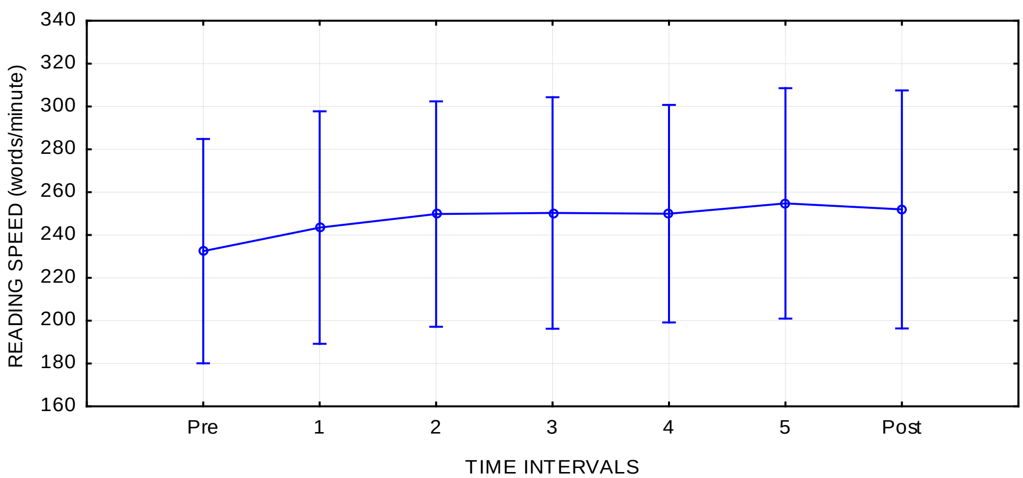

Figure 31. Reading speed ANOVA for the entire cycling duration across all time intervals. (Error bars depict 95% confidence intervals).

Figure 31 depicts the analysis of variance for the reading speed performance data for the 7 time intervals in all the conditions, where the first and last intervals represented the pre and post loaded-cycling phase. A gradual increase in reading speed can be observed from the warm-up interval to the cool-down interval. Statistical significance was observed at $p<0.01$.

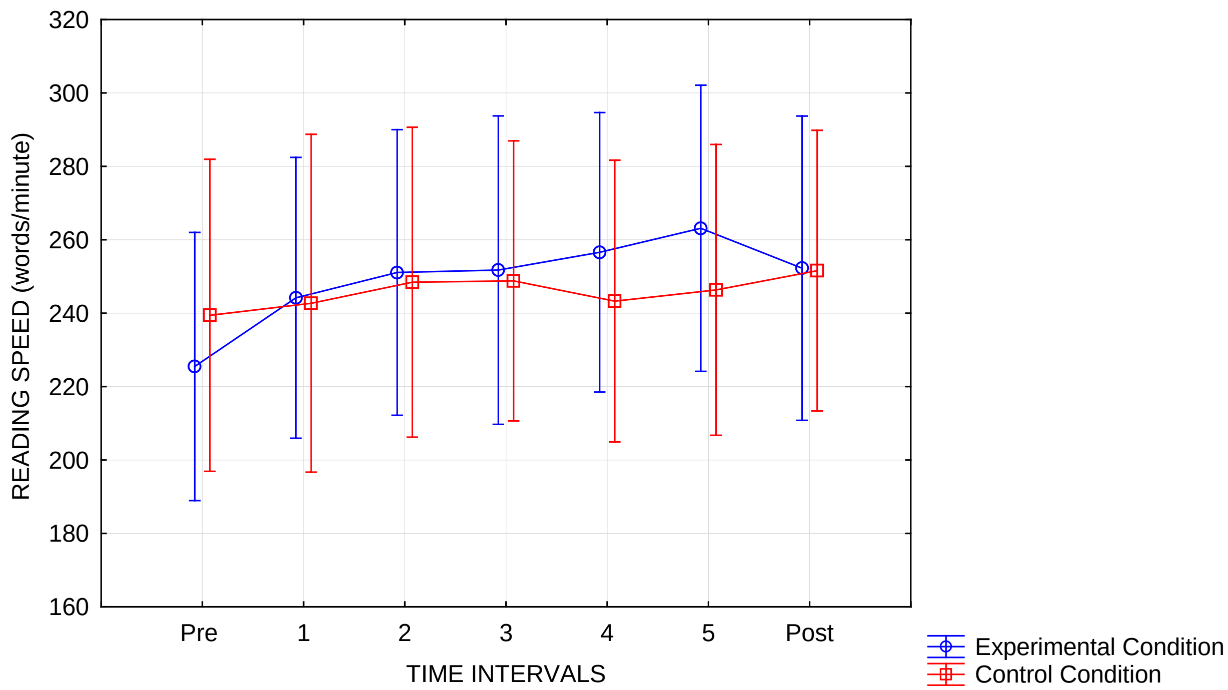

Figure 32. Reading speed ANOVA for the entire cycling duration between conditions and time intervals, where the experimental condition was one with cycling load and control the one with no load. (Error bars depict 95% confidence intervals).

Figure 32 shows the analysis of variance for the reading speed performance data between the conditions (cycling with load and cycling with no load) and the time intervals, where statistical significance was confirmed at $p=0.023311$. Reading speed was higher for the cycling with no load condition than the cycling with load at the start of each condition, but quickly rose for the cycling with load condition to end with a higher speed than the cycling with no load.

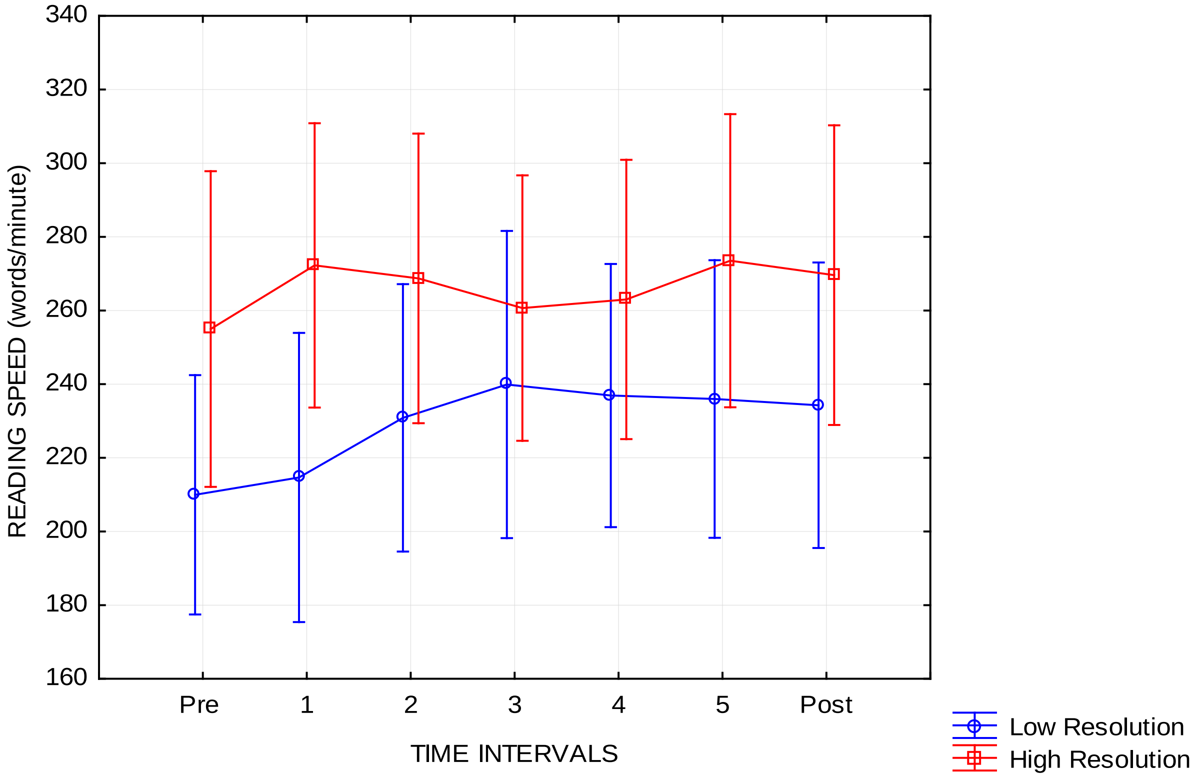

Figure 33. Reading speed ANOVA for the entire cycling duration between resolutions and time intervals. (Error bars depict 95% confidence intervals).

Figure 33 represents the analysis of variance for the reading speed performance data between the reading resolutions (low and high) and the time intervals, where statistical significance was observed at $p<0.01$. Reading speed for low resolution scripts started of slower than for high resolution with a reading of 210 words per minute, but progressively increased to end at 238 words per minute. High resolution scripts also experienced an irregular but progressive increase starting at 257 to end at 271 words per minute.

4.3.2.3 Reading speed ANOVA for the intervals before and after the loaded-cycling phase

Table VIII highlights the analysis of variance results for the reading speed performance data during both conditions (cycling with load and cycling with no load), for the before and after intervals, representing the warm-up and cool-down phases, respectively. Statistical significance ($p<0.01$) was observed between resolutions, between conditions, and across the time intervals.

Table VIII. Repeated measures analysis of variance for reading speed responses (For the intervals before and after the loaded-cycling phase, where the asterisk* highlights statistical significance).

Effect	Degree Of Freedom	F	p
RESOLUTIONS	1, 23	35.2169	<0.01*
CONDITIONS	1, 23	30.7886	<0.01*
INTERVALS	1, 23	12.8890	0.001547*
RESOLUTIONS*CONDITIONS	1, 23	3.1261	0.090313
RESOLUTIONS*INTERVALS	1, 23	0.0721	0.790753
CONDITIONS*INTERVALS	1, 23	2.0288	0.167771
RESOLUTIONS*CONDITIONS*INTERVALS	1, 23	2.1514	0.155982

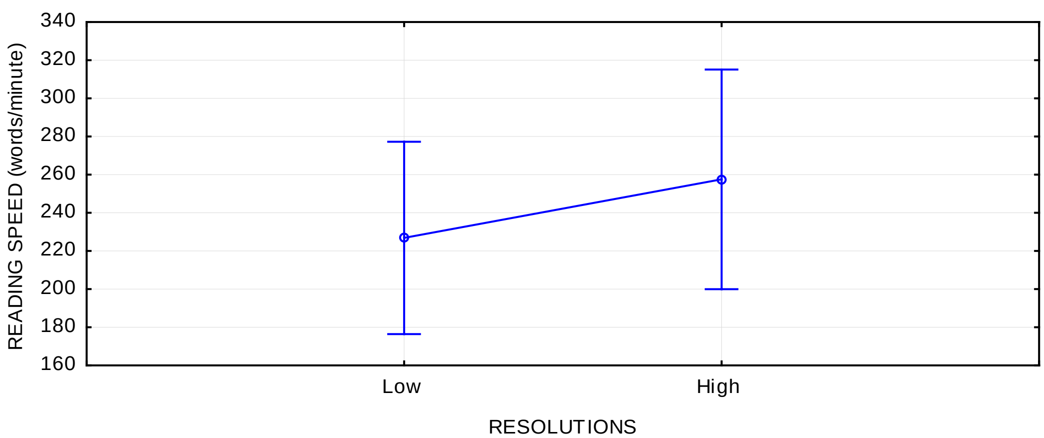

Figure 34. Reading speed ANOVA for the intervals before and after the loaded-cycling phase between resolutions. (Error bars depict 95% confidence intervals).

Figure 34 shows the analysis of variance for the reading speed performance data between the low and high resolutions readings for the before and after interval comparison, where high resolution readings had a faster reading speed than the low resolution readings. Statistical significance was observed at $p<0.01$.

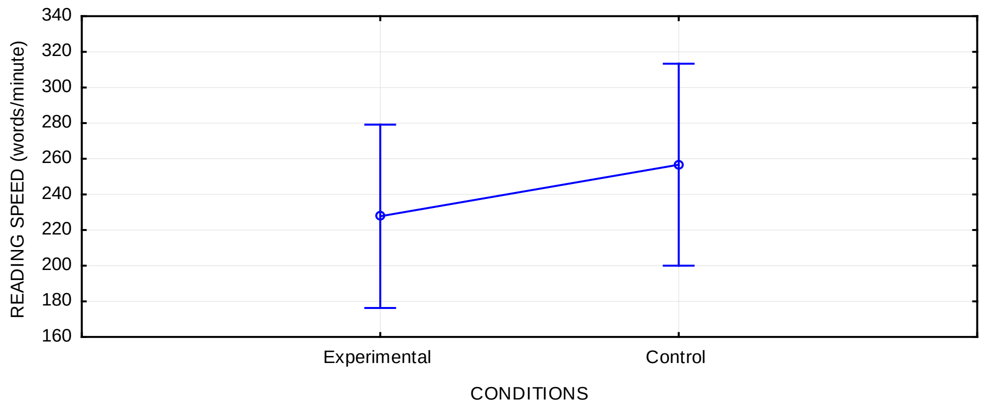

Figure 35. Reading speed ANOVA for the intervals before and after the loaded-cycling phase between conditions, where the experimental condition was one with cycling load and control the one with no load. (Error bars depict 95% confidence intervals).

Figure 35 illustrates the analysis of variance for the before and after reading speed performance data between the cycling with load and cycling with no load conditions, showing that the cycling with no load condition had faster readings speeds than the cycling with load condition. Statistical significance was confirmed at $p<0.01$.

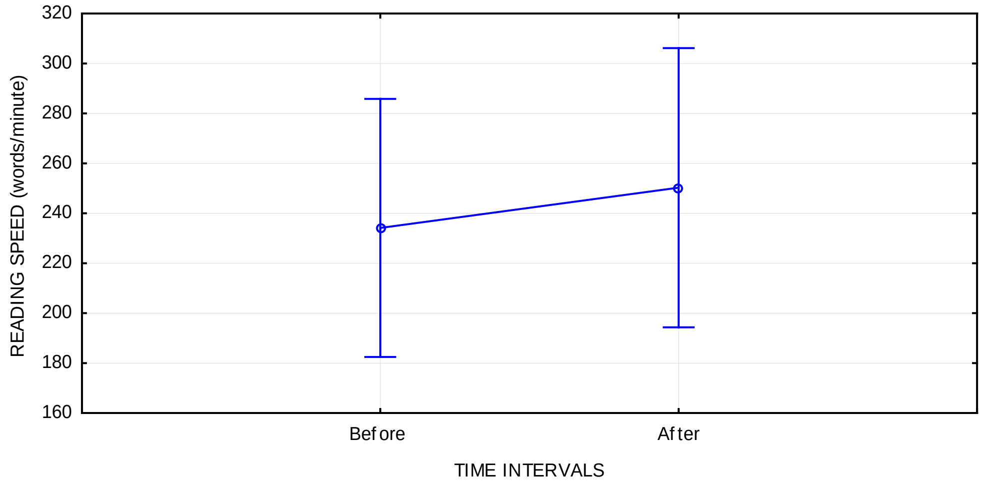

Figure 36. Reading speed ANOVA for the intervals before and after the loaded-cycling phase. (Error bars depict 95% confidence intervals).

Figure 36 depicts the analysis of variance for the reading speed performance data between the before and after loaded-cycling intervals. This is comparison of the reading speed performance during the warm-up and cool-down intervals showing that faster reading speeds were experienced in the cool-down interval than in the warm-up interval. Statistical significance was ascertained by p=0.001547.

4.3.2.4 Error detection rate performance

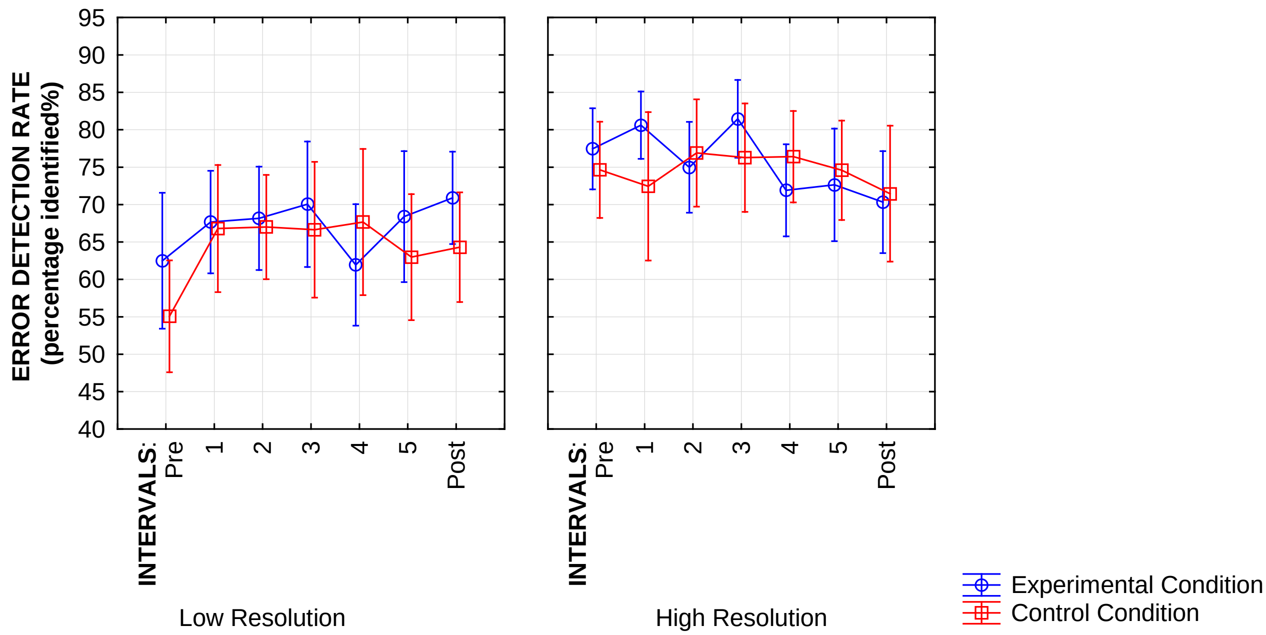

Figure 37. Error detection responses in high and low resolutions for both the cycling with load (experimental) and the cycling with no load (control) conditions across the time intervals. (Error bars depict 95% confidence intervals).

Figure 37 delineates the trends from the error detection rate data collected from both the cycling with load and cycling with no load conditions for both low and high resolutions. High resolutions readings (for both conditions) had higher error detection rates than low resolutions readings. In the high resolution readings alone, the detection rate started higher for the cycling with load condition than the cycling with no load but switched around the 3rd interval to conclude the conditions with the cycling with no load rate being higher than the experimental. As for the low resolution, the cycling with load condition detection rate was higher than the cycling with no load from the start, then briefly dropped during the 4th interval to once more rise above the cycling with no load for the remainder of the intervals.

4.3.2.5 Error detection rate ANOVA for the entire cycling duration.

Table IX portrays the analysis of variance results for the error detection rate performance data for all participants during the cycling with load and cycling with no load conditions for both the low and high resolution readings. Statistical significance ($p<0.05$) was observed between the resolutions, across the time intervals and between resolutions and intervals.

Table IX. Repeated measures analysis of variance for error detection rate responses (For the entire cycling duration, where the asterisk* highlights statistical significance).

Effect	Degree. Of Freedom	F	p
RESOLUTIONS	1, 23	60.3249	<0.01*
CONDITIONS	1, 23	1.1161	0.301724
INTERVALS	6, 138	2.5219	0.023941*
RESOLUTIONS*CONDITIONS	1, 23	0.9384	0.342763
RESOLUTIONS*INTERVALS	6, 138	2.5634	0.021950*
CONDITIONS*INTERVALS	6, 138	1.8982	0.085316
RESOLUTIONS*CONDITIONS*INTERVALS	6, 138	1.2043	0.307749

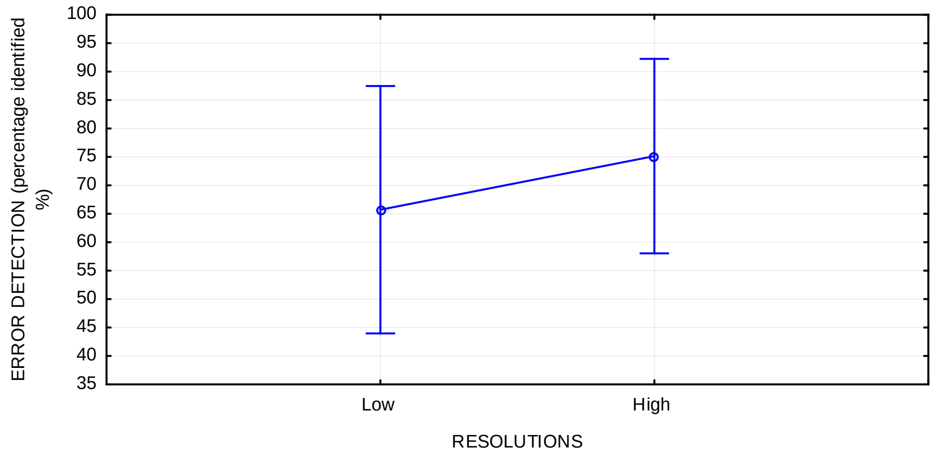

Figure 38. Error detection ANOVA for the entire cycling duration between the low and high resolutions. (Error bars depict 95% confidence intervals).

Figure 38 illustrates the analysis of variance for the error detection rate performance data between the low and high resolutions, where more errors were identified in the high resolution readings than the low resolution ones. Statistical significance was observed as p<0.01.

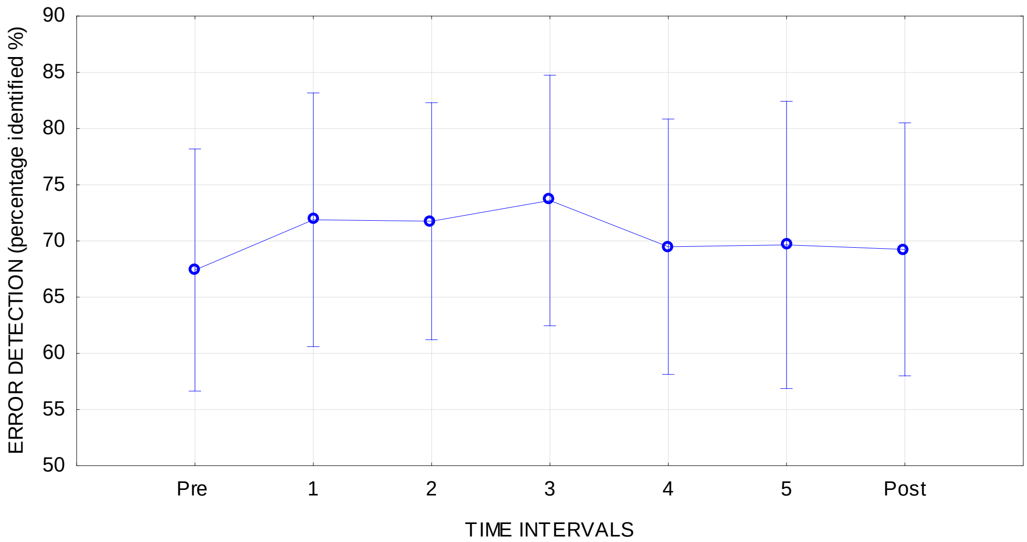

Figure 39. Error detection ANOVA for the entire cycling duration across the time intervals. (Error bars depict 95% confidence intervals).

Figure 39 shows the analysis of variance for error detection rate performance data across all 7 intervals of the cycling bout. An irregular increase in the error detection rate can be observed from an initial 68%, and a peak of 74% to eventually end at 69%. Statistical significance was observed at p=0.023941.

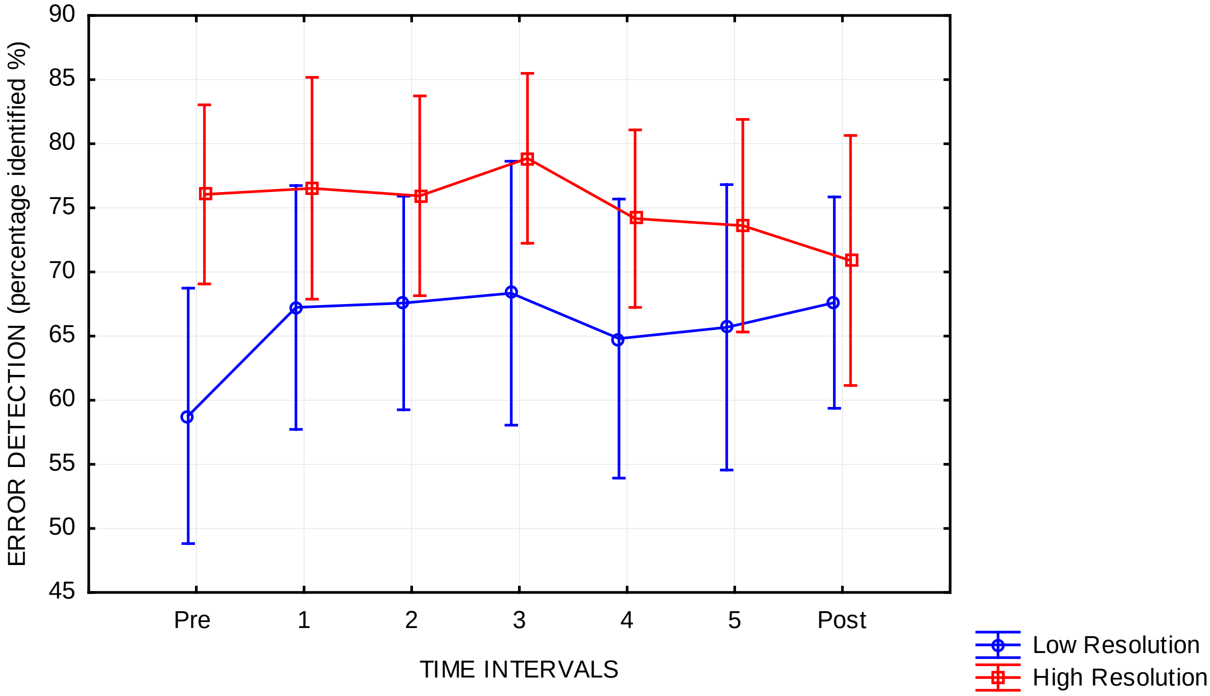

Figure 40. Error detection ANOVA for the entire cycling duration between the resolutions and time intervals. (Error bars depict 95% confidence intervals).

Figure 40 illustrates the analysis of variance for the error detection rate performance data between the resolutions (low and high) and the time intervals, with error detection for the low resolution starting quite low at 59% but ended at 67%, whereas high resolution readings had a high initial error detection rate of 76% that dropped to 71% for the cool-off interval. Statistical significance was confirmed at p=0.021950.

4.3.2.6 Error detection rate ANOVA for the intervals before and after the loaded-cycling phase

Table X outlines the analysis of variance results for the error detection rate performance data recorded from both the cycling with load and cycling with no load conditions, for the before and after the loaded cycling phase which corresponds to the warm-up and cool-down intervals. Statistical significance was confirmed between resolutions; between conditions; between resolutions and conditions; and between resolutions and time intervals.

Table X. Repeated measures analysis of variance for error detection rate responses (For the intervals before and after the loaded-cycling phase, where the asterisk* highlights statistical significance).

Effect	Degree. Of Freedom	F	P
RESOLUTIONS	1, 23	22.5106	<0.01*
CONDITIONS	1, 23	4.9007	0.037038*
INTERVALS	1, 23	1.0443	0.317458
RESOLUTIONS*CONDITIONS	1, 23	4.9890	0.035524*
RESOLUTIONS*INTERVALS	1, 23	14.8482	0.000809*
CONDITIONS*INTERVALS	1, 23	0.2628	0.613098
RESOLUTIONS*CONDITIONS*INTERVALS	1, 23	0.1751	0.679531

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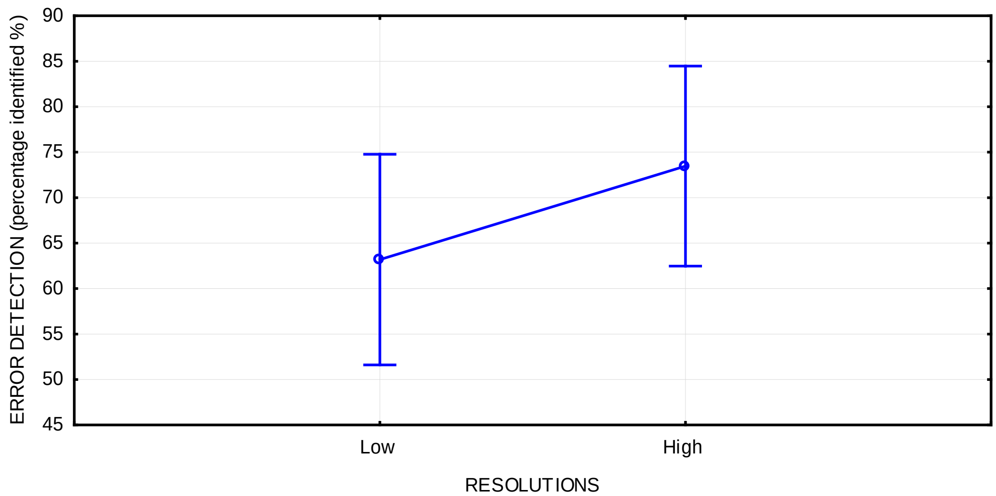

Figure 41. Error detection ANOVA for the intervals before and after the loaded-cycling phase between resolutions. (Error bars depict 95% confidence intervals).

Figure 41 illustrates the analysis of variance for the error detection rate performance data between the low and high resolutions readings for the before and after interval comparison, where high resolution had a higher error detection rate than low resolution. Statistical significance was observed at $p<0.01$.

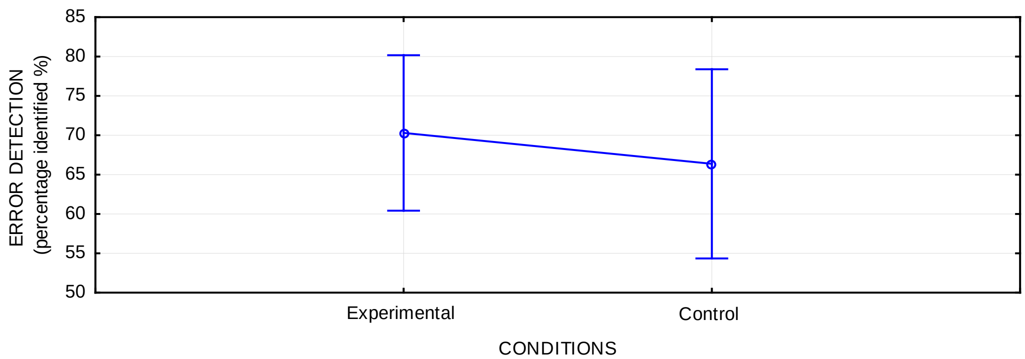

Figure 42. Error detection ANOVA for the intervals before and after the loaded-cycling phase between conditions, where the experimental condition was one with cycling load and control the one with no load. (Error bars depict 95% confidence intervals).

Figure 42 exhibits the analysis of variance for the error detection rate performance data between the cycling with load and cycling with no load conditions, with the cycling with load condition having a higher error detection rate than the cycling with no load. Statistical significance was confirmed at p=0.037038.

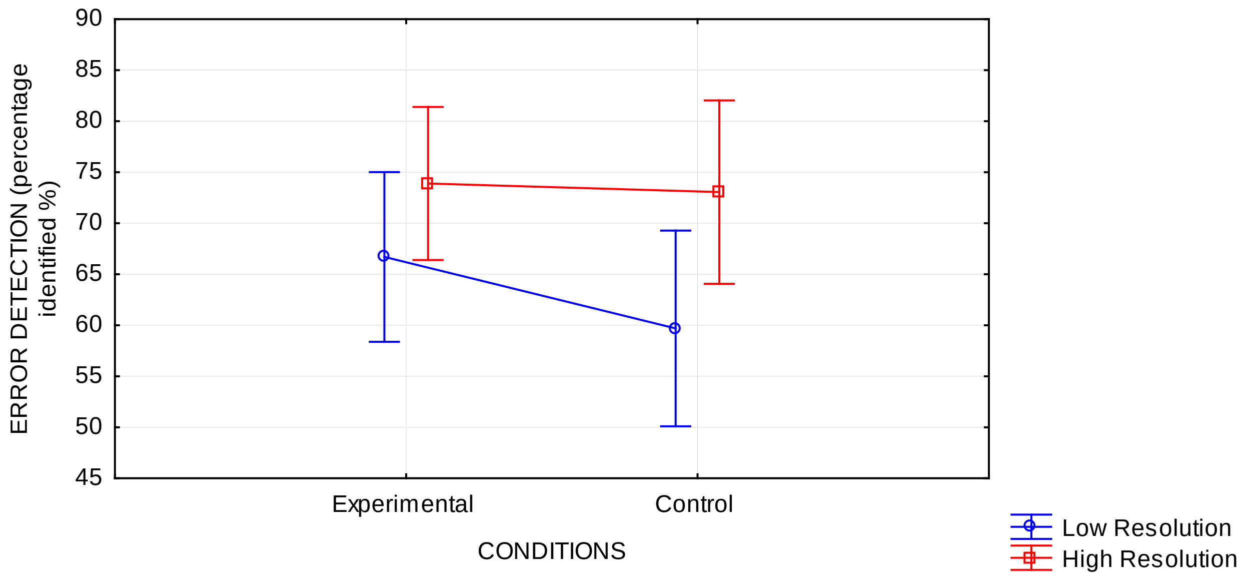

Figure 43. Error detection ANOVA for the intervals before and after the loaded-cycling phase between resolutions and conditions, where the experimental condition was one with cycling load and control the one with no load. (Error bars depict 95% confidence intervals).

Figure 43 shows the analysis of variance for the error detection rate performance data between the resolutions (low and high) and the conditions (cycling with load and cycling with no load). Higher detection rates were observed for the high resolution readings than for the low resolution where the detection rate dropped from 67% in the cycling with load to 60% in the cycling with no load condition. Statistical significance was confirmed at p=0.035524.

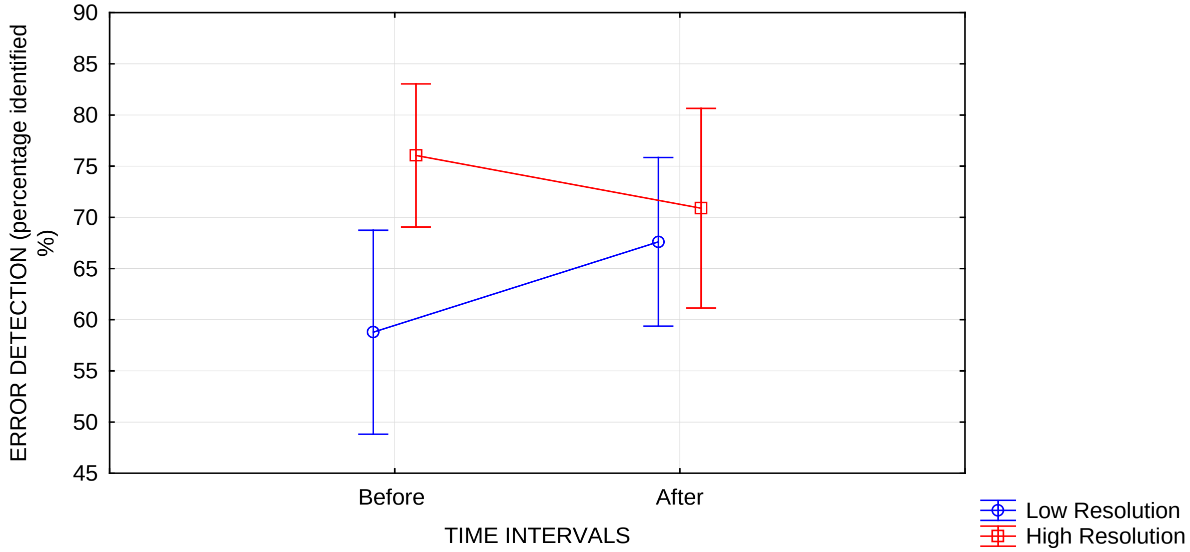

Figure 44. Error detection ANOVA for the intervals before and after the loaded-cycling phase between resolutions and time intervals. (Error bars depict 95% confidence intervals).

The above Figure 44 serves to illustrate the analysis of variance for the error detection rate performance data between the resolutions (low and high) and the time intervals. In this analysis the error detection rate suffered a decrease for the high resolution from 76-71%, whilst the low resolution had an increase from 59%-68%. Statistical significance was confirmed at p=0.000809.

4.3.3 Modified Fitts Task

The modified Fitts task was one where the participants had to respond to a green dot stimulus appearing on a LCD touch screen by tapping/touching it with their finger for it to disappear. This customized software was programmed to randomized the stimuli with the dot randomly appearing in either large or small sizes and either anywhere on the screen or centrally located. Two performance measures were then extrapolated from the task namely reaction time and target deviation. Reaction time was how quick the response to the stimuli was in milliseconds and Target deviation was how far the response was from the stimuli dot/mark measured in millimeters. Both measures were recorded every 10 minutes for the duration of both the cycling with load and the cycling with no load conditions.

4.3.3.1 Reaction time performance

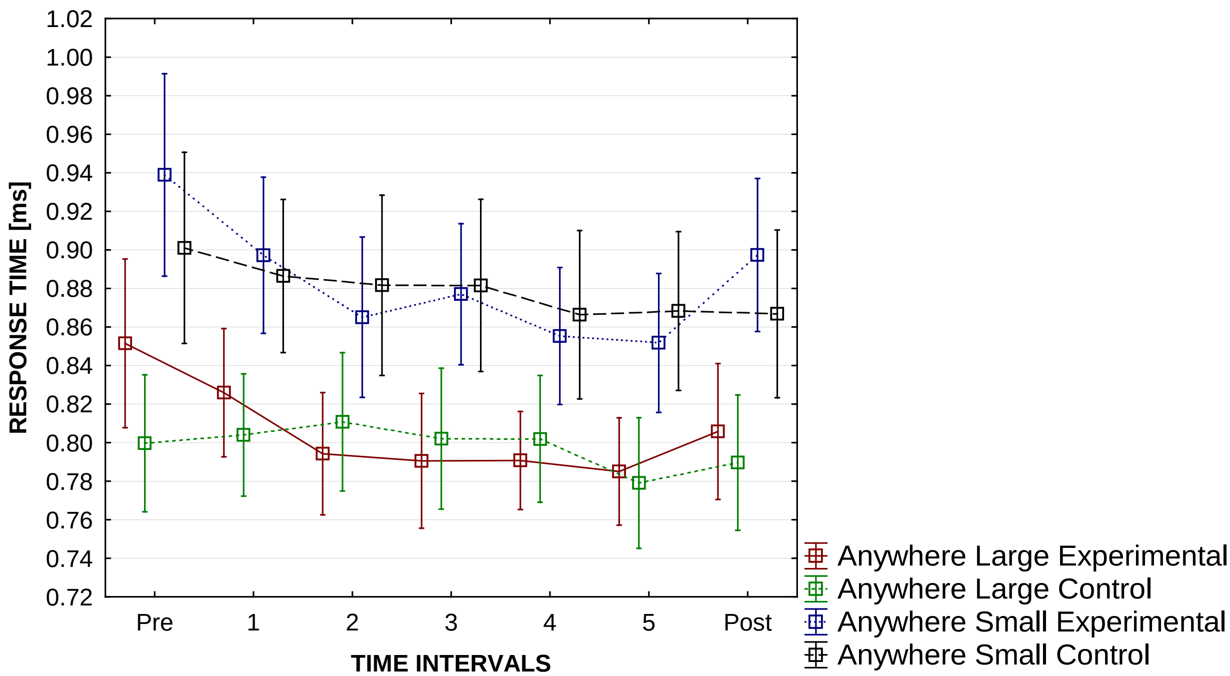

Figure 45. Response times for both the cycling with load (experimental) and cycling with no load (control) conditions across the time intervals for anywhere large and anywhere small responses. (Error bars depict 95% confidence intervals).

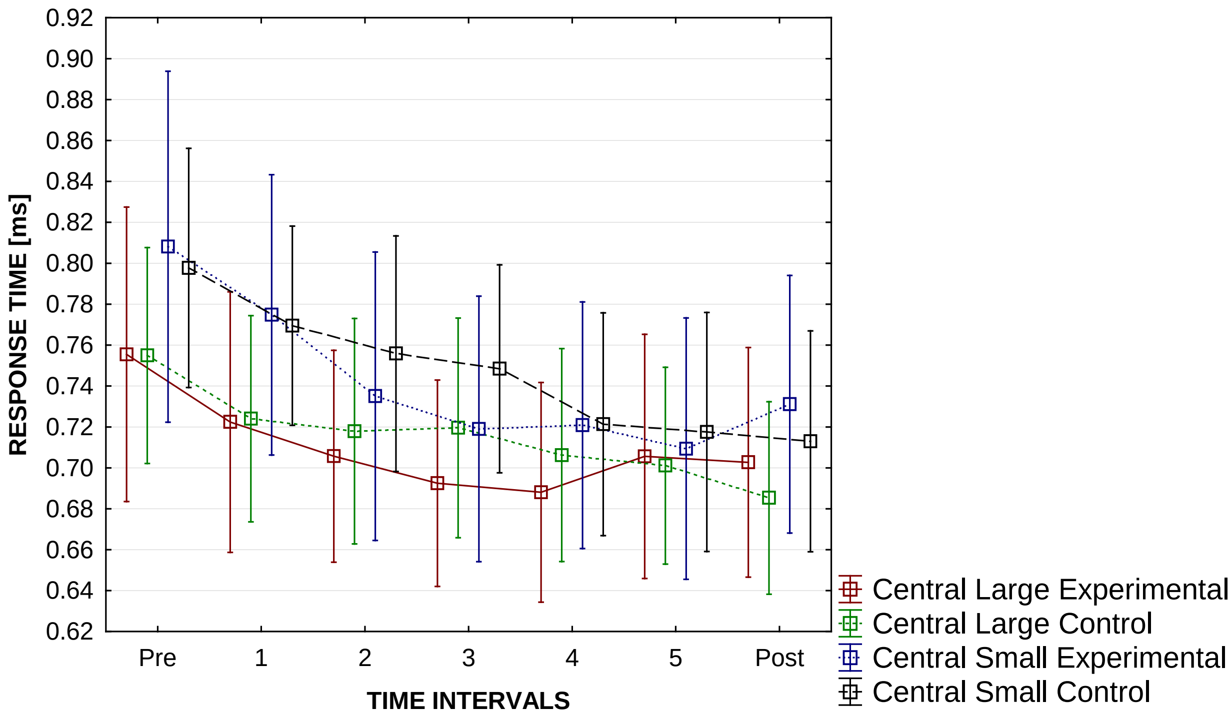

Figure 46. Response times for both the cycling with load (experimental) and cycling with no load (control) conditions across the time intervals for central large and central small responses. (Error bars depict 95% confidence intervals).

Figure 46 outlines the trends in the reaction time performance data collected from both the cycling with load and cycling with no load conditions, and categorized per the characteristics of the stimulus i.e., directions (anywhere and central) and sizes (large and small). It is clearly evident that central large for both the cycling with load and the cycling with no load conditions had the fastest reaction times, followed by central small for the cycling with load and cycling with no load, anywhere large (cycling with load and cycling with no load) and lastly anywhere small (cycling with load and cycling with no load) with the slowest average reaction times. This gives out a tendency for the conditions (cycling with load and cycling with no load) pairing in the speed of response classification from the slowest to the fastest. It is also interesting to note that in the four pairs classified, another propensity exists where the cycling with load conditions starts with a slower reaction times than the cycling with no load but this changes after the 1st interval where responses tend to be faster in the cycling with load condition, then revert after the 4th interval to see the cycling with no load condition once again dominating the faster reaction times.

4.3.3.2 Reaction Time ANOVA for the entire cycling duration

Table XI exhibits the analysis of variance results for the reaction time performance data in the cycling with load and cycling with no load conditions for the anywhere and central directions, and large and small sizes of the stimuli administered. Statistical significance was observed between directions; between sizes; across intervals; between directions and sizes; between directions and intervals; between sizes and intervals; between conditions and intervals; and lastly across directions, conditions and intervals.

Table XI. Repeated measures analysis of variance for reaction time responses (For the entire cycling duration, where the asterisk* highlights statistical significance).

Effect	Degree Of Freedom	F	p
DIRECTIONS	1, 23	84.774	<0.01*
SIZES	1, 23	66.496	<0.01*
CONDITIONS	1, 23	0.003	0.956177
TIME INTERVALS	6, 138	9.984	<0.01*
DIRECTIONS*SIZES	1, 23	112.801	<0.01*
DIRECTIONS*CONDITIONS	1, 23	0.667	0.422423
SIZES*CONDITIONS	1, 23	0.039	0.845736
DIRECTIONS*INTERVALS	6, 138	3.389	0.003775*
SIZES*INTERVALS	6, 138	3.104	0.006977*
CONDITIONS*INTERVALS	6, 138	2.445	0.028103*
DIRECTIONS*SIZES*CONDITIONS	1, 23	0.264	0.612041
DIRECTIONS*SIZES*INTERVALS	6, 138	1.715	0.121870
DIRECTIONS*CONDITIONS*INTERVALS	6, 138	2.173	0.049138*
SIZES*CONDITIONS*INTERVALS	6, 138	0.597	0.732249
1*2*3*4	6, 138	0.593	0.735823

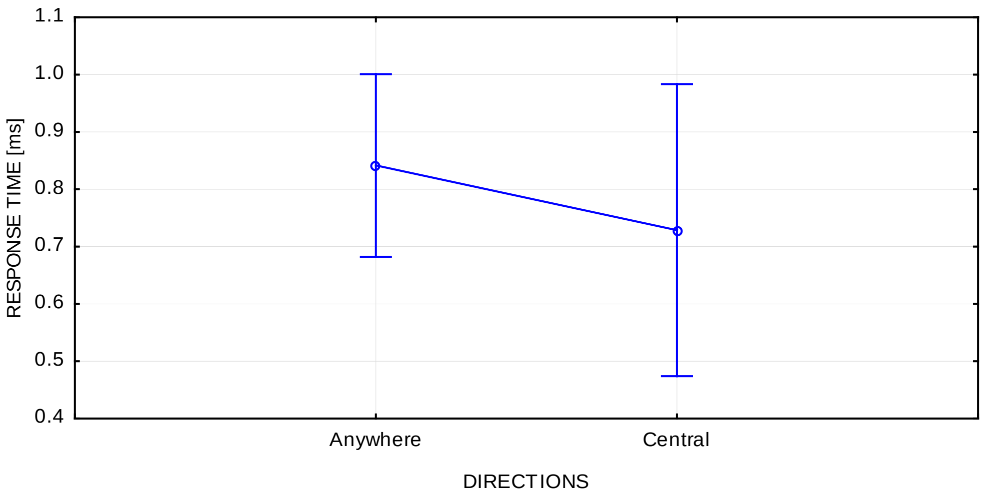

Figure 47. Reaction time ANOVA for the entire cycling duration between directions. (Error bars depict 95% confidence intervals).

Figure 47 shows the analysis of variance for the reaction time performance data between the anywhere and central directions of the generated stimuli. The graph shows that the central direction had faster responses than anywhere, where statistical significance was confirmed at $p<0.01$.

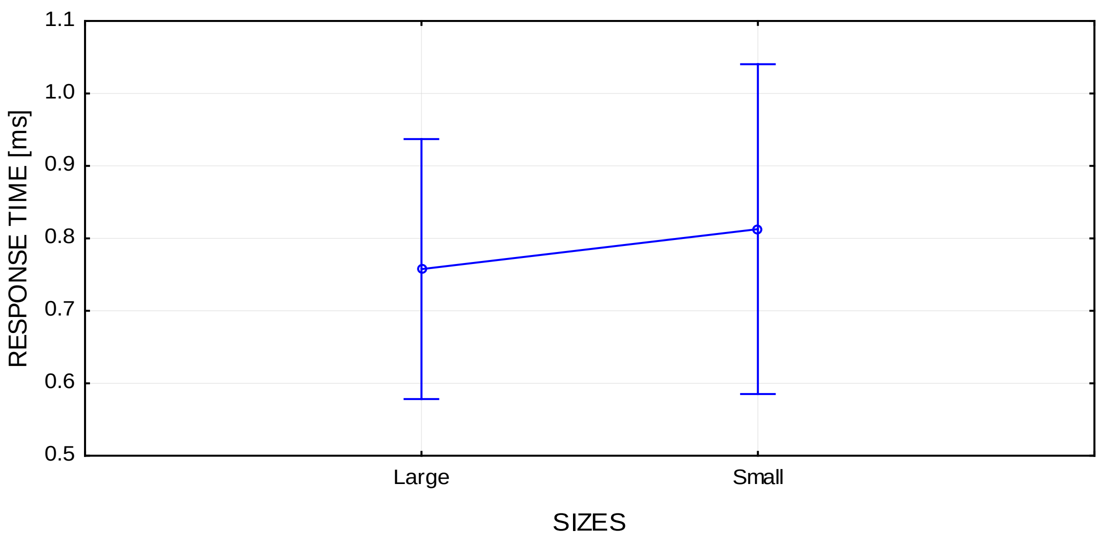

Figure 48. Reaction time ANOVA for the entire cycling duration between sizes. (Error bars depict 95% confidence intervals).

Figure 48 depicts the analysis of variance for the reaction time performance data between the large and small sizes of the generated stimuli in the conditions attempted. Faster times can be observed for the large sized stimuli than the small sizes. Statistical significance was observed at $p<0.01$.

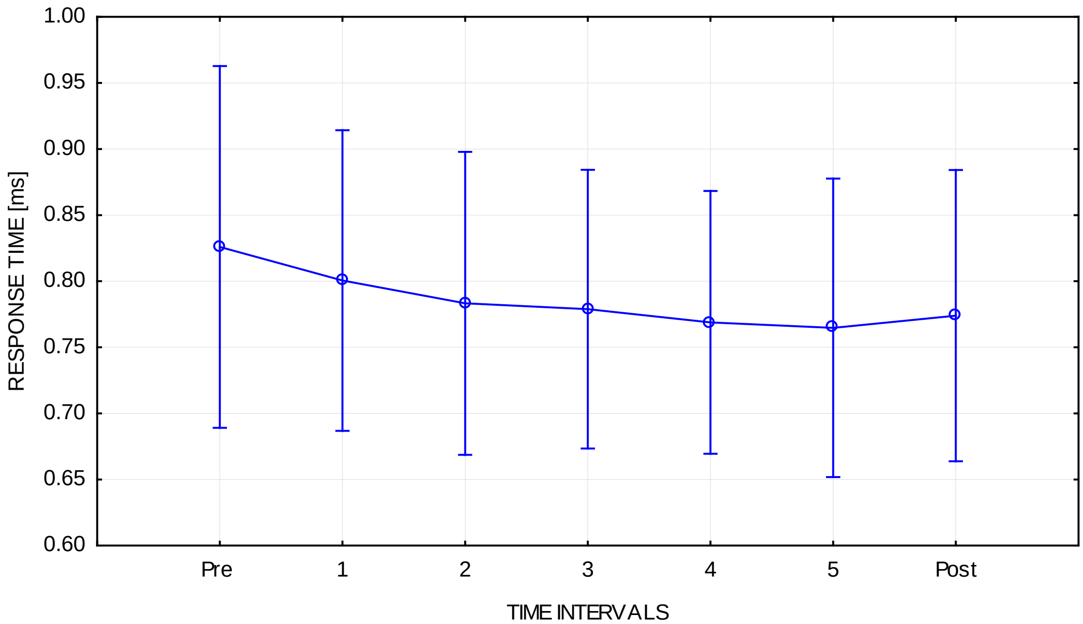

Figure 49. Reaction time ANOVA for the entire cycling duration across the time intervals. (Error bars depict 95% confidence intervals).

Figure 49 outlines the analysis of variance for the reaction time performance data across the 7 time intervals in the conditions attempted. Reaction time can be seen to decrease across the intervals from the pre-loaded cycling phase to the 4^{th} interval, but slightly recover in the post-loaded cycling phase (final interval). Statistical significance was confirmed at $p<0.01$.

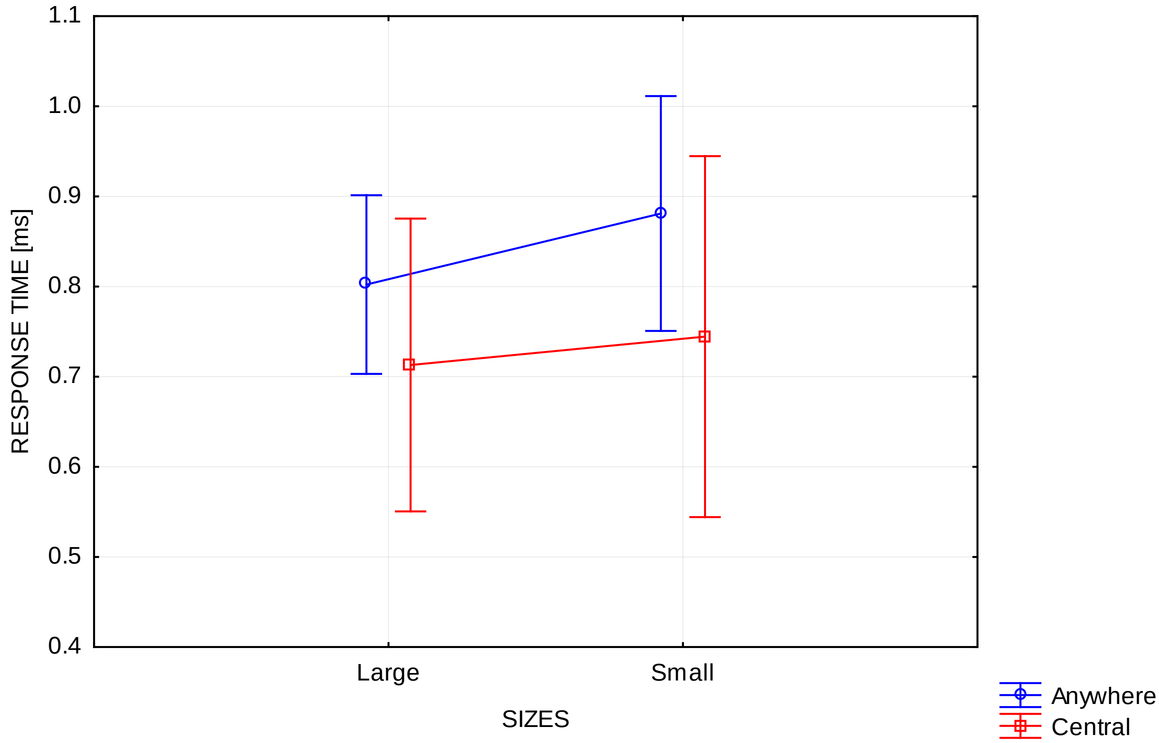

Figure 50. Reaction time ANOVA for the entire cycling duration between directions and sizes. (Error bars depict 95% confidence intervals).

Figure 50 illustrates the analysis of variance for the reaction time performance data between the directions (anywhere and central) and sizes (large and small) of the generated stimuli. It was be observed that responses in both directions were fastest when the stimuli were large than when it was small. Statistical significance was also observed at $p<0.01$

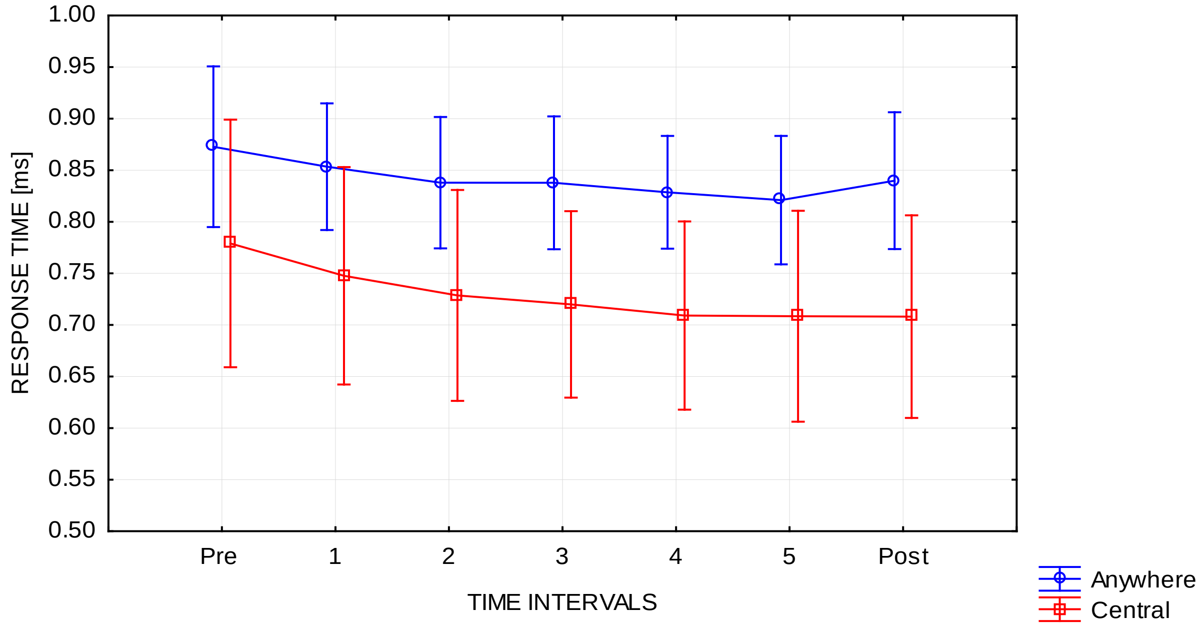

Figure 51. Reaction time ANOVA for the entire cycling duration between directions and time intervals. (Error bars depict 95% confidence intervals).

Figure 51 shows the analysis of variance for the reaction time performance data between the directions (anywhere and central) of the stimuli and the 7 time intervals. Responses were slowest in the warm-up phase and gradually got faster as time progressed for both directions, though responses got slower in the last interval for the anywhere direction. Statistical significance was conformed at p=0.003775

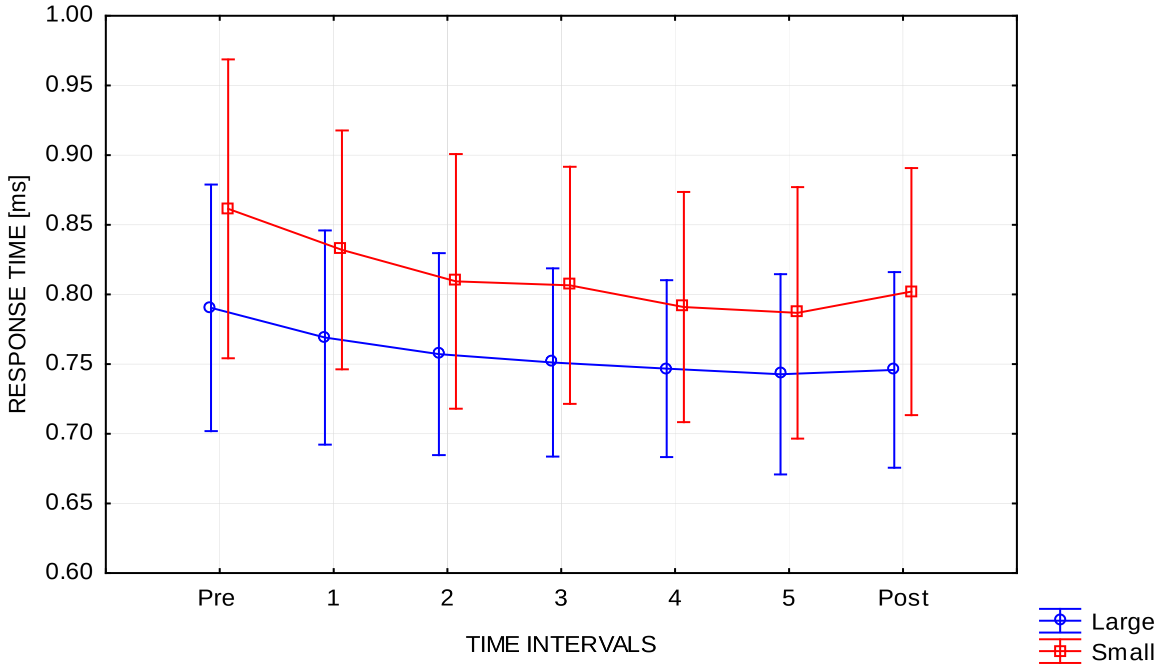

Figure 52. Reaction time ANOVA for the entire cycling duration between sizes and time intervals. (Error bars depict 95% confidence intervals).

Figure 52 illustrates the analysis of variance for the reaction time performance data between the sizes (large and small) of the stimuli and the 7 time intervals. As the cycling progressed, responses got faster for stimuli sizes, though the small stimuli got a slower response for the final interval. Statistical significance was confirmed at p=0.006977.

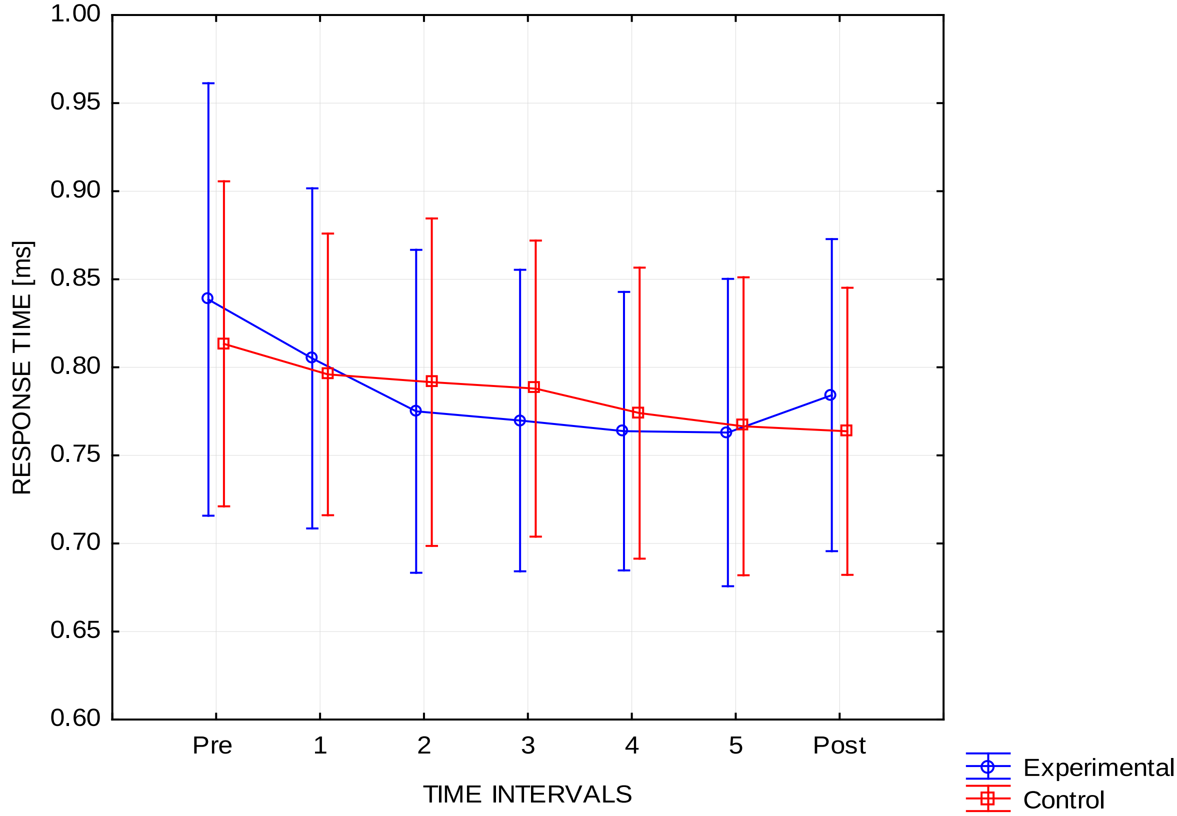

Figure 53. Reaction time ANOVA for the entire cycling duration between conditions and time intervals, where the experimental condition was one with cycling load and control the one with no load. (Error bars depict 95% confidence intervals).

Figure 53 shows the analysis of variance for the reaction time performance data between the conditions (cycling with load and cycling with no load) and the 7 time intervals. Responses started off slow in both conditions then got faster as the experiments progressed, though the cycling with load condition had a drop in reaction time during the recovery phase or cool-down interval. Statistical significance was confirmed at p=0.028103.

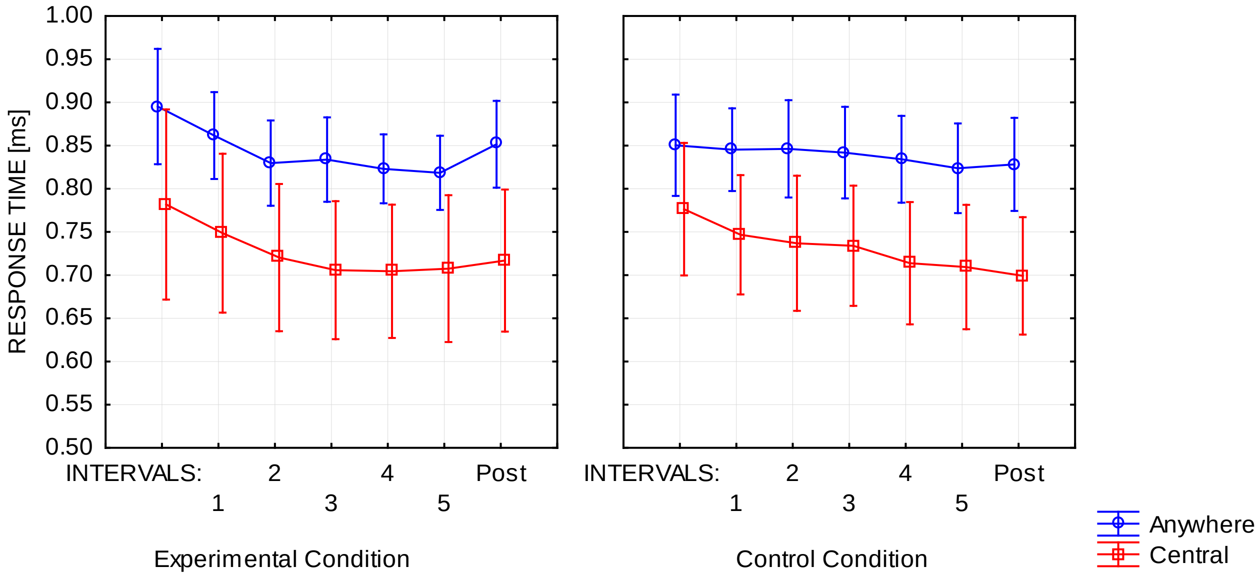

Figure 54. Reaction time ANOVA for the entire cycling duration across directions, conditions and time intervals. (Error bars depict 95% confidence intervals).

Figure 54 illustrates the analysis of variance for the reaction time performance data across the directions (anywhere and central) of the stimuli in both the cycling with load and cycling with no load conditions over the 7 time intervals. Responses in both directions started off slow, then gradually got faster and later slower in the final interval for the cycling with load condition, contrary to the cycling with no load condition where the response gradually picked speed with no final relapse. Statistical significance was confirmed at p=0.049138.

4.3.3.3 Target deviation performance

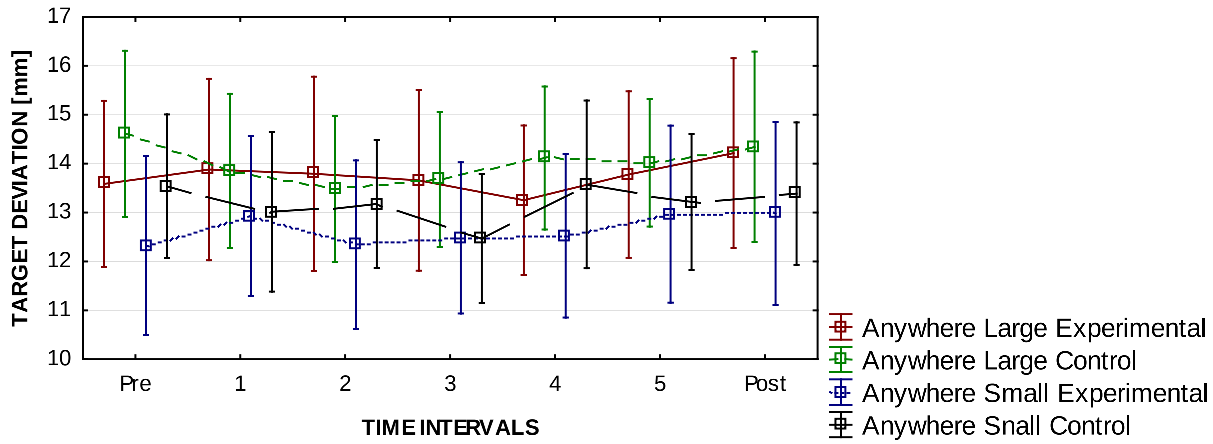

Figure 55. Target deviation responses for both the cycling with load (experimental) and cycling with no load (control) conditions across the time intervals for anywhere large and anywhere small responses. (Error bars depict 95% confidence intervals).

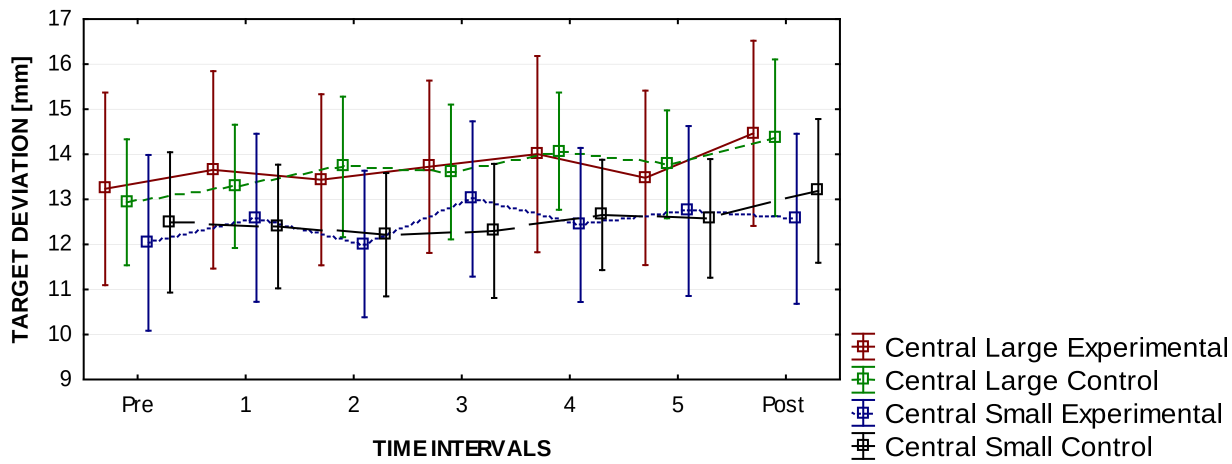

Figure 56. Target deviation responses for both the cycling with load (experimental) and cycling with no load conditions (control) across the time intervals for central large and central small responses. (Error bars depict 95% confidence intervals).

Figure 565 and 56 illustrates the trends in the target deviation performance data collected from both the cycling with load and cycling with no load conditions, and categorized per the characteristics of the stimulus i.e., directions (anywhere and central) and sizes (large and small).

4.3.3.4 Target Deviation ANOVA for The entire cycling duration

Table XII shows the analysis of variance results for the target deviation performance data in the cycling with load and cycling with no load conditions for the anywhere and central directions, and large and small sizes of the stimuli administered. Statistical significance was observed between directions, between sizes, across intervals and between directions and intervals.

Table XII. Repeated measures analysis of variance for target deviation responses (For the entire cycling duration, where the asterisk* highlights statistical significance).

Effect	Degree Of Freedom	F	p
DIRECTIONS	1, 23	4.5240	0.044366
SIZES	1, 23	59.5518	<0.01*
CONDITIONS	1, 23	0.0652	0.800772
INTERVALS	6, 138	2.3194	0.036448*
DIRECTIONS*SIZES	1, 23	0.8779	0.358501
DIRECTIONS*CONDITIONS	1, 23	2.6494	0.117212
SIZES*CONDITIONS	1, 23	0.6902	0.414641
DIRECTIONS*INTERVALS	6, 138	2.9561	0.009566*
SIZES*INTERVALS	6, 138	0.6370	0.700404
CONDITIONS*INTERVALS	6, 138	0.8724	0.517002
DIRECTIONS*SIZES*CONDITIONS	1, 23	0.1603	0.692588
DIRECTIONS*SIZES*INTERVALS	6, 138	1.1825	0.319208
DIRECTIONS*CONDITIONS*INTERVALS	6, 138	1.2319	0.293671
SIZES*CONDITIONS*INTERVALS	6, 138	0.7441	0.615068
1*2*3*4	6, 138	0.7643	0.599190

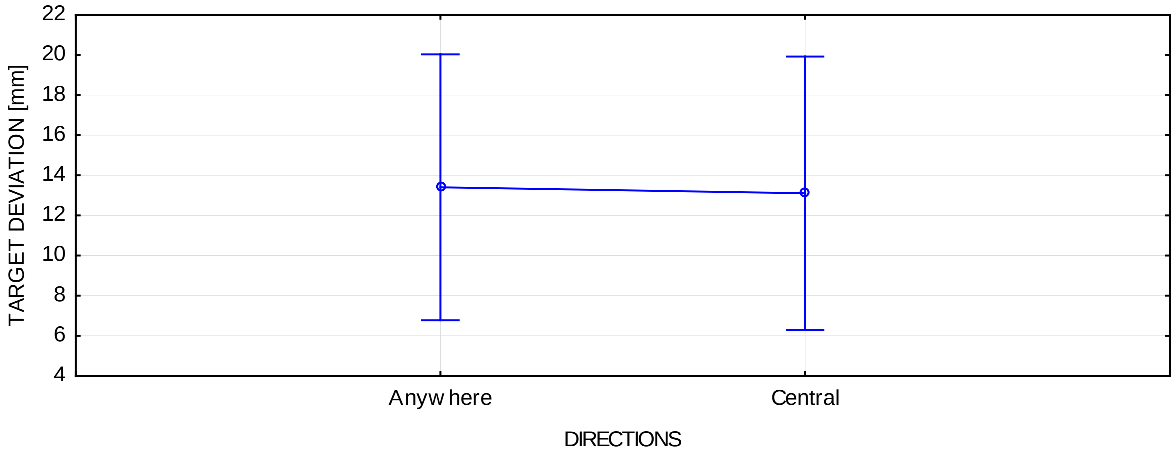

Figure 57. Target deviation ANOVA for the entire cycling duration between directions. (Error bars depict 95% confidence intervals).

Figure 57 shows the analysis of variance for the target deviation performance data between the anywhere and central directions of the generated stimuli, where responses to the central stimuli were closest to the target. Statistical significance was confirmed by $p=0.044366$.

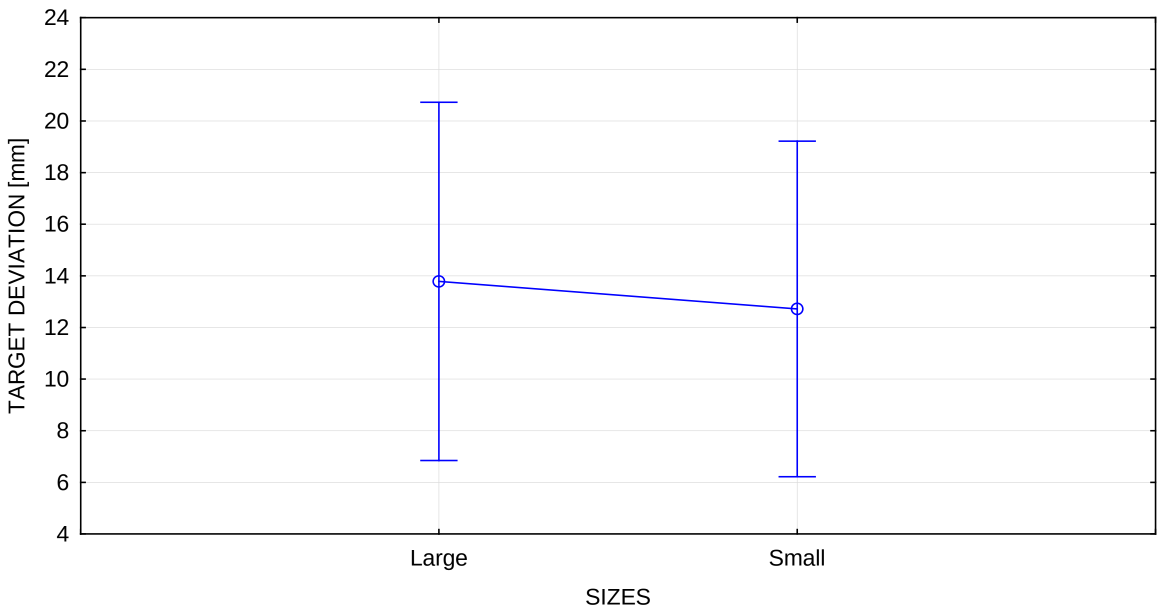

Figure 58. Target deviation ANOVA for the entire cycling duration between sizes. (Error bars depict 95% confidence intervals).

Figure 58 illustrates the analysis of variance for the target deviation performance data between the sizes (large and small) of the stimuli generated, where responses to the small stimuli were closer to the target than those for large stimuli. Statistical significance was confirmed by $p<0.01$.

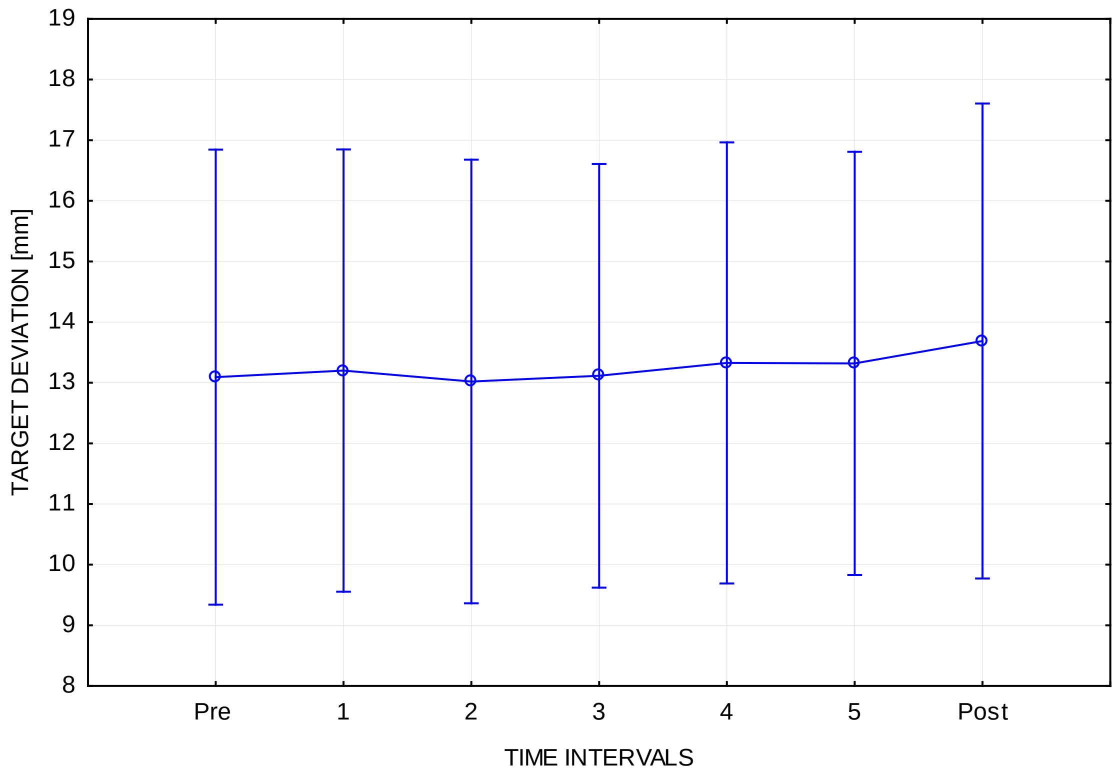

Figure 59. Target deviation ANOVA for the entire cycling duration across time intervals. (Error bars depict 95% confidence intervals).

Figure 59 depicts the analysis of variance for the target deviation performance data across the 7 time intervals in the conditions attempted. In this analysis responses made in the final interval were furthest from the target than all the other intervals. Statistical significance was confirmed by $p=0.036448$.

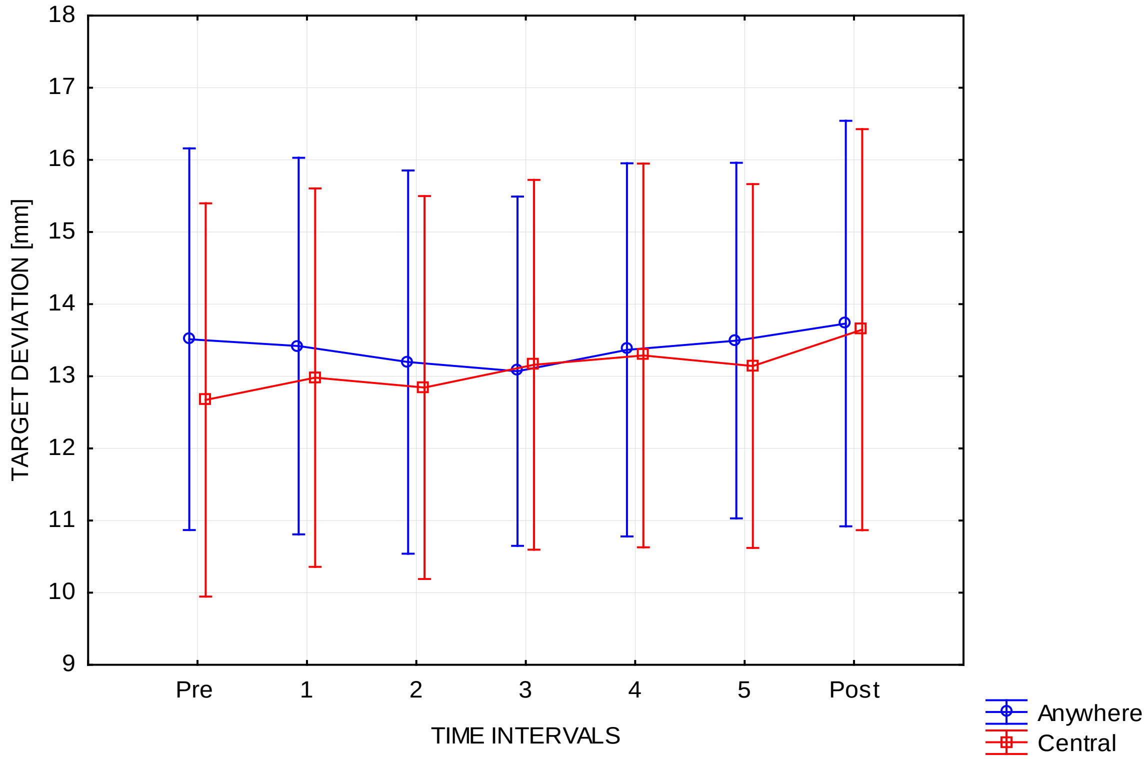

Figure 60. Target deviation ANOVA for the entire cycling duration between directions and intervals. (Error bars depict 95% confidence intervals).

Figure 60 shows the analysis of variance for the target deviation performance data between the directions (anywhere and central) of the stimuli and the 7 time intervals. Responses to both directions drew further from the target as the experiments progressed. Statistical significance was confirmed by p=0.009566.

CHAPTER 5

DISCUSSION

5.1 Discussion Introduction

This chapter seeks to annotate and expound on the findings presented in the results section (Chapter 4). It is also this chapter's primary objective to establish a relationship between the initial assumptions made in the hypotheses and the outcomes of the empirical procedures of this study.

The structure and approach of this discussion section is for the interactions of the psychophysiological responses and the cognitive performance to be reviewed simultaneously to give a comprehensive understanding of the trends that emerged from the experimental processes.

Three analyses were considered during the data reduction process, and these include; the analysis over the entire cycling duration, before and after the loaded-cycling phase analysis and during the loaded-cycling phase analyses. These analyses were made in a bid to respond to the research question whose aim was to investigate the extent of the impact that physical exertion has on cognitive performance. The analysis over the entire cycling duration looked at the general trends that arose all throughout the exercise bouts from the warm-up to the cool-off phase. In addition, the before and after the loaded-cycling phase analysis focused on the changes in cognitive responses between the initial warm-up phase and the final cool-off phase, to give an indication on the changes in cognitive performance immediately after aerobic exercise. Lastly, the loaded-cycling phase analysis examined the changes that occurred during the time intervals between warm-up and cool-off to see if cognitive performance was effected in any way by the load (60% of MAP) that was added during this period.

5.2 Response to the Hypothesis

The statistical analyses lead to the following response to the hypotheses:

1) Cognitive performance and psychophysiological responses were presupposed to be different between the moderate to high intensity exercise condition and the nil to minimal intensity exercise condition. No significant changes were found in the cognitive performance the two experimental conditions, though the psychophysiological responses changed significantly as can illustrated in Table XIII (Summary of results over the entire cycling duration) and explained in full in section 5.4.1 below).

2) Cognitive performance and psychophysiological responses were presupposed to change over time in the pre-exercise, during-exercise and post-exercise phases. Only the error detection rate performance measure of the proof reading task showed a significant improvement immediately after exercise implying a positive effect of aerobic exercise on visual search and perception performance after exercise However, none of the cognitive performance measures changed significantly during the exercise phase. Heart rate and RPE responses changed significantly immediately after exercise as well as during exercise (see Table XIV in section 5.4.1 below for more detail).

3) The change in cognitive and psychophysiological responses over time was posited to be different between the moderate to high intensity exercise condition and the nil to minimal intensity exercise condition. Exercise improved performance only in reading speed of the proof reading task and response time of the modified Fitts' task. Both heart rate and RPE response improved significantly as a result of exercise (see Table XIII below, and refer to section 5.4.3 for more detail).

5.3 Summary of Results

Table XIII lays a brief summary of results showing how each variable tested for the relevant categories that were considered. These categories include the effect of conditions, time intervals, condition over time intervals, complexity, complexity over time intervals and complexity across conditions on the dependent variable. The statistical relevance of these effects will thus depict the nature of relationship between the acute aerobic exercise conducted in the experimental protocols and each variable considered, i.e. cognitive and psychophysiological responses.

As can be seen in the Table XIII below, exercise had no significant impact on all the cognitive performance measures that were tested (condition effects). Performance however changed over time in the reading speed, error detection, reaction time and target deviation measures (time effects). When exercise effects when considered over the entire duration of the cycling, only reading speed and reaction time showed significant changes. As for the task complexity consideration, all cognitive measures showed significant changes, but it is only in reading speed, error detection, reaction time and target deviation performance that task difficulty changed significantly over the exercise duration. Exercise also showed a significantly positive impact on heart rate and RPE responses, across the exercise duration and also when the mean responses for the two experimental conditions were considered over time.

Table XIII. Summary of results over the entire cycling duration (for pre-, during- and post-exercise phases).

<table>
<tr><th colspan="2"></th><th>Condition</th><th>Time Intervals</th><th>Condition*Time</th><th colspan="2">Complexity</th><th>Complexity*Time</th></tr>
<tr><td colspan="2">Heart Rate</td><td>Exp. ↑</td><td>Post ↑</td><td>Exp. ↑</td><td colspan="2">N/A</td><td>N/A</td></tr>
<tr><td colspan="2">RPE</td><td>Exp. ↑</td><td>Post ↑</td><td>Exp. ↑</td><td colspan="2">N/A</td><td>N/A</td></tr>
<tr><td colspan="2">Memory Recall</td><td>–</td><td>–</td><td>–</td><td colspan="2">Five ↑</td><td>–</td></tr>
<tr><td rowspan="2">Proof Reading Task</td><td>Reading Speed</td><td>–</td><td>Post ↑</td><td>Exp. ↑</td><td colspan="2">High ↑</td><td>High. Post ↑</td></tr>
<tr><td>Error Detection</td><td>–</td><td>Post ↑</td><td>–</td><td colspan="2">High ↑</td><td>High. Pre ↑</td></tr>
<tr><td rowspan="2">Modified Fitts' Test</td><td>Reaction Time</td><td>–</td><td>Post ↓</td><td>Exp. ↑</td><td>Any ↑</td><td>Small ↑</td><td>Any. Post ↓
Small. Post ↓</td></tr>
<tr><td>Target Deviation</td><td>–</td><td>Post ↑</td><td>–</td><td>Any ↑</td><td>Small ↓</td><td>Any. Post ↑</td></tr>
</table>

Exp. = Experimental condition (Cycling with load condition)
Post = Post-exercise interval
↑ = increased/higher
↓ = decreased/lower
Five = Five digit complexity
High = High resolution
N/A = Analysis not applicable to the variable in question
Small = Small size
(—) = p>0.05, implying statistical insignificance
Any = Anywhere direction

5.4 Impact of Exercise on Cognitive Performance

The main objective of this study was to investigate the relationship between physical exertion for an extended duration and cognitive performance. Thus the experimental protocol involved participants engaging in two bouts of acute aerobic exercise in of indoor cycling while performing three cognitive tasks at 10 minute intervals to see if exercise would have any effects on cognitive performance. The two bouts of exercise represented the two conditions namely the cycling with load and the cycling with no load condition, where in the cycling with load condition participants cycled with predetermined personalized cycling load/resistance while no resistance was applied for the cycling with no load condition.

The results of this experimentation presented five significant effects across both the psychophysiological responses and the cognitive performance, as shown in the summary of results in Table XIII.

5.4.1 Differences in performance between the two experimental conditions

This section served as the primary findings of the study, where the two conditions (cycling with load and cycling with no load) that were considered in the protocol represented substantial physical exertion and nil to minimal physical exertion, respectively. Thus the research question was addressed by examining the differential condition effects on cognitive performance to give a clear indication of what impact exercise has on cognition.

However, as can be seen in the summary of results (see Table XIII above), there was no statistical significance between the conditions (cycling with load and cycling with no load) and any of the cognitive performance measures; i.e. memory recall, reading speed, error detection, reaction time and target deviation. Hence the primary findings of this study indicate that exercise had no effect on cognitive performance. Bullock and Giesbrecht, (2014) in a similar study which looked at the effects of a prolonged bout of physical activity on cognitive performance explained that the acute bout of exercise drains processing resources and while there are still sufficient resources for the learning effect to continue, there are not sufficient resources to support learning under the high activity load, which could have been the case for the cognitive measures in this study. It can also be suggested that the intensity of the exercise might have been too high resulting in insignificant performance changes as opposed to the expected performance increase, seeing that the RPE scores escalated to 17 which is an indication from the participants that they perceived the exercise as very hard. Looking at the inverted-U model of exercise arousal on cognition as described by McMorris (2011), high intensity exercise is associated with high arousal levels which elicits neural noise, resulting in poor cognitive performance.

Previous studies also indicate that the effects of acute exercise on cognitive performance generally tend to be small and affected by a range of behavioral-related, exercise intensity and duration related factors, where larger effects are possible and accomplished for particular cognitive outcomes when specific exercise parameters are utilized (Brisswalter *et al.*, 2002; McMorris and Graydon, 2000; Tomporowski, 2003; Lambourne *et al.,* 2010; Chang *et al.*, 2012).

In addition, the age range (18-24 years) used in this study might have posed as a negative factor to the influence on cognition by exercise, seeing that studies have suggested that it is difficult to ascertain an effect of physical exercise on cognitive performance in young adults due to the fact that cognitive health peaks during that time, hence not much room for improvement (Hillman *et al*., 2008; Salthouse and Davis, 2006).

Nonetheless, the results showed that there was statistical significance between the conditions and the psychophysiological measures (heart rate and RPE) that were considered. This was to be expected in this protocol as it confirmed the difference in the levels of physical exertion between the cycling with load and cycling with no load condition. As can be seen in Table XIII above, there was a significant increase in both the heart rate and RPE measures during the cycling with load condition.

Heart rate in the cycling with load condition can be seen to increase sharply once resistance is added at the 0th minute (see Figure 11, page 32). According to Almeida and Araújo (2003), one of the acute effects of exercise on the human body is elevation of heart rate at the onset of exercise and adjustment to training. This is due to inhibition of the vagus nerve that innervates the heart to slow cardiac muscle activity during rest via the parasympathetic pathway of the autonomic nervous system (Boron, 2011 and Maciel *et al.,* 1986).

RPE also increased due to load increase which made the cycling require more effort to maintain the same cadence of 80-90rpm which the participants had started with in the warm up where there was no cycling resistance. Since the subjective rating of the intensity of exertion perceived by the person exercising is generally a sound indicator of relative fatigue (Fletcher *et al.,* 2013), the increase in RPE scores that can be observed for the cycling with load condition (Figure 18, page 39) suggest that by the 5th interval the participants were experiencing an onset of fatigue as their average responses got to 16.5 on the RPE scale.

After the initial increase in heart rate in the cycling with load condition, a steady state is reached where only a gradual and slow increase in heart rate is observed from the 2nd minute all the way to the 50th minute when the resistance is removed. This suggests that as the exercise continues, heart rate increases again due to the adrenergic stimulation of the sinus node that controls cardiac muscle and the increase of serum norepinephrine (Almeida and Araújo, 2003, and Maciel *et al.,* 1986).

Thus the higher perfusion rate as well as the elevated metabolic rate to meet the demand in high energy, causes an overall increase in the body's temperature (Almeida and Araújo, 2003). This explains the further increase in RPE measures (see Figure 18, page 39), where participants felt the discomfort the increasing body heat as well as the sustained constant cycling load, hence their higher perceptions of their level of physical exertion.

The second statistical hypothesis postulated that both cognitive and psychophysiological responses would change over time for the pre-exercise, during exercise and post-exercise instances. This was addressed by the before and after the loaded-cycling phase analysis and the loaded-cycling phase analysis that were conducted during the data analysis process. Table XIV below shows the summary of these two analyses.

Table XIV. Summary of results for the pre-post exercise and during-exercise comparisons.

		Condition Effects between Pre- and Post-exercise	**Condition Effects for During-exercise**
Heart Rate		Exp. ↑	Exp. ↑
RPE		Exp. ↑	Exp. ↑
Memory Recall		–	–
Proof Reading Task	**Reading Speed**	–	–
	Error Detection	Exp. ↑	–
Modified Fitts' Test	**Reaction Time**	–	–
	Target Deviation	–	–

↑ = increased/higher ↓ = decreased/lower Exp. = Cycling with load condition (—) = $p>0.05$, implying statistical insignificance.

It can be observed in the table above that of all the cognitive performance measures only the error detection rate measures of the proof reading task showed statistical significance ($p<0.05$) between conditions for the before and after the loaded-cycling phase (pre- and post-exercise) analysis. The cycling with load condition had a higher error detection rate of 70% than the cycling with no load condition which had 66% (see Figure 42, page 63). This implies that the participants had a higher probability of correctly identifying more errors in the reading passages (both low and high resolution) whilst cycling with load (60% of their MAP) than when they cycled without any load across the pre- and post- exercise intervals. It is also an indicator that visual pattern recognition, which is the measure for error detection rate, improves in the recovery phase after an exercise bout from the level that would have been otherwise recorded in the warm-up phase.

These findings also confer well with findings from a study by Hogervorst *et al. (*1996), where participants performed psychomotor and cognitive tests before and immediately after endurance cycling at 75% of their maximal work capacity. Color word interference in the Stroop test that they attempted, which closely resembles the cognitive requirements in visual pattern recognition (Risko *et al.,* 2005; MacLeod, 1991 and Stroop, 1935), showed an increase in speed of performance after exercise than before. As such, an enhanced activation was suggested to be responsible for this better performance on psychomotor and cognitive tests (Hogervorst *et al.*, 1996). However, performance in visual search and perception has been seen not to improve significantly once the exercise duration and intensity pushes participants into physical fatigue (Bard and Fleury, 1978; Bullock and Giesbrecht, 2014).

The before and after loaded-cycling also showed condition significance for both heart rate and RPE measures (see Table XIV, page 87). The cycling with load had a heart rate of 100bpm whilst the cycling with no load condition had 86bpm in the comparison between the pre- and post-exercise phases, as can be seen in Figure 12 (page 34). All in all, a higher heart rate of 97bpm was recorded for the post-exercise phase than the 90bpm for the pre-exercise (see Figure 13, page 34), indicating more cardiac activity post-exercise than in the warm-up. Almeida and Araújo (2003) suggested that the time taken for heart rate to fall to resting levels (pre-exercise values) depends on the interaction among autonomic function, the level of physical fitness and the intensity of the exercise. Hence, the higher post-exercise heart rate in this study might as a result of the extended aerobic exercise (50 minutes of cycling) which would require a longer recovery time for heart rate to return to pre-exercise levels. The drop in heart rate after the exercise is stopped (as can be seen in Figure 11, page 32), was credited to the decrease of post-exercise norepinephrine concentration and vagal modulation that goes via the parasympathetic nervous pathway to down-regulate cardiac activity (Almeida and Araújo, 2003).

Results from a review by Chang *et al. (*2012) revealed that exercise intensity has a significant influence on how aerobic exercise impacts cognitive performance (during the post-exercise phase), such that positive effects that were significantly different were only observed when the exercise was very light, light and moderate. In the current study, the exercise started off at very light to light intensity as indicated by the subjective measures of the participants, i.e. RPE score of 8-10. However, the sustained cycling resistance increased the participants' perception of the exercise intensity to very hard, as can be seen in the RPE responses in Figure 24 (page 44). This was most likely the reason for exercise having no effects on response time and target deviation (motor perception), reading speed (information processing) and short-term memory performance immediately after exercise.

Chang *et al. (*2012) concluded the size of the effect of exercise cognitive performance following exercise is dependent on the interaction of the amount of time between the exercise and the cognitive testing and the intensity of the exercise. Specifically, when performed immediately after exercise, lighter intensity exercise is more beneficial, but when performed after a delay of more than a minute, very light intensity exercise no longer has positive effects and more intense exercise (very hard) effects bigger cognitive performance changes (Chang *et al.,* 2012).

Table XIV (page 87) serves to show that there were no cognitive performance changes during the exercise phase which lasted for 50 minutes. This goes in contrary with several studies which have confirmed that exercise for longer than 20 minutes results in positive cognitive performance effects (Brisswalter *et al.*, 2002; Lambourne and Tomporowski, 2010). Chang *et al. (*2012) observed that the time of cognitive test administration during exercise significantly influences the effects such that effects in the first 10 min were negligible, effects after 11–20min of exercise were negative, and effects after 20min of exercise were positive. However, it has been recommended from various studies that in protocols longer than 20 minutes, factors of physical fatigue and dehydration may become increasingly relevant and thus posing negative effects on cognitive performance, and as such these require further exploration (Cian *et al.*, 2001; Tomporowski, 2003; Chang *et al.*, 2012).

5.4.2 Differences in performance changes over time

Performance in two of the cognitive tests (the proof reading task and the modified Fitts' task) changed significantly over the total cycling duration of 50 minutes (time effects). The specific variables that were impacted were reading speed and error detection rate in the proof reading task, and response time and target deviation in the modified Fitts' task (see Table XIII, page 83).

In the proof reading task, the reading speed parameter experienced a general increase in the number of words read per minute from the initial warm-up interval to the end of the cycling bouts in the cool-off interval or the recovery phase as can be seen in Figure 31 (page 52). Thus the participants' reading got faster as the exercise bouts progressed which in an indication of a learning effect in the proof reading task. The post hoc analysis for reading speed across all time intervals (see Appendix E1a) showed that performance in the pre-exercise interval was significantly different from performance in the second interval all the way to the post-exercise interval. This showing that even though there was not much change in reading speed between the warm-up phase and the first 10 minutes of exercise, learning effect soon had the participants reading faster after the first interval all the way to the end of the exercise.

The error detection parameter also showed an increase in the rate at which participants were able to pick up errors embedded in the text, from the warm-up interval to reach a peak of 74% during the third interval which was about 20-30 minutes after starting the exercise (see Figure 39, page 60). The increase in performance shows a learning effect in detecting errors up to midway in the cycling bout. A post hoc analysis conducted on the error detection data across all time intervals showed that the third interval was significantly different from the pre-exercise interval. This indication suggests that performance in visual perception and visual search changes significantly within 30 minutes of exercise. The rate of error detection then dropped to plateau at 69% from the forth interval through to the recovery interval, which might have been cause by onset of physical fatigue kicking in and depleting resources that would have otherwise been used for cognitive function (Bullock and Giesbrecht, 2014).

As for the modified Fitts' task, the reaction time parameter had an improved performance over time with an initial response time mean of 0.83 milliseconds in the warm-up interval to 0.76 milliseconds in the fifth interval (see Figure 53, page 74), implying the participants got faster at responding to the stimulus over time which is another indication of a learning effect. However, the post-exercise interval experienced an increase in response time, meaning the participants got slower in the recovery phase which might merely have been a sign of boredom or lack of concentration in the task at this stage in anticipation of the end of the cycling bout. This is probable seeing that the average RPE responses at this stage were approximately the same as with those given in the warm-up interval (see Figure 18, page 39). The post hoc analysis on response time across the entire exercise duration showed that performance during the second interval to the post-exercise interval was significantly different from performance in the pre-exercise interval, confirming how a learning effect played a role in the improved performance over time (see Appendix E1c).

In the target deviation performance results, there was a slight but definite progressive increase in the distance between the site of the stimulus and the point of the response. The pre-exercise interval had a deviation of 13.0 millimeters but by the post-exercise interval, this distance had increased to 13.7 millimeters which suggests that even though the speed in response to stimulus improved significantly up to the fifth interval, the accuracy of the responses however, decreased over time as the exercise progressed. The post hoc analysis of target deviation responses across all the time intervals (see Appendix E1d) shows a significant change in performance between the second interval and the post-exercise interval. This doesn't say much about the overall performance change throughout the exercise because one cannot pin-point the exact instance of the significance in order to map out a sensible trend in performance.

5.4.3 Differences in performance changes over time between the two conditions.

The third statistical hypothesis of this study postulated that the change in cognitive performance over time would be different for the cycling with load and cycling with no load conditions. Thus it was of pertinent importance to consider the condition by time effects for the cognitive performance results. As can be seen in Table XIII (Summary of results for the entire cycling duration, page 83), only reading speed of the proof reading task and reaction time of the modified Fitts' task showed statistical significance out of all the cognitive performance measures. The memory recall task showed no changes between the conditions, implying that exercise had no effect on working memory over time. This fits with the observation of Chang *et al. (*2012) that there are no significant effects for working memory, digit span (forward), and figural learning. Tomporowski (2003) also concluded that acute exercise does not benefit short-term working memory but does impact positively on long-term memory.

In the case of the proof reading task, the cycling with load condition had a statistically significant (p=0.023) higher increase in the reading speed than was observed in the cycling with no load condition. The number of words read per minute were greater in the cycling with no load condition (239 words/minute) than in the cycling with load (225 words/minute) during the pre-exercise interval. Reading speed for the cycling with load condition increased thereafter to be more than the cycling with no load from the first interval to the post-exercise interval. This demonstrates the improvement in reading speed performance as a result of physical exertion over time, where reading speed is one of the indicators of central processing thus implying that physical exertion over time expedites the rate at which information is processed. The fastest speed was recorded at 263 words/minute in the cycling with load condition during the fifth interval, which was the last interval with cycling resistance. The cycling with load condition suffered a drop in reading speed from 263 to 252 words per minute between the fifth and post-exercise intervals, respectively. This drop in reading speed performance could have been a response to mental fatigue at the end of the exercise bout.

Reaction/response time, a measure of the modified Fitts' test showed a significant difference (p=0.028) between the cycling with load and the cycling with no load condition over time. The cycling with no load condition started with a faster response time of 0.813 milliseconds than the cycling with load (0.838 milliseconds) in the pre-exercise as well as the first interval. However, as the exercise progressed, the cycling with load condition measured faster response times from the second to the fifth interval, with the fastest response time being recorded during the fifth interval at 0.763 milliseconds. Physical exertion can thus, be associated with the amelioration of response time performance during the period between the second and fifth intervals, as participants performed better when they were cycling with load/resistance. However, the post-exercise interval saw a drop in performance for the cycling with load condition where the response time increased to 0.784 milliseconds. This decline in performance could have been an indication of mental fatigue settling in, or merely an issue of participants pulling back their effort in performance of the cognitive task in the recovery interval in anticipation of the termination of the cycling bout.

On the other hand, the cycling with no load condition had a gradual decrease in response time from a slower 0.813 milliseconds in the pre-exercise interval to a faster 0.764 milliseconds on the post-exercise interval. This improvement in performance during the cycling with no load condition was most likely a result of learning effect over time where participants got better at responding to the stimulus presented on the touch screen each time they repeated the task by mastering the nature/requirements of the task, the tendencies and patterns of the stimuli (i.e. the anticipation of the placement of each stimulus on the screen).

Literature puts both response time and information processing (reading speed), together with verbal fluency and decision making, under the executive tasks that have significant positive effects with exercise (Tomporowski, 2003; and Chang *et al.,* 2012).

Table XIII (page 83) also serves to illustrate the statistical significance for heart rate and RPE in the condition over time effect consideration, which was an expected finding of the study for physical exertion to induce differences in both the physiological and subjective responses, respectively. Thus a relatively similar average heart rate was recorded for the cycling with load and cycling with no load conditions (91 bpm and 88 bpm) during the pre-exercise interval. However, this quickly changed from the first interval as heart rate for the cycling with load condition increased to 141 bpm, where a plateau can be observed over the second through to the fifth interval that registered the highest heart rate of 152 bpm, before the drop to 108 bpm in the post-exercise interval. This coincides with the 60% of MAP cycling load that was added during the first interval and removed after the fifth interval, which clearly manifests the impact of exercise on heart rate responses which increases drastically at the onset of the cycling with load phase and recovers when the load is removed. This conclusion is supported by the responses in the cycling with no load condition where heart rate measures remained fairly constant from the pre-exercise interval at 88 bpm to the post-exercise interval at 85 bpm.

Furthermore, RPE responses portrayed a similar pattern as that of the heart rate responses where the cycling with load recorded an increase in RPE scores from the first interval (score of 9) to climax in the fifth interval at a score of 16, then drop down to a score of 9 in the post-exercise interval (see Figure 18, page 39). In contrast, the cycling with no load had a gradual increase from a score of 7 in the pre-exercise interval to a score of 9 in the post-exercise interval (similar to the post-exercise score of the cycling with load condition). Thus, as divulged by the contrast in the nature of the cycling with load and the cycling with no load conditions, exercise had a significant impact on the perceptual responses of the participants as they completed both cycling bouts. This also serves to indicate that the participants' perception of how hard they were working matched the physiological responses given by the heart rate measures, of how much work they were really doing.

5.5 The interaction between exercise and task complexity on performance

5.5.1 Differences in responses between the task complexity levels

As was expected, there was a significant complexity effect in all the cognitive performance tasks that were attempted, meaning there was improved performance in the simple tasks compared to the more complex tasks (see Table XIII, page 83).

Thus, when considering task difficulty differences in the memory recall task, performance was better for the five digit display with a 94% success rate than the seven digit one which had a 76% success rate (see Figure 26, page 47) Both error detection and reading speed in the proof reading task had improved performance with the high resolution passages than the low resolution ones, confirming that reading is better in terms of accuracy in spotting errors and speed if the text is clearer than when it is blurry.

As for the modified Fitts' task, short times were required to respond to stimuli that was large and centrally located as shown by the faster response times for both large and central stimuli than small and anywhere stimuli (see Figure 51 and Figure 52, page 72). However, shorter deviation distances were observed for stimuli that were small and centrally located, suggesting that participants made more effort to respond with accuracy to stimuli that was in a simple location (central) but small in size (see Figure 57 and Figure 58, page 78).

This relates well with inferences made by Payne *et al. (*1992) that the more complex a decision problem, the more people will use simplifying decision heuristics. Hence their performance gets better in the simpler tasks as they tend to prefer to attempt and concentrate more on the easier choices than they would for the more difficult tasks.

5.5.2 Differences in responses between the task complexity levels over time

More interesting from the complexity findings were the complexity over time effects, to check if there was any learning effect over time for both the simple and the complex tasks and to confirm the particular stage and intervals in the exercise bouts where there was prominent performance for either of the two complexities.

As shown in the summary of results for the entire cycling duration (see Table XIII, page 83), only the proof reading task and the modified Fitts' task showed statistical significance for the complexity over time effects consideration. The reading speed of the proof reading task had an initial measure of 255 words per minute for high resolution passages in the pre-exercise interval as compared to 210 words per minute for low resolution passages. This speed generally improved for both resolutions across the exercise duration. However, high resolution had an initial increase for the first interval (272 words per minute), followed by a gradual decline in speed to the 261 words per minute in the third interval, a second increase in speed which peaked in the fifth interval at 274 words per minute and thereafter a slight drop in the post-exercise interval (Figure 33, page 54). The initial increase in speed was a general effect of exercise on reading performance. Nonetheless, the drop that can be observed from the first to the third interval was most likely a learning factor where participants took slightly longer to read through the passages as they tried to identify more errors in the same passage, as can be confirmed by the increase in the error detection rate for high resolution readings, especially for the third interval (see Figure 40, page 61).

On the other hand, reading speed for low resolution passages had a relative increase to the third interval (240 words per minute), then a rather steady decline to 234 words per minute in the post-exercise interval (see Figure 33, page 54). Thus, a conclusion can be established that performance for both in resolution readings improved as a result of a learning effect existing across intervals, though high resolution had generally faster speeds because one is able to read faster and better when text is clearer.

Error detection also had better performance in the high resolution readings than the low resolution, where the error detection rate started off in the pre-exercise interval at 76% and 59% for high and low resolutions, respectively. There was a general increase in performance over time for the low resolution readings from 59% in the pre-exercise interval to 68% in the post-exercise interval (see Figure 40, page 61). This trend can be accredited to the learning effect that was mostly likely existent in the reading performance over time. High resolution reading experienced an increased that peaked in the third interval at 79% where participants mostly likely applied the most effort to perform better as their reading speed also decreased in a bid to identify more errors within the text. After the third interval, the rate of error detection gradually declined to 71% in the post-exercise interval (see Figure 40, page 61). This was probably a response to physical exhaustion because an increase in reading speed is also observed at this stage as participants probably scanned through the passages quickly while paying less attention to the errors in text.

Thus a relationship can be suggested to exist between information processing that existed in the reading speed variable and visual pattern recognition or visual search in the error detection, where visual search relies on thoroughly executed information processing as an aspect of accuracy.

In the modified Fitts' task, response time was fastest for the simpler combination (i.e. Central Large) over the entire exercise duration. Figure 51 (page 72) shows how both central responses progressively decrease from 0.779 milliseconds in the pre-exercise interval to 0.708 milliseconds in the post-exercise interval. This implies that performance for the direction entity of the stimuli improves over time, meaning motor programming gets automated as exercise progresses. Response times for stimuli in the anywhere direction also improved over time, though slower than the central responses, to reach the fastest time in the fifth interval at 0.821 milliseconds. Thereafter, an increase in response time can be observed for the post-exercise interval depicting a drop in performance during the recovery phase (which is a phenomenon that was also observed for both large and small stimuli).

Response times for large stimuli improved significantly over time than small stimuli, being fastest in the fifth interval at 0.743 milliseconds, as opposed to small stimuli that only got to 0.787 milliseconds. In other words, motor precision got better with the progression of the exercise, where participants able to respond faster to stimuli that was big enough to be selected easily. Both large and small stimuli show a notable increase in response time to 0.746 and 0.802 milliseconds, respectively, in the post-exercise interval. This increase in response time during the post-exercise interval (as observed for anywhere stimuli as well), leads to the conclusion that stopping the exercise (i.e. removal of cycling load) slows down or causes a decline in response time performance.

Target deviation only had a significant improvement of the direction entity of the stimuli for the complexity over time effects. The stimuli that came centrally started off in the in the pre-exercise interval with a smaller deviation distance (12.7 millimeters) than the anywhere stimuli (13.5 millimeters). However, performance for the central stimuli declined progressively over time, ending with a deviation distance of 13.6 millimeters in the post-exercise interval (Figure 60, page 80). There were brief improvements for the second and fifth intervals as compared to their preceding intervals, but this did not reverse the overall deterioration in performance for centrally located stimuli that was otherwise expected to improve with time. This finding draws inferences that accuracy for central stimuli got poor even though the response time got faster over time.

Anywhere stimuli responses initially improved in performance up to the third interval where the shortest deviation distance was recorded at 13.1 millimeters, thereafter declining to eventually give a post-exercise deviation distance on 13.7 millimeters (see Figure 60, page 80). The initial improvement in performance can be explained by the learning effect phenomenon that existed in most of the cognitive task performances that were considered. However, the decline after the third interval for stimuli in the anywhere direction might have been caused by the automated motor programming of the central stimuli where over time participants concentrated more on responding faster to the central stimuli and less on the anywhere. Thus, accuracy in the responses receded even though an initial increase from the start of the exercise to the third interval had been established.

CHAPTER 6

CONCLUSION

6.1 Study Outcomes

This study focused on understanding the acute effects of aerobic exercise on cognitive performance, where responses to specific cognitive tasks were compared between a moderate-to-high intensity exercise bout and a nil-to-low intensity exercise bout.

The findings from the experimentation adopted in this study show that even though aerobic exercise did not result in a significant impact on visual perception, information processing, working memory performance and motor responses in the overall analysis of the entire testing duration, it did however, influence an improved performance in visual perception immediately after exercise. No significant change in cognitive performance was observed during exercise. When responses were analyzed over time, across the seven 10 minute intervals in the cycling bouts, exercise was associated with improved performance in response time and reading speed (information processing).

In addition, task difficulty showed a significant change where performance in simpler tasks was better than in the more difficult levels of the task. This was expected as it confirms the validity of the cognitive task requirements by showing the normal trend of preference and performance being better in the simpler than the more difficult levels of each task. However, exercise did not influence any improvement in the task difficulty related performance.

6.2 Limitations

There are a few aspects that were noted to have limited this study in ways that could have, perhaps, had a negative influence on the results obtained. These include the nature of the cognitive tasks, especially the proof reading task which consisted of text passages (with high and low resolution complexity levels) embedded with double letter misspellings or errors that were to be identified as part of the performance measures. It was an observation from this task that English literacy might have been a third party factor influencing performance where participants were observed and suspected to be guessing the misspelt words in the text, due to them showing signs of uncertainty when pointing out the words they thought to be errors.

Still under cognitive task limitations, it is worth mentioning that the task habituation might not have been as long as would have been necessary. Ideally, the habituation of cognitive tasks in contexts such as this is designed to ensure that the participants effectively learn the tasks and reach an optimized performance level in the tasks. However, in this study, there was still an extended and prominent learning effect observed way into the progression of the exercise conditions indicating that the participants only mastered the tasks at a later stage in the exercise. This then implies that the participants' cognitive performance did not start at an overall optimum level from the warm-up phase, which could have resulted in varied responses to the aerobic exercise intervention.

It is interesting to note that a number of the limitations were participant related. To begin with, some participants might not have given an indication of their true MAP (maximum aerobic output) in the habitation session. Establishment of a relative MAP was a control measure to ensure a relatively constant exercise intensity for all participants where each participant cycled at 60% of their pre-determined MAP. However, some participants were seen to over-push themselves in the habituation session and thus give a MAP that was too high such that when they were required to cycle at 60% of that MAP they fatigued too early in the experimental condition, and completed the exercise with struggling effort. For those who gave a low MAP, their exercise intensity was too light as a result, and not the moderate intensity that was hoped for. Ultimately, in the actual experimentation exercise intensity might not have been as standard as it was hoped it would be. The main challenge seen in controlling exercise intensity was that the determination of MAP was based on a subjective perception of exhaustion (volitional exhaustion) which might not have been as accurate as it relied on each participants' subjective measurement of their maximum effort.

Most participants got disinterested in the cognitive tasks as fatigue settled in towards the end of the exercise, as they looked and seemed quite annoyed. This phenomenon might have had a negative impact on their overall cognitive performance, with low morale causing them to perform badly as their concentration on the cognitive task was reduced. A similar trend was also observed in the cycling with no load where the exercise duration seemed to have been a factor influencing their low moral as they felt they were not doing any work physically, and yet repeating the cognitive test cycles every 10 minutes.

Participant fitness level might have also been a negative factor in this study, although it was controlled by having individuals who are fit according to the PAR-Q (Physical activity readiness questionnaire) and those who engage in spinning/cycling as a form of exercise at least 3 days a week. This control measure might not have taken into account the intensity at which each participant exercises a week and their experience with the cycling exercise in general. As such, fitness levels might have influenced the overall cognitive responses given by the participants where studies have observed the more fit individuals to perform better cognitively (Chang *et al.,* 2012).

Lastly, many complaints were given by the participants concerning the cycle ergometer's saddle which become uncomfortable with time and made it hard for participants to completely concentrate on both the physical and cognitive tasks. Even though there were two available saddles of different sizes that were offered to the participants to try out and choose according to their preference, the extended cycling duration (50 minutes + 20 minutes warm-up and cool-off) might have been too long and the pressure build up in their gluteal region eventually resulted in pain. This was because the nature of the procedure would not allow them (participants) to cycle while standing like professional cyclists would to relieve the building tension in the gluteal region, due to them being required to be performing the cognitive tasks while they cycled. As such, the discomfort experienced by the participants from the ergometer's saddle might have distracted their full attention in performance of the cognitive tasks and as a result distort the effects of exercise on cognition which was the focus of this study.

6.3 Recommendations

The following recommendations are made for future studies that will further explore the relationship between acute aerobic exercise and cognitive performance:

1. Having longer task habituation sessions to get the participants fully accustomed to the cognitive tasks, thus minimizing learning effect to ensure that any changes in cognitive performance be as a result of the aerobic exercise.

2. Adjusting the protocol to have each cognitive measure analyzed separately to prevent or minimize the interaction of the cognitive tasks in on test battery. Thus, each performance measure i.e. response time, would be investigated independently and the same for the rest of the measures.

3. Having an objective method for MAP determination might be necessary, where a set heart rate of about 85-90% of the age predictive maximum can be used to either determine or confirm each participants' MAP. This is because 85-90% of age predictive heart rate maximum has been associated with the onset of physical fatigue, which is the intensity level experienced at the MAP (Bushman, 2011). This will hopefully ensure that the MAP determination is optimized and standardized in all participants.

4. The close monitoring of participants as they perform the cognitive tasks to closely assess their motivation and drive to attempt the cognitive tasks. A possible motivation strategy might be adopted to encourage the participants' exercise performance though this might act as a third party stimulus to their performance in the cognitive tasks

5. It may also be of relevant importance to consider participants who are in the same activity level or category i.e. taking only professional cyclists, or members of the same cycling club with the same or similar workout regimes, or if it's to be participants from a spinning class, it might be worth considering those who have been spinning for a similar duration. This will hopefully enable selection of a sample with similar exercise

experience and thus of a similar fitness level, in a bid to optimize the participants' motivation for the exercise and standardize their overall endurance in the exercise

6. Future studies might also look at the comparison of the effects of different exercise intensities on cognition i.e. 20%, 40%, 60%, 80% of MAP over an extended exercise duration. This would then be valid for application in a wider variety of professional situations seeing that worker requirements are different i.e. certain work stations involving high intensity activities/tasks like construction workers, soldiers, athletes and sports persons; whereas there are still those workstations with low intensity activities for example office workers, teachers, doctors, factory supervisors, etc. It would then be very interesting to see how cognitive performance changes at different intensities of physical exertion.

7. Lastly, it would be interesting to add a variable that measures cognitive effort (e.g. Heart Rate Variability) in addition to the physiological effort exerted in the cycling bouts, thus enable a wholesome analysis and comparisons of the changes in physical performance against cognition.

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APPENDICES

APPENDIX A

General Information

1. Letter of Information to the subject
2. Consent form
3. Physical Activity Readiness Questionnaire for Everyone
4. Borg's Rate of Perceived Exertion Scale
5. Pilot Test

APPENDIX A1

Information to the Participant

To Whom It May Concern:

Dear Participant

Firstly, I would like to thank you for agreeing to participate in this study. The purpose of this letter is to inform you about the various details of the study which you will be participating in. It is advised that you read everything carefully before signing the consent form that will be available for you to sign in you first session. If there be any issues that are not clear, please feel free to contact me using the contact details given below, and I'll clarify any uncertainties.

The main purpose of this research study is to investigate and understand the nature and change in mental performance during continuous physical exertion. This will be achieved through pedaling on a cycle ergometer for duration of 50 minutes with a set load that is relative to your Maximum Aerobic Power.

Various researches have shown that regular exercise generally improves cognitive function in humans. This research will however, focus on how physical exertion influences this cognitive function by assessing performance in a set of mental tasks. And hopefully this research will enable full comprehension of the nature of the various professionals that require the respective personnel to exert physically as well as mentally, such as fire-fighters, soldiers, soccer players, just to name a few.

As a result, this study constitutes a cycling protocol and a cognitive test battery with three tasks to assess mental performance. Your participation in this study will require you to come to the Human and Kinetics Department thrice for the different sessions involved. In all the three sessions, the following is what will be required of you:

DOs

- Rest well the night previous
- Come dressed in appropriate exercise attire (i.e. shorts/tights/sweat pants, t-shirt/vest, and comfortable footware/trainers)
- Bring a towel and water bottle
- Ask as many questions as possible if you do not fully understand the protocol

DONTs

- Do not eat and smoke for 3 hours before the testing sessions
- Do not drink alcoholic or caffeinated beverages for at least 24 hours before the testing sessions.
- Do not perform unusual strenuous physical activity for at least 12 hours before testing

(Pina *et al.,* 1995, Fletcher *et al.,* 2001 and Fletcher *et al.,* 2013).

The first will be a habituation session where you will have the full experimental protocol explained to you in detail and given a chance to ask questions pertaining to what will be expected of you. Your eligibility to participate in this study will also be confirmed by you filling out a Physical Activity Readiness Questionnaire, which contains a set of questions designed to assess and rate whether or not you are physically fit to participate in this cardiopulmonary demanding protocol. An informed consent form will be given to you to sign after your confirmation to a thorough comprehension of your participation in this study. You will also be given an opportunity to familiarize with the mental tasks to be used in the study as well as the cycle ergometer which will be adjusted to match your height.

A Maximal Aerobic Power (MAP) determination test will then be carried out to determine your maximum cycling limits so that through this MAP, a cycling resistance that is specific to you will be calculated for the cycling with load session. The test protocol will start with 5 minutes of unloaded pedaling as warm up. The load will then be increased to 125W for 5 minutes. After this, the resistance will be increased by 25W every minute up until a point at which you will feel you cannot cycle any further. The highest power output reached in this test bout will be recorded as the MAP. To end the test, you will be allowed 10 minutes of unloaded pedaling as cool down from the exercise and water will also be provided to replenish fluids at this stage. At this point, you will be allowed to leave after scheduling two separate dates for the cycling with load and cycling with no load sessions.

In the second and third sessions you will be required to come dressed appropriately, in attire that will enable you to cycle comfortably and with relevant accessories for the exercise session i.e. towel and water bottle. The second and third session will either be the cycling with load or cycling with no load session according to the researcher's scheduling which will be randomized.

During the cycling with load session you will have a brief run-down of the procedure just as a reminder, after which the heart rate monitor will be attached onto your upper abdominal region and a baseline reading taken down. Then you will asked to take a sit on the cycle ergometer which would have been adjusted to your specific measurements, thereafter you will be given 10 minutes of unloaded pedaling (self-paced, nil load cycling) during which a pre-test cognitive test will be administered which will include a recording of your subjective measures i.e. Rate of Perceived Exertion. A stop-clock will be started simultaneously to the commencement of this pre-exercise cognitive testing, which will be used to mark 10 minute intervals to determine when the subsequent cognitive tests will be conducted up until the end of the session (indicated by your full recovery after the exercise).

After the first 10 minute interval the workload will be increased to 60% of your Maximal Aerobic Power, that would have been determined in the habituation session. You will also be requested to maintain a pedaling cadence of 80 to 90 rpm (revolutions per minute).

At this intensity or workload you will continue cycling with your cognitive performance and subjective measures assessed every 10 minutes for a set duration of 50 minutes. However, you will be given the liberty to request for termination of this loaded phase of the cycling with load session if you feel you cannot continue. Otherwise at the end of 50 minutes, you will be requested to continue pedaling with no load while a post-test cognitive test will be conducted during that recovery period. This will mark the end of the session and the heart rate monitor will be then removed before you leave the laboratory.

In the cycling with no load session, the protocol will be explained to you before a heart rate monitor is attached to your upper abdomen/lower thoracic boundary. Thereafter, you will be requested to get on the cycle ergometer where you will be given a continuous 70 minutes of unloaded pedaling. This duration is equivalent to the summation of the average time taken for the pretest period (10 minutes), loaded phase (50 minutes) and recovery period (10 minutes) in the cycling with load condition. However, cognitive performance tests will be administered every 10 minutes for the duration of this session, after which you will be requested to stop pedaling and demount the cycle ergometer to mark the end of the cycling with no load session.

This study will have cardiovascular and muscular risks as a result of the nature of the protocol where you will be required to perform a MAP test in the habituation session to determine your relative capabilities and in the cycling with load session for 50 minutes at a constant load of 60% of your MAP. These risks may include Chest pain, Hypertension, Sudden pallor, Loss of coordination, Dizziness or faintness, and excessive Muscle Fatigue.

However, measures will be put in place to attenuate these risks on all participants. These include the Physical Readiness Questionnaire which ensures that individuals with a high probability and history of complicated medical conditions, more especially of a cardiovascular nature, are ineligible for the study. Both the MAP testing and the cycling with load sessions will be conducted in a temperature controlled laboratory with good air access and circulation to prevent your body from overheating. You will be given the liberty to terminate any of the sessions in instances when you will feel uncomfortable or feel you can no longer proceed.

More importantly the research will make sure their sessions are scheduled at times when either Dr. Swantje Zschernack or Mr. Tyrone Douglas are present in the HKE department, due to the fact that they both hold Medical Aid qualification in case of any emergency. The researcher will also keep the State Ambulance (10177) and the Net

Care emergency services (082 911) contact numbers on speed dial just in case of the worst possible scenarios.

The nature of this study makes it difficult to totally eradicate the possibility of any risk whatsoever onto you the participant because firstly, the MAP test has to be conducted to determine your relative load for the cycling with load session. Secondly, the main objectives of the study requires you to cycle for 50 minutes in the cycling with load session to observe effects in the cognitive performance. However, your health and wellness will be the top priority throughout experimentation.
Participation in this study might benefit you by having you discover your aerobic exercise limits and power. You will again benefit physically from the experience as the protocol has a major component of endurance and strength training. Moreover, this study will contribute towards the understanding of how cognition and physical performance relate. More especially, the limits upon which one can exert themselves physical while maintaining a substantial level of mental performance.

All the information collected in this study will be kept very confidential and all participant data will be confined to codes for anonymity. Also the findings of this research may be referenced in future studies for the purposes of thorough exploration of this area. Should you feel the need to withdraw from the study, you are welcome to do so without any consequences whatsoever on your part.

Thank you in advance for your interest in my research study. I have provided my contact details below for your convenience, should you have any questions regarding the study.

Yours sincerely,

Tendayi Tichiwanhuyi

MSc Human Kinetics and Ergonomics

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0738539061

APPENDIX A2

Informed Consent

I, …………………………………………………… have been fully informed of the research study entitled: **AN INVESTIGATION INTO THE EXTENT TO WHICH AEROBIC EXERCISE, IN THE FORM OF CYCLING OVER AN EXTENDED DURATION, AFFECTS COGNITIVE PERFOMANCE.**

I have read the letter of information and understand the testing procedure that will take place. I have been told of the potential risks and benefits involved, as well as that which will be expected of me once I have enrolled into the study. I understand that all information collected from this study, including photography where faces will be completely obscured in all publications, will be kept strictly confidential with participant code names being used to retain my anonymity, and that the data obtained might be used and published for statistical and/or scientific purposes.

In light of all this, I hereby freely agree to participate in this study, with the understanding that I may withdraw my participation at any time without any consequences. Should I have any questions regarding the study, I will not hesitate to contact the researcher.
In agreeing to participate in this research I waive any legal recourse against the researchers of Rhodes University, from any and all claims resulting from personal injuries sustained whilst partaking in the investigation. This waiver shall be binding upon my heirs and personal representatives. I realize that it is necessary for me to promptly report to the researchers any signs or symptoms indicating any abnormality or distress as a result of my participation in this study.

By giving my email address in the slot provided below, I give permission to the researcher to send me a summarized feedback of the study so I can see the effect of my participation:……………………………………………………………………………..

I therefore consent to voluntarily participate in this research project.

PARTICIPANT:

(Print name)	(Signed)	(Date)

WITNESS 1:

(Print name)	(Signed)	(Date)

WITNESS 2:

(Print name)	(Signed)	(Date)

RESEARCHER:

(Print name)	(Signed)	(Date)

APPENDIX A3

Physical Activity Readiness Questionnaire for Everyone

2013 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physically active is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	**YES**	**NO**
1) Has your doctor ever said that you have a heart condition ☐ OR high blood pressure ☐ ?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** ____________	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** ____________	☐	☐
6) Do you have a bone or joint problem that could be made worse by becoming more physically active? Please answer **NO** if you had a joint problem in the past, but it ***does not limit your current ability*** to be physically active. For example, knee, ankle, shoulder or other. **PLEASE LIST CONDITION(S) HERE:** ____________	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
Go to Page 4 to sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow International Physical Activity Guidelines for your age (www.who.int/dietphysicalactivity/en/).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at **www.eparmedx.com** before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

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FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1.	**Do you have Arthritis, Osteoporosis, or Back Problems?** If the above condition(s) is/are present, answer questions 1a-1c	If **NO** ☐ go to question 2
1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐
2.	**Do you have Cancer of any kind?** If the above condition(s) is/are present, answer questions 2a-2b	If **NO** ☐ go to question 3
2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐
3.	**Do you have a Heart or Cardiovascular Condition?** *This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm* If the above condition(s) is/are present, answer questions 3a-3d	If **NO** ☐ go to question 4
3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐
4.	**Do you have High Blood Pressure?** If the above condition(s) is/are present, answer questions 4a-4b	If **NO** ☐ go to question 5
4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐
5.	**Do you have any Metabolic Conditions?** *This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes* If the above condition(s) is/are present, answer questions 5a-5c	If **NO** ☐ go to question 6
5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, OR the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

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6.	**Do you have any Mental Health Problems or Learning Difficulties?** *This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome)*	
	If the above condition(s) is/are present, answer questions 6a-6b	If **NO** ☐ go to question 7
6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	**YES** ☐ **NO** ☐
6b.	Do you **ALSO** have back problems affecting nerves or muscles?	**YES** ☐ **NO** ☐
7.	**Do you have a Respiratory Disease?** *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*	
	If the above condition(s) is/are present, answer questions 7a-7d	If **NO** ☐ go to question 8
7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	**YES** ☐ **NO** ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	**YES** ☐ **NO** ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	**YES** ☐ **NO** ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	**YES** ☐ **NO** ☐
8.	**Do you have a Spinal Cord Injury?** *This includes Tetraplegia and Paraplegia*	
	If the above condition(s) is/are present, answer questions 8a-8c	If **NO** ☐ go to question 9
8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	**YES** ☐ **NO** ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	**YES** ☐ **NO** ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	**YES** ☐ **NO** ☐
9.	**Have you had a Stroke?** *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*	
	If the above condition(s) is/are present, answer questions 9a-9c	If **NO** ☐ go to question 10
9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	**YES** ☐ **NO** ☐
9b.	Do you have any impairment in walking or mobility?	**YES** ☐ **NO** ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	**YES** ☐ **NO** ☐
10.	**Do you have any other medical condition not listed above or do you have two or more medical conditions?**	
	If you have other medical conditions, answer questions 10a-10c	If **NO** ☐ read the Page 4 recommendations
10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	**YES** ☐ **NO** ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	**YES** ☐ **NO** ☐
10c.	Do you currently live with two or more medical conditions?	**YES** ☐ **NO** ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: ____________________

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

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If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional (with advanced university training) to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20-60 min of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of activity.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the **ePARmed-X+ at www.eparmedx.com** before becoming more physically active
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that the Trustee maintains the privacy of the information and does not misuse or wrongfully disclose such information.

NAME ______________________________ DATE ______________________________

SIGNATURE ______________________________ WITNESS ______________________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________________

For more information, please contact

www.eparmedx.com
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Citation for PAR-Q+
Warburton DER, Jamnik VK, Bredin SSD, and Gledhill N on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.

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Key References
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2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-s298, 2011.

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APPENDIX A4

Borg's Rate of Perceived Exertion:

Borg's RPE Scale	Description
6	No exertion
7	Extremely Light
8	
9	Very Light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very Hard
18	
19	Extremely hard
20	Maximal exertion

APPENDIX A5

Pilot Test:

Table XV **Table XV. The conditions that were tested in the pilot test**below shows all the conditions that was reviewed and assessed in the pilot test. It also shows the exercise intensity (cycling resistance) and the cadence that was used in each condition together with the time it took to volitional exhaustion (point at which the test subjects could not proceed any further due to physical exhaustion.

Table XV. The conditions that were tested in the pilot test

Test	Cycling Load	Cadence	% Age Predictive Heart Rate Max at the time of Termination	Time Taken To Volitional Exhaustion (taken as the end point of the exercise testing)
1	50% MAP	60rpm	76%	(intensity perceived as too light by subject, thus test was terminated after over 30 minutes of a constant RPE and Heart Rate reading)
2	55% MAP	70 rpm	68%	(intensity perceived as too light by subject, thus test was terminated after over 30 minutes of a constant RPE and Heart Rate reading)
3	55% MAP	85 rpm	94%	80mins
4	60% MAP	85 rpm	89%	50mins
5	65% MAP	85 rpm	89%	30mins

It is from this pilot test that the intensity consisting of a cadence range of 80 to 90rpm and cycling load of 60% of MAP was eventually chosen due its 50 minute duration that allows for up to 5 cognitive test batteries (each lasting 8 minutes) to be conducted and used for determining the progressive changes in cognitive performance during the exercise session

APPENDIX B

Physiological and subjective ANOVAS

1. Heart rate responses

2. RPE responses

APPENDIX B1

HEART RATE ANOVA FOR THE ENTIRE CYCLING DURATION:

Table XVI. Repeated measures analysis of variance for heart rate responses for the entire cycling duration (where the asterisk* highlights statistical significance).

Effect	Degree of Freedom	F	p
CONDITIONS	1, 23	605.522	<0.01*
INTERVALS	6, 138	380.908	<0.01*
CONDITIONS*INTERVALS	6, 138	390.738	<0.01*

APPENDIX B2

RPE ANOVA FOR THE ENTIRE CYCLING DURATION

Table XVII. Repeated Measures Analysis of Variance for RPE responses for the entire cycling duration (where the asterisk* highlights statistical significance).

Effect	Degree. Of Freedom	F	p
CONDITIONS	1, 23	294.177	<0.01*
INTERVALS	6, 138	139.200	<0.01*
CONDITIONS*INTERVALS	6, 138	109.860	<0.01*

APPENDIX C

Cognitive performance ANOVAs

1. Memory recall performance (loaded-cycling phase ANOVA)
2. Proof reading performance:
    a. Reading speed (loaded-cycling phase ANOVA)
    b. Error detection (loaded-cycling phase ANOVA)
3. Modified Fitts task performance
    c. Response time:
        i. Before and after the loaded cycling phase ANOVA
        ii. Loaded-cycling phase ANOVA
    d. Target deviation:
        i. Before and after the loaded cycling phase ANOVA
        ii. Loaded-cycling phase ANOVA

APPENDIX C1

Memory recall ANOVA for the period during the loaded cycling phase.

Effect	Degree. Of Freedom	F	p
COMPLEXITIES	1, 23	45.282	<0.01*
CONDITIONS	1, 23	0.249	0.622615
INTERVALS	4, 92	1.340	0.261071
COMPLEXITIES*CONDITIONS	1, 23	0.108	0.745477
COMPLEXITIES*INTERVALS	4, 92	0.624	0.646457
CONDITIONS*INTERVALS	4, 92	0.944	0.442239
COMPLEXITIES*CONDITIONS*INTERVALS	4, 92	0.765	0.550421

APPENDIX C2a

Reading speed ANOVA for the period during the loaded cycling phase.

Effect	Degree. Of Freedom	F	p
RESOLUTIONS	1, 23	222.0770	<0.01*
CONDITIONS	1, 23	0.8470	0.366951
INTERVALS	4, 92	2.1958	0.075528
RESOLUTIONS*CONDITIONS	1, 23	0.0335	0.856287
RESOLUTIONS*INTERVALS	4, 92	8.1238	<0.01*
CONDITIONS*INTERVALS	4, 92	1.4005	0.240030
RESOLUTIONS*CONDITIONS*INTERVALS	4, 92	1.0909	0.365778

APPENDIX C2b

Error detection rate ANOVA for the period during the loaded cycling phase.

Effect	Degree Of Freedom	F	p
RESOLUTIONS	1, 23	51.6690	<0.01*
CONDITIONS	1, 23	0.2210	0.642704
INTERVALS	4, 92	1.6949	0.157895
RESOLUTIONS*CONDITIONS	1, 23	0.0001	0.992108
RESOLUTIONS*INTERVALS	4, 92	0.1508	0.962203
CONDITIONS*INTERVALS	4, 92	2.8564	0.027884*
RESOLUTIONS*CONDITIONS*INTERVALS	4, 92	1.1998	0.316281

APPENDIX C3a

i. Reaction time ANOVA for before and after the loaded cycling phase.

Effect	Degree. Of Freedom	F	p
DIRECTIONS	1, 23	75.181	<0.01*
SIZES	1, 23	113.686	<0.01*
CONDITIONS	1, 23	3.950	0.058896
INTERVALS	1, 23	6.126	0.021120*
DIRECTIONS*SIZES	1, 23	68.807	<0.01*
DIRECTIONS*CONDITIONS	1, 23	5.114	0.033494*
SIZES*CONDITIONS	1, 23	0.575	0.455924
DIRECTIONS*INTERVALS	1, 23	0.499	0.487249
SIZES*INTERVALS	1, 23	0.117	0.734986
CONDITIONS*INTERVALS	1, 23	8.239	0.008648*
DIRECTIONS*SIZES*CONDITIONS	1, 23	0.397	0.535005
DIRECTIONS*SIZES*INTERVALS	1, 23	1.423	0.245006
DIRECTIONS*CONDITIONS*INTERVALS	1, 23	14.083	0.001038*
SIZES*CONDITIONS*INTERVALS	1, 23	21.049	0.000130*
1*2*3*4	1, 23	6.705	0.016397*

ii. Reaction time ANOVA for the period during the loaded cycling phase.

Effect	Degree Of Freedom	F	p
DIRECTIONS	1, 23	85.519	<0.01*
SIZES	1, 23	57.002	<0.01*
CONDITIONS	1, 23	0.221	0.642505
INTERVALS	4, 92	5.075	0.000968*
DIRECTIONS*SIZES	1, 23	55.340	<0.01*
DIRECTIONS*CONDITIONS	1, 23	0.169	0.684480
SIZES*CONDITIONS	1, 23	0.184	0.671835
DIRECTIONS*INTERVALS	4, 92	0.988	0.417932
SIZES*INTERVALS	4, 92	2.118	0.084811
CONDITIONS*INTERVALS	4, 92	1.317	0.269413
DIRECTIONS*SIZES*CONDITIONS	1, 23	0.216	0.646309
DIRECTIONS*SIZES*INTERVALS	4, 92	2.261	0.068477
DIRECTIONS*CONDITIONS*INTERVALS	4, 92	1.312	0.271262
SIZES*CONDITIONS*INTERVALS	4, 92	0.701	0.593276
1*2*3*4	4, 92	0.445	0.775718

APPENDIX C3b

i. Target deviation ANOVA for before and after the loaded cycling phase.

Effect	Degree Of Freedom	F	p
DIRECTIONS	1, 23	8.3668	0.008213*
SIZES	1, 23	3.1285	0.090197
CONDITIONS	1, 23	0.2572	0.616906
INTERVALS	1, 23	0.3941	0.536341
DIRECTIONS*SIZES	1, 23	2.8776	0.103314
DIRECTIONS*CONDITIONS	1, 23	12.0085	0.002098*
SIZES*CONDITIONS	1, 23	1.8789	0.183691
DIRECTIONS*INTERVALS	1, 23	0.5149	0.480264
SIZES*INTERVALS	1, 23	0.6925	0.413888
CONDITIONS*INTERVALS	1, 23	0.2691	0.608866
DIRECTIONS*SIZES*CONDITIONS	1, 23	0.0122	0.913052
DIRECTIONS*SIZES*INTERVALS	1, 23	0.1454	0.706480
DIRECTIONS*CONDITIONS*INTERVALS	1, 23	2.8792	0.103225
SIZES*CONDITIONS*INTERVALS	1, 23	6.1855	0.020573*
1*2*3*4	1, 23	2.6427	0.117652

ii. Target deviation ANOVA for the period during the loaded cycling phase.

Effect	Degree. Of Freedom	F	p
DIRECTIOS	1, 23	2.3095	0.142212
SIZES	1, 23	49.7772	<0.01*
CONDITIONS	1, 23	0.0240	0.878335
INTERVALS	4, 92	1.3509	0.257195
DIRECTIONS*SIZES	1, 23	1.5627	0.223842
DIRECTIONS*CONDITIONS	1, 23	1.8618	0.185621
SIZES*CONDITIONS	1, 23	0.0576	0.812409
DIRECTIONS*INTERVALS	4, 92	0.8164	0.517906
SIZES*INTERVALS	4, 92	1.0371	0.392474
CONDITIONS*INTERVALS	4, 92	0.9196	0.456091
DIRECTIONS*SIZES*CONDITIOS	1, 23	0.9430	0.341605
DIRECTIONS*SIZES*INTERVALS	4, 92	0.8324	0.507979
DIRECTIONS*CONDITIONS*INTERVALS	4, 92	0.8035	0.526008
SIZES*CONDITIONS*INTERVALS	4, 92	1.1921	0.319605
1*2*3*4	4, 92	1.1946	0.318533

APPENDIX D

Sex Differences

1. Heart rate responses with sex as a covariant

    i. Entire cycling duration
    ii. Before and after the loaded cycling phase
    iii. Loaded-cycling phase

2. RPE responses with sex as a covariant

    i. Entire cycling duration
    ii. Before and after the loaded cycling phase
    iii. Loaded-cycling phase

3. Memory recall task performance with sex as a covariant

    i) Entire cycling duration
    ii) Before and after the loaded cycling phase
    iii) Loaded-cycling phase

4. Reading speed performance (Proof reading task) with sex as a covariant

    i) Entire cycling duration
    ii) Before and after the loaded cycling phase
    iii) Loaded-cycling phase

5. Error detection rate performance (Proof reading task) with sex as a covariant

    iv) Entire cycling duration
    v) Before and after the loaded cycling phase
    vi) Loaded-cycling phase

6. Response time performance (Modified Fitts' task) with sex as a covariant

    i) Entire cycling duration

ii) Before and after the loaded cycling phase
iii) Loaded-cycling phase

7. Target deviation performance (Modified Fitts' task) with sex as a covariant
iv) Entire cycling duration
v) Before and after the loaded cycling phase
vi) Loaded-cycling phase

APPENDIX D1

Heart rate responses ANOVA with sex as a covariant

i. Entire cycling duration

	SS	Degr. of Freedom	MS	F	p
SEX	3753	1	3753	3.488	0.075183
CONDITIO	186204	1	186204	622.695	0.000000
CONDITIO*SEX	494	1	494	1.652	0.212010
INTERVAL	41445	6	6908	373.860	0.000000
INTERVAL*SEX	64	6	11	0.574	0.750104
CONDITIO*INTERVAL	41789	6	6965	379.261	0.000000
CONDITIO*INTERVAL*SEX	36	6	6	0.324	0.923202

ii. Before and after the loaded cycling phase

	SS	Degr. of Freedom	MS	F	p
SEX	724.0	1	724.0	2.431	0.133237
CONDITIO	4332.3	1	4332.3	116.607	0.000000
CONDITIO*SEX	91.7	1	91.7	2.469	0.130412
INTERVAL	1217.2	1	1217.2	45.138	0.000001
INTERVAL*SEX	2.1	1	2.1	0.076	0.785264
CONDITIO*INTERVAL	2280.5	1	2280.5	71.689	0.000000
CONDITIO*INTERVAL*SEX	14.9	1	14.9	0.469	0.500736

iii. Loaded-cycling phase

	SS	Degr. of Freedom	MS	F	p
SEX	3077	1	3077	3.697	0.067561
CONDITIO	219911	1	219911	706.363	0.000000
CONDITIO*SEX	410	1	410	1.316	0.263574
INTERVAL	552	4	138	18.621	0.000000
INTERVAL*SEX	14	4	3	0.469	0.758056
CONDITIO*INTERVAL	1470	4	368	50.831	0.000000
CONDITIO*INTERVAL*SEX	13	4	3	0.463	0.762405

APPENDIX D2

RPE responses ANOVA with sex as a covariant

i. Entire cycling duration

	SS	Degr. of Freedom	MS	F	p
SEX	12.57	1	12.57	0.559	0.462617
CONDITIO	1848.05	1	1848.05	303.924	0.000000
CONDITIO*SEX	10.71	1	10.71	1.762	0.197982
INTERVAL	911.29	6	151.88	147.053	0.000000
INTERVAL*SEX	14.24	6	2.37	2.298	0.038394
CONDITIO*INTERVAL	568.66	6	94.78	112.478	0.000000
CONDITIO*INTERVAL*SEX	7.83	6	1.30	1.548	0.167399

ii. Before and after the loaded cycling phase

	SS	Degr. of Freedom	MS	F	p
SEX	0.010	1	0.010	0.0013	0.972072
CONDITIO	16.667	1	16.667	14.8649	0.000857
CONDITIO*SEX	0.042	1	0.042	0.0372	0.848904
INTERVAL	38.760	1	38.760	17.9443	0.000339
INTERVAL*SEX	0.844	1	0.844	0.3906	0.538404
CONDITIO*INTERVAL	16.667	1	16.667	15.1724	0.000779
CONDITIO*INTERVAL*SEX	1.042	1	1.042	0.9483	0.340745

iii. Loaded-cycling phase

	SS	Degr. of Freedom	MS	F	p
SEX	18.15	1	18.15	1.146	0.295962
CONDITIO	2331.27	1	2331.27	364.995	0.000000
CONDITIO*SEX	16.02	1	16.02	2.508	0.127565
INTERVAL	180.38	4	45.09	75.418	0.000000
INTERVAL*SEX	7.81	4	1.95	3.265	0.015172
CONDITIO*INTERVAL	52.11	4	13.03	20.600	0.000000
CONDITIO*INTERVAL*SEX	1.44	4	0.36	0.570	0.685129

APPENDIX D3

Memory recall task performance ANOVA with sex as a covariant

i) Entire cycling duration

	SS	Degr. of Freedom	MS	F	p
{1}SEX	503	1	503	0.119	0.733236
{2}COMPLEXI	44007	1	44007	53.832	0.000000
COMPLEXI*SEX	252	1	252	0.308	0.584300
{3}CONDITIO	34	1	34	0.100	0.754547
CONDITIO*SEX	923	1	923	2.724	0.113080
{4}INTERVAL	560	6	93	1.044	0.400047
INTERVAL*SEX	418	6	70	0.778	0.588394
COMPLEXI*CONDITIO	343	1	343	2.232	0.149357
COMPLEXI*CONDITIO*SEX	359	1	359	2.337	0.140575
COMPLEXI*INTERVAL	341	6	57	0.621	0.713404
COMPLEXI*INTERVAL*SEX	872	6	145	1.590	0.154973
CONDITIO*INTERVAL	1119	6	187	1.689	0.128486
CONDITIO*INTERVAL*SEX	1014	6	169	1.531	0.172885
COMPLEXI*CONDITIO*INTERVAL	1005	6	167	1.588	0.155409
2*3*4*1	1094	6	182	1.730	0.118843

ii) Before and after the loaded cycling phase

	SS	Degr. of Freedom	MS	F	p
{1}SEX	354	1	354	0.320	0.577388
{2}COMPLEXI	11361	1	11361	64.617	0.000000
COMPLEXI*SEX	225	1	225	1.281	0.269988
{3}CONDITIO	567	1	567	3.484	0.075368
CONDITIO*SEX	588	1	588	3.616	0.070419
{4}INTERVAL	64	1	64	1.305	0.265505
INTERVAL*SEX	36	1	36	0.736	0.400200
COMPLEXI*CONDITIO	839	1	839	12.766	0.001699
COMPLEXI*CONDITIO*SEX	678	1	678	10.320	0.004012
COMPLEXI*INTERVAL	31	1	31	1.046	0.317596
COMPLEXI*INTERVAL*SEX	1	1	1	0.041	0.841658
CONDITIO*INTERVAL	78	1	78	0.638	0.432981
CONDITIO*INTERVAL*SEX	198	1	198	1.628	0.215354
COMPLEXI*CONDITIO*INTERVAL	81	1	81	1.289	0.268394
2*3*4*1	0	1	0	0.002	0.968289

iii) Loaded-cycling phase

	SS	Degr. of Freedom	MS	F	p
{1}SEX	214	1	214	0.066	0.799189
{2}COMPLEXI	32688	1	32688	43.540	0.000001
COMPLEXI*SEX	86	1	86	0.115	0.737638
{3}CONDITIO	67	1	67	0.256	0.618132
CONDITIO*SEX	425	1	425	1.630	0.215001
{4}INTERVAL	493	4	123	1.332	0.264546
INTERVAL*SEX	316	4	79	0.854	0.494838
COMPLEXI*CONDITIO	13	1	13	0.105	0.749446
COMPLEXI*CONDITIO*SEX	35	1	35	0.286	0.598016
COMPLEXI*INTERVAL	267	4	67	0.651	0.627905
COMPLEXI*INTERVAL*SEX	811	4	203	1.978	0.104760
CONDITIO*INTERVAL	442	4	111	0.968	0.429066
CONDITIO*INTERVAL*SEX	727	4	182	1.591	0.183828
COMPLEXI*CONDITIO*INTERVAL	416	4	104	0.778	0.542254
2*3*4*1	740	4	185	1.386	0.245453

APPENDIX D4a

Reading speed performance ANOVA with sex as a covariant

i) Entire cycling duration

	SS	Degr. of Freedom	MS	F	p
{1}SEX	186606	1	186606	1.7991	0.193499
{2}RESOLUTI	232132	1	232132	259.3012	0.000000
RESOLUTI*SEX	1013	1	1013	1.1313	0.299035
{3}CONDITIO	1958	1	1958	0.2298	0.636392
CONDITIO*SEX	6651	1	6651	0.7806	0.386515
{4}INTERVAL	32035	6	5339	7.1456	0.000001
INTERVAL*SEX	3912	6	652	0.8725	0.517056
RESOLUTI*CONDITIO	87	1	87	0.0643	0.802248
RESOLUTI*CONDITIO*SEX	198	1	198	0.1458	0.706264
RESOLUTI*INTERVAL	21012	6	3502	6.0500	0.000013
RESOLUTI*INTERVAL*SEX	2425	6	404	0.6983	0.651402
CONDITIO*INTERVAL	14146	6	2358	2.4402	0.028626
CONDITIO*INTERVAL*SEX	827	6	138	0.1426	0.990191
RESOLUTI*CONDITIO*INTERVAL	3607	6	601	1.0352	0.405425
2*3*4*1	1504	6	251	0.4317	0.856715

ii) Before and after the loaded cycling phase

	SS	Degr. of Freedom	MS	F	p
{1}SEX	64099	1	64099	2.1314	0.158444
{2}RESOLUTI	77456	1	77456	88.7518	0.000000
RESOLUTI*SEX	1378	1	1378	1.5786	0.222147
{3}CONDITIO	2108	1	2108	1.3831	0.252136
CONDITIO*SEX	1027	1	1027	0.6742	0.420399
{4}INTERVAL	18202	1	18202	15.6377	0.000674
INTERVAL*SEX	473	1	473	0.4066	0.530272
RESOLUTI*CONDITIO	71	1	71	0.0692	0.794925
RESOLUTI*CONDITIO*SEX	96	1	96	0.0931	0.763172
RESOLUTI*INTERVAL	1127	1	1127	3.0003	0.097250
RESOLUTI*INTERVAL*SEX	28	1	28	0.0743	0.787710
CONDITIO*INTERVAL	2563	1	2563	1.9662	0.174807
CONDITIO*INTERVAL*SEX	378	1	378	0.2901	0.595545
RESOLUTI*CONDITIO*INTERVAL	1140	1	1140	2.2149	0.150875
2*3*4*1	102	1	102	0.1980	0.660711

iii) Loaded-cycling phase

	SS	Degr. of Freedom	MS	F	p
{1}SEX	123202	1	123202	1.6621	0.210706
{2}RESOLUTI	155280	1	155280	215.1110	0.000000
RESOLUTI*SEX	201	1	201	0.2785	0.602940
{3}CONDITIO	6625	1	6625	0.8372	0.370111
CONDITIO*SEX	5811	1	5811	0.7343	0.400732
{4}INTERVAL	1007	4	252	0.3012	0.876402
INTERVAL*SEX	2863	4	716	0.8570	0.493144
RESOLUTI*CONDITIO	33	1	33	0.0322	0.859141
RESOLUTI*CONDITIO*SEX	110	1	110	0.1080	0.745596
RESOLUTI*INTERVAL	12622	4	3155	5.2091	0.000819
RESOLUTI*INTERVAL*SEX	960	4	240	0.3962	0.810841
CONDITIO*INTERVAL	17775	4	4444	5.5253	0.000514
CONDITIO*INTERVAL*SEX	192	4	48	0.0596	0.993311
RESOLUTI*CONDITIO*INTERVAL	1368	4	342	0.6448	0.632011
2*3*4*1	2217	4	554	1.0450	0.388719

APPENDIX D4b

Error detection rate performance ANOVA with sex as a covariant

i) Entire cycling duration

	SS	Degr. of Freedom	MS	F	p
{1}SEX	8980	1	8980	2.3490	0.139616
{2}RESOLUTI	14942	1	14942	65.7444	0.000000
RESOLUTI*SEX	697	1	697	3.0663	0.093865
{3}CONDITIO	573	1	573	1.1018	0.305267
CONDITIO*SEX	366	1	366	0.7045	0.410292
{4}INTERVAL	2489	6	415	2.4852	0.026074
INTERVAL*SEX	666	6	111	0.6655	0.677634
RESOLUTI*CONDITIO	133	1	133	0.9585	0.338199
RESOLUTI*CONDITIO*SEX	207	1	207	1.4932	0.234652
RESOLUTI*INTERVAL	2493	6	415	2.5607	0.022286
RESOLUTI*INTERVAL*SEX	950	6	158	0.9754	0.444520
CONDITIO*INTERVAL	1872	6	312	1.8887	0.087318
CONDITIO*INTERVAL*SEX	876	6	146	0.8838	0.508784
RESOLUTI*CONDITIO*INTERVAL	1082	6	180	1.2393	0.290324
2*3*4*1	1458	6	243	1.6698	0.133273

ii) Before and after the loaded cycling phase

	SS	Degr. of Freedom	MS	F	p
{1}SEX	2030.8	1	2030.8	1.7386	0.200881
{2}RESOLUTI	5073.6	1	5073.6	23.7463	0.000072
RESOLUTI*SEX	483.4	1	483.4	2.2625	0.146758
{3}CONDITIO	740.1	1	740.1	5.9298	0.023452
CONDITIO*SEX	727.6	1	727.6	5.8296	0.024521
{4}INTERVAL	161.8	1	161.8	1.0373	0.319511
INTERVAL*SEX	132.2	1	132.2	0.8473	0.367297
RESOLUTI*CONDITIO	455.8	1	455.8	5.0189	0.035498
RESOLUTI*CONDITIO*SEX	103.3	1	103.3	1.1378	0.297678
RESOLUTI*INTERVAL	2346.9	1	2346.9	14.5795	0.000938
RESOLUTI*INTERVAL*SEX	94.0	1	94.0	0.5838	0.452950
CONDITIO*INTERVAL	68.2	1	68.2	0.2518	0.620770
CONDITIO*INTERVAL*SEX	11.2	1	11.2	0.0414	0.840711
RESOLUTI*CONDITIO*INTERVAL	28.8	1	28.8	0.1834	0.672595
2*3*4*1	329.6	1	329.6	2.1009	0.161323

iii) Loaded-cycling phase

	SS	Degr. of Freedom	MS	F	p
{1}SEX	6993	1	6993	2.4807	0.129525
{2}RESOLUTI	9917	1	9917	53.0302	0.000000
RESOLUTI*SEX	300	1	300	1.6059	0.218316
{3}CONDITIO	124	1	124	0.2119	0.649794
CONDITIO*SEX	31	1	31	0.0536	0.819110
{4}INTERVAL	1141	4	285	1.6742	0.163109
INTERVAL*SEX	491	4	123	0.7200	0.580495
RESOLUTI*CONDITIO	0	1	0	0.0001	0.991700
RESOLUTI*CONDITIO*SEX	550	1	550	3.4660	0.076055
RESOLUTI*INTERVAL	97	4	24	0.1521	0.961579
RESOLUTI*INTERVAL*SEX	769	4	192	1.2028	0.315357
CONDITIO*INTERVAL	1513	4	378	2.8425	0.028753
CONDITIO*INTERVAL*SEX	473	4	118	0.8875	0.474935
RESOLUTI*CONDITIO*INTERVAL	730	4	183	1.2065	0.313812
2*3*4*1	682	4	171	1.1269	0.349069

APPENDIX D5a

Response time performance ANOVA with sex as a covariant

i) Entire cycling duration

	SS	Degr. of Freedom	MS	F	p
{1}SEX	0.2329	1	0.2329	0.500	0.486877
{2}DIRECTIO	4.2867	1	4.2867	82.456	0.000000
DIRECTIO*SEX	0.0193	1	0.0193	0.371	0.548609
{3}SIZES	1.0220	1	1.0220	63.788	0.000000
SIZES*SEX	0.0010	1	0.0010	0.063	0.803753
{4}CONDITIO	0.0003	1	0.0003	0.003	0.956480
CONDITIO*SEX	0.0637	1	0.0637	0.705	0.410241
{5}INTERVAL	0.5279	6	0.0880	9.646	0.000000
INTERVAL*SEX	0.0121	6	0.0020	0.222	0.969114
DIRECTIO*SIZES	0.1885	1	0.1885	107.897	0.000000
DIRECTIO*SIZES*SEX	0.0000	1	0.0000	0.000	0.996724
DIRECTIO*CONDITIO	0.0095	1	0.0095	0.639	0.432770
DIRECTIO*CONDITIO*SEX	0.0002	1	0.0002	0.015	0.905234
SIZES*CONDITIO	0.0001	1	0.0001	0.038	0.847379
SIZES*CONDITIO*SEX	0.0013	1	0.0013	0.529	0.474629
DIRECTIO*INTERVAL	0.0413	6	0.0069	3.599	0.002454
DIRECTIO*INTERVAL*SEX	0.0278	6	0.0046	2.419	0.029914
SIZES*INTERVAL	0.0271	6	0.0045	3.159	0.006293
SIZES*INTERVAL*SEX	0.0121	6	0.0020	1.411	0.215011
CONDITIO*INTERVAL	0.0889	6	0.0148	2.428	0.029381
CONDITIO*INTERVAL*SEX	0.0306	6	0.0051	0.836	0.543944
DIRECTIO*SIZES*CONDITIO	0.0006	1	0.0006	0.318	0.578382
2*3*4*1	0.0109	1	0.0109	5.686	0.026153
DIRECTIO*SIZES*INTERVAL	0.0131	6	0.0022	1.844	0.095285
2*3*5*1	0.0193	6	0.0032	2.731	0.015614
DIRECTIO*CONDITIO*INTERVAL	0.0171	6	0.0028	2.255	0.041894
2*4*5*1	0.0141	6	0.0024	1.862	0.091951
SIZES*CONDITIO*INTERVAL	0.0057	6	0.0009	0.607	0.724492
3*4*5*1	0.0128	6	0.0021	1.375	0.229416
2*3*4*5	0.0043	6	0.0007	0.626	0.709530
2*3*4*5*1	0.0158	6	0.0026	2.281	0.039719

ii) Before and after the loaded cycling phase

	SS	Degr. of Freedom	MS	F	p
{1}SEX	0.0610	1	0.0610	0.383	0.542430
{2}DIRECTIO	0.6930	1	0.6930	72.539	0.000000
DIRECTIO*SEX	0.0025	1	0.0025	0.259	0.615615
{3}SIZES	0.0801	1	0.0801	8.501	0.008011
SIZES*SEX	0.0076	1	0.0076	0.812	0.377430
{4}CONDITIO	0.1477	1	0.1477	25.867	0.000043
CONDITIO*SEX	0.0172	1	0.0172	3.015	0.096506
{5}INTERVAL	0.3827	1	0.3827	91.776	0.000000
INTERVAL*SEX	0.0013	1	0.0013	0.301	0.588792
DIRECTIO*SIZES	0.1024	1	0.1024	72.330	0.000000
DIRECTIO*SIZES*SEX	0.0031	1	0.0031	2.177	0.154223
DIRECTIO*CONDITIO	0.0495	1	0.0495	20.976	0.000146
DIRECTIO*CONDITIO*SEX	0.0000	1	0.0000	0.001	0.978902
SIZES*CONDITIO	0.0010	1	0.0010	0.269	0.608959
SIZES*CONDITIO*SEX	0.0000	1	0.0000	0.004	0.951765
DIRECTIO*INTERVAL	0.0006	1	0.0006	0.145	0.707235
DIRECTIO*INTERVAL*SEX	0.0003	1	0.0003	0.087	0.770657
SIZES*INTERVAL	0.0005	1	0.0005	0.093	0.762790
SIZES*INTERVAL*SEX	0.0208	1	0.0208	3.767	0.065191
CONDITIO*INTERVAL	0.0888	1	0.0888	9.216	0.006068
CONDITIO*INTERVAL*SEX	0.0003	1	0.0003	0.029	0.866239
DIRECTIO*SIZES*CONDITIO	0.0928	1	0.0928	18.708	0.000273
2*3*4*1	0.0019	1	0.0019	0.383	0.542350
DIRECTIO*SIZES*INTERVAL	0.1186	1	0.1186	8.457	0.008152
2*3*5*1	0.0366	1	0.0366	2.610	0.120460
DIRECTIO*CONDITIO*INTERVAL	0.2165	1	0.2165	33.432	0.000008
2*4*5*1	0.0048	1	0.0048	0.736	0.400095
SIZES*CONDITIO*INTERVAL	0.0079	1	0.0079	0.523	0.476977
3*4*5*1	0.0037	1	0.0037	0.245	0.625763
2*3*4*5	0.0643	1	0.0643	28.083	0.000026
2*3*4*5*1	0.0208	1	0.0208	9.080	0.006395

iii) Loaded-cycling phase

	SS	Degr. of Freedom	MS	F	p
{1}SEX	0.1721	1	0.1721	0.552	0.465271
{2}DIRECTIO	3.0655	1	3.0655	82.514	0.000000
DIRECTIO*SEX	0.0071	1	0.0071	0.192	0.665670
{3}SIZES	0.6429	1	0.6429	54.967	0.000000
SIZES*SEX	0.0021	1	0.0021	0.179	0.676509
{4}CONDITIO	0.0149	1	0.0149	0.215	0.647790
CONDITIO*SEX	0.0208	1	0.0208	0.299	0.589797
{5}INTERVAL	0.0796	4	0.0199	4.067	0.004512
INTERVAL*SEX	0.0232	4	0.0058	1.187	0.322108
DIRECTIO*SIZES	0.1255	1	0.1255	54.325	0.000000
DIRECTIO*SIZES*SEX	0.0013	1	0.0013	0.578	0.455038
DIRECTIO*CONDITIO	0.0021	1	0.0021	0.162	0.691177
DIRECTIO*CONDITIO*SEX	0.0000	1	0.0000	0.003	0.954592
SIZES*CONDITIO	0.0004	1	0.0004	0.178	0.677151
SIZES*CONDITIO*SEX	0.0005	1	0.0005	0.239	0.629451
DIRECTIO*INTERVAL	0.0396	4	0.0099	3.618	0.008892
DIRECTIO*INTERVAL*SEX	0.0024	4	0.0006	0.219	0.927115
SIZES*INTERVAL	0.0163	4	0.0041	1.977	0.104949
SIZES*INTERVAL*SEX	0.0043	4	0.0011	0.526	0.716801
CONDITIO*INTERVAL	0.0263	4	0.0066	1.989	0.103099
CONDITIO*INTERVAL*SEX	0.0014	4	0.0003	0.104	0.980978
DIRECTIO*SIZES*CONDITIO	0.0005	1	0.0005	0.299	0.589949
2*3*4*1	0.0150	1	0.0150	9.817	0.004834
DIRECTIO*SIZES*INTERVAL	0.0129	4	0.0032	1.699	0.157451
2*3*5*1	0.0125	4	0.0031	1.638	0.171873
DIRECTIO*CONDITIO*INTERVAL	0.0107	4	0.0027	1.220	0.308010
2*4*5*1	0.0085	4	0.0021	0.966	0.430400
SIZES*CONDITIO*INTERVAL	0.0226	4	0.0056	3.398	0.012408
3*4*5*1	0.0010	4	0.0003	0.156	0.959709
2*3*4*5	0.0096	4	0.0024	1.532	0.199890
2*3*4*5*1	0.0198	4	0.0050	3.165	0.017652

APPENDIX D5b

Target deviation performance ANOVA with sex as a covariant

i) Entire cycling duration

	SS	Degr. of Freedom	MS	F	p
{1}SEX	1.0	1	1.0	0.0019	0.965382
{2}DIRECTIO	29.0	1	29.0	4.3282	0.049341
DIRECTIO*SEX	0.0	1	0.0	0.0043	0.948485
{3}SIZES	382.6	1	382.6	57.4173	0.000000
SIZES*SEX	1.2	1	1.2	0.1756	0.679272
{4}CONDITIO	15.2	1	15.2	0.0625	0.804959
CONDITIO*SEX	11.1	1	11.1	0.0456	0.832894
{5}INTERVAL	57.8	6	9.6	2.2551	0.041879
INTERVAL*SEX	9.3	6	1.6	0.3628	0.901248
DIRECTIO*SIZES	4.5	1	4.5	0.8464	0.367556
DIRECTIO*SIZES*SEX	0.9	1	0.9	0.1732	0.681287
DIRECTIO*CONDITIO	13.3	1	13.3	2.5471	0.124764
DIRECTIO*CONDITIO*SEX	0.6	1	0.6	0.1117	0.741400
SIZES*CONDITIO	2.8	1	2.8	0.8210	0.374706
SIZES*CONDITIO*SEX	18.1	1	18.1	5.3589	0.030335
DIRECTIO*INTERVAL	27.2	6	4.5	2.9413	0.010005
DIRECTIO*INTERVAL*SEX	8.2	6	1.4	0.8849	0.508004
SIZES*INTERVAL	6.2	6	1.0	0.6350	0.702024
SIZES*INTERVAL*SEX	9.0	6	1.5	0.9263	0.478332
CONDITIO*INTERVAL	26.7	6	4.5	0.8605	0.525918
CONDITIO*INTERVAL*SEX	21.3	6	3.6	0.6858	0.661374
DIRECTIO*SIZES*CONDITIO	0.6	1	0.6	0.1579	0.694915
2*3*4*1	2.7	1	2.7	0.6594	0.425458
DIRECTIO*SIZES*INTERVAL	13.1	6	2.2	1.2107	0.304732
2*3*5*1	16.8	6	2.8	1.5498	0.166918
DIRECTIO*CONDITIO*INTERVAL	11.3	6	1.9	1.2212	0.299400
2*4*5*1	7.4	6	1.2	0.7996	0.571861
SIZES*CONDITIO*INTERVAL	8.7	6	1.4	0.7953	0.575190
3*4*5*1	28.1	6	4.7	2.5831	0.021266
2*3*4*5	7.1	6	1.2	0.7746	0.591238
2*3*4*5*1	11.9	6	2.0	1.3090	0.257469

ii) Before and after the loaded cycling phase

	SS	Degr. of Freedom	MS	F	p
{1}SEX	0.06	1	0.06	0.0004	0.984377
{2}DIRECTIO	16.40	1	16.40	7.9368	0.010035
DIRECTIO*SEX	1.97	1	1.97	0.9528	0.339622
{3}SIZES	6.97	1	6.97	1.7837	0.195350
SIZES*SEX	0.51	1	0.51	0.1295	0.722332
{4}CONDITIO	8.22	1	8.22	0.6275	0.436719
CONDITIO*SEX	1.11	1	1.11	0.0844	0.774163
{5}INTERVAL	46.37	1	46.37	4.5383	0.044571
INTERVAL*SEX	8.59	1	8.59	0.8403	0.369252
DIRECTIO*SIZES	79.52	1	79.52	46.9829	0.000001
DIRECTIO*SIZES*SEX	1.24	1	1.24	0.7339	0.400845
DIRECTIO*CONDITIO	2.19	1	2.19	0.2218	0.642328
DIRECTIO*CONDITIO*SEX	1.45	1	1.45	0.1470	0.705101
SIZES*CONDITIO	1.71	1	1.71	0.2309	0.635586
SIZES*CONDITIO*SEX	0.15	1	0.15	0.0198	0.889252
DIRECTIO*INTERVAL	10.44	1	10.44	1.8923	0.182786
DIRECTIO*INTERVAL*SEX	1.91	1	1.91	0.3461	0.562306
SIZES*INTERVAL	3.72	1	3.72	0.5716	0.457626
SIZES*INTERVAL*SEX	7.24	1	7.24	1.1135	0.302770
CONDITIO*INTERVAL	1.59	1	1.59	0.0485	0.827757
CONDITIO*INTERVAL*SEX	1.97	1	1.97	0.0600	0.808777
DIRECTIO*SIZES*CONDITIO	15.16	1	15.16	2.8766	0.103982
2*3*4*1	0.10	1	0.10	0.0190	0.891569
DIRECTIO*SIZES*INTERVAL	0.02	1	0.02	0.0023	0.962222
2*3*5*1	0.37	1	0.37	0.0421	0.839269
DIRECTIO*CONDITIO*INTERVAL	11.53	1	11.53	0.5393	0.470473
2*4*5*1	0.23	1	0.23	0.0108	0.918258
SIZES*CONDITIO*INTERVAL	20.93	1	20.93	8.6059	0.007688
3*4*5*1	3.45	1	3.45	1.4192	0.246229
2*3*4*5	18.64	1	18.64	13.0148	0.001563
2*3*4*5*1	1.10	1	1.10	0.7650	0.391211

iii) Loaded-cycling phase

	SS	Degr. of Freedom	MS	F	p
{1}SEX	1.1	1	1.1	0.0029	0.957637
{2}DIRECTIO	12.3	1	12.3	2.2244	0.150042
DIRECTIO*SEX	0.8	1	0.8	0.1527	0.699729
{3}SIZES	255.6	1	255.6	48.7007	0.000001
SIZES*SEX	2.6	1	2.6	0.5025	0.485839
{4}CONDITIO	3.8	1	3.8	0.0230	0.880828
CONDITIO*SEX	13.6	1	13.6	0.0819	0.777353
{5}INTERVAL	12.3	4	3.1	1.0309	0.395940
INTERVAL*SEX	6.4	4	1.6	0.5349	0.710411
DIRECTIO*SIZES	5.5	1	5.5	1.4972	0.234045
DIRECTIO*SIZES*SEX	0.1	1	0.1	0.0363	0.850662
DIRECTIO*CONDITIO	7.2	1	7.2	1.7812	0.195649
DIRECTIO*CONDITIO*SEX	0.0	1	0.0	0.0046	0.946413
SIZES*CONDITIO	0.2	1	0.2	0.0722	0.790673
SIZES*CONDITIO*SEX	21.2	1	21.2	6.8120	0.015988
DIRECTIO*INTERVAL	7.8	4	2.0	1.1008	0.361336
DIRECTIO*INTERVAL*SEX	12.9	4	3.2	1.8113	0.133761
SIZES*INTERVAL	3.9	4	1.0	0.5486	0.700505
SIZES*INTERVAL*SEX	1.3	4	0.3	0.1781	0.949145
CONDITIO*INTERVAL	17.4	4	4.4	1.3415	0.260962
CONDITIO*INTERVAL*SEX	18.8	4	4.7	1.4425	0.226719
DIRECTIO*SIZES*CONDITIO	3.0	1	3.0	0.9066	0.351373
2*3*4*1	0.4	1	0.4	0.1108	0.742397
DIRECTIO*SIZES*INTERVAL	8.5	4	2.1	1.1534	0.336993
2*3*5*1	11.4	4	2.8	1.5526	0.194082
DIRECTIO*CONDITIO*INTERVAL	4.7	4	1.2	1.0408	0.390858
2*4*5*1	5.0	4	1.2	1.0977	0.362803
SIZES*CONDITIO*INTERVAL	5.5	4	1.4	0.9745	0.425707
3*4*5*1	10.4	4	2.6	1.8377	0.128717
2*3*4*5	4.5	4	1.1	0.8552	0.494191
2*3*4*5*1	10.3	4	2.6	1.9463	0.109804

APPENDIX E

Post hoc analyses

1. Time Intervals

   a) Reading speed performance
   b) Error detection performance
   c) Reaction time performance
   d) Target deviation performance
   e) Heart rate
   f) RPE

2. Condition*Time Intervals

   a) Reading speed performance
   b) Reaction time performance
   c) Heart rate
   d) RPE

APPENDIX E1

Time Intervals

a. Reading speed

Cell No.	Tukey HSD test; variable DV_1 (RS ANOVA.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 743.06, df = 138.00							
	TIMEINT	{1} 232.46	{2} 243.46	{3} 249.78	{4} 250.28	{5} 249.95	{6} 254.75	{7} 251.94
1	1		0.076745	0.000235	0.000140	0.000196	0.000026	0.000039
2	2	0.076745		0.677981	0.592446	0.648957	0.062202	0.320276
3	3	0.000235	0.677981		1.000000	1.000000	0.868214	0.998083
4	4	0.000140	0.592446	1.000000		1.000000	0.916976	0.999579
5	5	0.000196	0.648957	1.000000	1.000000		0.886559	0.998807
6	6	0.000026	0.062202	0.868214	0.916976	0.886559		0.991688
7	7	0.000039	0.320276	0.998083	0.999579	0.998807	0.991688	

b. Error detection rate

Cell No.	Tukey HSD test; variable DV_1 (ED ANOVA.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 164.49, df = 138.00							
	TIMEINT	{1} 67.415	{2} 71.880	{3} 71.759	{4} 73.602	{5} 69.482	{6} 69.647	{7} 69.251
1	1		0.193264	0.221894	0.014582	0.923275	0.892171	0.955941
2	2	0.193264		1.000000	0.967763	0.854292	0.892045	0.791002
3	3	0.221894	1.000000		0.955033	0.882681	0.915569	0.825737
4	4	0.014582	0.967763	0.955033		0.281409	0.330965	0.219978
5	5	0.923275	0.854292	0.882681	0.281409		1.000000	1.000000
6	6	0.892171	0.892045	0.915569	0.330965	1.000000		0.999992
7	7	0.955941	0.791002	0.825737	0.219978	1.000000	0.999992	

c. Reaction time

Cell No.	Tukey HSD test; variable DV_1 (RT ANOVA.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = .00881, df = 138.00							
	TIMEINT	{1} .82592	{2} .80053	{3} .78328	{4} .77885	{5} .76887	{6} .76473	{7} .77395
1	1		0.111395	0.000192	0.000042	0.000026	0.000026	0.000027
2	2	0.111395		0.547426	0.261962	0.016521	0.003534	0.080909
3	3	0.000192	0.547426		0.999271	0.742400	0.456497	0.959742
4	4	0.000042	0.261962	0.999271		0.944316	0.761012	0.998715
5	5	0.000026	0.016521	0.742400	0.944316		0.999513	0.998404
6	6	0.000026	0.003534	0.456497	0.761012	0.999513		0.961971
7	7	0.000027	0.080909	0.959742	0.998715	0.998404	0.961971	

d. Target deviation

Cell No.	Tukey HSD test; variable DV_1 (TD ANOVA.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 4.1569, df = 138.00							
	TIMEINT	{1} 13.093	{2} 13.201	{3} 13.021	{4} 13.115	{5} 13.328	{6} 13.319	{7} 13.689
1	1		0.998643	0.999860	1.000000	0.920120	0.932956	0.063540
2	2	0.998643		0.977778	0.999632	0.996506	0.997660	0.221397
3	3	0.999860	0.977778		0.999353	0.760066	0.784438	0.022430
4	4	1.000000	0.999632	0.999353		0.949236	0.958598	0.084368
5	5	0.920120	0.996506	0.760066	0.949236		1.000000	0.591053
6	6	0.932956	0.997660	0.784438	0.958598	1.000000		0.562094
7	7	0.063540	0.221397	0.022430	0.084368	0.591053	0.562094	

e. Heart rate

Cell No.	Tukey HSD test; variable DV_1 (HR ANOVA.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 7.2426, df = 92.000					
	TIMEINT	{1} 114.77	{2} 115.96	{3} 117.30	{4} 118.15	{5} 119.01
1	1		0.200261	0.000232	0.000118	0.000118
2	2	0.200261		0.114929	0.001356	0.000120
3	3	0.000232	0.114929		0.536055	0.020291
4	4	0.000118	0.001356	0.536055		0.520313
5	5	0.000118	0.000120	0.020291	0.520313	

f. RPE

Cell No.	Tukey HSD test; variable DV_1 (RPE ANOVA.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = .65679, df = 92.000					
	TIMEINT	{1} 10.208	{2} 11.104	{3} 11.667	{4} 12.292	{5} 12.646
1	1		0.000121	0.000118	0.000118	0.000118
2	2	0.000121		0.008731	0.000118	0.000118
3	3	0.000118	0.008731		0.002655	0.000118
4	4	0.000118	0.000118	0.002655		0.212017
5	5	0.000118	0.000118	0.000118	0.212017	

APPENDIX E2

Condition and Time Intervals

a. Reading speed

Tukey HSD test; variable DV_1 (RS ANOVA.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 930.19, df = 138.00

Cell No.	COND	TIME	{1} 225.50	{2} 244.19	{3} 251.11	{4} 251.75	{5} 256.60	{6} 263.15	{7} 252.28	{8} 239.43	{9} 242.72	{10} 248.44	{11} 248.82	{12} 243.31	{13} 246.36	{14} 251.60
1	1	1		0.136889	0.003111	0.002022	0.000071	0.000023	0.001403	0.601385	0.241450	0.016304	0.013095	0.194977	0.050371	0.002239
2	1	2	0.136889		0.998000	0.995230	0.772503	0.122702	0.990926	0.999967	1.000000	0.999991	0.999976	1.000000	1.000000	0.996078
3	1	3	0.003111	0.998000		1.000000	0.999834	0.808659	1.000000	0.839394	0.987232	1.000000	1.000000	0.993442	0.999968	1.000000
4	1	4	0.002022	0.995230	1.000000		0.999959	0.862255	1.000000	0.781544	0.975903	1.000000	1.000000	0.986543	0.999865	1.000000
5	1	5	0.000071	0.772503	0.999834	0.999959		0.998874	0.999989	0.246114	0.607890	0.990153	0.993660	0.676456	0.934265	0.999941
6	1	6	0.000023	0.122702	0.808659	0.862255	0.998874		0.899426	0.010342	0.062574	0.508545	0.553754	0.082580	0.280687	0.850415
7	1	7	0.001403	0.990926	1.000000	1.000000	0.999989	0.899426		0.726560	0.961428	0.999997	0.999999	0.977079	0.999618	1.000000
8	2	1	0.601385	0.999967	0.839394	0.781544	0.246114	0.010342	0.726560		1.000000	0.976158	0.966539	0.999997	0.997973	0.796106
9	2	2	0.241450	1.000000	0.987232	0.975903	0.607890	0.062574	0.961428	1.000000		0.999735	0.999471	1.000000	0.999999	0.979118
10	2	3	0.016304	0.999991	1.000000	1.000000	0.990153	0.508545	0.999997	0.976158	0.999735		1.000000	0.999921	1.000000	1.000000
11	2	4	0.013095	0.999976	1.000000	1.000000	0.993660	0.553754	0.999999	0.966539	0.999471	1.000000		0.999824	1.000000	1.000000
12	2	5	0.194977	1.000000	0.993442	0.986543	0.676456	0.082580	0.977079	0.999997	1.000000	0.999921	0.999824		1.000000	0.988556
13	2	6	0.050371	1.000000	0.999968	0.999865	0.934265	0.280687	0.999618	0.997973	0.999999	1.000000	1.000000	1.000000		0.999902
14	2	7	0.002239	0.996078	1.000000	1.000000	0.999941	0.850415	1.000000	0.796106	0.979118	1.000000	1.000000	0.988556	0.999902	

b. Reaction time

Cell No.	Tukey HSD test; variable DV_1 (RT ANOVA.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = .00606, df = 138.00														
	COND	TIME	{1} .83850	{2} .80508	{3} .77502	{4} .76978	{5} .76374	{6} .76296	{7} .78423	{8} .81334	{9} .79599	{10} .79154	{11} .78792	{12} .77399	{13} .76651	{14} .76368
1	1	1		0.147217	0.000024	0.000023	0.000023	0.000023	0.000135	0.600649	0.011395	0.002382	0.000579	0.000024	0.000023	0.000023
2	1	2	0.147217		0.292937	0.093961	0.016707	0.012958	0.850203	0.999979	0.999937	0.995547	0.962888	0.241227	0.038812	0.016351
3	1	3	0.000024	0.292937		1.000000	0.999313	0.998606	0.999926	0.041608	0.844637	0.972790	0.997233	1.000000	0.999971	0.999268
4	1	4	0.000023	0.093961	1.000000		1.000000	0.999998	0.991701	0.007984	0.530085	0.806187	0.942827	1.000000	1.000000	0.999999
5	1	5	0.000023	0.016707	0.999313	1.000000		1.000000	0.865964	0.000854	0.190535	0.426034	0.664971	0.999757	1.000000	1.000000
6	1	6	0.000023	0.012958	0.998606	0.999998	1.000000		0.830671	0.000626	0.160701	0.377238	0.613715	0.999456	1.000000	1.000000
7	1	7	0.000135	0.850203	0.999926	0.991701	0.865964	0.830671		0.345626	0.998926	0.999995	1.000000	0.999758	0.952203	0.863128
8	2	1	0.600649	0.999979	0.041608	0.007984	0.000854	0.000626	0.345626		0.959412	0.804134	0.582475	0.030801	0.002492	0.000832
9	2	2	0.011395	0.999937	0.844637	0.530085	0.190535	0.160701	0.998926	0.959412		1.000000	0.999984	0.793757	0.324752	0.187837
10	2	3	0.002382	0.995547	0.972790	0.806187	0.426034	0.377238	0.999995	0.804134	1.000000		1.000000	0.955606	0.608822	0.421766
11	2	4	0.000579	0.962888	0.997233	0.942827	0.664971	0.613715	1.000000	0.582475	0.999984	1.000000		0.994139	0.824067	0.660647
12	2	5	0.000024	0.241227	1.000000	1.000000	0.999757	0.999456	0.999758	0.030801	0.793757	0.955606	0.994139		0.999994	0.999739
13	2	6	0.000023	0.038812	0.999971	1.000000	1.000000	1.000000	0.952203	0.002492	0.324752	0.608822	0.824067	0.999994		1.000000
14	2	7	0.000023	0.016351	0.999268	0.999999	1.000000	1.000000	0.863128	0.000832	0.187837	0.421766	0.660647	0.999739	1.000000	

c. Heart rate

Cell No.	Tukey HSD test; variable DV_1 (HR ANOVA.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 7.0621, df = 92.000										
	CONDITIO	TIMEINT	{1} 140.73	{2} 145.24	{3} 148.39	{4} 150.17	{5} 152.00	{6} 88.799	{7} 86.675	{8} 86.208	{9} 86.125	{10} 86.017
1	1	1		0.000161	0.000159	0.000159	0.000159	0.000159	0.000159	0.000159	0.000159	0.000159
2	1	2	0.000161		0.003516	0.000159	0.000159	0.000159	0.000159	0.000159	0.000159	0.000159
3	1	3	0.000159	0.003516		0.385421	0.000488	0.000159	0.000159	0.000159	0.000159	0.000159
4	1	4	0.000159	0.000159	0.385421		0.344156	0.000159	0.000159	0.000159	0.000159	0.000159
5	1	5	0.000159	0.000159	0.000488	0.344156		0.000159	0.000159	0.000159	0.000159	0.000159
6	2	1	0.000159	0.000159	0.000159	0.000159	0.000159		0.163254	0.034379	0.025032	0.016294
7	2	2	0.000159	0.000159	0.000159	0.000159	0.000159	0.163254		0.999839	0.999386	0.997343
8	2	3	0.000159	0.000159	0.000159	0.000159	0.000159	0.034379	0.999839		1.000000	1.000000
9	2	4	0.000159	0.000159	0.000159	0.000159	0.000159	0.025032	0.999386	1.000000		1.000000
10	2	5	0.000159	0.000159	0.000159	0.000159	0.000159	0.016294	0.997343	1.000000	1.000000	

d. RPE

Cell No.	Tukey HSD test; variable DV_1 (RPE ANOVA.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = .62056, df = 92.000										
	CONDITIO	TIMEINT	{1} 12.542	{2} 14.000	{3} 14.958	{4} 15.667	{5} 16.333	{6} 7.8750	{7} 8.2083	{8} 8.3750	{9} 8.9167	{10} 8.9583
1	1	1		0.000159	0.000159	0.000159	0.000159	0.000159	0.000159	0.000159	0.000159	0.000159
2	1	2	0.000159		0.002382	0.000159	0.000159	0.000159	0.000159	0.000159	0.000159	0.000159
3	1	3	0.000159	0.002382		0.070541	0.000160	0.000159	0.000159	0.000159	0.000159	0.000159
4	1	4	0.000159	0.000159	0.070541		0.111849	0.000159	0.000159	0.000159	0.000159	0.000159
5	1	5	0.000159	0.000159	0.000160	0.111849		0.000159	0.000159	0.000159	0.000159	0.000159
6	2	1	0.000159	0.000159	0.000159	0.000159	0.000159		0.901964	0.465257	0.000712	0.000425
7	2	2	0.000159	0.000159	0.000159	0.000159	0.000159	0.901964		0.999244	0.070541	0.042949
8	2	3	0.000159	0.000159	0.000159	0.000159	0.000159	0.465257	0.999244		0.348820	0.249441
9	2	4	0.000159	0.000159	0.000159	0.000159	0.000159	0.000712	0.070541	0.348820		1.000000
10	2	5	0.000159	0.000159	0.000159	0.000159	0.000159	0.000425	0.042949	0.249441	1.000000	