The Effects of Fatiguing Exercise on Cognition and Physical Performance

by

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ABSTRACT

The overall objective of this work was to examine the use of a psychomotor battery to detect changes in cognitive function in relation to decrements in performance during fatiguing exercise of physically active men. Three types of investigations were conducted. First, a systematic literature review was conducted to provide evidence-based information regarding the use of psychomotor batteries as an early detection marker for overtraining. Second, a methodological investigation was conducted to examine the reliability of a CogState battery to measure cognitive function under repeat exposure, according to two different testing schedules. A massed group (n = 6) performed the battery three times per day for 5 days, while the distributed group (n = 5) completed the battery once per day for 15 days. For simple and choice reaction time, findings supported the repeated use of CogState. Third, a randomized control trial was conducted to document the time course of cognitive and physiological changes when exposed to a high training load. Eleven active males were randomly assigned to a training or control group. The training group completed a 20 km cycling time trial on 5 days; while the control group maintained their usual activity. Baseline and post-tests (maximal aerobic power, time-trial performance, cognition, Muscle Soreness, Sleep Quality, and Stress-Recovery) were collected one week prior to, and following training. During training, pre- and post-session measurements of cognitive function were administered (via a CogState battery). Other measurements included morning heart rate variability, muscle soreness, and sleep quality. A one-week period of recovery followed training, wherein cognitive function was assessed daily. Results revealed no differences in time-trial performances across days for the training group (p = .325). The training protocol did not produce levels of physical fatigue required to induce performance decrements in participants; subsequently, no cognitive changes associated to the training were observed. Anecdotally, participants reported feelings of fatigue, stress, and discomfort. These findings demonstrate that recreational exercisers do not perceive appropriately objective measures of their own performance. Recommendations are provided to address the limitations of the training protocol administered to induce performance decrements in recreational exercisers for further research in this area.

PREFACE

This thesis document was written by Danielle Beaudoin under the guidance of Dr. Shannon S.D. Bredin. All data presented in this thesis was collected in the Physical Activity and Chronic Disease Prevention Unit at the University of British Columbia. Specifically, the work was conducted in the Cognitive and Functional Learning Laboratory, the Systematic Reviews Research Laboratory, and the Cardiovascular Physiology and Rehabilitation Laboratory.

Conceptualization of the research investigations presented in this document was done by Danielle Beaudoin and Dr. Shannon Bredin, with input on the main investigation of this thesis from Dr. Darren Warburton and Dr. Don M^c^Kenzie. For all research involving participants, Danielle Beaudoin was responsible entirely for participant recruitment, data entry, and statistical analysis (Chapters 4 and 5). Ms. Beaudoin also collected the majority of data for both research projects. Ms. Natalie Goodfellow should also be acknowlegded for her contribution to this thesis as she assisted Ms. Beaudoin in the collection of data. The systematic review of the literature (Chapter 3) was conducted by Danielle Beaudoin. Ms. Natalie Goodfellow also served as a second reviewer for the systematic literature review. None of the research presented in this document has been published to-date.

All research involving human participants received ethical approval. The CogState Reliability Investigation (Chapter 4) obtained approval from the University of British Columbia Behavioural Research Ethics Board (see UBC BREB Number: H11-00495). The main investigation of this thesis (Chapter 5) obtained approval from the University of British Columbia Clinical Research Ethics Board (see UBC CREB : H10-03290).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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GLOSSARY OF OPERATIONAL DEFINITIONS

Cognition: the mental act or process by which knowledge is acquired; the act of knowing.

Cognitive function From an information processing perspective, it refers to the capacity of the central nervous system to identify and perceive a stimulus, to select an appropriate response, and to program the corresponding response. These processes are involved in the acquisition and use of knowledge, including sensation, perception, attention, learning, memory, language, thinking, and reasoning (Purves, 2005; Schmidt, 1982).

Early detection: Identification of a state, at its onset, before the signs and symptoms reach full intensity (i.e., at the very beginning of the state). Early detection allows for prevention of a more severe condition (Raglin & Wilson, 2000).

Early detection marker: A psychological, neurological, biochemical, or physiological parameter whose change (from baseline) allows for early detection of a particular human state (Meeusen et al., 2006; Nederhof, Zwerver, Brink, Meeusen, & Lemmink, 2008).

Full recovery: The state after an imbalance in stress-recovery homeostasis when adverse symptoms dissipate and the individual returns to previous levels of performance. It necessitates the regeneration of physical and psychological resources (Kallus & Kellmann, 2000).

Functional overreaching: According to Nederhof and colleagues, it is the first state of three on the overtraining continuum, characterized by mild symptoms and a decrement in performance, and from which one will recover whithin 2 weeks (Nederhof, Lemmink, Visscher, Meeusen, & Mulder, 2006).

Non-functional overreaching: According to Nederhof and colleagues, it is the second state of three associated with negative adaptations to physical training, characterized by mild to severe symptoms and a decrement in performance from which one will recover within a few months (Nederhof et al., 2006).

Overtraining continnum: The ensemble of three hierarchical states: functional overreaching, non-functional overreaching, and the overtraining syndrome, that is characterized by a negative adaptation to physical training.

Overtraining period: A duration of time, whereby training volume and/or training intensity is purposefully increased in an attempt to elicit higher levels of performance (also known as higher training load period or training overload period (Hassmén, 1998; Kreider, Fry, & O'Toole, 1998; Snyder, Jeukendrup, Hesselink, Kuipers, & Foster, 1993), or overload training period (Nederhof, Lemmink, Zwerver, & Mulder, 2007).

Overtraining syndrome: A condition characterized by a decrease in performance that is not explained by any other condition. It is associated with a group of psychological and physical symptoms, including excessive fatigue, and occurs in athletes engaging in a highly taxing training regimen. Several months to years are required for complete recovery (Birch & George, 1999; Boto, González, & Márquez, 2008; Nederhof et al., 2006; Peterson, 2009).

Performance decrement: Occurs when an indvidual is unable to maintain customary levels of training, or exhibits a diminished level of performance from his or her normal level as measured formally, with a standardized test (e.g., maximal aerobic power, time trial, maximal power output) or informally, by monitoring and recording an objective value (e.g., time, speed, distance, power) reached during a regular exercise bout across training.

Physical adaptations: Changes, either with positive or negative consequences, which occur in the various bodily systems following an exercise episode. These changes then influence one's performance in any physical activity (e.g., change in oxygen transport to the muscles, or change in the ways the body utilizes energy resources).

Psychomotor markers: An objective variable yielding information regarding the cognitive and motor state of a human system as measured by cognitive function (stimuli processing, response selection, actions programming) and activity of the motor system.

Psychosocial markers: A variable yielding information regarding the state of a human system as measured by psychological and social aspects, including (but not limited to): emotions, perception of self and others, and mood.

Reaction time: The interval of time between the presentation of a stimulus and observable movement (or response) (Schmidt & Lee, 1999); a potential psychomotor marker for the early identification or onset of physiological-related decrements in performance.

Retrospective diagnosis: Identification of a condition (disease or syndrome) made once the condition has ended. With respect to the overtraining syndrome, final diagnosis is made based on the duration of recovery, which explains the need to wait until the recovery is complete before establishing a final diagnosis (Meeusen et al., 2010).

Stress-regeneration balance: A term that refers to the delicate relationship (or balance) between training load (volume and intensity) versus recuperation (or adequate recovery) of the system. An individual is thought to have achieved a balanced state when recuperation allows for complete restoration of the resources used over a planned period of training (Rietjens et al., 2005).

Stressor: A stress agent, or a source of stress (e.g., increased training volume, frequent competitions, illness, deadline at work), which induces a physiological or psychological responses (e.g., diminished substrate resources within the muscle and liver, or feelings of fatigue) possibly leading to adaptation (e.g., greater storage of energy, lowered perceived effort) (Hassmén, 1998; Nederhof et al., 2006).

Training load: In the following text, “training load” will refer to a stressor imposed on an individual in the form of physical exercise. It refers to both the volume (the amount of training, calculated in time, distance or other) and the intensity (the power, calculated in speed, watts, or other) of the exercise.

1 CHAPTER ONE: Introduction to the Thesis

The purpose of this chapter is to provide an overview of the thesis document. More specifically, it includes a brief introduction of the central concepts of the present work, as well as an overview of two investigations. It is concluded by a succinct overview of the six main chapters of this document.

1.1 Introduction

Physical adaptations to exercise in the human body are observed by changes in performance that may be positive or negative in nature. For high performance athletes and recreational exercisers alike, a gain in speed, strength, or accuracy is seen as a positive outcome, whereby a loss of speed, strength, or accuracy is considered to be a negative outcome. In sport, a goal of a training session is to trigger positive physical adaptations in the human body to reach higher levels of performance. This can only be achieved by introducing and implementing successfully an appropriate training load that is challenging enough to produce positive body adaptations but not too severe that the training load leads to negative outcomes on performance. Therefore, a priority in sport performance is finding and maintaining a delicate balance in training load, whereby positive adaptation is facilitated and undesirable consequences are minimized.

A major factor in regulating this balance is determining and planning an appropriate amount of recovery for the training load. Recovery refers to the elimination of fatigue, as well as the ability to utilize again the same resources or system for which the recovery was needed (Kellmann, 2002). Importantly, in the high performance domain, athletes are always striving to improve upon their performance in an attempt to reach higher levels of achievement. This pursuit for excellence continues to push the limits of human capabilities, whereby performance standards increase persistently for each generation of performers (Kentta & Hassmen, 1998). Therefore, examining methods to maintain the delicate balance between training stress and recovery is an important area of study in the field of high performance.

Indeed, negative consequences associated with a training load that is too heavy for the recovery provided, a phenomenom most often called “overtraining”, should be avoidable if the training load and its effects on the athlete are closely monitored, controlled, and interpreted. However, the exact mechanism(s) underlying the initiation and development of an overtrained state are still unknown (Armstrong & VanHeest, 2002; Meeusen et al., 2010), which makes prevention difficult. Several factors may to be linked to the onset of an overtrained state, namely the presence of an injury or infectious disease (Meeusen et al., 2006), a significant stress in one’s personal or professional life (such as a death, or a difficult relationship with co-workers (Nederhof, Lemmink, Zwerver, & Meeusen, 2006)), a negative experience within one’s athletic carreer (such as losing an important competition (Noce et al., 2008)) or a recent increase in training load (Lehmann et al., 1997). It has been suggested that an augmentation of stressors, whether from physical or psychological sources, trigger the onset of an overtrained state. However, there is currently no objective and reliable method available to determine whether the accumulation of various stressors is beyond an athlete’s adaptive capabilties. Early identification of overtraining and the development of tools to assist in early detection would facilitate the prevention of aggravated states that not only hinder the training and performance of the individual, but also prevent adverse training-related effects on the health and well-being of the individual.

In previous literature, a number of markers have been proposed for the early detection of overtraining. These markers have generally been physiological or biochemical in nature and includes the examination of such measures as: muscle enzymes (e.g., creatine kinase) (Budgett, 1998; Hooper et al., 1995), hormonal changes (namely cortisol, testosterone, or their ratio) (Elloumi et al., 2008), blood composition (haemoglobin or leukocytes count) (Birch & George, 1999; Coutts et al., 2007), lactate (Coutts et al., 2007; Urhausen et al., 1998), maximal power output (Urhausen et al., 1998), or changes in rest, submaximal, and maximal heart rate (Coutts et al., 2007; Urhausen et al., 1998). Unfortunately, empirical work suggests that these measures are not reliable predictors of overtraining. However, more recently another category of tests assessing specific aspects of motor behaviour has emerged (Hynynen et al., 2008; Nederhof et al., 2007; Nederhof et al., 2008; Nederhof et al., 2006; Nederhof, Visscher, & Lemmink, 2008; Rietjens et al., 2005). These tests have focused to-date on psychomotor variables such as reaction time. Previously Bredin and Warburton (manuscript under review) have shown that decrements in simple reaction time precede decrements in performance after a short-term period of high intensity fatiguing exercise in endurance-trained athletes. These preliminary findings support the idea that simple psychomotor tests may be useful in the early detection of physiological changes of the body, thereby serving as an early warning signal for the potential onset of overtraining. More specifically, the purpose of the proposed research is to continue the work of Bredin and Warburton and examine the influence of various psychomotor tests on the capability to detect the onset of fatigue-related physiological changes in the human body. Knowing what aspects of cognitive processing exhibit changes prior to measurable decrements in performance would facilitate the development of a screening tool for the early diagnosis of an overtrained state. We chose to investigate the relationship between cognitive and physical changes in performance in a sample of recreational exercisers because we believe that this mind-body relationship should reflect a basic principle of human behaviour, and should be present across populations. Additionally, this work sheds light on recreational exercisers perception of physical fatigue, which may help provide further information as to the influence of fatigue on physical activity participation.

1.2 Overview of the Research

This thesis consists of two investigations: a primary investigation and a smaller, methodological investigation. The purpose of the main investigation was to examine the use of a simple, cognitive test battery to detect changes in cognitive performance in comparison to physiological changes of healthy active adult males after exposure to a high training load. Eleven healthy active males were recruited and randomly assigned to either a training (n = 6) or a control (n = 5) group. All participants completed baseline testing on two consecutive days, whereby assessments of cognitive function (CogState test battery), maximal aerobic power, and physical performance (via a cycling time trial) were completed. In addition, the Delayed Onset of Muscle Soreness Questionnaire and a Sleep Quality Questionnaire were administered. One week following baseline testing, the training group completed a 20 km time trial of stationary cycling on 5 conscutive days, while participants assigned to the control group maintained their usual daily activities (as determined by random group assignment). During the training period, a Cogstate test battery was administered at the start and at the end of each training session. Other daily measurments for both groups included morning heart rate variability (from home) and completion of the Delayed Onset of Muscle Soreness Questionnaire and a Sleep Quality Questionnaire. During the week following the training protocol (also referred to as recovery), cognitive performance, muscle soreness, and sleep quality were assessed daily for both the training and control group. Post-test measures were completed one week following the completion of training and were carried out in exact accordance with baseline testing.

Based on Bredin and Warburton's preliminary work, we postulated that when implementing a training protocol of high load, decrements in cognitive performance would emerge prior to significant physiological decrements in performance. However, the sensitivity of each cognitive test employed in the selected battery is unknown. Accordingly, the purpose of this work is to also explore differences between psychomotor tests to determine the most viable test to use in the prediction of performance decrements. The identification of an objective, reliable, non-invasive early detection marker that requires little time for administration in the applied setting would allow for the frequent monitoring of individuals engaging in a training protocol, as well as various associated stressors.

Prior to collection of the main investigation, a smaller methodological investigation was conducted, whereby reliability of the CogState Test battery was examined. According to the company, the CogState computerized test battery was developed specifically for repeat testing in the same individuals to examine a wide variety of cognitive functions (e.g., processing speed, working memory, attention, and learning (Collie, Maruff, Darby, & McStephen, 2003). However, there is no published information confirming its reliability across extensive repeat testing. This is particularly important given that in the main thesis investigation, numerous test sessions were needed throughout and across days, to observe cognitive performance. Therefore, the purpose of the methodological investigation was to examine cognitive performance when the selected CogState battery is administered across 15 testing sessions according to two different testing schedules. Specifically, 13 apparently healthy adults were recruited to participate in the investigation and were randomly assigned to either a massed (n = 6) or a distributed group (n = 7). The massed group performed the CogState battery 15 times over one week at a rate of 3 times per day. The distributed group performed the CogState battery 15 times, over 15 days, at a rate of once per day. It was hypothesized that improvements in performance would occur between the first and the second testing session as a result of familiarization to the test and/or the occurrence of some learning, after which a levelling off (or a stabilization in performance) would occur for both groups. The results of this investigation were needed from a research design perspective as they provided information to be used in the design of baseline measurements for our main research, as well as to provide information regarding the utility and sensitivity of a CogState battery for repeated use in both a test setting and/or an applied training environment.

1.3 Overview of the Thesis Document

The present document is organized into six chapters. An introdution to the thesis is presented in Chapter 1, while the purpose of Chapter 2 is to present a general overview of the literature as it pertains to the general concepts of overtraining and the use of early detection markers. More specifically, Chapter 2 is comprised of six sections, which provides a description of the overtraining syndrome and associated conditions; possible causes and consequences of overtraining; the most common signs and symptoms of overtraining; the estimated prevalence of the condition; as well as an overview of the current methods of diagnosis and/or identification of overtraining including previous research that has been conducted on early detection markers specifically. In Chapter 3, the research to-date on the use of psychomotor markers for the early detection of overtraining is examined via a systematic review of the literature. The methodological investigation is presented in Chapter 4. Presentation of the primary investigation of the thesis is presented in Chapter 5. Chapter 6 concludes the thesis with a discussion of the main findings of the work, as well as their importance to applied research. Limitations of the research, as well as recommendations for future research will be discussed in the final chapter of the thesis.

2 CHAPTER TWO: General Overview of the Literature

The purpose of Chapter 2 is to present a general overview of the literature on overtraining and related concepts, which serves to set the context of the proposed thesis work. This chapter is presented in six main sections. The first section presents the general notion of training; focusing on the concept of supercompensation for the improvement of human performance. The objective of the second section is to discuss what is meant by the term 'overtraining' as it is presented in the literature to-date. The focus of the third section is on the presentation of Nederhof's continuum of overtraining (2006), which is followed by discussion of the most common signs and symptoms of overtraining (Section Four). The objective of Section Five is to outline the limitations of current methods of diagnosis for overtraining, especially as it relates to the concept of early detection. Finally, the use of psychomotor markers in the context of overtraining and early detection is discussed in Section Six.

2.1 Introduction

In Sports Science, athletic training is often broken down into four periods, which include the athlete's baseline (or initial level of performance), training, recovery, and the supercompensation period. The baseline level of performance of the athlete refers to the current performance level of the athlete. Baseline measures indicate the capability of the athlete to complete a training session; or conversely, to tolerate the stressors associated with a training session.

When engaged in a training session, energy stores are depleted and tissues are damaged which causes a homeostatic imbalance in the system. Following training, the body enters the recovery period, during which energy substrates are stored again, and affected tissues are repaired. Performance capacity is therefore restored when the system returns to homeostasis. Moreover, the body will also build resources to minimize future disruptions in homeostasis if a similar stressor is applied again (Fry, Morton, & Keast, 1992; Hassmén, 1998).

The readiness of resources to tolerate better a stressor is referred to as supercompensation. Also called “reaching” (Steinacker & Lehmann (2002) in Kellmann, 2002), supercompensation is described as an increase in level of performance, or training capacity, following a previous training session (Meeusen et al., 2006). The period of time when the inidvidual exhibits the effects of supercompensation (e.g., an increase in performance capacity) is termed the supercompensation phase. To enhance performance, a common strategy is to plan a training session during the supercompensation phase. In contrast, if no stressor (i.e., another training session) is applied during this time period, the performance level of the athlete will return to baseline levels (Meeusen et al., 2006; Nederhof et al., 2006). From one perspective, the supercompensation phase can be viewed as a window of opportunity to enhance one’s level of performance. Figure 2.1 shows a conceptual organization of the four training phases as they relate to enhancing an athlete’s performance capacity.

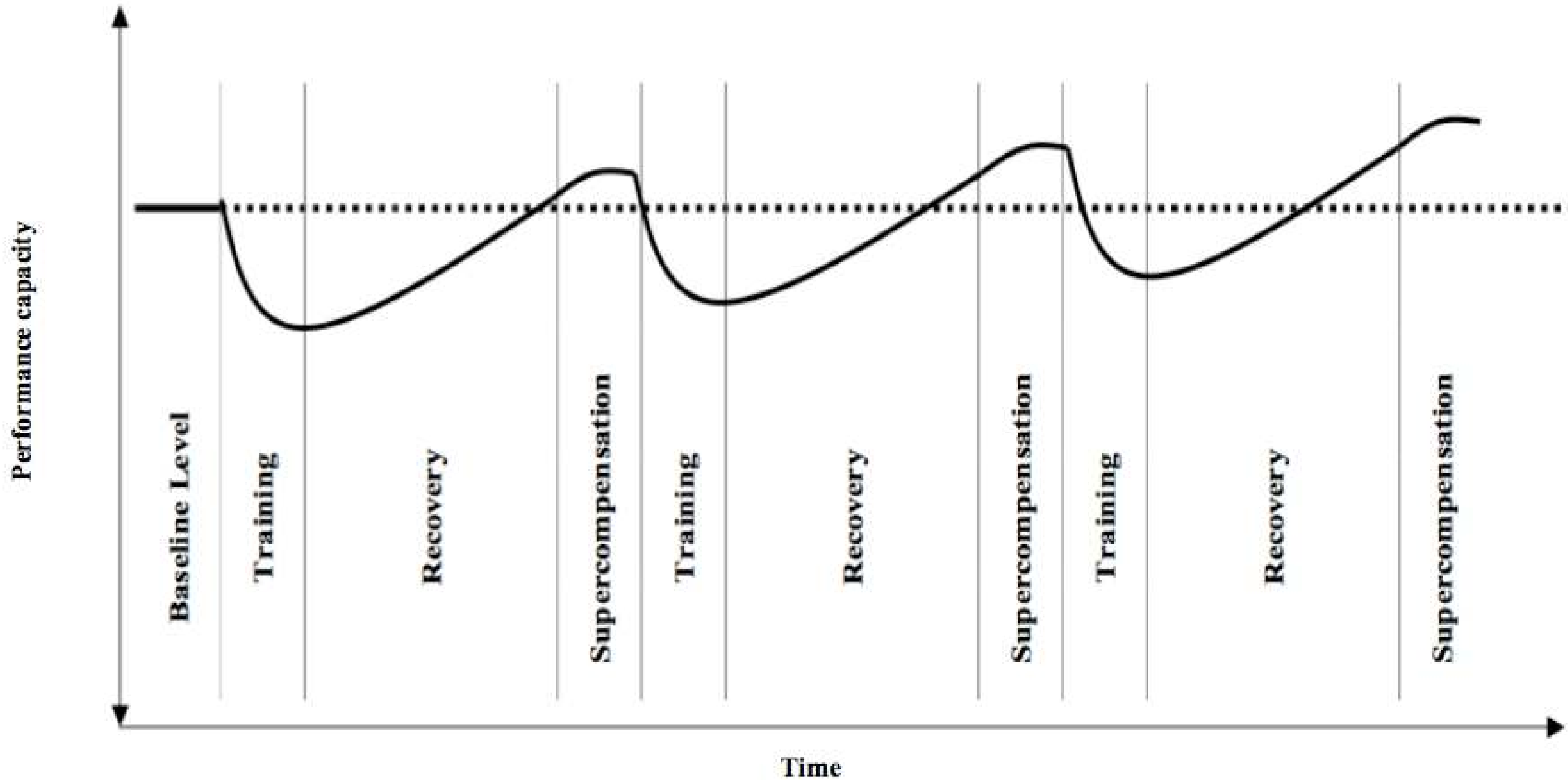

Figure 2.1. A conceptual representation of performance capacity as it relates to baseline level of performance, subsequent training sesions, recovery following training, and the supercompensation phase.

In common training practice, it is often suggested that the greater the stressor, the greater the supercompensation will be, a belief that encourages athletes to undergo increased training loads persistently (Hassmén, 1998). However, such training loads can easily disturb the delicate stress-regeneration balance (Rietjens et al., 2005). Importantly, when the system has not been provided optimum opportunity to regenerate and adapt, the athete becomes highly susceptible to staleness, overtraining, or burn-out, and in extreme cases, can even lead to athlete drop-out (especially at the youth levels of sport) (Boto, González, & Márquez, 2008; Lehmann, Foster, & Keul, 1993; Morgan et al., 1987; Canadian Sport Centres, 2011). Indeed, it is widely accepted that an imbalance between stress and recovery, or more simply, too much training and too little rest, will induce fatigue and/or limited training capacity, decrease interest or motivation for training, and ultimately influence performance in a negative manner (Lehmann et al., 1997; Meeusen et al., 2010; Nederhof et al., 2008). Negative consequences associated with a training load that is too heavy for the recovery provided, a phenomenom most often called "overtraining", can be avoided if the training load and its effects on the athlete are closely monitored, controlled, and interpreted (Meeusen et al., 2006). As such, examining the concept of overtraining is an important line of investigation from several perspectives. For example, understanding the concept is important for the prevention, detection, and appropriate management of an overtrained state in athletes. Alternatively, a deepened understanding of the fine balance between stress and regeneration, can lead to improved training protocols and/or increase the trainability of an athlete (Kellmann, 2010).

2.2 What Is Overtraining?

The term overtraining is usually used in the European literature to refer to what is called the "Overtraining Syndrome" in North American literature (Nederhof, Lemmink, Visscher, Meeusen, & Mulder, 2006). Overtraining has also been referred to using such terms as failure adaptation, underrecovery, training stress syndrome, unexplained underperformance syndrome, overused, overstrained, overworked, overstressed, and stagnation or staleness (Boto et al., 2008; Hassmén, 1998; Morgan et al., 1987; Nederhof et al., 2006). The term burn-out is also widely used to refer to negative physical and psychological adaptation following a physical training that is above an optimum training load and has been associated with decreased performance (Hassmén, 1998; Lemyre, Hall, & Roberts, 2008; Peterson, 2009). Peterson (2009) has suggested the difference between athletic burn-out and the overtraining syndrome is that the cause of athletic burn-out is psychological and physical stressors, whereby the cause of the overtraining syndrome is physical stressors. In contrast, others suggest that the overtraining syndrome is a result of a mixture of both physical and psychological stressors (Kallus & Kellmann, 2000; Kreider et al., 1998; Noce et al., 2008). Although some use the term ‘burn-out’ to refer to an overtrained state; the term ‘burn-out’ will not be utilised in this document, as it is often used in the literature to refer to professional burn-out. Other terms such as chronic fatigue syndrome has been associated with the overtraining syndrome (Hassmén, 1998); however, it is more commonly accepted that the overtraining syndrome is actually a precipitant of chronic fatigue syndrome (Nederhof, Lemmink, Zwerver, & Meeusen, 2006) and the terms do not refer to the same condition (i.e., the two conditions have different aetiology) (Shephard, 2001). Moreover, chronic fatigue syndrome is characterized by a disproportionate level of fatigue when compared to energy expenditure, and unlike the overtraining syndrome, is present in nonathletes and/or inactive populations. Shephard (2001) reported that between 1% and 3% of patients complaining of fatigue fit the criteria of the chronic fatigue syndrome, and it is suggested that this discrepancy is similar in an athletic population. Therefore, a very small percentage of athletes complaining of fatigue would in fact have chronic fatigue syndrome. Moreover, from our perspective, despite a commonly shared symptom (i.e., unexplained excessive fatigue), chronic fatigue syndrome and overtraining refer to different aetiologies, and rarely overlap in the athletic population.

In more recent years, the term ‘overreaching’ has been used when discussing the concept of overtraining. Kreider (1998) defined the term ‘overreaching’ as a short-term decrement in performance, caused by training and non-training related stressors for which recovery lasts several days to several weeks. In contrast, ‘overtraining’ was defined as a long-term decrement in performance caused by training and non-training related stressors, for which the recovery lasts several weeks to several months. Nederhof (2006) then proposed a modification to this approach by suggesting a three-phase continuum that increases in intensity and severity. These categories are: (a) functional overreaching, (b) non-functional overreaching, and (c) the overtraining syndrome. The conceptual framework for the present research investigation is based on this three-phase continuum of overtraining, which is presented in greater detail below.

2.3 Nederhof’s (2006) Three-phase Continuum of Overtraining

Nederhof’s (2006) classification system, as represented by the categories of functional overreaching, non-functional overreaching, and the overtraining syndrome, is defined according to the outcome of overload training. Moreover, it takes into consideration the time an individual needs to overcome a performance decrement caused by the training. The continuum is considered to be hierarchical in nature, whereby the individual experiences functional overreaching before non-functional overreaching, and non-functional overreaching before exhibiting the overtraining syndrome.

2.3.1 Functional overreaching

According to Nederhof (2006), functional overreaching refers to only a temporary state of performance decrement and fatigue. This state is easily reversible within a preplanned period of time, is charaterized by light (or mild) symptoms (e.g., feelings of fatigue, diminished interest), and has no long-term negative effect on training (Coutts, Wallace, & Slattery, 2007; Nederhof et al., 2006). In fact, this type of overreaching is often identified as having a positive effect on overall performance; hence, the term 'functional'. For example, experiencing functional overreaching may be a training goal within the design of a program because of its potential to enhance skill acquisition and long-term retention and transfer of performance. Gains in performance in functional overreaching may occur as a result of supercompensation (Halson & Jeukendrup, 2004; Lehmann, Foster, Gastmann, Keizer, & Steinacker, 1999). That is, when subjected to a training stimulus, an athlete will adapt to the physical demand by building resources to face this type of stimuli more successfully in the future. The amount of physical stress that can be applied during one training session is rarely sufficient enough for high performance athletes. As a result, a functional overreaching cycle will consist of a high number of training sessions with very little rest. It is postulated that the accumulation of several training sessions with an insufficient level of recovery between each session will generate a greater stimulus. When finally allowed sufficient recovery time, the athlete will exhibit supercompensation that is greater than the supercompensation associated with only one training session (Fry et al., 1992, Lehmann, Foster, Gastmann, Keizer, & Steinacker, 1999).

Time considerations for recovery from a stressor depend on the magnitude of the stimulus. Successive training sessions and incomplete recovery (i.e., a functional overreaching cycle) will require longer recovery afterwards in comparison to only one training session (Fry et al., 1992). Most importantly, during the recovery phase, the athlete is said to be functionally overreached. Specifically, the athlete will demonstrate decrements in performance prior to his or her adaptation to the stimulus. However, functional overreaching is characterized by full recovery (i.e., restoration of pre-overload performance capacity, and/or improved performance) which occurs within a few days or at most, within a period of two weeks (Meeusen et al., 2006; Nederhof, Zwerver, Brink, Meeusen, & Lemmink, 2008; Nederhof et al., 2006). In essence, functional overreaching is an important phase of the training plan as it allows athletes to achieve new heights of performance.

2.3.2 Non-functional overreaching

Non-functional overreaching refers to a form of overtraining that causes detrimental performance effects, whereby full recovery does not occur within a preplanned period of two weeks. The time frame of two weeks is used generally because of issues related to deconditioning in recovery cycles lasting longer than 2 weeks (Nederhof, Lemmink, Visscher, Meeusen, & Mulder, 2006). Although deconditioning occurs differently for each system of the body (e.g., cardiorespiratory versus muscular) as well as for each individual (e.g., moderately active versus strength or endurance trained); a time range of 2 to 6 weeks is typical for most individuals (Godfrey, Ingham, Pedlar, & Whyte, 2005; Smorawinski et al., 2001). Moreover, it is reported that a reduction in training load of 8 to 14 days, represents the ideal balance between complete recovery and the effects of detraining (García-Pallarés, Sánchez-Medina, Pérez, Izquierdo-Gabarren, & Izquierdo, 2010; Nederhof, Lemmink, Zwerver, & Meeusen, 2006b). In contrast, when an individual requires at least two weeks to several months of rest to recover fully from the training load they are exhibiting non-functional overreaching. As such, this form of overreaching is non-functional (Nederhof et al., 2008) because it can interfere with planned training and the achievement of an athlete's goals.

2.3.3 Overreaching vs. overtraining

The term 'overreaching' is used within the literature instead of overtraining to highlight the difference in severity between overreaching (functional and non-functional) and overtraining. Functional and non-functionally overreached individuals are most likely involved in training programs with a planned period of performance decrement that leads into a supercompensation phase. In the case of a non-functional overreached state, it is possible that the monitoring of the trainee was not precise enough, or the training plan was too ambitious, which resulted in an undesirable effect on performance. Fortunately, the recovery of both situations is of a relatively short duration (in comparison to the more severe overtraining syndrome) and is not likely to interrupt the long-term practice of an athlete.

2.3.4 Overtraining syndrome

If no specific considerations are taken for an individual exhibiting non-functional overreaching, an overtraining syndrome may emerge (Lehmann et al., 1999; Nederhof et al., 2006). Overtraining syndrome represents the extreme upper end of the continuum and is representative of the most intense cases of athletic overtraining. The overtraining syndrome is characterized by significant decrements in performance, fatigue, disinterest in sport, changes in physiological and biochemical status, as well as disturbed mood, sleep, and appetite (Birch & George, 1999; Boto et al., 2008; Lehmann et al., 1997; Morgan et al., 1987; Nederhof et al., 2006; Nederhof, Visscher, & Lemmink, 2008; Rietjens et al., 2005). The recovery time for the overtraining syndrome requires several months or even years for the individual to reach full recovery (Kreider, Fry, & O'Toole, 1998; Nederhof et al., 2006).

In a low to moderately active population, overtraining syndrome is not likely to be seen because the overtraining syndrome usually emerges amongst athletes who possess various sources of intrinsic and extrinsic motivations, leading to continued adherence to the practice of a sport even when symptoms are very severe.

2.3.5 Recovery

The amount of recovery needed (whether it is a few days as in a state of functional overreaching or a few years when exhibiting the overtraining syndrome) is related to the type of stress the athlete has been exposed to. The planned recovery must offer a change or reduction of the stressors (active recovery) or even a complete cessation of the stressors (passive recovery) (Kallus & Kellmann, 2000). Passive recovery (complete rest) is generally recommended for athletes exhibiting overtraining syndrome (Hassmén, 1998; Moeller, 2004; Morgan et al., 1987). Unfortunately, a significant period of rest can lead to deconditioning (Hooper, Mackinnon, Howard, Gordon, & Bachmann, 1995; Nederhof et al., 2006), which will also have an influence on an individual's capacity to perform at his or her fullest potential following the period of recovery. Today, active recovery tends to be more widely investigated and is the type of recovery most often incorporated into pre-planned functional overreaching training regimens (Fry et al., 1994; Hanin, 2000; Lehmann, Foster, Gastmann, Keizer, & Steinacker, 1999).

2.4 Reported Signs and Symptoms

Often the first readily observable sign that brings attention to the possibility that an athlete is experiencing a form of overtraining is the emergence of some sort of significant decrement in physical performance (Coutts, Slattery, & Wallace, 2007; Hohl et al., 2009; Meeusen et al., 2010; Meeusen et al., 2006; Nederhof et al., 2008; Nederhof et al., 2006). The magnitude of the performance decrement is highly variable, as is the range and severity of the symptoms affecting each athlete (Coutts et al., 2007; Hassmén, 1998; Maso, Lac, Filaire, Michaux, & Robert, 2004; Nederhof et al., 2006). Examples of the symptoms identified in the literature include: disturbed sleep patterns or sleep disorders (Fry et al., 1994; Hartwig, Naughton, & Searl, 2009; Hassmén, 1998; Main & Grove, 2009; Nederhof et al., 2007; Peterson, 2009; Sogabe et al., 2009; Urhausen et al., 1998), decreased appetite or eating disorders (Fry et al., 1994; Hassmén, 1998; Nederhof et al., 2007), difficulty concentrating (Hassmén, 1998; Nederhof et al., 2007; Sogabe, Sasaki, Kaya, Nagaki, & Yamasaki, 2009), and hormonal changes (Nederhof et al., 2007). For example, in female athletes specifically, a long-term consequence of overtraining syndrome is lower levels of estrogen, which will result in a decrease in mineral bone density (Birch & George, 1999). A decrease in mineral bone density is a serious problem because it is associated with higher risk for a stress fracture during training, or at a more advanced age. Lower levels of estrogen are also associated with higher risk for cardiovascular disease (Birch & George, 1999).

Other widely reported signs and symptoms are muscle soreness (Hassmén, 1998; Peterson, 2009), altered libido (Budgett, 1998), and in females, amenorrhea (Birch & George, 1999; Kuipers, 1996). It has also been reported that athletes suffering from overtraining show higher rates of injuries (Birch & George, 1999; O'Connor, 2007; Tidball, 1995), as well as illness (e.g., increased diagnosis of upper respiratory tract infections), which may be related to reduced immune function (Budgett, 1998; Fry et al., 1994; Hassmén, 1998; Lehmann et al., 1997). Athletes may also experience variations of mood state, whereby they demonstrate higher rates of fatigue (Fry et al., 1994; Morgan et al., 1987; Nederhof et al., 2007) and anger, accompanied by lower rates of vigour (Morgan et al., 1987), increased perception of effort (O'Connor, Morgan, & Raglin, 1991; Urhausen, Gabriel, Weiler, & Kindermann, 1998), and a decreased motivation to train or perform (Boto et al., 2008; Budgett, 1998). In its most severe form, a state of depression can emerge (Miranda Rohlfs, de Carvalho, Rotta, & Krebs, 2004; Main & Grove, 2009; Nederhof et al., 2007), and even a complete withdrawal from the sport can result (Boto et al., 2008). Importantly, not all athletes will experience the same symptoms (Birch & George, 1999) and the severity of the symptoms present increases for each category on the overtraining continuum (Nederhof et al., 2007). However, according to Nederhof (2006, 2007), the physiological symptoms reach a clinical level (i.e., pronounced hormonal disturbance) only in an overtraining syndrome situation (Nederhof et al., 2007; Nederhof et al., 2006).

2.5 What is the Prevalence of the Overtraining Syndrome in Athletics?

Description of the overtraining syndrome varies widely in the literature. For example, the vocabulary used to describe the same condition has changed over the years. In some cases, a description of the athlete's symptoms or the physical demands of training and competitions are not reported. As such, the incidence and prevelence of functional overreaching, non-functional overreaching, and the overtraining syndrome within the athletic population remains unclear (Halson & Jeukendrup, 2004) and estimates vary widely. For example, Morgan (1987) reported staleness (i.e., a decrease in performance and an inability to maintain high training volume and intensity) in 5 to 10% of swimmers during the most intense micro-cycle of the season. Using the occurrence of decrements in performance, increased fatigue, and incidence of illness as markers, Hooper (1995) reported that 21% of swimmers demonstrated overtraining during a regular training year. Moreover, Morgan has suggested that more than 60% of long distance runners experience overtraining at least once during their career (Morgan et al., 1987). Overtraining has also been reported in team sports such as soccer (where greater than 50% of athletes are shown to experience overtraining) (Lehmann et al., 1992) and hockey (Koutedakis & Sharp, 1998). Halson (2004) reports percentage of staleness or overtraining as varying between 5% and 15% for multiple sports throughout the literature. However, this estimation is limited given the wide variation in definitions used.In fact, Nederhof (2006) suggests there is an overestimation of athletes at the overtraining syndrome stage (Nederhof et al., 2006) and the estimates provided in the literature are more indicative of the prevalence of athletes experiencing non-functional reaching. In light of these findings, it appears that the ambiguous definitions of functional overreaching, non-functional overreaching, and overtraining syndrome make it difficult to estimate and distinguish incidence and prevalence for each of these three conditions. Proper identification of each condition is desirable because it would allow appropriate prevention, which in turn could lower the incidence of more serious consequences; development of the overtraining syndrome or even drop-out from the sport (Boto et al., 2008).

2.6 How do you Diagnose Overtraining?

To-date, research has focused primarily on methods for prevention of non-functional overreaching or the overtraining syndrome. Prevention at any stage of the continuum depends on high quality recovery (i.e., low physical and psychological stress), good nutrition (i.e., sufficient hydration and carbohydrate consumption to maintain energy stores), and close monitoring of the training and its effects on the athlete to identify changes in performance, mood, and levels of fatigue following a change in the training plan. Importantly, the occurrence of a performance decrement alone is not necessarily indicative of a negative adaptation to training; therefore, subjective measurements of mood, fatigue, and perceived stress have been viewed as important components of monitoring for prevention, despite their arguable success (Halson & Jeukendrup, 2004). Prevention of an overreached or overtrained state is complicated by the absence of an objective tool for diagnosis of the conditions. Indeed, diagnosis of functional and non-functional overreaching and the overtraining syndrome via an objective and accurate tool (i.e., test or marker) could allow athletes to achieve new levels of performance by knowing if the body is responding positively, or negatively to the training plan. The early detection of functional or non-functional overreaching and the overtraining syndrome before the condition is fully recognized could help prevent more serious negative adaptations (non-functional overreaching for a functional overreached athlete, or the overtraining syndrome for a non-functional overreached athlete). Thus far, methods of early detection have not been established for any of the three conditions, and diagnosis has been possible only retrospectively (Nederhof et al., 2008).

Symptoms of functional overreaching, non-functional overreaching, and the overtraining syndrome increase in severity across the overtraining continuum (Nederhof et al., 2007). However, a limitation for diagnosing or identifying the three conditions is that symptoms will vary greatly from athlete to athlete. In addition, the triggers for a stress-recovery imbalance are also quite diverse (e.g., too much endurance training, too many competitions, unfavorable recovery conditions) which leads to various sets of symptoms across athletes. Therefore, diagnosis has been done largely retrospectively, based on the duration of the decrement in performance and the time needed to fully recover from the decrement (Meeusen et al., 2010). For example, a diagnosis is made generally after an athlete demonstrates a significant decrement in performance and the accompanying symptoms cannot be explained by other pathologies (Nederhof et al., 2008). Further, the time needed by the athlete to return to normal levels of performance identifies whether the athlete was experiencing functional overreaching, non-functional overreaching, or the overtraining syndrome (Nederhof et al., 2006). Unfortunately, such diagnosis is not helpful in preventing more serious adverse conditions or preventing adverse effects on his or her athletic career. In brief, a diagnosis based on behavioral or performance symptoms is inadequate and an objective marker for diagnosis is needed.

In previous literature, a number of markers have been proposed for the early detection of a stress-recovery imbalance. These markers have been generally physiological or biochemical in nature and includes the examination of such measures as: muscle enzymes (e.g., creatine kinase) (Budgett, 1998; Hooper et al., 1995), hormonal changes (namely cortisol, testosterone, or their ratio) (Elloumi et al., 2008), blood composition (haemoglobin or leukocytes count) (Birch & George, 1999; Coutts et al., 2007), lactate (Coutts et al., 2007; Urhausen et al., 1998), maximal power output (Urhausen et al., 1998), or changes in rest, submaximal, and maximal heart rate (Coutts et al., 2007; Urhausen et al., 1998). Unfortunately, empirical work to-date suggests that these measures are not reliable predictors of the overtraining syndrome (Meeusen et al., 2006).

2.6.1 Creatine kinase

Research has shown that creatine kinase is not a reliable predictor of an overreached or overtrained state because elevated creatine kinase (as well as other variations of muscle enzymes) is observed without the presence of functional or non-functional overreaching, or the overtraining syndrome. For example, elevated creatine kinase has been reported in muscles after a single bout of exercise (Budgett, 1998; Halson & Jeukendrup, 2004).

2.6.2 Blood lactate

Accumulation of blood lactate is modified with training. However, investigation has revealed that blood lactate concentration is not sensitive enough to distinguish between overreached or overtrained states as a stand-alone marker. Moreover, the delayed changes in accumulation can be misinterpreted as an improvement of lactate threshold (Coutts et al., 2007; Urhausen et al., 1998). In addition, blood lactate concentration is influenced by the availability of glycogen stores, and lower than usual lactate concentration during exercise can simply indicate glycogen depletion (Budgett, 1998; Snyder, Kuipers, Cheng, Servais, & Fransen, 1995).

2.6.3 Glycogen status

It is shown that glycogen stores are affected by heavy training loads (Halson & Jeukendrup, 2004). The capacity to tolerate important training sessions is linked to one's resources in glycogen, and insufficient glycogen availability will result in poor performance (Halson & Jeukendrup, 2004; Kentta & Hassmen, 1998). Unfortunately, even when provided with enough carbohydrates, athletes can still become overtrained (Snyder et al., 1995), which leads researchers to suggest that glycogen status cannot be a marker of functional overreaching, non-functional overreaching, or the overtraining syndrome (Snyder et al., 1995).

2.6.4 Hormones

The testosterone/cortisol ratio, or changes in cortisol or testosterone alone, is said to reflect physical adaptations to training (Coutts et al., 2007; Filaire et al., 2004). Cortisol and testosterone saliva concentrations show changes in accordance to normal circadian rhythm, as well as following a training session (cortisol concentration increases with training whereas testosterone concentration decreases). In addition, a smaller testosterone/cortisol ratio is present immediately after a training overload period (Coutts, Wallace, & Slattery, 2007; Elloumi et al., 2008; Filaire, Legrand, Lac, & Pequignot, 2004). The use of this ratio, or of the individual values, as predictors of an overreached state is limited, as higher testosterone/cortisol ratio and high levels of testosterone are associated with an anabolic state, and a lower ratio or higher cortisol levels correspond to a catabolic state (Elloumi et al., 2008). A state of anabolism means that the body is recovering from a stress and re-building resources whereas a state of catabolism is present during or immediately after an applied stress (e.g., physical training) when resources are being used. In brief, the testosterone/cortisol ratio, or changes in cortisol or testosterone levels are indicators of physical adaptations to training more than a state of fatigue, and is not recommended as tangible method to predict a state of overreaching (Fry, 2007).

2.6.5 Other biochemical markers

Coutts (2007) subjected triathletes to a 4-week training overload period and concluded that biochemical markers (e.g., free testosterone, serum urea and prolactin, full blood count, plasma volume changes, and nocturnal urinary catecholamine) are not predictors of an overtrained state. No significant changes in leucocyte counts were observed, and it was suggested that increased serum urea corresponds to muscle protein catabolism and changes in hemoglobin is associated to changes in plasma volume. Therefore, free testosterone, serum urea and prolactin, blood count, plasma volume changes, or nocturnal urinary catecholamine were not indicative of a negative physical response to training (Coutts et al., 2007). In addition, low erythrocyte counts, hemoglobin, and ferritine levels have not been associated with an overtrained state as lower than normal values have been observed in athletes who were not experiencing the overtraining syndrome (Birch & George, 1999). Overall, research has produced contradictory results for various biochemical markers (muscle enzymes, lactate or glycogen changes, and blood count) and it is unlikely that they can be used as a reliable marker for functional overreaching, non-functional overreaching, or overtraining syndrome (Halson & Jeukendrup, 2004).

2.6.6 Heart rate

Other research has shown that using adverse changes in submaximal heart rate alone, or changes in resting heart rate, do not predict overreaching in an athlete, nor are they predictive of changes in performance (Coutts et al., 2007; Urhausen et al., 1998).

2.6.7 Changes in performance

A decrease in maximal power output (resulting in a decrease in performance) is often used in conjunction with other markers to identify the presence of functional overreaching, non-functional overreaching, or the overtraining syndrome (Nederhof et al., 2006). Unfortunately, there are no available reference values to differentiate the magnitude of the change in power output, or in performance decrement, associated with conditions of overtraining (Halson & Jeukendrup, 2004). In addition, reductions of maximal physiological measurements, such as maximal oxygen uptake, can also be related to the decrease in performance, and therefore is not a reliable marker to distinguish between the different stages of the overtraining continuum (Halson & Jeukendrup, 2004).

2.6.8 Summary: Physiological or biochemical markers

Although variables such as muscle enzymes, hormones, blood composition, lactate, maximal power output, as well as changes in heart rate have been investigated, no research to-date has emerged that supports the use of such objective markers to predict reliability the onset of overreaching (Halson & Jeukendrup, 2004; Hynynen, Uusitalo, Konttinen, & Rusko, 2008; Nederhof et al., 2008; Rietjens et al., 2005). Therefore, further research is required to identify a useful objective marker of an overtrained state, especially as it relates to its use in an applied setting.

2.6.9 Psychosocial markers

Since the early 1980's, the use of subjective tools, such as questionnaires about one's mood state, levels of stress, perception of recovery and/or various complaints, have gained in popularity (Coutts, Slattery, & Wallace, 2007; Elloumi et al., 2008; Fry et al., 1994; Gonzalez-Boto, Salguero, Tuero, Gonzalez-Gallego, & Marquez, 2008; Morgan et al., 1987). These types of tests are administered in an athletic context to evaluate the psychological well being of an individual in relation to the social aspects of the athletic environment. For example, psychosocial factors in an athletic context might refer to an athlete's mood in relation to or self-perception of his or her adaptation to training, work, or academic-related stress (if present), training-related stress (coach and team) and/or family-related stress (Foster, 1998; González-Boto, Salguero, Tuero, Márquez, & Kellmann, 2008; Meeusen et al., 2006; Morgan et al., 1987). Several psychosocial markers are available, namely: the Profile of Mood States (POMS) (Morgan et al., 1987); the Recovery-Stress Questionnaire for Athlete (RestQ-sport) (Kellmann & Kallus, 2001); the Ratings of Percived Exertion (RPE) and associated measures of load, monotony, and strain (Foster, 1998; Dupuy, Renaud, Bherer, & Bosquet, 2010); the Daily Analysis of Life Demands of Athletes (Rushall, 1990); the Perceived Stress Scale (Main, Dawson, Grove, Landers, & Goodman, 2009); the Sport Competition Anxiety Test (Elloumi et al., 2008); and the French Society for Sport Medicine questionnaires (Maso, Lac, Filaire, Michaux, & Robert, 2004). All of these tests provide pertinent information regarding how the individual is adapting to training, which includes both training-related items (e.g., perceived performance or effort, levels of fatigue) and/or non training-related factors (e.g., sleep, relationship with others). Unfortunately, none of these tests can be used as a stand alone marker. These subjective tests are influenced by the training load alone, and may exhibit changes in normal values that are not related to the occurrence of a decrement in performance (Urhausen & Kindermann, 2002). At best, results of the POMS or the RestQ-sport are used in conjunction with other markers (such as a decrement in performance) to identify some levels of overtraining (Hartwig, Naughton, & Searl, 2009; Nederhof, Lemmink, Zwerver, & Mulder, 2007).

2.6.10 New avenues: Psychomotor testing

In more recent years, another category of tests assessing specific aspects of motor behaviour has emerged (Hynynen et al., 2008; Nederhof et al., 2007; Nederhof et al., 2008; Nederhof et al., 2006; Nederhof, Visscher, & Lemmink, 2008; Rietjens et al., 2005). These tests have focused to-date on mental chronometric measures of information processing such as reaction time. Reaction time (i.e., the interval of time between the presentation of a stimulus and the beginning of an observable response) is a measure of the time needed for the processing of information in the central nervous system. According to an information processing framework, cognitive processing requires stimulus identification (detection and recognition of incoming sensory information), response selection (selection of an appropriate response) and response programming (programming of the selected reponse) (Schmidt, 1982). The time needed to execute this processing is influenced by various physiological (e.g., illness or drug consumption (Wareing, Fisk, Montgomery, Murphy, & Chandler, 2007)), psychological (e.g., arousal or attention (Schmidt, 1982)), and task specific factors (e.g., nature and complexity of the task or one's familiarity with the task (Falleti, Maruff, Collie, & Darby, 2006)). Reaction time is therefore thought to be indicative of the physiological and psychological state of the individual. A decline in reaction time from baseline measures indicates impaired information processing or conversely, impaired cognitive function as a result of physiological of psychological changes in the central nervous system.

The use of reaction time tests to detect early stages of overtraining is promising. Not only are these tasks an objective method of measurement, but they are also much less invasive than some physiological or biochemical markers (e.g., blood tests), and much less time consuming than many tests, such as administration of performance tests (e.g., a time trial). Early research has shown slower performance in various reaction time tests following increased training loads (Dupuy, Renaud, Bherer, & Bosquet, 2010; Nederhof, Lemmink, Zwerver, & Mulder, 2007). In addition, Hynynen (2008) showed that athletes suffering from overtraining syndrome exhibited lower accuracy during the most stressful conditions of the Stroop task, while Rietjens (2005) showed reduced cognitive performances in overreached athletes during difficult conditions of a finger pre-cuing task following training overload versus healthy athletes. However, this research only provides evidence that changes in cognitive function have occurred from a pre-test condition to a post-test condition. These investigations do not provide evidence based support for the use of psychomotor tests in a predictive capacity. More recently, Bredin and Warburton (manuscript under review) have provided early evidence that cognitive impairment occurs prior to physiologically-based decrements in performance when endurance-trained athletes are exposed to training sessions of high intensity. This work serves as the first empirical evidence to provide support for the use of psychomotor tests to predict the onset of overreaching or overtraining in an applied setting. As such, the purpose of the thesis is to continue this work and extend the findings of Bredin and Warburton. In the work presented in this document, we chose to investigate the relationship between cognitive and physical changes in performance in a recreational exercisers sample. Not only do we believe that the relationship reflects a basic cognition principle, and should be present across populations, but also additional work is needed in this population. Indeed, the relationships between recreational exercisers, physical fatigue, and physical activity participation can benefit from increased attention. Recreational exercisers represent an important sample of the population, and their perception of physical fatigue as a barrior to physical activity is misunderstood.

2.7 Chapter Summary

Athletes may demonstrate an overtrained state as a result of a significant training load paired with an insufficient period of recovery. While aiming to reach gains in performance associated with a supercompensation phase following a functionally overreached state, athletes and their coaches are provided with very few effective and reliable tools to measure athletes adaptation to the training protocol. As a result, many athletes experience non-functional overreaching, or even the overtraining syndrome at least once during their carreer (Morgan et al., 1987). Several markers (biochemical, physiological, or psychosocial in nature) have been proposed, but offer to-date limited support for their use in the prevention of an overtrained status (Coutts, Slattery, & Wallace, 2007). Objective psychomotor markers, such as tests utilising various measurements of reaction time, have gained in popularity (Dupuy, Renaud, Bherer, & Bosquet, 2010; Nederhof, Zwerver, Brink, Meeusen, & Lemmink, 2008). The goal of the proposed work is to continue the work of Bredin and Warburton (manuscript under review), and evaluate the ability of various psychomotor markers to predict the onset of physiologically-based performance decrements associated with a high training load in recreational exercisers.

3 CHAPTER THREE: Using Psychomotor Markers for the Early Detection of Overtrained Conditions: A Systematic Review

The purpose of this chapter is to present a systematic review of the literature that identifies and discusses the use of psychomotor markers as early detection markers of an overtrained state.

3.1 Introduction

Researchers in the sport domain have tried for several years to identify an easy-to-use and accurate method to predict the onset of overtraining. Numerous markers have been examined: muscle enzymes (e.g., creatine kinase) (Budgett, 1998; Hooper et al., 1995), hormonal changes (namely cortisol, testosterone, or their ratio) (Elloumi et al., 2008), blood composition (haemoglobin or leukocytes count) (Birch & George, 1999; Coutts et al., 2007), lactate (Coutts et al., 2007; Urhausen et al., 1998), maximal power output (Urhausen et al., 1998), or changes in rest, submaximal, and maximal heart rate (Coutts et al., 2007; Urhausen et al., 1998); but to-date have garnered limited empirical support. More recently, it has been suggested that psychomotor variables (such as reaction time) may serve as a potential early detection marker of athletic overtraining. For example, Nederhof (2006) has suggested that psychomotor speed is generally impaired in athletes presenting with non-functional overreaching and the overtraining syndrome (Nederhof, Lemmink, Zwerver, & Meeusen, 2006). Recently, Bredin and Warburton (manuscript under review) have shown that decrements in simple reaction time precede decrements in performance after a short term period of fatigue-inducing training in endurance-trained athletes. Therefore, the purpose of the presented work (see Chapter 5) is to continue the work of Bredin and

Warburton and examine various psychomotor tests on the capability to detect the onset of a physical performance decrement. To facilitate this work, a systematic review was conducted to identify the various psychomotor tests administered to-date in the overtraining literature, as well as the results of these investigations. The purpose of this systematic review is to assist in the development of the methodology for the main investigation of this thesis.

3.2 Methods

3.2.1 Criteria for considering investigations for this review

A rigorous, systematic, and evidence-based approach was implemented to critically examine the use of psychomotor tests for the early detection of overtraining. Any study that used a psychomotor test to evaluate the onset of an overtrained condition in otherwise healthy participants was eligible for inclusion. A psychomotor test refers to any test that yields objective values relative to the cognitive and motor state of an individual. Overtrained conditions refer to the presence of adverse symptoms (such as a physical decrement in performance, a disturbance in mood, or a significant imbalance between stress and recovery). An article was excluded if it was not based on original research (i.e., reviews, guidelines, summaries, letters, conference up-dates, lectures, position statements, and commentaries were not included). Only published studies in English and the French language were included. There was no restriction on study design. Articles using any type of psychomotor evaluations to assess cognitive performance during and/or after a training protocol purposefully designed to be highly challenging for the participants were included. Articles assessing psychomotor performances of individuals having received a diagnosis (retrospective and/or by exclusion of other possible conditions) of functional and non-functional overreaching, and overtraining syndrome were included.

3.2.2 Search strategy

Literature searches were conducted in the following electronic bibliographical databases:

- EMBASE (1980- May 24th 2011, OVID Interface),
- MEDLINE (1950- May 24th 2011, OVID Interface),
- PsycINFO (1840- May 24th 2011, Scholars Portal Interface),
- PUBMED (1947- May 24th 2011),
- SPORTDiscus (1837- May 24th 2011, EBSCO Interface).
- Web of Science (1900- May 24th 2011, Institute for Scientific Information),

Medical Subject Headings (MeSH) were used for the database search and in general were kept broad. An example of the search strategy and keywords used is presented in Table 3.1. The citations and applicable electronic versions of the articles were downloaded to an online research management system (RefWorks, Bethesda, Maryland, USA).

3.2.3 Screening

A reviewer (DB) screened all titles and abstracts of all citations. The full article of each relevant citation was retreived. For publication purposes, a second reviewer will also screen all titles and abstract to confirm all relevant articles were included in the analysis.

3.2.4 Data extraction

A reviewer (DB) identified and extracted data using a common template. Information regarding the participants' characteristics, the sample size, the study design, the modality of training, the effect of the training, control group characteristics (when applicable), the methodologies employed, the types of psychomotor tests administered, and the major

Table 3.1

Results of the EMBASE (ovid - 1980 to May 24th 2011) Literature Search Examining the Use of Psychomotor Tests as Early Detection Markers of Athletic Overtraining

Search #	**Searches (May 24th 2011)**	**Results**
1	cognitive.tw.	209330
2	neuromotor.tw.	1632
3	psychomotor.tx.	31987
4	reation time.tw.	50606
5	overreaching.tw.	107
6	overtraining.tw.	697
7	staleness.tw.	44
8	burnout.tw.	7785
9	burn-out.tw.	605
10	1 or 2 or 3 or 4	278843
11	5 or 6 or 7 or 8 or 9	8845
12	10 and 11	277

outcomes of the investigations were recorded. A second reviewer (NG) also completed the process of data extraction.

3.3 Level of Evidence

The level and grade of evidence of the literature accessed was critically assessed by a reviewer (DB) using a standardized scale, made of pre-defined objective criteria (see Tables 3.2-3.3) (Cluzeau et al., 2003). A second reviewer (NG) also performed the evaluation of the level and grade of evidence for each article.

3.4 Quality of Assessment

The quality of each article was assessed by a reviewer (DB) using a modified version of the Downs and Black scale (Downs & Black, 1998; Prince et al., 2008). A modified version was chosen as it included components that were more directly applicable to the type of investigations reviewed. The modified version included 15 items (1-4, 6-7, 9-13, 16-18, and 20) of the original Downs and Black scale, for a maximal score of 15; a higher score represents a superior quality of investigation. A second reviewer also completed the Downs and Black scale during data extraction.

3.5 Results

A total of 1829 citations were retreived during the electronic database search (see Figure 3.1). Of these, 277 were identified in Embase, 131 in Medline, 434 in PsycInfo, 249 in Pubmed, 59 in SportDiscus and 679 in Web of Science. After reviewing all titles and abstracts, 39 citations remained. Following removal of duplicate citations, 13 articles were left for full review. From these articles, a total of 6 articles were included in the systematic review. Articles were excluded because they were not in English or in the French language (n = 3), did not evaluate psychomotor measurements in relation to negative responses to

Citations from Electronic Database Search	
EMBASE	277
MEDLINE	131
PsycINFO	434
Pubmed	249
SportDiscus	59
Web of Science	679
Total	1829

↓

Citations after Scanning Titles and Abstracts (N = 39)

Full Articles Assessed for Eligibility after Exclusion of Duplicates Titles (N = 13)

↓

Articles Excluded after Full Review (N = 7)

Reasons : Not in English or in the French langage (N = 3), no psychomotor measurements in relation to early stages of overtraining (N = 1), review (N = 1), conference abstract (N = 1), and unable to retreive (N = 1).

↓

Total Articles Included in Review (N = 6)

Figure 3.1. Result of the Literature Search for the use of psychomotor tests as early detection markers of athletic overtraining.

Table 3.2

Investigations Examining the Use of Psychomotor Testing as a Detection Marker for Overreaching

Publication Study Design Quality Score	Objective(s)	Population	Psychomotor Measures	Performance Measures	Training Protocol	Measurements Schedule	Key Findings
Dupuy et al. 2010 Non-randomized control trial D & B Score = 10	To examine the effect of a training overload protocol on different components of reaction time (initiation and execution time) and executive functioning using the Modified Stroop task.	n = 10 sex = m age = 31±6 characteristics: provincial standard, endurance-trained, 3-7 sessions/wk	Simple RT task Modified Stroop Test	Constant speed test at 85% peak treadmill speed (as detemined by a maximal continuous graded exercise test) to volitional exhaustion	2-wks, 100% increase in volume	Baseline and following overload	50% participants identified as overreached Overreached athletes: simple RT slower post-training
Hynynen et al. 2008 Non-randomized control trial D & B Score = 13	To compare cardiac autonomic responses to an active orthostatic test to the Stroop Colour Word Test and to a relaxation period in overtrained and control athletes.	n = 24 (12 exp, 12 con) sex exp = 6 m, 6 f sex con = 6 m, 6 f age exp = 25 ± 7 age con = 24 ± 5	Stroop Colour-word Test	Incremental graded maximal exercise test	No training protocol, observation during training season	3 to 6 wks after diagnosis of OTS	OTS athletes: decreased accuracy HRV results: Low frequency power during standing up in the active orthostatic test lower in OTS athletes
Jeukendrup et al. 1992 Non-randomized control trial D & B Score	To evaluate the ability of physiological markers (max power output, max and submax lactate values, sleeping and max HR) to detect an	n = 8 sex = m age = 24.5 ± 7 characteristics : raced for at least 2	RT test and a Perception task (undefined)	Incremental graded maximal exercise test	2-wks overload training (17.5 hrs/week, mostly high intensity intervals	Tests taken at baseline and following the overload period	100% athletes displayed symptoms of overtraining No cognitive changes Decreased max and submax levels of lactate, decline in max heart rate, an increase

Publication Study Design Quality Score	Objective(s)	Population	Psychomotor Measures	Performance Measures	Training Protocol	Measurements Schedule	Key Findings
= 10	overtrained state.	years					in sleeping heart rate
Nederhof et al. 2007 Prospective cohort study D & B Score = 12	To evaluate psychomotor slowness as a possible marker for early detection of functional overreaching	n = 28 (14 exp, 14 con) sex exp = 10 m, 4 f sex con = 9 m, 5 f age exp = 25±4.1 age con = 25±4.6 characteristics exp: well-trained, 13.4 hrs/wk ±4.3 characteristics con: 5.6 hrs/wk ±4.3	Finger pre-cueing task Determination Test (Vienna Test System)	Incremental graded maximal exercise test	No training protocol, observation during a 2-wk training camp	Baseline and following overload	35% of participants in experimental group were overreached Functional overreached athletes: slower than control during Vienna test and more complex tasks of Finger pre-cuing (trends but NOT significant).
Nederhof et al. 2008 Case-control study D & B Score = 7	To report scores of reaction time, stress-regeneration balance, mood, cortisol and ACTH before and after the 2 bouts of maximal exercise, in a healthy athlete, a non-functional overreached athlete, and an athle recovering from non-funcitonal overreaching.	n = 3 sex = f 1 control: 17 yrs old; 1 recovering from non-functional overreaching, 19 yrs old; 1 non-functional overreached 16 yrs old	Vienna Determination test	Incremental graded maximal exercise test	Same day double exercise protocol (2 maximal exercise bouts separated by 4 hours)	Tests were taken before and after the 2 maximal exercise tests	Non-functional overreached athletes: slowest RT, performance decreased under shorter tasks (vs. typical pattern of healthy athletes) Athlete recovering from non-functional overreaching: shortest RT.

Publication Study Design Quality Score	Objective(s)	Population	Psychomotor Measures	Performance Measures	Training Protocol	Measurements Schedule	Key Findings
Rietjens et al. 2005 Non-randomized control trial D & B Score = 13	To establish whether early overreaching could be diagnosed by a combination of a selected number of parameters, representative for the status of the central nervous, neuro-endocrine and peripheral systems.	n = 14 (7 control, 7 athletes) sex = m age = 25.3 ± 4.7 training characteristics: well-trained, 7hrs/wk ±3.4	Finger pre-cuing test	Incremental graded maximal exercise test	2-week training, volume increased by 100%, intensity increased by 15%	Tests taken at baseline and following the overload period	Increase in training load, strain and monotony suggests all athletes reached overreaching. Interaction between tasks and group; practice effect is greater in control group in most difficult tasks.

Note. Con = control group, Exp = experimental group, HRV = heart rate variability, OTS = overtraining syndrome, RT = reaction time.

physical training (n = 1), was a conference abstract (n = 1), or could not be retrieved (n = 1). The investigations included were of an acceptable quality with a mean score of 11.6 out of 15 (range 10-13) on the modified Downs and Black scale. The results from these 6 investigations are summarized in Table 3.4.

3.5.1 Study characteristics

The articles included in this review covered an 18 year period, ranging from 1992 to 2010; however, 5 out of 6 articles (83%) were published within the last 6 years (i.e., between 2005 and 2010). The studies involved a total of 73 athletes, of which 66 athletes (90%) were identified as endurance-trained (38 cyclists, 6 road runners, 2 triathletes, and 20 unclassified endurance athletes). The remaining 7 athletes included hockey players (n = 3) speed skaters (n = 3), and a sprint runner (n = 1). Five out of 6 studies (83%) included maximal aerobic power with a reported average of 60.5ml/kg/min. The mean age of athletes was 23.3 ± 4.6 years; while 74% of the participants were male.

Sixty-six percent of the studies were non-randomized control trials and 33% (2 studies) were observational studies (i.e., prospective cohort study and case-control study). In the non-randomized control trials, the type of training intervention varied between investigations. Training emphasized increasing volume (n = 1), increasing intensity (n = 1), increasing both volume and intensity (n = 1), and assessment of overall training load only (n = 1). The observational studies did not report details of the training routine (n = 2).

3.5.2 Overreaching and psychomotor performance

All of the investigations used computerized tests to examine cognitive functioning. The most commonly administered psychomotor tests were the Stroop Colour Word test, the Finger Pre-Cuing task, and the Vienna Determination test, each test being used twice. Other tests included: Simple Reaction Time, and an undefined reaction time test (see table 3.5 for description of the tests).

Table 3.3

Level of Evidence Scaling Criteria

Level of Evidence	Criteria
Level 1	Randomized control trials without important limitations
Level 2	▪ Randomized control trials with important limitations ▪ Observational studies (non-randomized clinical trials or cohort studies) with overwhelming evidence
Level 3	• Other observational studies (prospective cohort studies, case-control studies, case series)
Level 4	▪ Inadequate or no data inpopulation of interest ▪ Anecdotal evidence or clinical experience

Table 3.4

Grade of Evidence Scaling Criteria

Grade of Evidence	**Criteria**
Grade A	Strong recommendation (marker can detect early stages of overtraining in most individuals) Evidence is at Level 1, 2, or 3
Grade B	Weak recommendation (use of marker as an early detection tool is not conclusive) Evidence is at Level 1, 2, or 3
Grade C	Consensus recommendation (alternative markers may be equally useful) Evidence is at Level 3 or 4

Finding revealed mixed results regarding the role of cognitive markers in the early detection of overtrained states. Overall, four investigations obtained results suggesting that some form of cognitive impairment (such as psychomotor slowness or decreased attention) may be associated with increased training load and an overtrained status.

3.6 Discussion

To-date, no marker is available for the early detection of an overtrained state. The use of objective psychomotor markers has been postulated for predicting the onset of an overtrained state (Nederhof, Lemmink, Zwerver, & Mulder, 2007a; Nederhof, Lemmink, Visscher, Meeusen, & Mulder, 2006; Rietjens et al., 2005). Due to the promising nature of this line of research, the purpose of this systematic review was to identify the various psychomotor tests administered to-date in the overtraining literature and the general findings of these investigations.

A total of 6 investigations were included in the systematic literature review. Literature on this topic is scarce because of the novelty and emerging nature of this area of research. Overall, the results of the 6 investigations included for review suggest that the use of psychomotor markers is a promising tool, as most investigations demonstrated cognitive impairment in association with increased training load. However, a lack of consistency in the cognitive tests employed, the type of performance assessments administered, and the types of study design (e.g., lack of randomized control trials) across the 6 investigations makes a consensus statement regarding the role of cognitive markers in the early detection of an overtrained state diffcult. Four investigations (Dupuy et al., 2010; Hynynen et al., 2008; Nederhof et al., 2008; Rietjens et al., 2005) observed cognitive impairment, in various forms, in association with an increased training load, or a previously diagnosed state of non-functional overreaching. Dupuy (2010) observed slower performance in a simple reaction time test following increased training loads in overreached athletes.

Table 3.5

Description of Administered Psychomotor Tests

Test	Test Description as Administered	Outcome Measures
Stroop Colour Word test	▪ Consisted of 4 tasks : Congruent, Denomination, Interference, and Switching task. ▪ Congruent task: consists of 4 possible stimulus-response pairs (4 names of colour, i.e., red, blue, yellow and green, written in the corresponding colour are mapped to the keys "u" , "i" , "o" and "p" on a QWERTY Keyboard. ▪ Denomination task: participants identify the colour of unrelated words. ▪ Interference task: participants identify the colour of a colour-word the meaning of the word being incongruent with the colour itself (e.g., the word blue written in green). ▪ In the first 3 tasks, a fixation cross appeared during 500 ms, followed by the word during 3000 ms. ▪ The Switching task was identical to the Interference task, except that for 25% of the trials, a square appeared instead of the fixation cross, and participants have to identify the colour-word, instead of its colour.	Reaction time Number of errors
Finger Pre-Cuing task	▪ The Finger Pre-Cuing task consists of a choice reaction time, including 4 stimulus-response pairs (i.e., 4 horizontal crosses refer to the first two fingers of both hands, placed on the keyboard). ▪ There is a presentation of a "cue" signal, prior to the stimulus, consisting of crosses in the location where the stimulus might occur in the upcoming trial. ▪ The cue signal possibly diminishes the number of possible stimulus-response pairs in more or less complex ways (e.g. in some case, the possible responses can be performed only with one hand, or the same finger of the two hands. In other cases, the cue does not diminish the number of possible stimulus-response pairs). ▪ The most complex tasks are uncued (when the cue signal displays 4 crosses), or neither cured (cue signal displays 2 crosses refering to a different finger, of each hand, e.g., the left-middle and right-index fingers)	Median reaction times of correct responses, per test and per pre-cuing condition
Vienna Determination test	▪ The Vienna Determination test consists of a choice reaction time including 8 stimulus-response pairs. ▪ The test includes five different visual stimuli to which a manual reaction is required, two visual stimuli to which a pedal reaction is required and one auditory stimulus to which again a manual reaction is required. ▪ The test is divided in two parts : Action mode and Reaction mode. ▪ During the Action mode, a new stimulus occurs as soon as a correct response is provided. ▪ During the Reaction mode, only 6 stimulus-response pairs are being used, and the stimuli occur in six blocks with pre-set presentation times of 1.225, 0.948, 0.834, 0.734, 0.646 and 0.834 s.	Median reaction times for correct responses
Simple Reaction Time test (Initation and Execution time)	▪ The task begins with the word "OK", appearing in the middle of the screen. The participants depress the home-key to start. ▪ The participants maintain the home-key depressed, until the stimulus occurs, at which time, participants leave the home-key and depress the response-key, located on the right of the home-key. ▪ Initiation time corresponds to the time elapsed between the occurrence of the stimulus, and the release of the home-key. ▪ Excecution time correspons to the time elapsed between the release of the home-key and the depression of the response-key.	Initiation time (i.e., simple reaction time, ms) and Execution time (i.e., movement time, ms)

Hynynen (2008) showed that athletes suffering from overtraining syndrome exhibited lower accuracy during the most stressful conditions of the Stroop colour word task; while Rietjens (2005) showed underperformance in athletes during difficult conditions of a finger pre-cuing task following training overload versus healthy athletes. Nederhof (2008) showed that the reaction time of a control athlete, and of an athlete recovering from non-functional overreaching were faster than the reaction time of athletes classified as non-functionally overreached. Contrary to these results, Jeukendrup (1992) did not observe any cognitive change in athletes after a training overload period. Taken these results together, further research investigating the use of psychomotor tests to predict the onset of overtraining in a more systematic and rigorous way is needed before coming to conclusions regarding the use of psychometric markers in the context of identifying overtrained conditions.

All investigations partly or only included athletes who were endurance trained. Focus on such a specific population limits how conclusions from these investigations can be applied to other athletes, or even a greater part of the population, such as recreational exercisers. Endurance trained athletes are exposed to unique physiological and neurological stressors that may interact with athletes' executive function, which in turn influences performances on psychometric tests (Dupuy et al., 2012; Lehmann, Foster, Dickhuth, & Gastmann, 1998a). As such, cognitive changes identified in endurance-trained athletes may not be basic human cognitive principles that are found in across populations. In addition, the training protocols needed to physically fatigue endurance-trained athletes is specific to that population, as these athletes are accustomed to high volume, low intensity routines.

To induce an overtrained state, as measured by a physical performance decrement, in endurance trained athlete, a combination of increased volume and increased intensity must be used (Meeusen et al., 2006). Each investigation reported different increases in volume, intensity, and duration of the increase. For example, Dupuy (2010) increased the training volume by doubling the time spent exercising for a duration of two weeks; while Rietjens et al. (2005) also increased by 100% the training volume for two weeks, and also increased the training intensity by 15% (based on target heart rate). Using such training protocols, 50% and 71% of participants, respectively were classified as overtrained. Jeukendrup (1992) also produced an overtrained state in 100% of participants by increasing volume and intensity (details not presented) for a duration of two weeks. Nederhof (2007) only reported overreaching in 35% of participants in an experimental group, whereby participants engaged in a training camp consisting of self-administered training sessions for 9.5 days, distributed over a two-week schedule. Overall, based on the articles included in this literature review, recommendations for a training protocol inducing physical performance decrements, as an indicator of an overtrained condition in a group of endurance trained athletes are: a two-week protocol combining a 100% increase in time spent exercising with a 15% or more increase in intensity, based on heart rate or aerobic power prior to investigation.

Importantly, despite an aim to identify markers able to predict non-functional overreaching or overtraining, none of the investigations measured cognitive and physical performance often enough to detect cognitive impairment prior to physical performance decrements. Three investigations subjected participants to a training protocol involving increases in training load (Dupuy et al., 2010; Jeukendrup et al., 1992; Rietjens et al., 2005), and one investigation observed a 2-week training camp (Nederhof, Lemmink, Zwerver, & Mulder, 2007a). However, all four investigations measured cognitive and physical performance pre and post investigation only. This is a significant limitation in this line of research. If psychomotor markers are to be used to predict the onset of physical decrements in performance, both cognitive and physical performance must also be measured throughout the administration of the training protocol.

Another limitation in many of the investigations regards the training protocol and its characteristics. All investigations included in this systematic review made an effort to report some information regarding the athlete's training. However, only one investigation (i.e., Rietjens et al., 2005) reports enough information to allow comparisons to be made between volume (in min/week) and intensity (heart rate at exercise) to baseline levels of performance. Therefore, work in this area needs to systematically report such variables as training volume (e.g., time, distance), as well as training intensity (e.g., power, speed, heart rate) in an objective manner, to make comparisons between investigations possible.

3.7 Conclusion: Current literature

The current literature examining the use of psychomotor markers for the early detection of overtraining yields inconclusive results. Even if it appears that cognitive impairment is present in non-functional overreaching and overtraining syndrome, investigations have not been designed to observe the predictive capabailities of psychomotor markers. That is, their research designs are constrained to only observing whether changes have occurred in cognitive performance from pre- to post-tests following a training load. Further research needs to focus on investigating the timeline between the occurrence of decrements in cognition compared to the occurrence of decrements in physical performance if psychomotor tests are to be used in an applied setting as an early detection marker of overtraining. As such, measurement of cognitive performance via psychomotor tests should be performed regularly and frequently between baseline and expected onset of an overtrained condition. In addition, the specific physical stressors, or training protocol, needed to induce an overtrained state is not clearly established, and the scarce evidence currently available is limited to endurance-trained athletes. Therefore, training protocols used in this line of investigation should be clearly reported (volume and intensity) and attention should be directed towards a greater variety of populations (e.g., high-intensity sport athletes, or recreational exercisers).

4 CHAPTER FOUR: Investigating the Reliability of a CogState Test Battery

The purpose of Chapter 4 is to present a methodological investigation that was collected prior to the primary investigation of this thesis. Specifically, the secondary investigation was warranted to provide an evidence-base to support the administration of the selected CogState battery repeatedly across extensive testing and training sessions.

4.1 Introduction

Computerized cognitive test batteries have become a popular assessment method due to their ease of use, and high sensitivity to mild cognitive changes (Collie, Darby, & Maruff, 2001; Makdissi et al., 2001; Westerman, 2001). Computerized tests are more powerful than written ones (Collie et al., 2001; Makdissi et al., 2001) and have been shown to be reliable across repetitive assessment (Harris, Cleland, Collie, & McCrory, 2009). Repetitive assessments are often central in the monitoring of acute and/or chronic changes in cognition of a group of individuals. For example, in an athletic setting, it is possible to obtain a baseline measurement of cognitive performance and then compare one's performance to baseline measures following a traumatic event (e.g., a concussion). This comparison provides a method of examining whether or not an impairment in functioning exists. Repeated assessment of cognitive functions via computerized psychometric tests is useful in monitoring an individual's changes over time, and as such, serial assessments are now performed regularly in research settings.

When administering psychometric tests several times to the same group of individuals, changes from test to test should be clinically meaningful. That is, changes in performance should be a result of a change in cognitive status of the individual being tested (e.g., as influenced by such factors as fatigue, alcohol, or ageing), and not influenced by practice or exposure to the task itself. Serial investigations, whereby performance is assessed at different time points, are becoming increasingly popular (Bartels, Wegrzyn, Wiedl, Ackermann, & Ehrenreich, 2010; Falleti, Maruff, Collie, & Darby, 2006); yet research exploring changes attributed to the effects of repeat testing is limited.

CogState computerized cognitive tests were specifically developed to assess cognitive function (e.g., speed of executive processing, working memory) under conditions of repeat testing (Collie, Maruff, Darby, & McStephen, 2003). There are 13 different cognitive tests, from which one can build a test battery for a given context. In field tests, a CogState test battery has demonstrated less variability in comparison to written tests (Harris et al., 2009). Further, CogState tests have been found to be sensitive to mild cognitive impairment (Maruff et al., 2009), concussion (Collie et al., 2004; Moriarity et al., 2004), as well as fatigue and alcohol (Falleti, Maruff, Collie, Darby, & McStephen, 2003). These findings provide support for the use of Cogstate tests to identify mild cognitive impairment in relation to exercise-induced fatigue. However, there has not been a systematic assessment of the reliability of a CogState test battery across multiple testing days or according to various schedules in frequency (i.e., the amount of time provided between testing sessions). Previous research has assessed the CogState battery over a period of 4 occasions in 1 day (Collie et al., 2003; Falleti et al., 2006), as well as after one week and one month (Falleti et al., 2006) only. Therefore, examining a CogState battery across multiple testing days and schedules is warranted.

The purpose of the present investigation was to observe cognitive performance (as measured by a Cogstate test battery) under multiple testing sessions and according to two different frequency schedules. Specifically, the CogState battery was either administered according to a distributed schedule (i.e., once a day across 15 separate days) or according to a massed schedule (i.e., three times a day across 5 separate days). It was hypothesized that improvements in performance would occur from the first to second test sessions (as a result of greater familiarization or exposure to the test battery), but no significant differences would emerge across the remaining test days. This postulation was based on the assumption that the selected CogState battery would demonstrate good reliability across repeat sessions (Collie et al., 2003). Similar results were reported previously, whereas improvement in performance was identified between the first and second testing session, while using a very similar CogState battery of tests (Collie et al., 2003). Second, we hypothesized that there would be no significant differences between massed and distributed testing schedules, given that we expected cognitive performance results to stabilize after the second testing session.

4.2 Methodology

4.2.1 Participants

Thirteen university-aged participants (n = 11 females, 2 males), were recruited for this investigation. Only participants free of any illness or medication that could affect their cognitive performance were included (as self-reported). All participants were right-handed. Participants were randomly assigned to either a massed schedule (n = 6) or a distributed schedule (n = 7). This investigation was approved and carried out in exact accordance with the ethical guidelines set forth by the University of British Columbia's Behavioural Research Ethics Board for research involving human participants. See Appendix D for ethics documentation.

4.2.2 CogState test battery

All participants performed the selected test battery using a laptop computer and mouse running CogState Research software (CogState, CT, USA). The presentation order of the cognitive tests was randomized and counterbalanced across groups.

4.2.2.1 Detection task

Each participant was seated in front of a monitor displaying a green background and a deck of cards (placed face down). The indivdual's dominant hand was placed on the mouse. The participant was then required to answer the question "Has the card turned over?". The participant was required to respond as quickly as possible by left clicking the mouse (or right clicking for left-handed participants) when the card displayed on the monitor turned face up. This task was repeated for the presentation of 35 trials. Reaction time (in ms) was recorded for statistical analysis. This task required approximately 2 minutes to complete.

4.2.2.2 Identification task

Using the exact same set-up as in the Detection Task, the participant was required to answer the question "Is the card red?" as rapidly as possible after the card displayed on the monitor turned face up. A card either presented itself as red or as black. This task was repeated for the presentation of 30 trials. Reaction time (in ms) was recorded for correct responses, as well as the accuracy (or number of correct responses) represented as a percentage. This task required approximately 2 minutes to complete.

4.2.2.3 Continuous paired associate learning task

This task was divided in two stages. In Stage 1, one ball was presented in the middle of the monitor, around which seven other balls were displayed. The participant was required to click on each of the peripheral balls to reveal a hidden picture. During this process, the participant was asked to memorize the pictures hidden under the balls, as well as their respective locations. In Stage 2, the participant was required to answer the question “In what locations do these pictures belong?”. The ball in the middle displayed a picture, and the participant was asked to click on the peripheral ball hiding the same picture. Seven rounds of eight stimuli were presented to the participant, for a total of 56 stimuli. The duration (measured in minutes to complete the entire task) was recorded. Accuracy (%) was also measured by the total number of errors that occured during the execution of the task. This task lasted approximately 5 minutes.

4.2.1 Procedure

All participants were asked to complete 15 test sessions; however, participants completed the sessions in either a massed manner (all 15 sessions within 5 days) or in a distributed manner (spread across 15 days). Specifically, the massed group performed the cognitive battery three times per day (separated by approximately 4 hours: early morning, mid-day, and late afternoon) for 5 consecutive days. The distributed group completed the cognitive battery once per day for 15 days (at the same time each day). Each testing session took approximately 10-15 minutes to complete.

4.3 Statistical Analysis

A 2 (Group: massed, distributed) x 15 (Time) analysis of variance (ANOVA), with repeated measures on the last factor was conducted for each dependent variable. Statistical significance was set a priori at $p < 0.05$. Post-hoc comparisons (Tukey HSD) were conducted if a main effect or an interaction effect was found.

4.4 Results

4.4.1 Participants

A total of 13 participants were recruited for this investigation. However, one participant (distributed group) was unable to come at the same time each day for testing, and dropped-out of the study after 5 testing sessions. Another participant (distributed group) was unable to follow the instructions for each task; therefore, the individual's data was excluded from the data analysis. As such, a total of 11 participants (20-27 y) were included for data analysis (massed group: $n = 6$, mean age = 24.2 ± 2.4 y; distributed group: $n = 5$, mean age = 25.0 ± 1.0 y).

4.4.2 Detection task

No main effect for time ($F(14, 140) = 1.32$, $p = .205$) or group ($F(1, 8) = .105$ $p = .755$) was found. No interaction effect was found ($F(14, 126) = 1.08$, $p = .382$) for the detection task (see Figure 4.1).

4.4.3 Identification task

There was no main effect for time ($F(14, 126) = 1.553$, $p = .102$) or group ($F(1, 9) = 1.357$, $p = .274$). There was also no interaction effect ($F(14, 126) = .853$, $p = .611$) found (see Figure 4.2).

4.4.4 Continuous paired associate learning task

A significant main effect for time was revealed for duration ($F(14, 126) = 10.177$, $p < .0001$). Tukey's post hoc comparisons showed that session 1 was significantly longer than all other sessions, and session 2 was different than most sessions (7-8, and 11-15). No other significant differences were shown across sessions starting at session 4 (see Figure 4.3). There was no main effect for group ($F(1, 9) = .629$, $p = .448$) nor any interaction effect ($F(15, 126) = 1.620$, $p = .092$) found for duration.

A significant main effect for time was shown for number of errors ($F(14,1255) = 3.130$, $p < .001$). Tukey's post-hoc comparisons revealed that session 1 was different from sessions 6 thru 8 and Sessions 10 through 15 (see Figure 4.4). No main effect for group ($F(1, 9) = 1.189$, $p = .304$) was shown. There was also no interaction effect found ($F(15, 126) = .322$, $p = .990$).

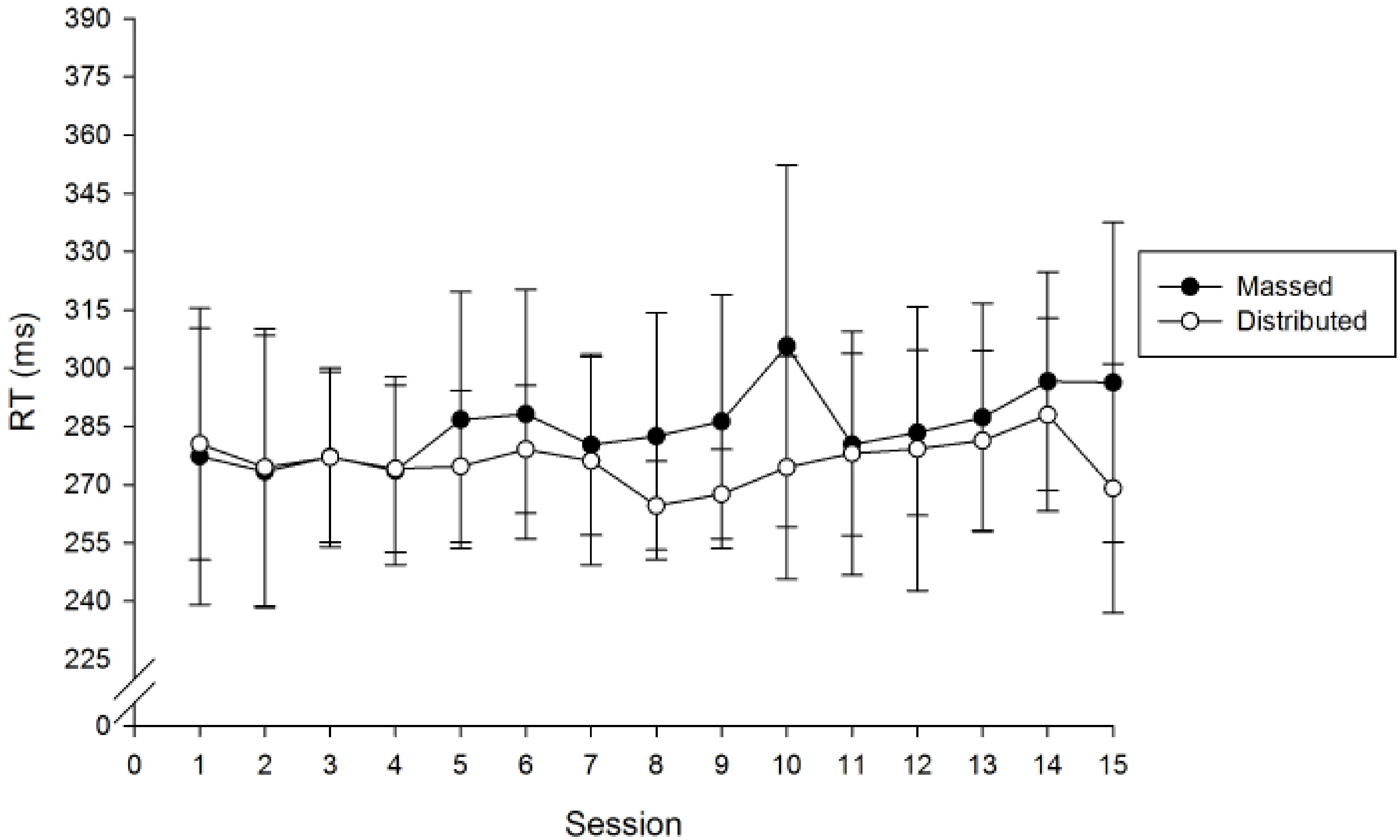

Figure 4.1. Reaction time for the detection task by group across sessions (Mean ± SD).

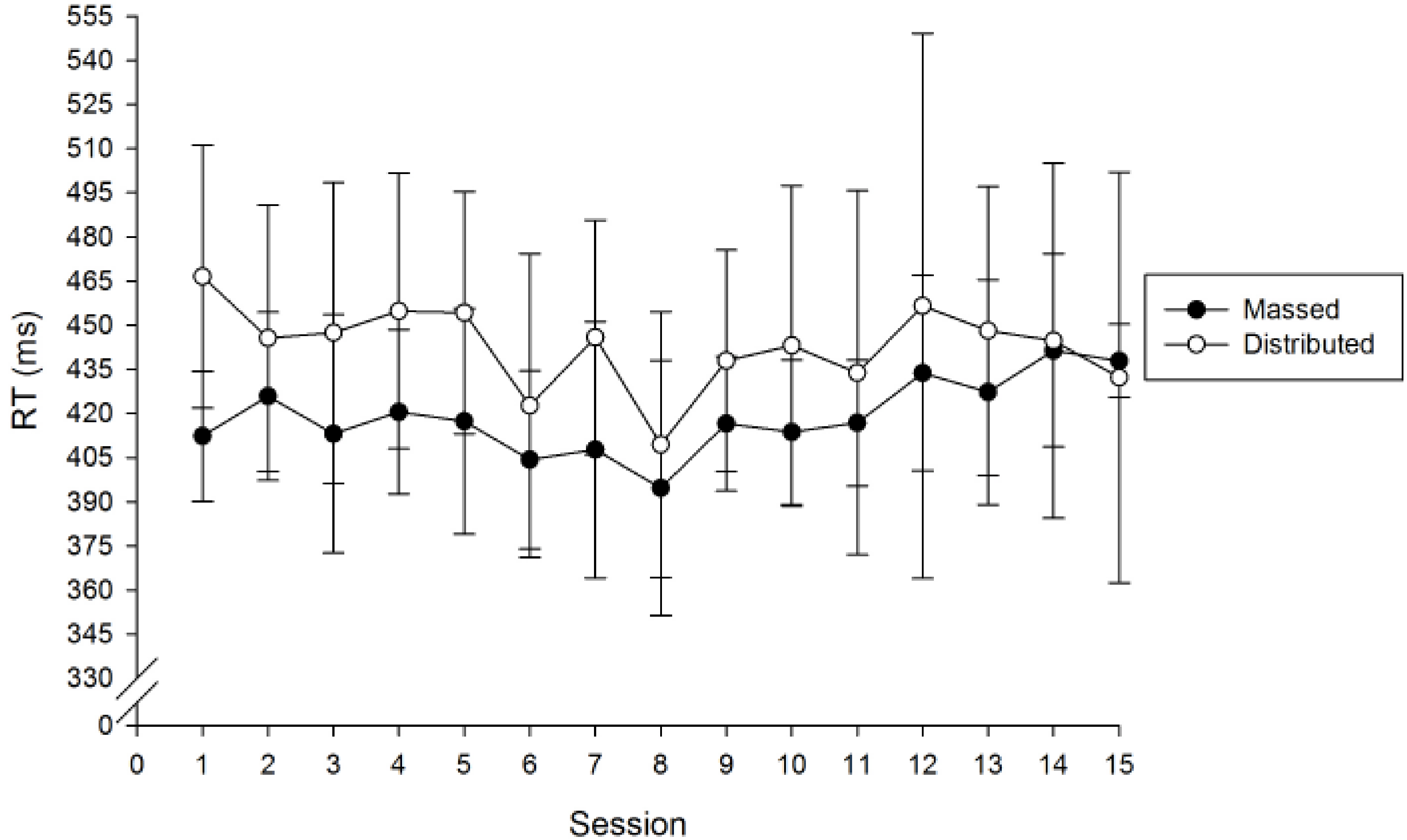

Figure 4.2. Reaction time for the identification task by group across sessions (Mean ± SD).

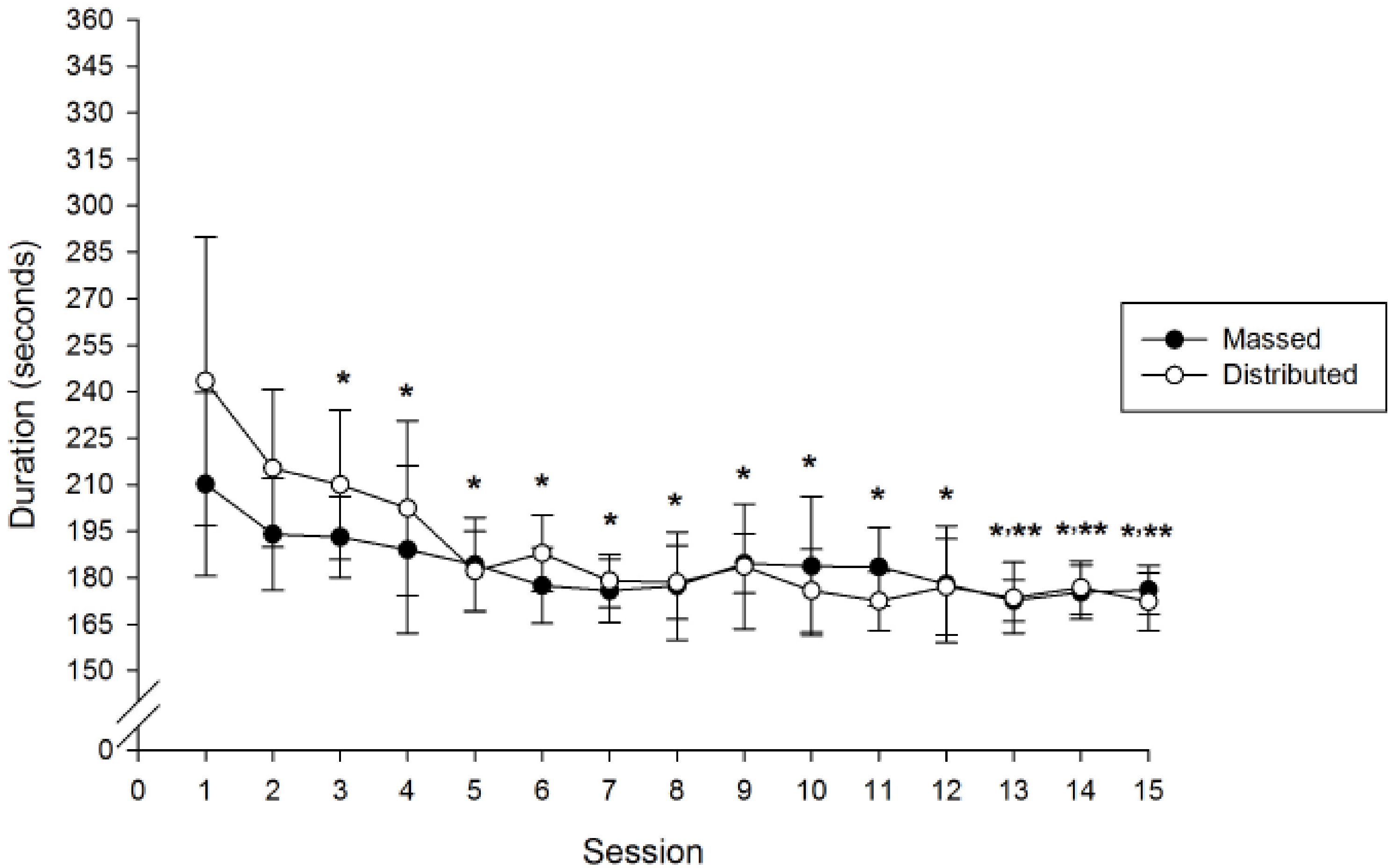

Figure 4.3. Duration of the continuous paired associate learning task by group across sessions (Mean ± SD).

* indicates significant difference (p < .05) from session 1
** indicates significant difference (p < .05) from session 3

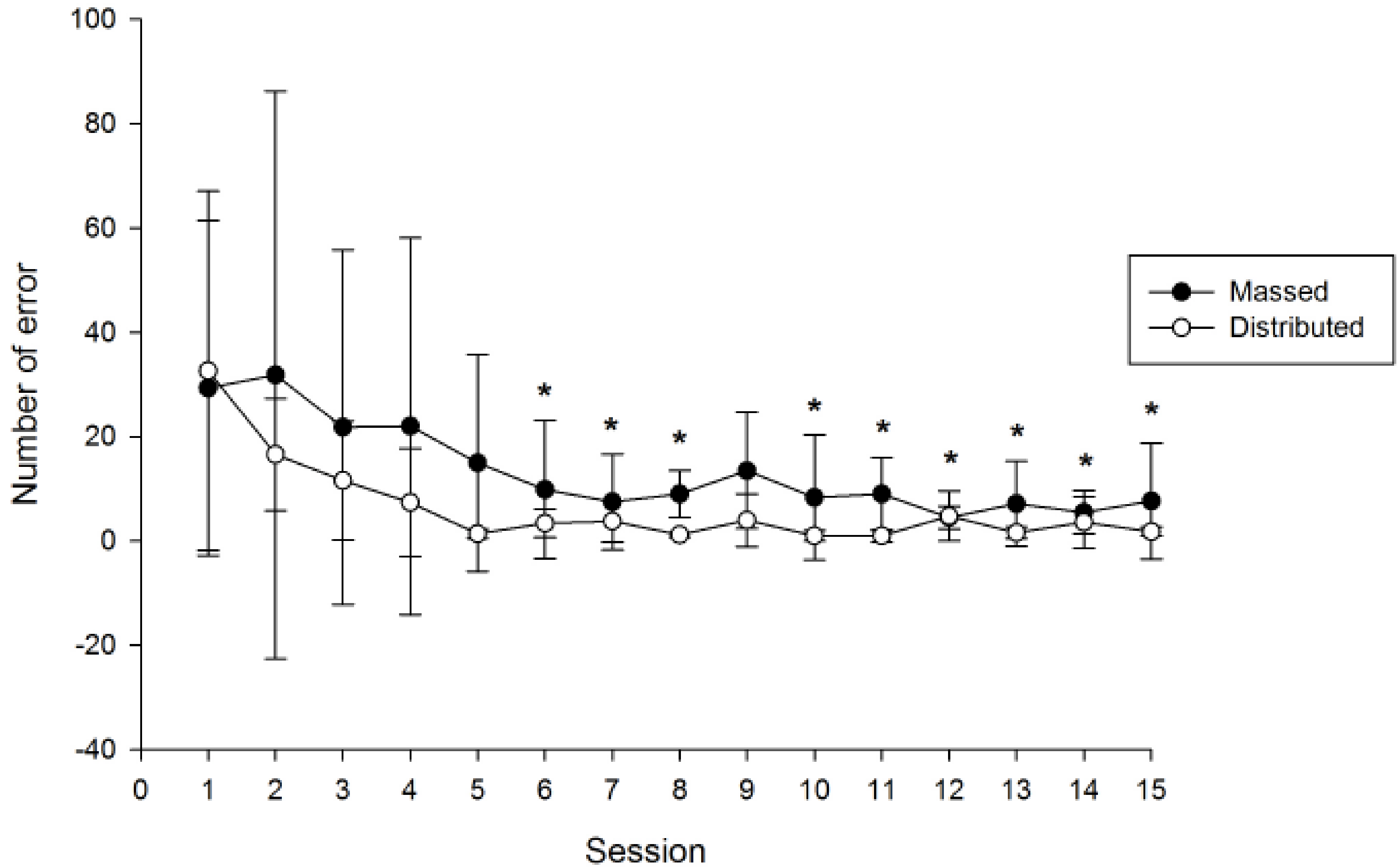

Figure 4.4. Number of error of the continuous paired associate learning task by group across sessions (Mean ± SD).

* indicates significant difference (p < .05) from session 1

4.5 Discussion

The purpose of this investigation was to examine the reliability of a CogState test battery when administered repeatedly within a relatively short duration to a healthy group of university-aged young adults. The design of this investigation allowed us to compare cognitive performance for two types of scheduling (massed versus distributed) across time. Therefore, the objective of this research was to determine whether a select CogState test battery could be implemented repeatedly in a frequent (massed scheduling) or less frequent manner (distributed scheduling). In addition, an important aspect of this research was to determine the influence of practice across repeated exposure to the test battery. This methodological information is critical to obtain if a reliable baseline measure is to be collected in the research setting. Therefore, research investigating how many practice trials need to be performed before obtaining a measure of stable pre-training cognitive performance was needed to inform the main investigation of this thesis.

No effect for time was identified for the detection task, nor for the identification task. This finding suggests that in an experimental setting, the administration of one test session is adequate to obtain a baseline of cognitive function. Importantly, the absence of any significant difference between groups (massed versus distributed), or amongst testing sessions suggests that for a healthy, young adult population, this test can be reliably administered repeatedly irrespective of scheduling frequency.

The number of errors that the participants committed in the continuous paired associate learning task significantly improved and stabilized starting at session 2. However, task duration continued to improve until session 4, indicating that the participants required at least three sessions to familiarize themselves with the task. During the initial sessions, participants anecdotally reported developing a simple strategy to improve performance, which consisted of giving names to the shapes that are presented in the task. Participants reported that naming the shapes helped them remember the location of the shapes. Irrespective of the strategy employed, these findings show that practice influenced performance significantly in the first sessions. As such, we suggest that a minimum of three practice sessions should be administered before establishing baseline values for a participant. Given an appropriate period of practice, our findings show that the task can be used repeatedly and frequently in a group of healthy young adults.

The results of this investigation are similar to those reported by Falleti (2006) where a practice effect was documented in tasks such as matching. However, Falleti (2006) suggested that the time elapsed between testing sessions influenced the effect of practice, whereas shorter test-retest intervals increased the strength of the practice effect. In contrast, we observed that after a sufficient number of practice sessions (≥ 4), performance on the task stabilized (as shown across 11 more sessions). This stabilization occurred in both a massed and a distributed scheduling.

For all three tests, the absence of a group effect indicates that these selected tests can be administered repeatedly within a short period of time, or in a more extended manner. Importantly, performance on the tests were not negatively influenced with repeated test administration indicating that the participants did not lose motivation to perform well, despite the redundancy of the task. Together these findings suggest that the Cogstate test battery can be used in research settings involving high repetition testing, and/or various testing schedules.

Some limitations may limit the strength of our findings. Participants were all young and well educated (all had at least a university degree). Adults who are younger, as well as those with higher levels of education demonstrate in the literature a greater capability to read and understand the task requirements thereby influencing the presence, or the magnitude of a practice effect (Collie et al., 2004). Also, the small sample size may have limited the ability to distinguish statistical differences. For example, no statistical differences were found between session 4 and session 5 of the task on both main outcome variables (duration and number of errors). However, the average duration decreases from 3.25 min to 3.06 min (see Figure 4.3), and the average number of errors decreases from 15.4 to 8.8 (see Figure 4.4). These changes have practical meaning, and may have been identified as statistically different with increased power.

4.6 Conclusion

Performance on the detection and identification task were consistant between groups (massed and distributed) and across time, which provides support for the administration of the test battery to healthy, young adults, using a single baseline test. From our results, we suggest planning at least 3 practice sessions before collecting baseline values for the continuous paired associate learning task. This will allow participants an opportunity to familiarize themselves with the test and acquire an adequate level of proficiency in order to obtain a reliable and stable baseline measure.

5 CHAPTER FIVE: The Use of Psychomotor Tests to Predict Decrements in Physical Performance

The overall goal of the present investigation was to examine the use of a psychomotor test battery to detect changes in cognitive function under fatigue producing conditions. A group of active males was subjected to a one-week fatigue-inducing training protocol on a cycle ergometer. Along with daily physical performance measurements, cognitive performance (as measured by a Cogstate test battery) was assessed daily, before and after a training session. Other daily measurments included morning heart rate variability and completion of the Delayed Onset of Muscle Soreness Questionnaire and a Sleep Quality Questionnaire.

5.1 Introduction

Athletes engage in highly demanding training routines, which puts them at risk of developing an overtrained state (Rietjens et al., 2005). A short-term overtrained state can lead to increased performance, however more severe overtrained states are associated with a decrease in performance, as well as various symptoms, namely fatigue, disinterest in sport, changes in physiological and biochemical status, as well as disturbed mood, sleep, and appetite (Birch & George, 1999; Boto et al., 2008; Lehmann et al., 1997; Morgan et al., 1987). The early detection of decrements in performance is important because identification can help prevent more severe, or long-lasting, maladaptations. Thus far, methods for the early detection of overtraining have not been established, and diagnosis has been possible only by exclusion and retrospective analysis (Meeusen et al., 2010).

The identification of an overtraining early detection marker is usually done by monitoring various variables (e.g., hormonal, or physiological markers) in an athletic population, during an increase in training load (volume and/or intensity). The increased training load is either designed by the research team, or inherently associated to a training season (Purvis, Gonsalves, & Deuster, 2010). A marker is considered effective when displaying changes prior to the onset of overtraining signs and symptoms. The most commonly used overtraining sign is a decrement in physical performance. As such, markers displaying changes in association with the presence of a physical performance decrement are promising avenues to investigate, to identify an overtraining marker.

Early research has shown impaired cognitive performance in association with increased training loads (Dupuy, Renaud, Bherer, & Bosquet, 2010; Hynynen et al., 2008; Nederhof, Lemmink, Zwerver, & Mulder, 2007; Rietjens et al., 2005). Researchers have turned their focus towards the psychomotor domain for the identification of potential early detection markers of overtraining (Hynynen et al., 2008; Nederhof et al., 2007; Nederhof et al., 2008; Nederhof et al., 2006; Nederhof, Visscher, & Lemmink, 2008; Rietjens et al., 2005). These tests have focused largely on tasks that measure speed of cognitive processing via such measures as reaction time. Speed of processing is thought to provide important information on the physiological and psychological status of an individual (Nederhof, Lemmink, Visscher, Meeusen, & Mulder, 2006; Schmidt, 1982).

The use of psychomotor tests to detect early stages of overtraining is promising. Not only are these tasks an objective method of measurement, but they also are much less invasive than blood tests and much less time consuming than other tests, such as performance tests. Thus far, it remains uncertain whether cognitive performance changes are yet another symptom of an overtrained state, or if cognitive impairment occurs prior to physiologically-based decrements in performance, allowing for the prediction of an overtrained state, although previous work done in our lab justified the use of psychomotor markers in the identification of physical fatigue. Therefore, future investigations must plan regular and frequent evaluations of physical and cognitive performance allowing cognitive changes to be observed in relation to physical performance changes.

To-date there has not been a randomized control trial conducted to observe the time course of cognitive and physiological changes when exposed to fatigue-inducing training load. As such, the primary purpose of this investigation was to examine further the effects of fatigue on cognitive and physical performance and the time course of this relationship in a group of recreational exercisers. Moreover, a second purpose of the investigation was to identify differences (or level of sensitivity) between various types of cognitive tests. Based on the work of Bredin and Warburton, we hypothesized that cognitive decrements (as measured by a selected CogState Test Battery) would emerge prior to the emergence of physiologically based performance decrements.

5.2 Methodology

5.2.1 Participants

Twelve university-aged males were recruited for this investigation. All participants reported being healthy and free of medication, and were regularly active, meeting the current Canadian physical activity recommendations for adults (150 minutes of physical activity per week) (Tremblay et al., 2011). Participants were randomly assigned to either the stationary training group (n = 7) or the control group (n = 5). Participants were cleared for physical activity by the Physical Activity Readiness Questionnaire+ for All Individuals

Across the Lifespan (PAR-Q+) (www.healthandfitnessjournalofcanada.com) (also see Appendix D). This investigation was reviewed and approved by the Clinical Board of Ethics of the University of British Columbia.

5.2.2 Assessment of cognitive function

All tests of cognitive function were collected using CogState Research computerized testing software. Three tests were selected (detection task, identification task, and continuous paired associate learning task) to form a CogState test battery. All three tests were administered using a computer, whereby the participant was asked to view a computer monitor and respond according to a standardized set of directions using either the mouse or the computer keyboard.

5.2.2.1 Detection task

An overturned deck of cards was displayed on the computer monitor. Participants were asked to depress a key as soon as the top card (from the card deck) turned over. Reaction time was recorded in ms. There was 35 trials, preceeded by three practice trials.

5.2.2.2 Identification task

This test followed similar procedures as above, except that the participant was required to identify as quickly as possible whether or not the card displayed was red, by pressing the "K" key for "yes" and the "D" key for "no" (and vice versa for left handed participants). Reaction time was recorded in ms. There was 30 trials, preceeded by three practice trials.

5.2.2.3 Continuous paired associate learning task

This task was divided in two stages. In Stage 1, one ball was presented in the middle of the monitor, around which seven other balls were displayed. The participant was required to click on each of the peripheral balls to reveal a hidden picture underneath. During this process, the participant was asked to memorize the pictures hidden under the balls, and their respective locations. In Stage 2, the participant was required to answer the question "In what locations do these pictures belong?". The ball in the middle displays a picture, and the participant was required click on the peripheral ball hiding the same picture. Seven rounds of eight stimuli were presented to the participant, for a total of 56 stimuli. Time needed (duration) to complete each trial is recorded in ms. Accuracy was measured by the total number of errors that occur during the execution of the task.

5.2.3 Assessment of physical activity

Participants' physical activity level was assessed using the Godin-Shephard Leisure-Time Physical Activity Questionnaire. Participants were asked to answer one question, which asked their frequency of physical activity according to three different levels of intensity: mild, moderate, and strenuous. The number of times the participant reported engaging in moderate to strenuous physical activity were converted into an arbitrary unit, reflecting how active participants were. More specifically, the number of times an individual engage in mild, moderate, or strenuous exercise for more than 15 minutes was multiplied by 3, 5, and 9 respectively. Results above 24 indicated an individual was considered to be active (Godin, 2011).

5.2.4 Assessment of maximal aerobic power

A testing protocol specific to a cycle ergometer was utilized (see the Canadian Society for Exercise Physiology, 1998). Participants began pedalling at a comfortable pace (e.g., 90 rpm) at low resistance (e.g., 135 Watts) for 2 minutes. The pedalling rate remained the same, and the resistance increased by small increments (e.g., 50 watts) every two minutes, until completion of the test. The test was terminated at volitional exhaustion, if systolic blood pressure was over or equal to 260 mmHg, if diastolic blood pressure was over or equal to 115 mm Hg, or until heart rate or aerobic power reached a plateau. Participants wore a mask connected to a metabolic cart (Medi-Soft) to measure expired gas. Rate of Perceived Exertion (RPE) was also collected at each stage of the test.

5.2.5 Assessment of endurance performance

Participants were asked to complete 20 km on a cycle ergometer as fast as possible. Participants were informed of their pace, as well as the distance completed. The time to complete the distance was recorded. Rate of Perceived Exertion (RPE) was collected at each stage of the test.

5.2.6 Assessment of morning heart rate variability

Heart rate varaiability was self-collected upon participant awakening using a heart rate monitor (S810, Polar Electro Oy, Kempele, Finland) for 5 minutes while supine, and for 3 minutes while standing. Mean of the NN interval (meanNN) and square root of the mean squared successive differences between adjacent RR intervals (rMSSD) were calculated and analyzed for both the supine and upright position.

5.2.7 Assessment of muscle soreness

A subjective method was used to examine an individual's perceived level of muscle soreness via the Delayed Onset of Muscle Soreness scale. After sitting down for 5 minutes, participants were asked to rate on a visual analogue scale (from "no soreness" to "worst soreness ever felt") how much muscle soreness they experienced when sitting down. See Appendix A for a copy of the Delayed Onset of Muscle Soreness questionnaire.

5.2.8 Assessment of recovery: Recovery-Stress Questionnaire (RestQ-Sport)

To assess perceived balance between stress and recovery, participants were asked to complete the shortened version of the Recovery-Stress Questionnaire (RestQ-Sport) consisting of 52 items, each to be rated by the individual on a 6-point scale. Ratings were based on the last three days leading up to the assessment. Items focused on general and sport specific stress (26-items), as well as general and sport specific recovery (26-items). A total stress score and a total recovery score were calculated by the sum of the 26 stress-related items and the sum of the total recovery score, respectively. Higher scores indicated greater stress or a condition of greater recovery. A final score was calculated by substracting the total stress score from the total recovery score. A higher score reflects a state of greater recovery (Kellmann & Kallus, 2001). See Appendix B for a copy of the questionnaire.

5.2.9 Assessment of sleep quality

Each participant was asked to complete the Groningen Sleep Quality Questionnaire (Jafarian, Gorouhi, Taghva, & Lotfi, 2008), a 15-item true or false questionnaire assessing sleep quality of the previous night with a maximal score of 14. A higher score is indicative of worse sleep quality. See Appendix C for a copy of the questionnaire.

5.3 Procedure

Participants were asked to engage in a total of 14 days of testing, which consisted of pre- and post-testing, training, and a one week recovery period. The procedures are summarized in Figure 4.1.

Figure 4.1

Schematic representation of the procedures

Baseline			**Training**	**Recovery Week**	**Post-Test**	
Day 1	**Day 2**	**Days 3-7**	**Days 8-12**	**Days 13-21**	**Day 22**	**Day 23**
Clearance (PAR-Q+) Cognitive Battery DOMS Sleep Quality Questionnaire Stress-Recovery Questionnaire	HRV (at awakening)* Cogntive Battery DOMS Sleep Quality Questionnaire	Daily HRV (at awakening)*	HRV (at awakening)* Cognitive Battery DOMS Sleep Quality Questionnaire Stress-Recovery Questionnaire on Days 3 and 7	HRV (at awakening)* Cognitive Battery on Days 15-19 (week days) DOMS Sleep Quality Questionnaire	HRV (at awakening)* Cognitive Battery DOMS Sleep Quality Questionnaire Stress-Recovery Questionnaire	HRV (at awakening)* Cognitive Battery DOMS Sleep Quality Questionnaire
Maximal aerobic power test	Time trial		Time trial : 20 km for cyclists		Aerobic power test	Time trial
Cognitive Battery DOMS	Cognitive Battery DOMS		Cognitive Battery DOMS		Cognitive Battery DOMS	Cognitive Battery DOMS

Note. PAR-Q+ = Physical Activity Readiness Questionnaire, DOMS = Delayed Onset of Muscle Soreness questionnaire, HRV = Heart Rate Variability. *Heart rate variability measurements were taken from home.

5.3.1 Pre- and post-tests

On Day 1, the following assessments were administered in order: 1) cognitive function (via a cognitive test battery); 2) muscle soreness (Delayed Onset of Muscle Soreness scale); 3) sleep quality (Groningen Sleep Quality Questionnaire); 4) current level of stress versus recovery (Stress-Recovery Questionnaire), and 5) maximal aerobic power (VO_2 max). Following the test of maxinal aerobic power, measurements of cognitive function and muscle soreness were taken again. Participants were also provided instructions on how to perform the heart rate variability test. Day 2 consisted of the same measurements with the exception of maximal aerobic power. Instead participants were asked to complete the endurance performance test (time trial). This exact procedure was repeated one week following the completion of training. Heart rate variability was collected every day/night of the investigation.

5.3.2 Training

One week following Baseline testing, participants assigned to the training group engaged in five consecutive days of training. The protocol consisted of one 20 km time trial per day performed at the same time each day. Participants were instructed to complete the distance as fast as possibly can. Prior to and directly following the time trial, participants completed the cognitive test battery, as well as the muscle soreness scale.

Participants assigned to the control group were instructed to maintain their customary levels of physical activity. In addition, they were asked to complete the cognitive test battery once a day, prior to the completion of the muscle soreness questionnaire, stress-recovery questionnaire, and sleep quality questionnaire.

5.3.3 Recovery

Following the 5 training days, both groups were asked to continue collecting heart rate variability at awakening every day. All participants were also required to complete the cogntive test battery once per day for 5 consecutive days, as well as the sleep quality and muscle soreness questionnaires.

5.4 Statistical Analysis

Each test of cognitive function was analysed using a 2 (Group: control, training) x 14 (Day) analysis of variance (ANOVA), with repeated measures on the last factor. Each test of cognitive function of the training group were also analysed using a 2 (Time: pre-session, post-session) x 9 (Day) analysis of variance (ANOVA), with repeated measures on the last factor.

Time trial performance was analysed using a 2 (Group: control, training) x 2 (Time: pre-test, post-test) analysis of variance (ANOVA), with repeated measures on the last factor. Time trial performances of the training group were also analysed using a one x 7 (Time) analysis of variance (ANOVA), with repeated measures on the last factor.

Where statistical differences were revealed, Tukey's post-hoc comparisons were performed. Results were reported as significant at $p < .05$.

5.5 Results

During this investigation, there were no exercise-related adverse events to report and no participants' dropped out of the investigation. All participants completed all testing sessions and assessments with the exception of one individual. Specifically, one participant failed to collect all morning heart rate variability measurements; therefore, this data could not be analyzed.

5.5.1 Participant characteristics

A total of 12 participants were recruited for this investigation. One participant (training group) did not follow the guidelines of most assessments, and their data was not included for analysis. As a result, a total of 11 participants were included for data analysis (control group : n = 5, mean age = 27.4 ± 4.5 y; training group : n = 6, mea nage = 25.8 ± 3.2 y). Participants characteristics are presented in table 5.1.

5.5.2 Maximal aerobic power

There were no main effect for group ($F (1, 9) = 3.0181$, $p = .116$) or time, ($F (1, 9) = .518$, $p = .490$) on the maximal aerobic power results. There was an interaction between time and group ($F (1, 9) = 6.35$, $p = .033$), however Tukey's post-hoc comparisons were not significantly different. Results of the maximal aerobic power are shown on Figure 5.1.

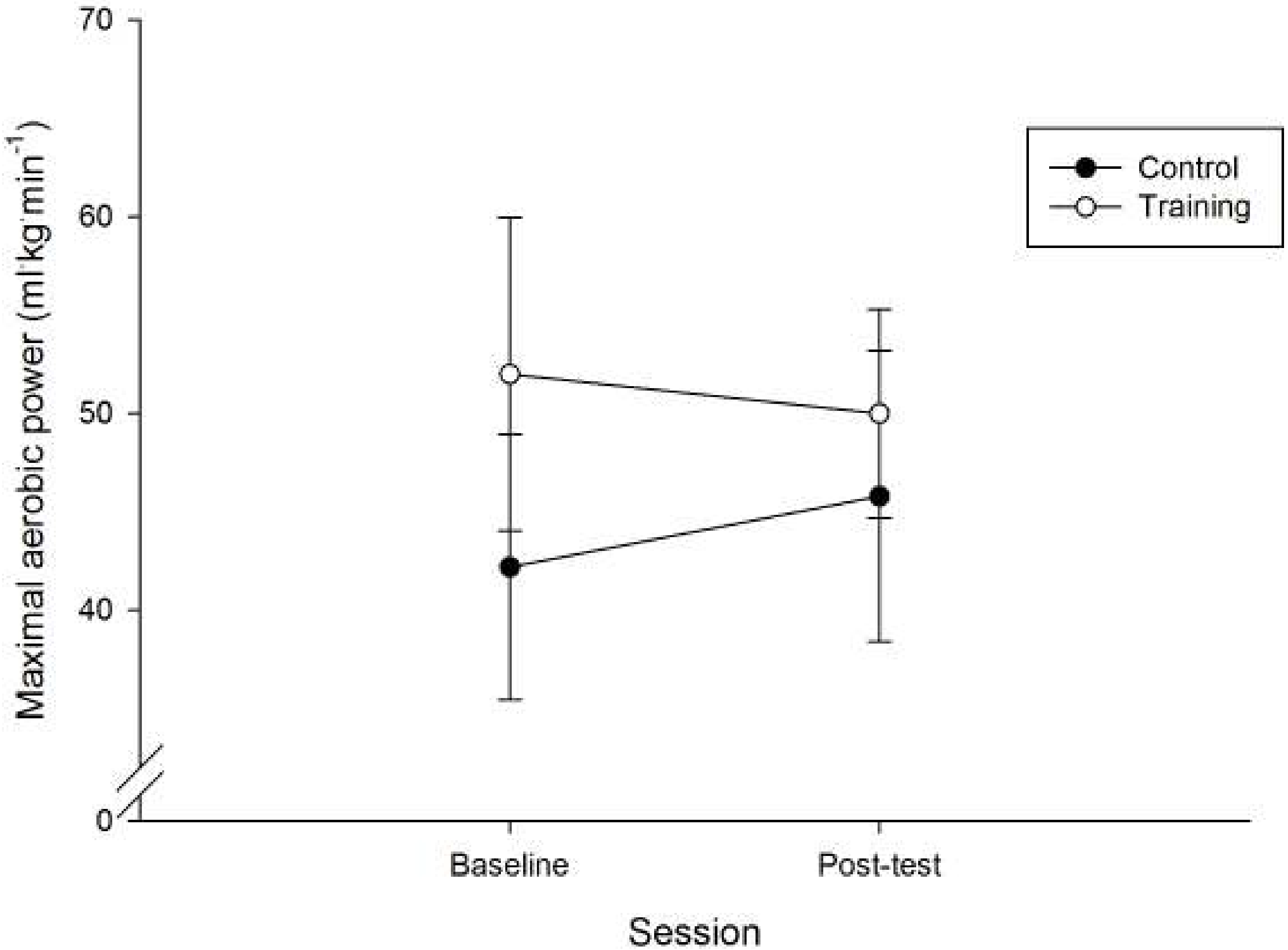

Figure 5.1 Maximal aerobic power by group (Mean ± SD).

5.5.3 Cognitive performance

5.5.3.1 Detection task

Statistical analysis revealed no main effect for group ($F (1, 9) = .864, p = .377$) or time ($F (13, 117) = .415, p = .962$) when comparing pre-session cognitive reaction time across days. There was also no significant differences in pre-session cognitive performance errors for group ($F (1, 6) = 4.91, p = .069$) or time ($F (13, 78) = .965, p = .493$). No significant interaction effects were found.

No significant differences were found for time ($F (1, 10) = .107, p = .751$) and day ($F (8, 80) = 1.095, p = .376$) between pre-session cognitive reaction time to post-session performance. There was also no significant differences in pre-session cognitive performance errors for time ($F (1, 7) = .626, p = .455$) or day ($F (8, 56) = 1.235, p = .296$). No significant interaction effects were found. Results of the detection task are shown in Figures 5.2 to 5.5, respectively.

5.5.3.1 Identification task

Statistical analysis revealed no main effect for group ($F (1, 9) = .015, p = .906$) and time ($F (13, 117) = 1.201, p = .287$) when comparing pre-session reaction time performances across days, for the identification task. There was a main effect for group ($F (1, 6) = 23.316, p = .003$) when comparing pre-session number of error cognitive performances across days. Tukey's post hoc comparisons showed that the training group made more errors than the control group. No main effect for time ($F (13, 78) = .424, p = .957$) was revealed. No significant interaction effects were found.

Analyses revealed no main effect for time ($F (1, 10) = .010, p = .921$) and day ($F (8, 80) = .660, p = .725$) between pre-session reaction time performances to post-session performances, for the identification task. There was also no significant difference in pre-session number of errors for time ($F(1, 7) = .092$, $p = .770$) or day ($F(8, 56) = .902$, $p = .521$). No significant interaction effects were found. Results of the identification task are shown in Figures 5.5 to 5.9, respectively.

Table 5.1

Participant Characteristics

	Age (yrs ± SD)	Height (cm ± SD)	Weight (kg ± SD)	Maximal aerobic power ($ml \cdot kg \cdot min^{-1}$ ± SD)	Godin's value
Control (n = 5)	27.4 ± 4.5	180.0 ± 8.3	77.9 ± 2.9	42.2 ± 6.7	70.8 ± 26.7
Training (n = 6)	25.8 ± 3.2	181.3 ± 6.8	77.1 ± 8.1	52.0 ± 8.0	78.1 ± 19.9
p-value	P = .513	p = .776	p = .825	p = .057	p = .596

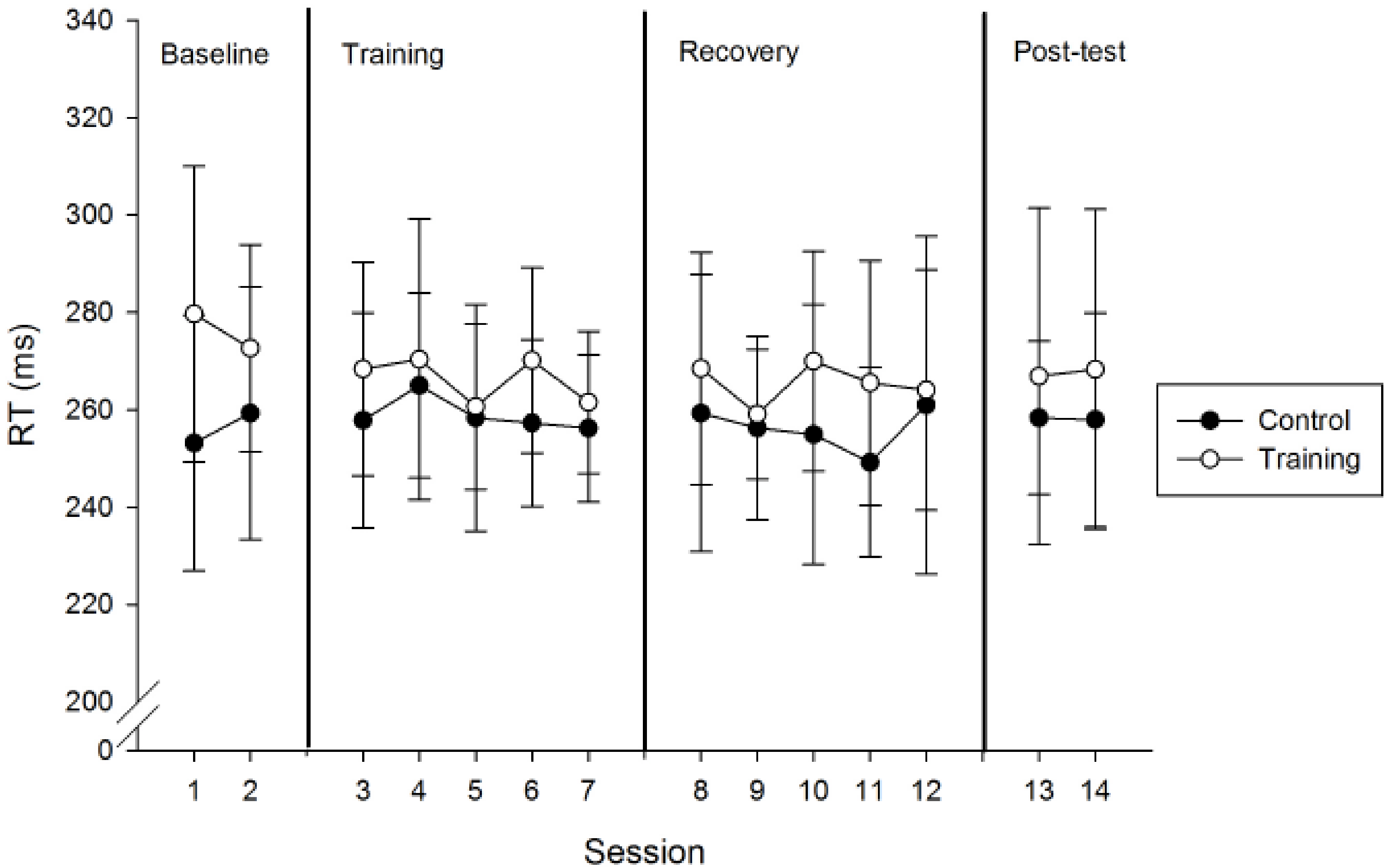

Figure 5.2. Pre-session reaction time (RT) by group across days for the detection task (Mean ± SD).

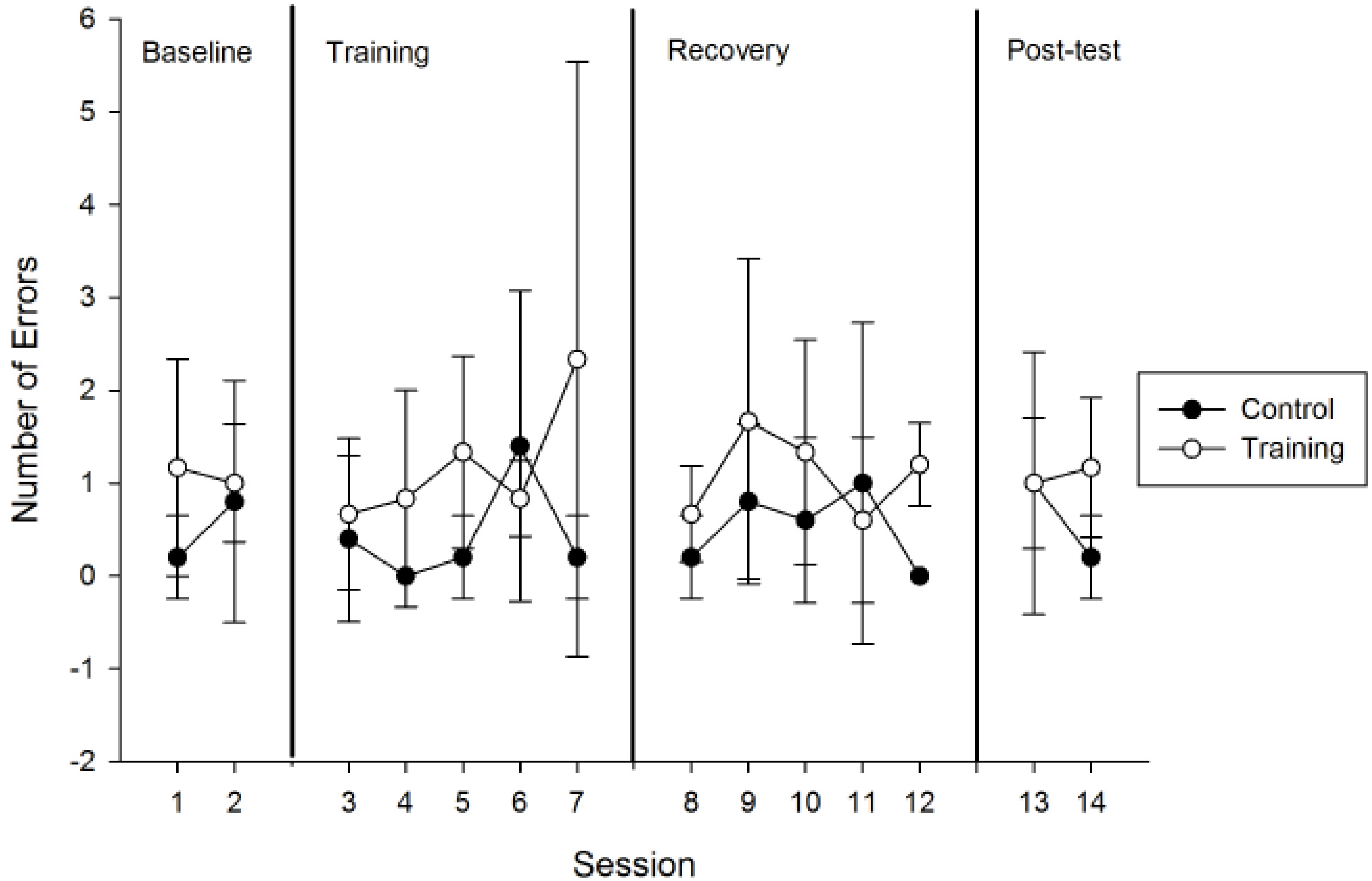

Figure 5.3. Pre-session number of errors across days for the detection task (Mean ± SD).

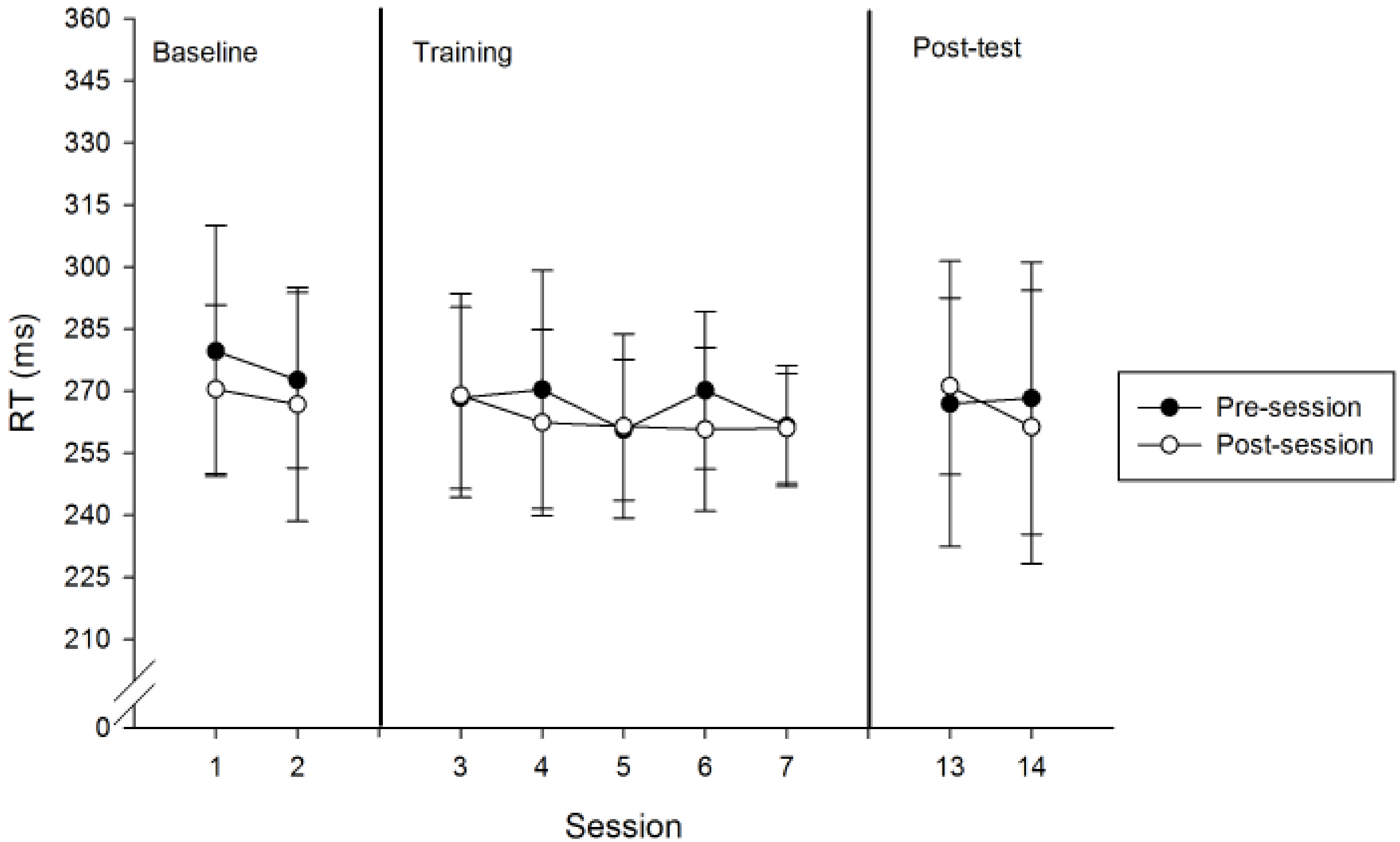

Figure 5.4. Pre-session versus Post-session reaction time (RT) for the training group across days for the detection task (Mean ± SD).

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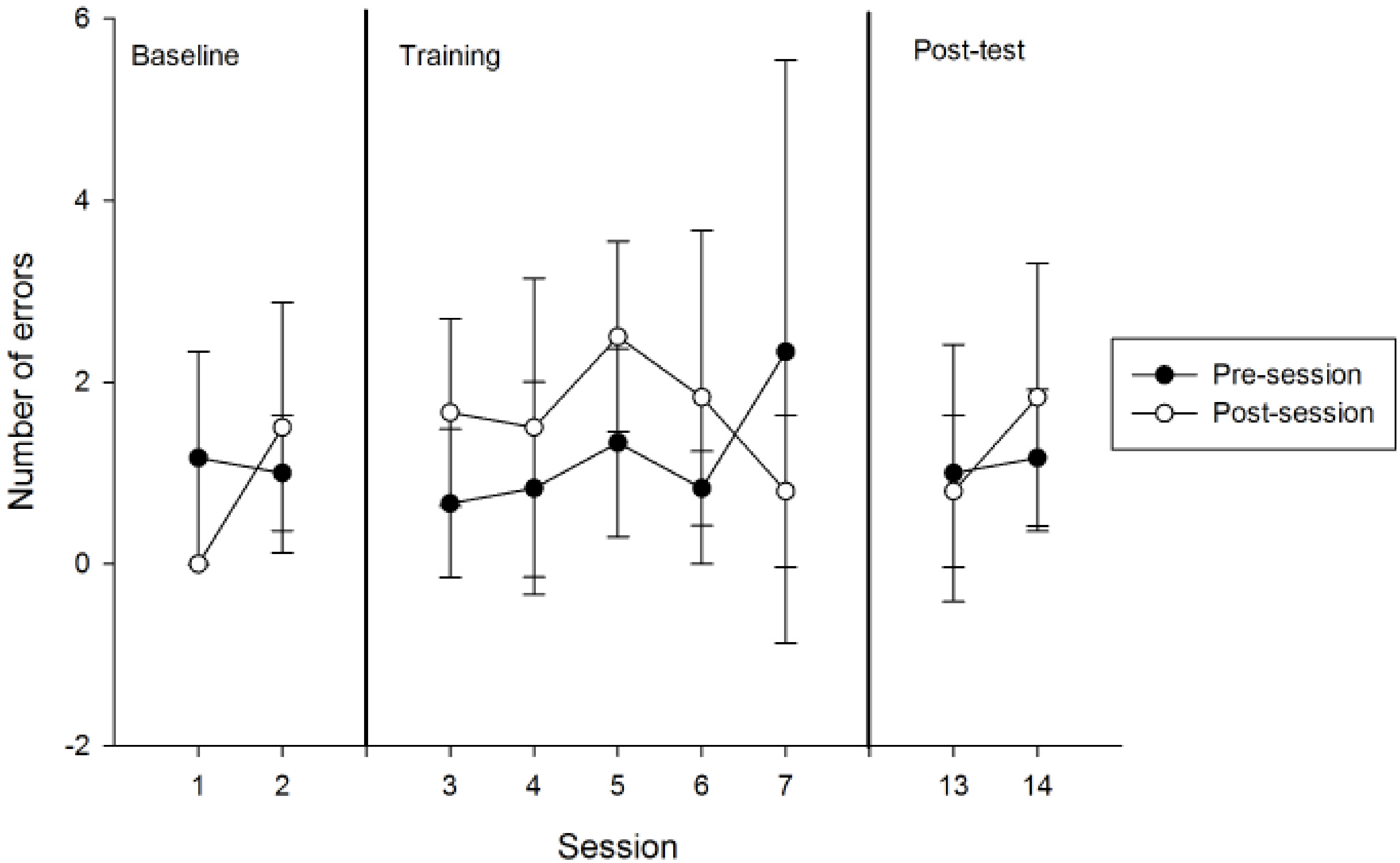

Figure 5.5. Training number of errors for the training group across days for the detection task (Mean ± SD).

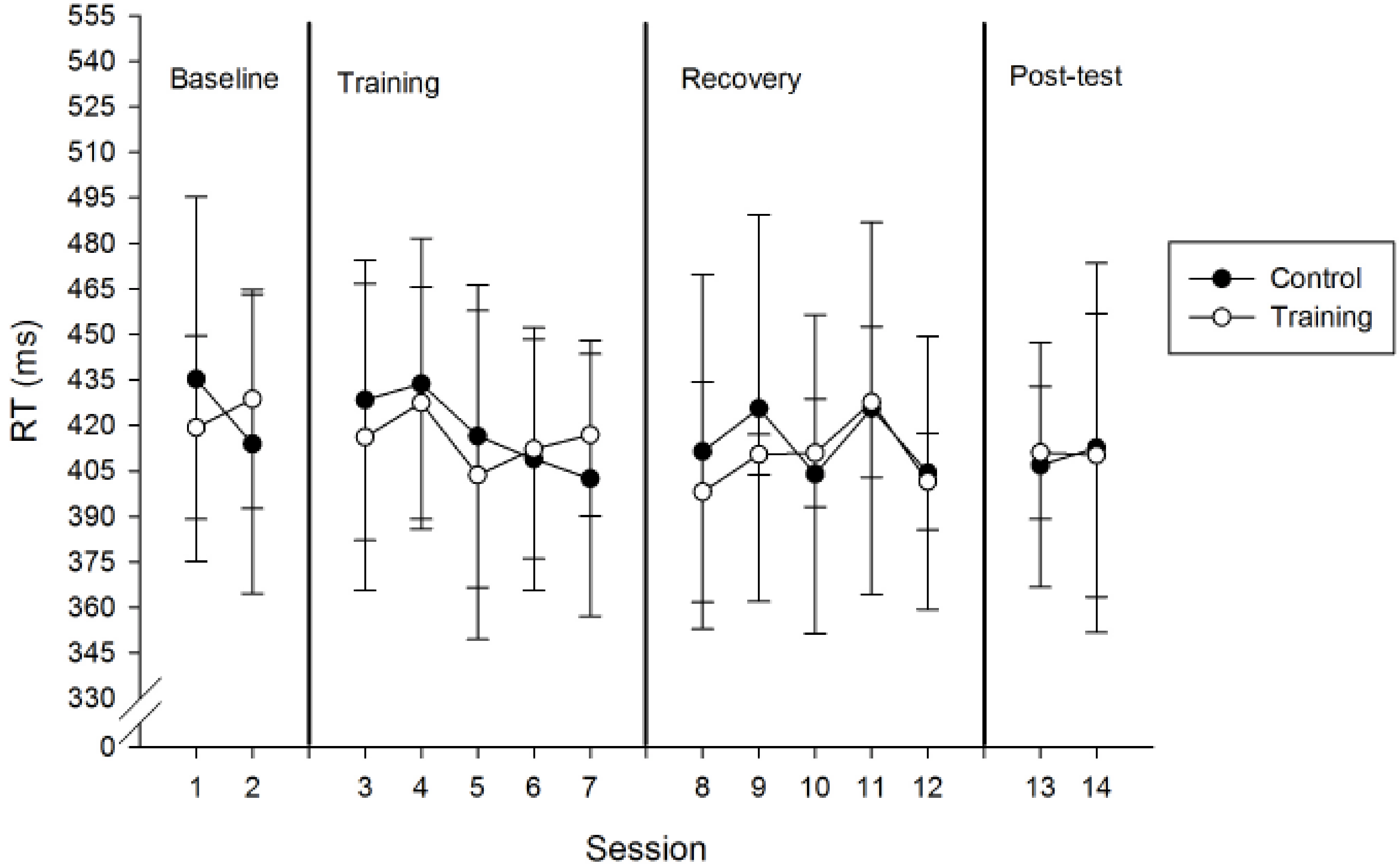

Figure 5.6. Pre-session reaction time (RT) by group across days for the identification task (Mean ± SD).

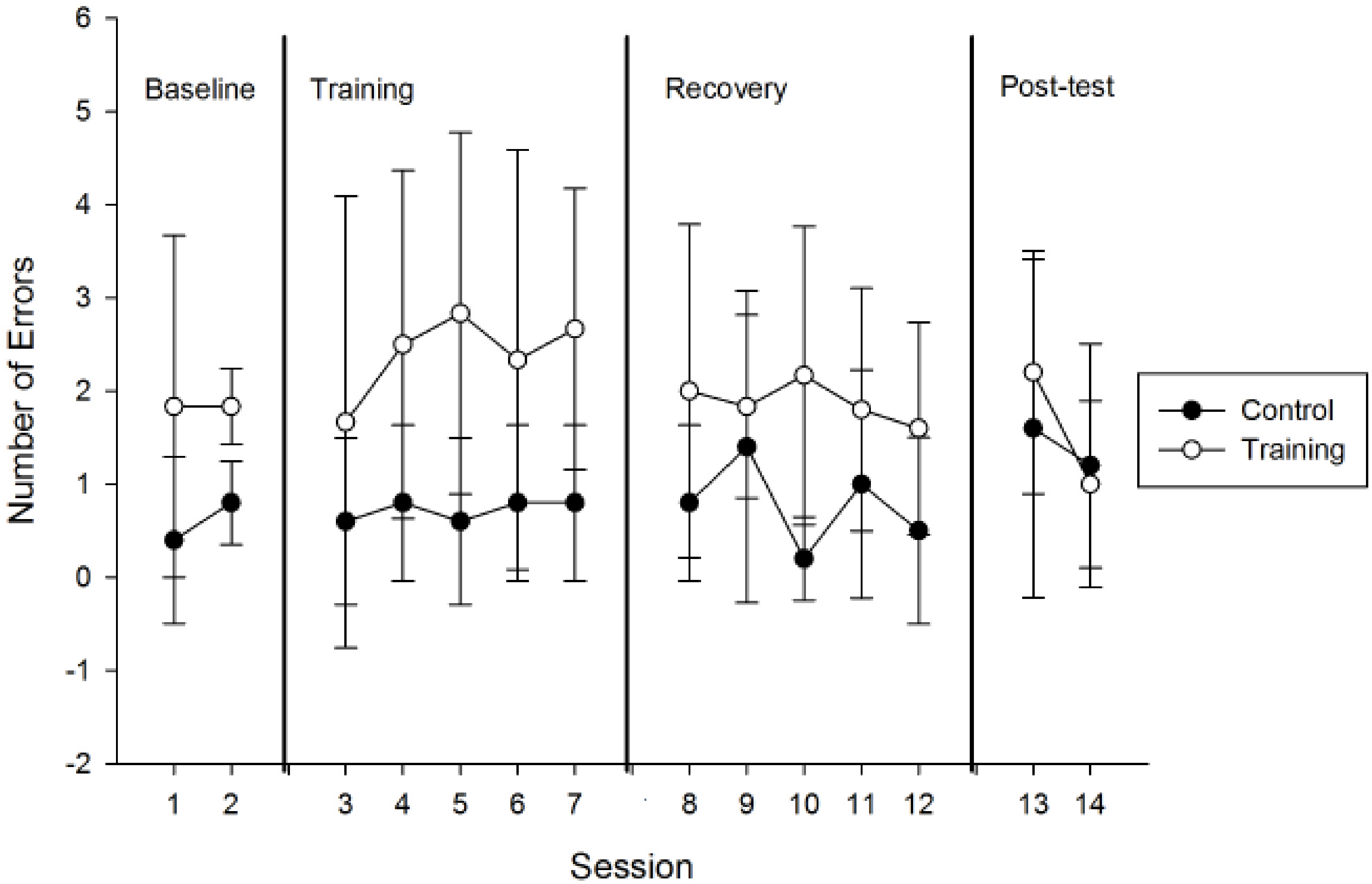

Figure 5.7. Pre-session number of errors by group across days for the identification task (Mean ± SD).

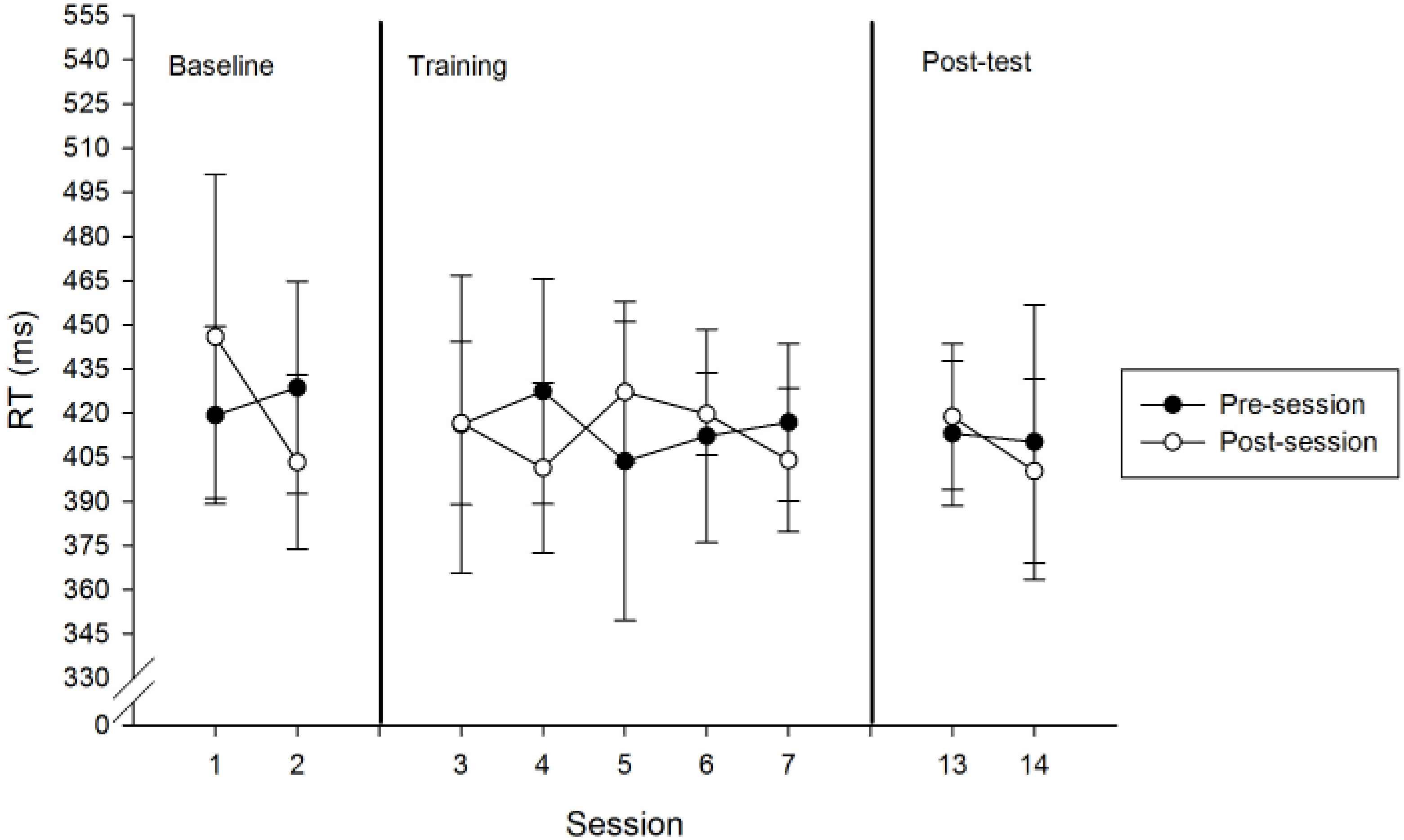

Figure 5.8. Training reaction time for the training group across days for the identification task (Mean ± SD).

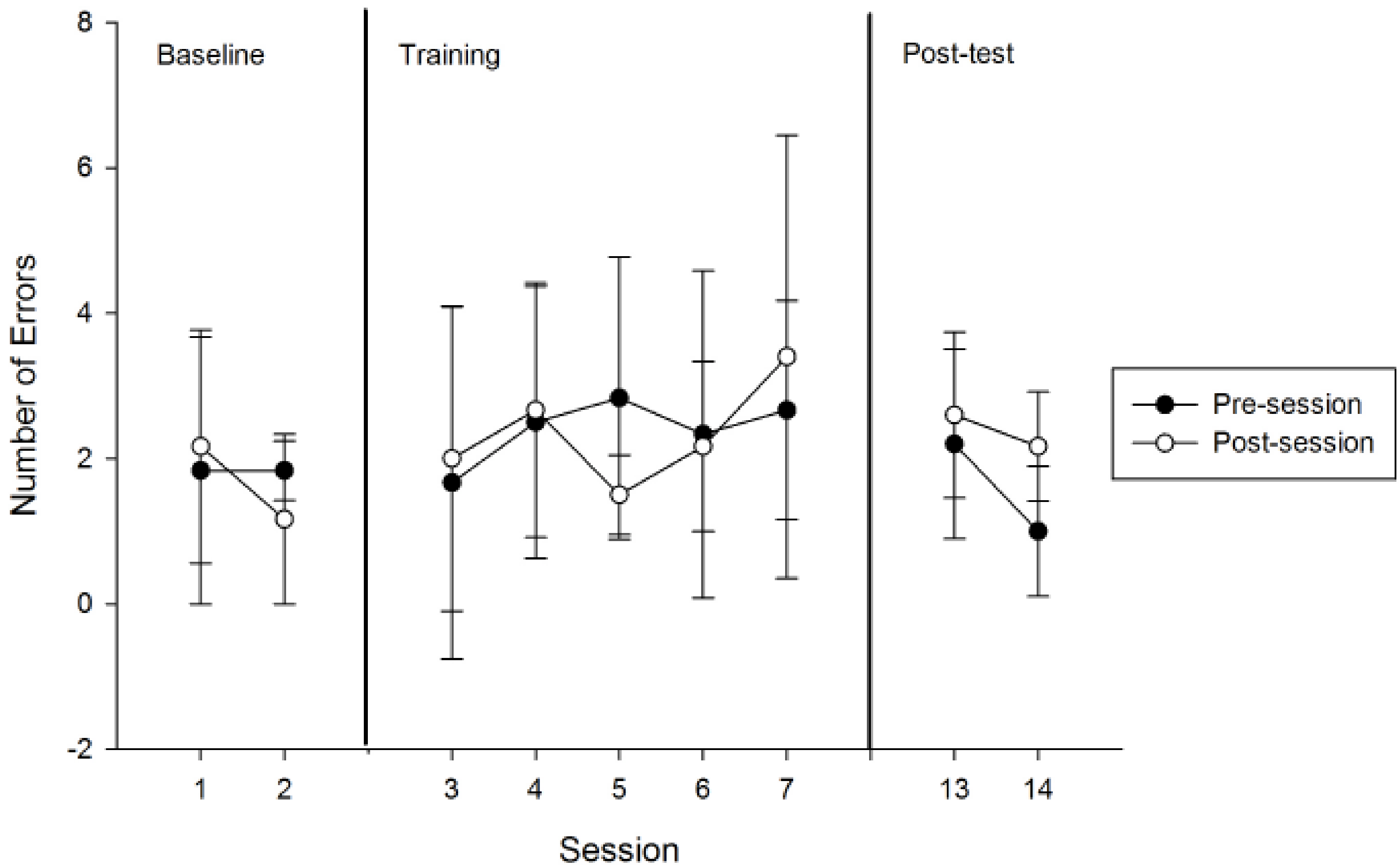

Figure 5.9. Training number of errors for the training group across days for the identification task (Mean ± SD).

5.5.3.2 Continuous paired associate learning task.

Statistical analysis revealed no main effect for group ($F(1, 5) = .038$, $p = .853$) when comparing pre-session duration across days. A main effect for time ($F(13, 65) = 9.733$, $p = .000$) was revealed, and post hoc comparisons showed that session 1 took significantly longer for participants to complete, than any other session. Session 2 was longer than session 8, 10, 11, 12, 13, and 14. There was no significant differences in pre-session cognitive performance errors for group ($F(1, 4) = 1.780$, $p = .253$) and time ($F(13, 52) = 1.616$, $p = .111$). No significant interaction effects were found.

No significant differences were found for time ($F(1, 7) = 1.091$, $p = .331$) between pre-session cognitive duration to post-session performance. A main effect for duration cognitive performance was revealed for day ($F(8, 56) = 9.550$, $p = .000$). Tukey's post hoc comparisons showed that session 1 was significantly longer than all other sessions, and session 2 was longer than session 14 only. There was also no significant differences between pre and post-session cognitive performance errors for time ($F(1, 7) = .027$, $p = .873$). A main effect for day was revealed ($F(8, 56) = 3.103$, $p = .006$), and post-hoc comparisons showed that session 1 was longer than all other sessions but 2.

An interaction between time and day ($F(8, 56) = 2.521$, $p = .020$) was revealed for duration of cognitive performance when comparing pre and post-session. Participants in the training group were slower during their first testing session, compared to all other sessions, with the exception of second testing session. In addition, the training group displayed shorter duration to complete the task at post test, compared to the second day of baseline. Results of the task are shown in Figures 5.10 to 5.13, respectively.

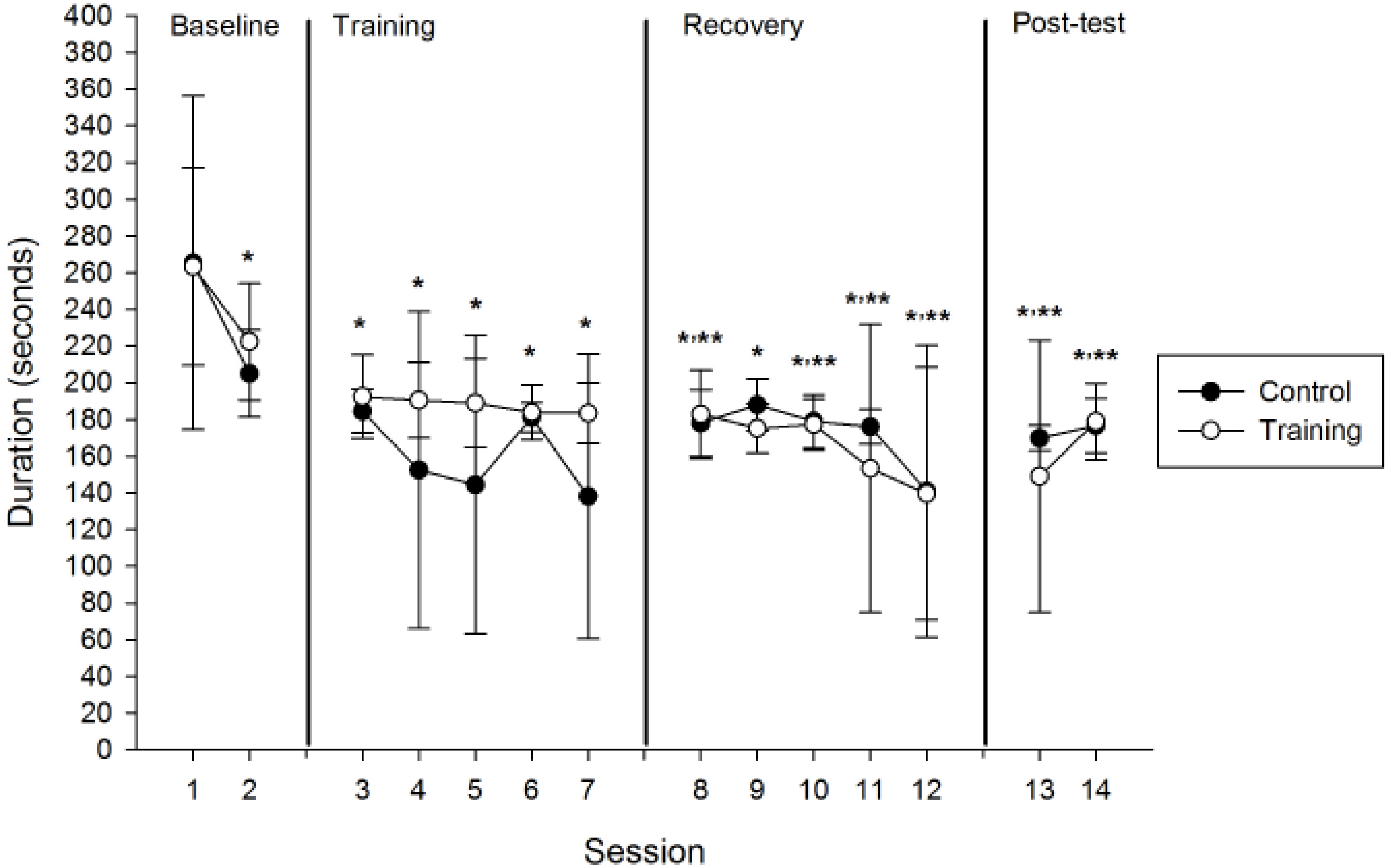

Figure 5.10. Pre-session reaction time across days, for the continuous paired associate learning task(Mean ± SD).
* indicate statistically different (p < .05) from session 1
** indicates statistically (p < .05) different from session

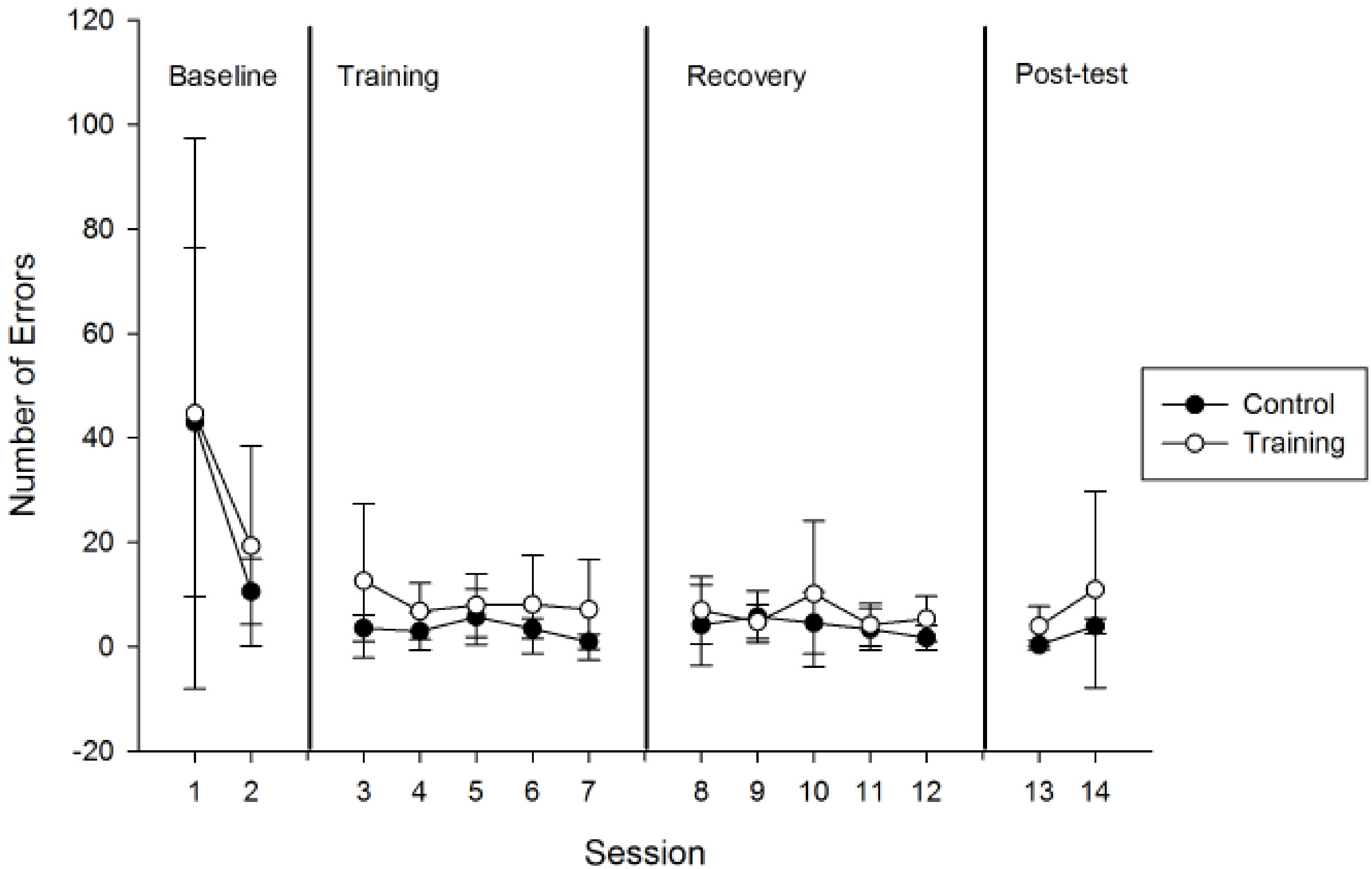

Figure 5.11. Pre-session number of errors by group for the continuous paired associate learning task (Mean ± SD).

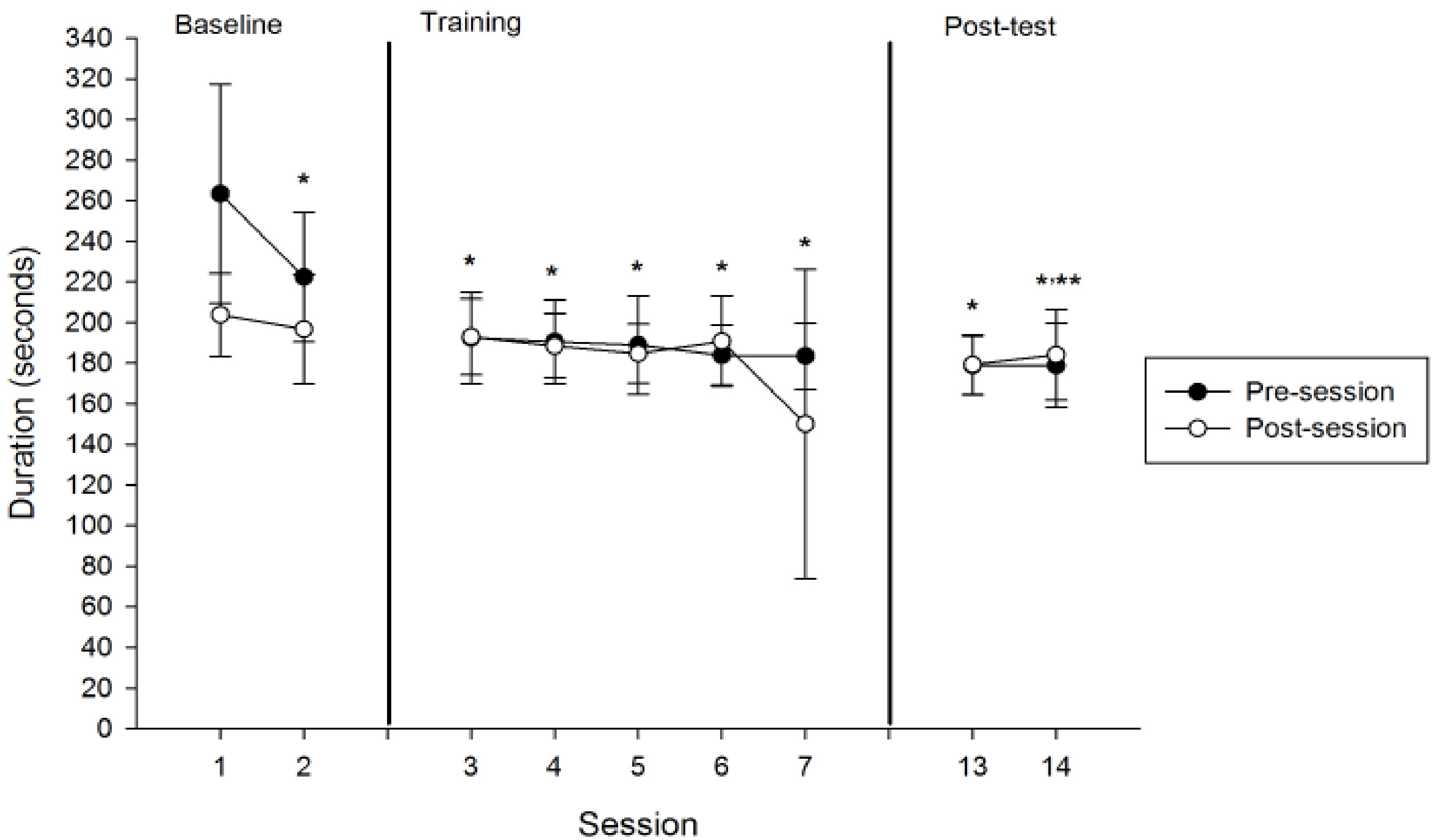

Figure 5.12. Training duration for the training group across days for the continuous paired associate learning task (Mean ± SD).
* indicate statistically different ($p < .05$) from session 1
** indicates statistically ($p < .05$) different from session 2

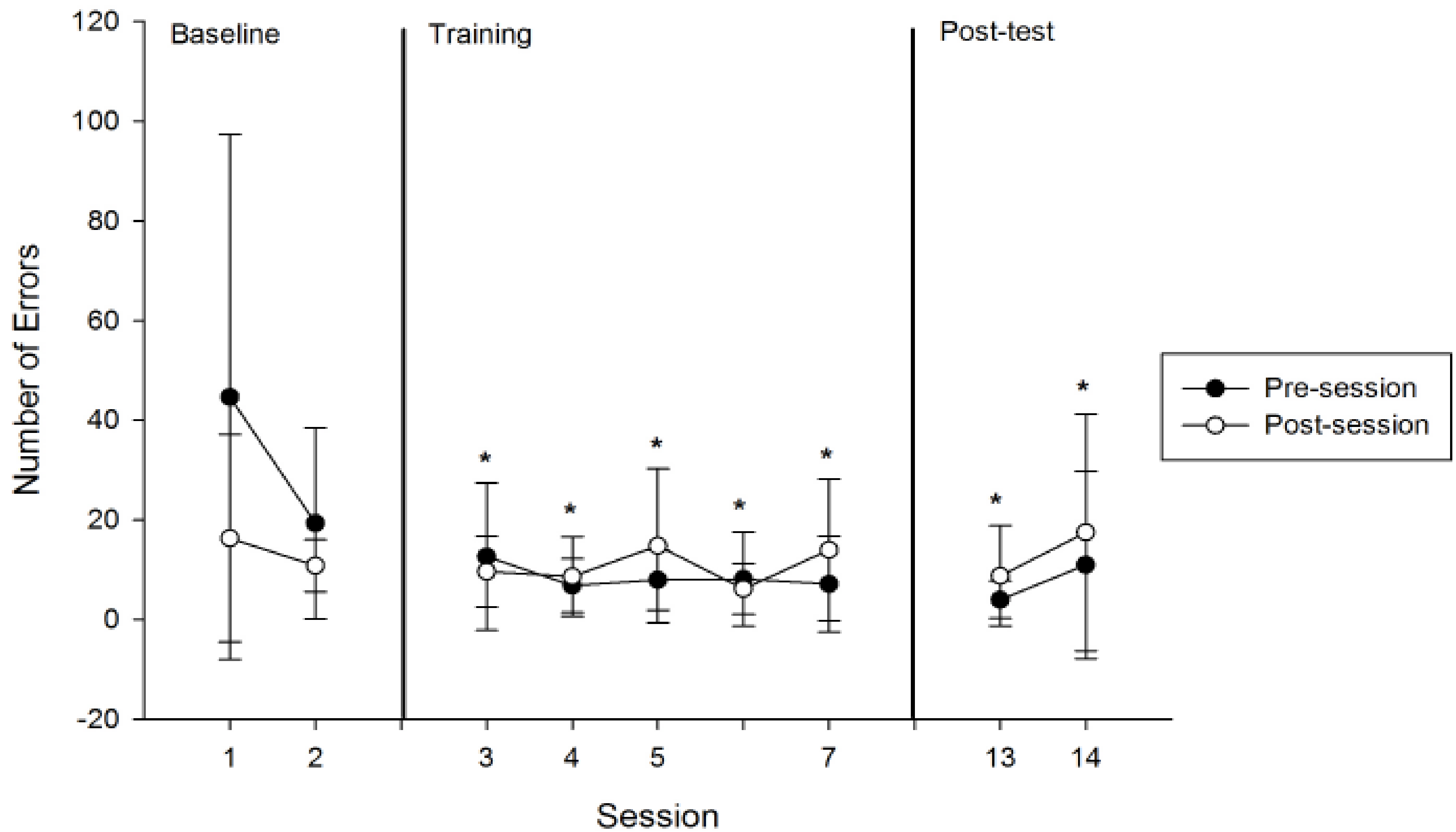

Figure 5.13. Training number of errors for the training group across days for the continuous paired associate learning task (Mean ± SD).
* indicate statistically different (p < .05) from session 1

5.5.4 Time trial performance

We first compared baseline and post-test results for the 20 km time trial for both groups. Statistical analysis revealed no main effect for group ($F(1, 9) = 3.520$, $p = .093$) or time ($F(1, 9) = 1.086$, $p = .325$). No significant interaction effects were found. There was also was no time effect ($F(6, 30) = .359$, $p = .899$) when comparing physical performance of the training group during training. As we can observe on Figure 5.14, the mean of time-trial results remains practically unchanged across days. Individual data for time-trial performances is shown on Figure 5.15.

5.5.1 Recovery-stress balance

5.5.1.1 General stress

Statistical analysis revealed no main effect for group ($F(1, 9) = .377$, $p = .554$) or time ($F(3, 27) = 2.00$, $p = .138$) when comparing the general stress scale of the RestQ-Sport across days. However, a significant group versus time interaction was found ($F(3, 27) = 4.018$, $p = .017$). General stress results were higher (more stress) at post-testing (i.e., following the one week of recovery) compared to baseline and pre-training results for the training group. The results of the general stress scale are presented in Figure 5.16.

5.5.1.2 General recovery

No significant differences were found for group ($F(1, 9) = .206$, $p = .660$) and time ($F(3, 27) = 2.648$, $p = .069$) when comparing the general recovery item across days. No significant interaction effects were found. The results of the general stress scale are presented in Figure 5.17.

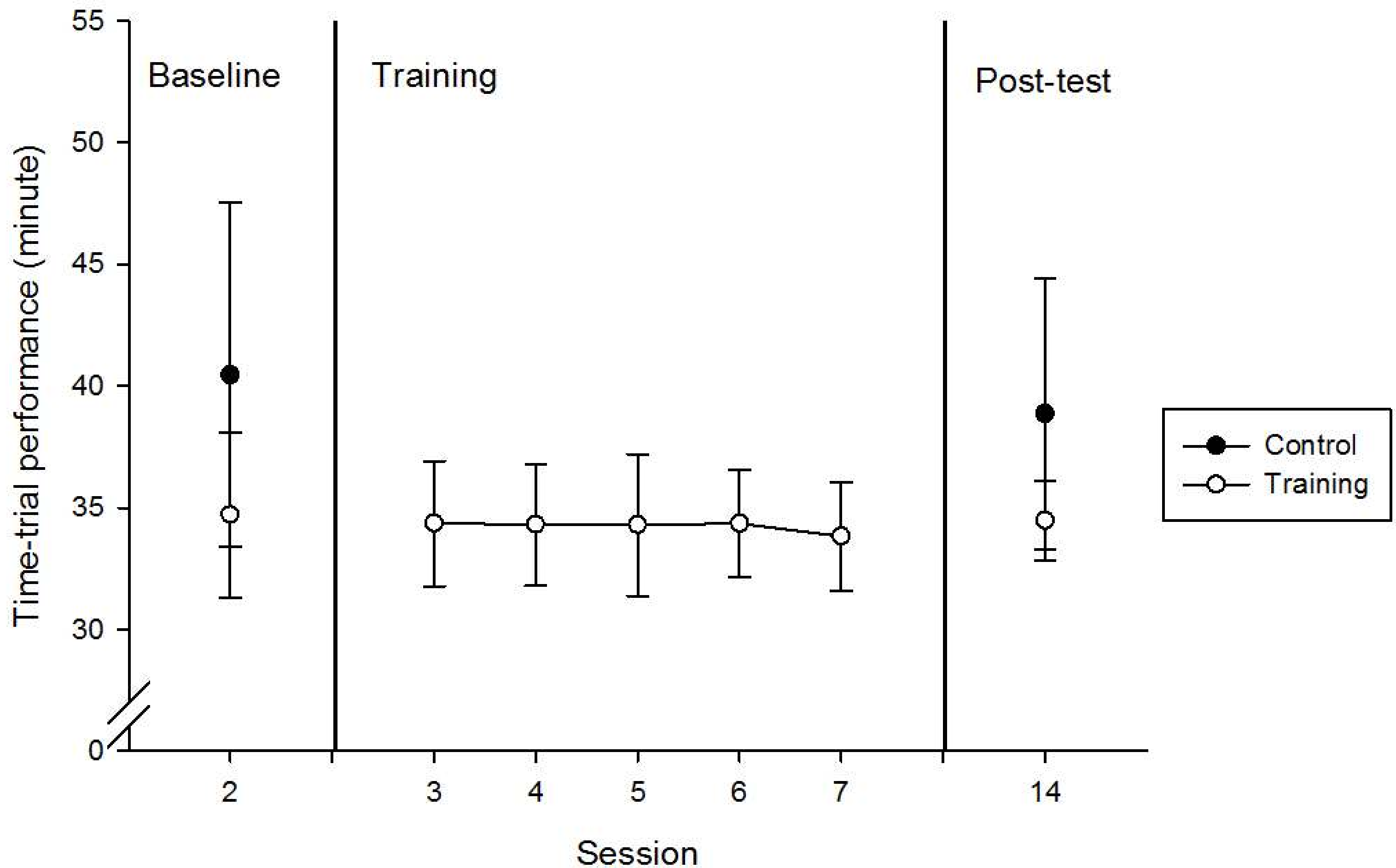

Figure 5.14. Time-trial performances by group across days (Mean ± SD).

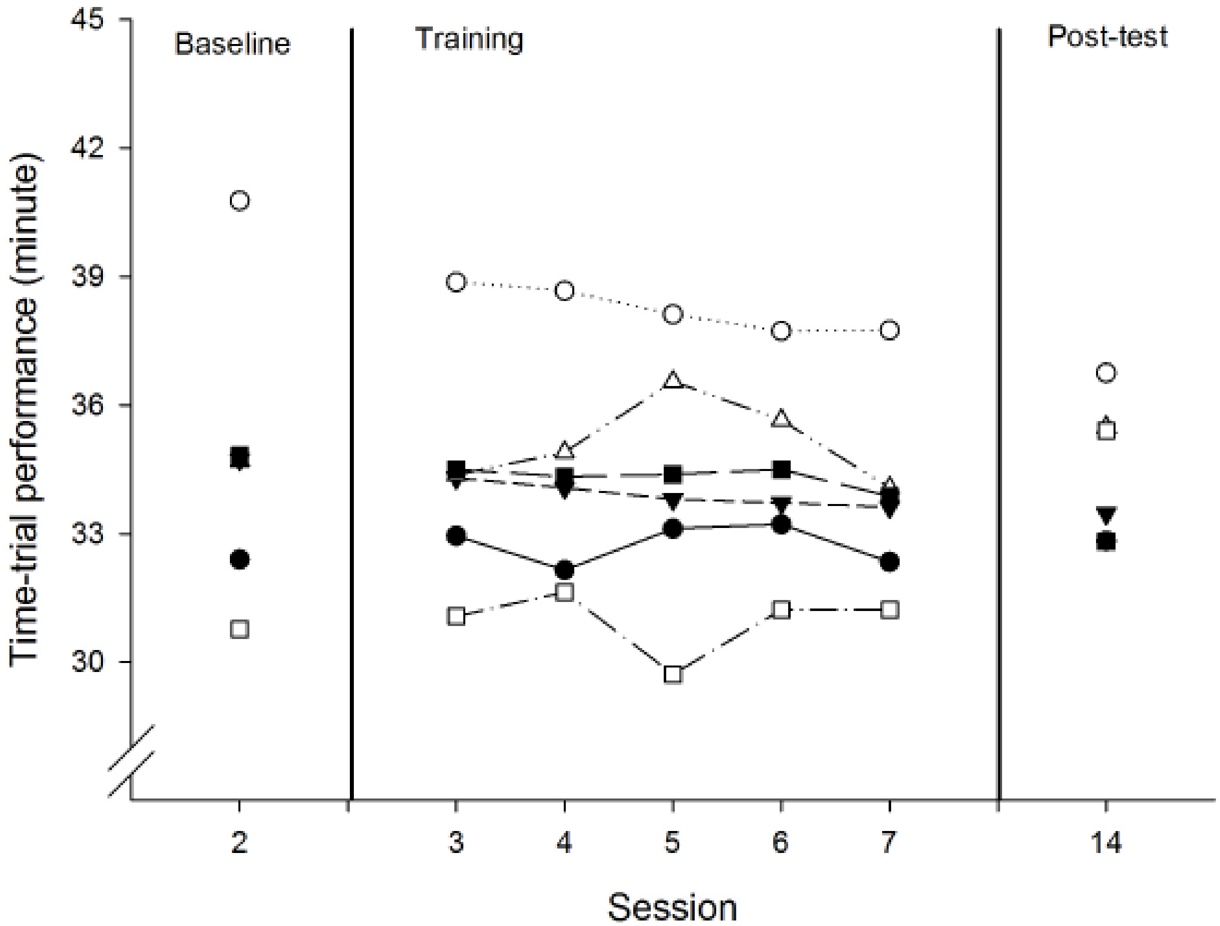

Figure 5.15. Individual data for time-trial performances for the training group across days.

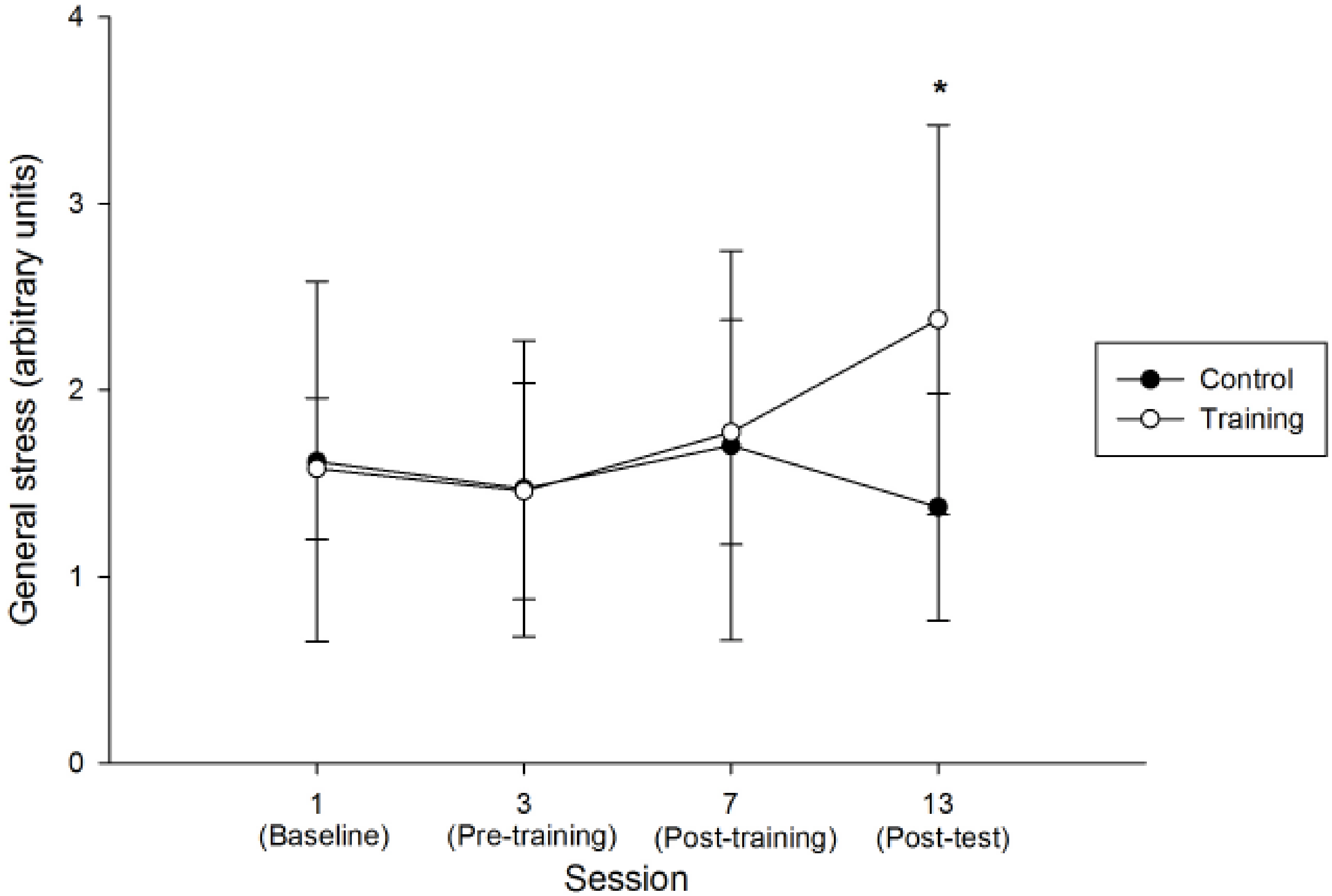

Figure 5.16. General stress scores by group across days (Mean ± SD).
* indicate statistically different (p < .05) from baseline and pre-training, for the training group only

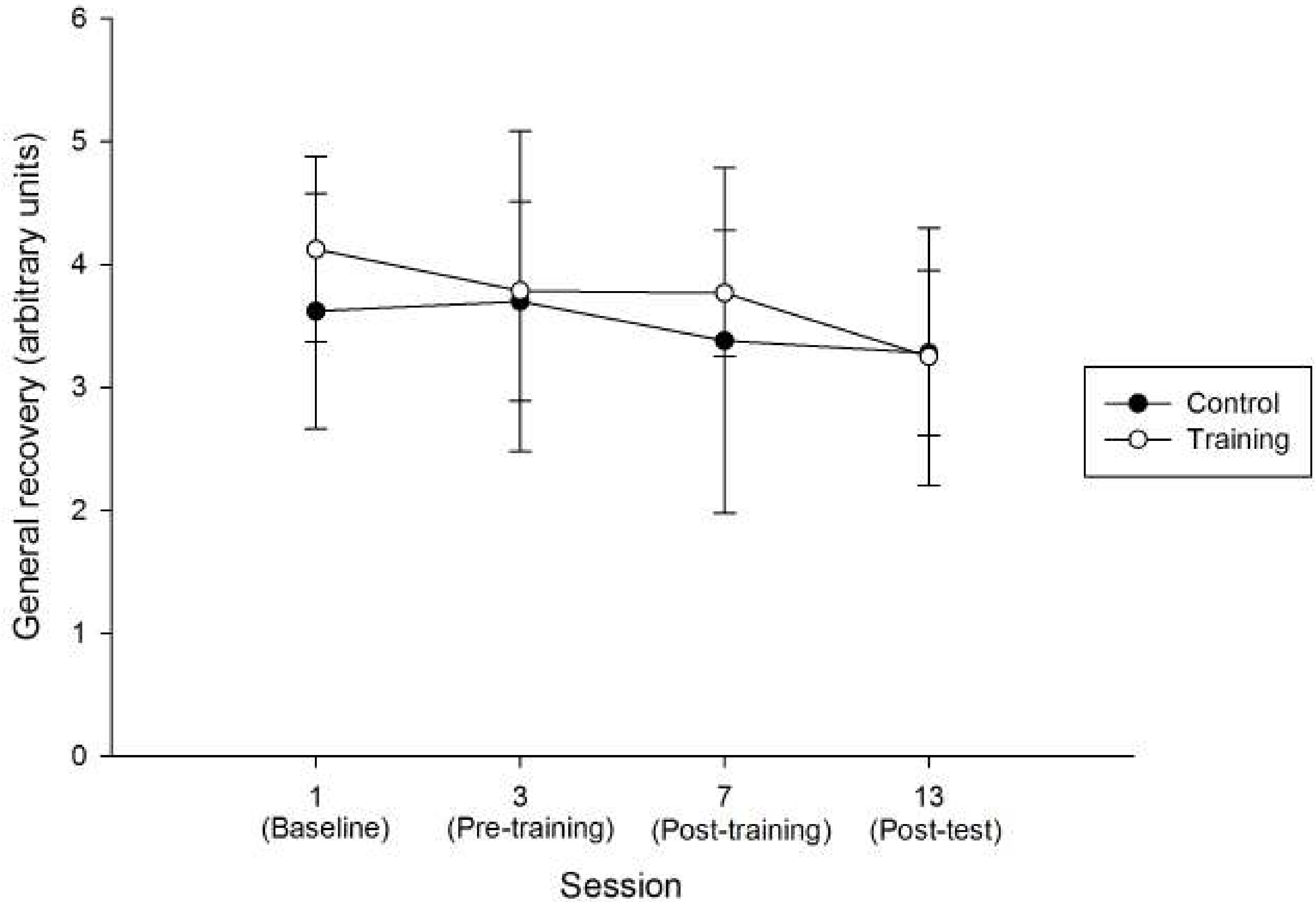

Figure 5.17. General recovery score by group across days (Mean ± SD).

5.5.1.3 Sport stress

Statistical analysis revealed no main effect for group (F (1, 9) = .877, p = .373) and time (F (3, 27) = 1.570, p = .219) when comparing the sport stress scale. No significant interaction effects were found. The results of the general stress scale are presented in Figure 5.18.

5.5.1.4 Sport recovery

A main effect for time was found for the sport recovery scale (F (3, 27) = 3.020, p = .047). Tukey's post hoc comparisons showed that post-test values are lower than baseline. There were no main effect for group (F (1, 9) = 1.254, p = .292), and no significant interaction was shown. The results of the general stress scale are presented in Figure 5.19.

5.5.1.5 Overall score

Statistical analysis revealed a main effect for time for the overall score (final stress score substracted to the final recovery score) (F (3, 27) = 3.515, p = .029). Post hoc comparisons showed that post-test values (following recovery) were lower (i.e., lower recovery to stress ratio) compared to baseline testing. This change in the overall score is attributed mostly to reduced recovery. There was no main effect for group (F (1, 9) = .034, p = .856) on the overall score. An interaction between time and group occurred, where the training group showed a reduced recovery to stress ratio at post-testing compared to baseline. The change in overall score can be explained by both a decrease in recovery and an increase in stress for the training group. The results of the general stress scale are presented in Figure 5.20.

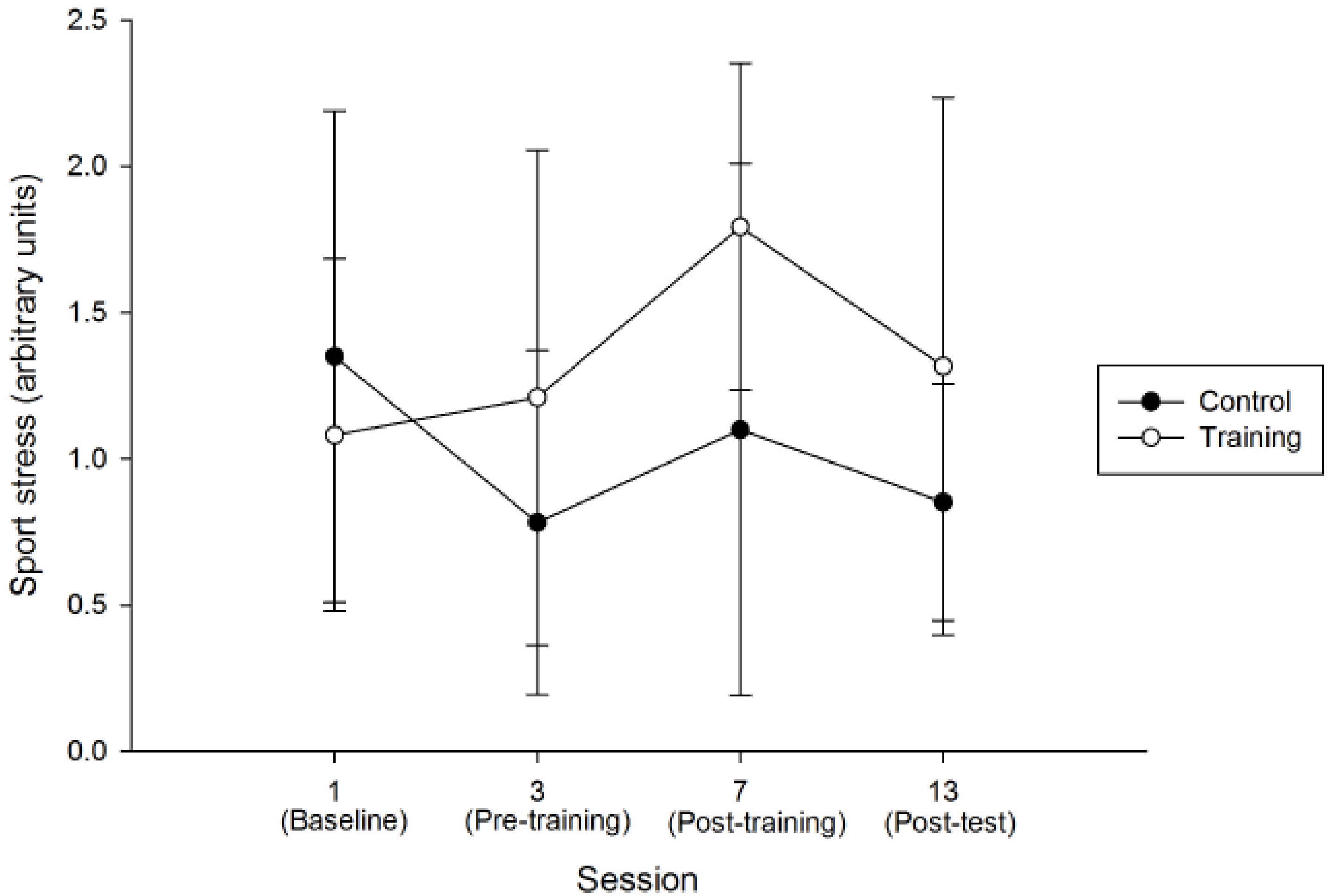

Figure 5.18. Sport stress score by group across days

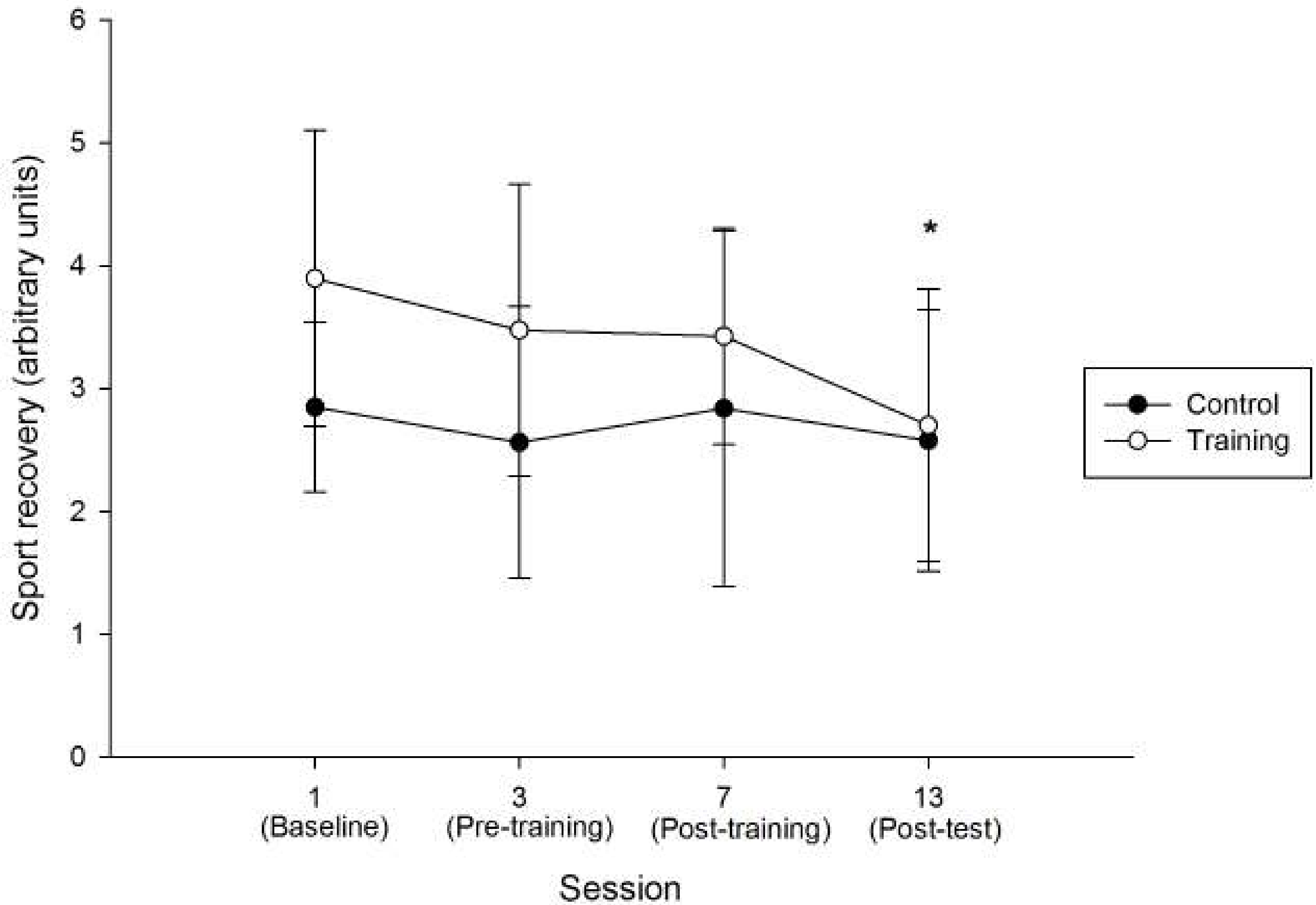

Figure 5.19. Sport recovery score by group across days (Mean ± SD).
* indicate statistically different (p < .05) from baseline

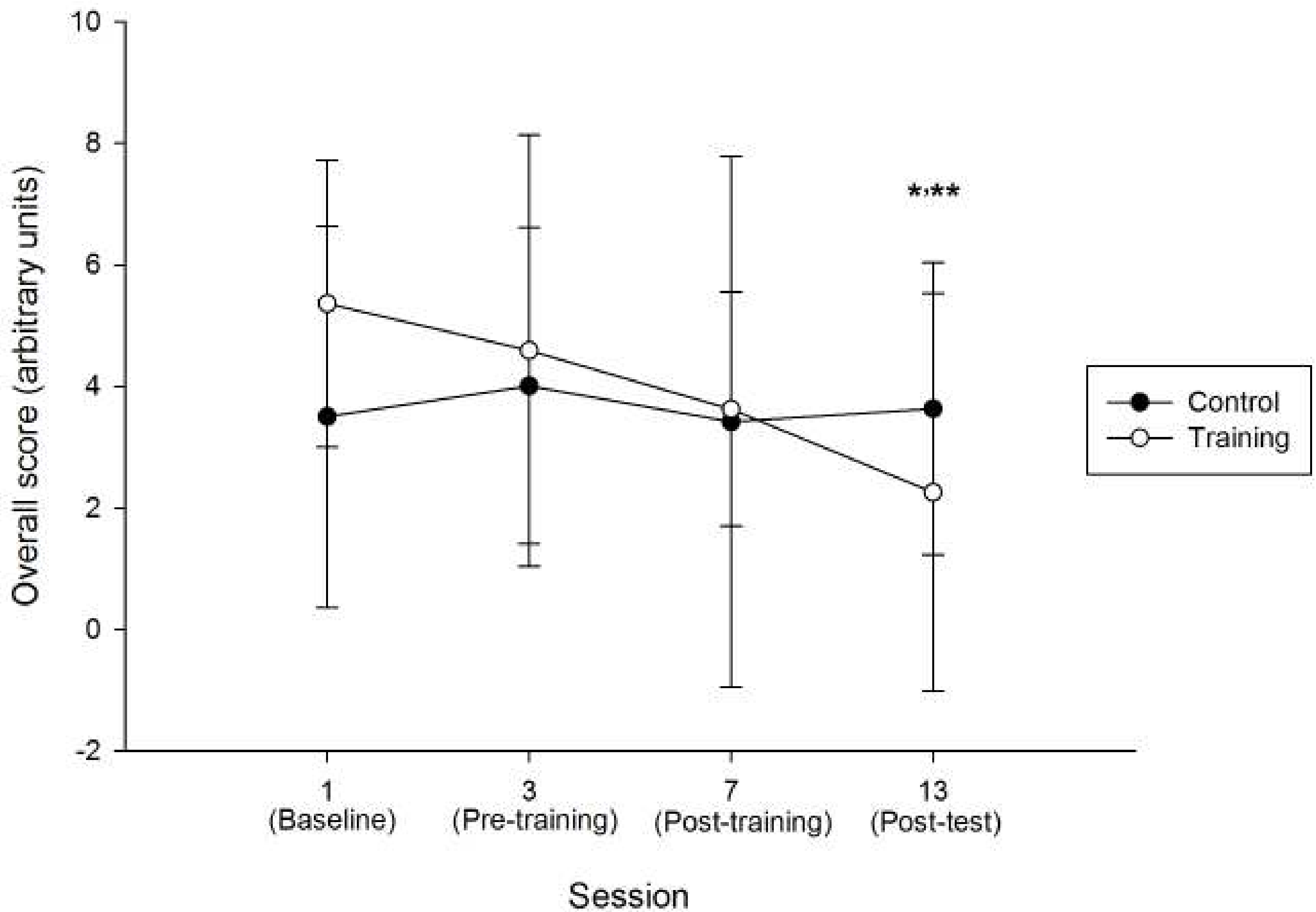

Figure 5.20. Overall score by group across days (Mean ± SD).

* indicate statistically different ($p < .05$) from baseline and pre-training

** indicate statistically different ($p < .05$) from baseline only for the training group

5.5.2 Morning heart rate variability results

5.5.2.1 Mean of the NN interval

There were no statistical differences between group (F (1, 4) = 2.051, p = .225) or across time (F (11, 44) = .873, p = .572) for the mean of the NN intervals, in the supine position. No significant differences were found for group (F (1 ,4) = .767, p = .431) or time (F (11, 44) = 1.046, p = .425) for the mean of the NN intervals, in the upright position. No significant interaction effects were found.

5.5.2.2 Square root of the mean squared between adjacent rr intervals

Statistical analysis revealed no main effect for group (F (1,2) = .488, p = .557) for the square root of the mean squared between adjacent RR intervals, in the supine position. There was a main effect for time (F (11, 22) = 2.487, p = .033), although Tukey's post-hoc comparisons were not significant. In the upright position, there was no main effect for group (F (1, 2) = .003, p = .963). There was a main effect for time (F (11, 22) = 2.348, p = .042), however Tukey's post-hoc comparisons were not significant. No significant interaction effects were found.

5.5.3 Sleep quality results

No significant differences were found for group (F (1, 9) = .040, p = .846) or time (F (13, 117) = .827, p = .630). No significant interaction effects were found.

5.5.4 Muscle soreness results

Statistical analysis revealed no main effect for group (F (1, 9) = .111, p = .746) or time (F (11, 99) = 1.100, p = .370) when comparing pre-session Delayed Onset of Muscle Soreness (DOMS) results across days. There were no significan interaction. Visual inspection of the results showed that even though not statistically siginificant, participants in the training group reported more muscle soreness during the cycling week.

No significant differences were found for group ($F(1, 10) = 3.525$, $p = .090$) or time ($F(6, 60) = 1.627$, $p = .155$) between pre and post-session DOMS. There were no significant interaction effects.

5.6 Discussion

The main purpose of this investigation was to document the relationship between cognitive and physical changes during a fatigue-inducing protocol. Unfortunately, we could not assess the time course of this relationship because no physical performance change occured, suggesting that participants did not get physically fatigued to the extent that was required for the purpose of our investigation. That is, we failed to induce a state of physical fatigue in participants, because of insufficiant training load (training volume and/or training intensity). As a result of the absence of physical fatigue in our participants, we could not document cognitive changes prior to a decrement in physical performance. Ratings of stress and recovery, as well as morning heart rate variability were in accordance with this finding, whereas no significant changes on these outcomes were associated to the training.

Anecdotally, individuals reported sore throat, or being more tired, stressed, and/or anxious on the last 3 days of the training protocol. However, these symptoms were not sufficient to relate to cognitive or physical performance. This finding questions how accurately recreational exercisers perceive their adaptation to their training or physical activities. Perceptions of tiredness, stress, or overall unreadiness to exercise did not in fact translate into cognitive or physical decrements. Including recreational exercisers in this investigation allows us to explore how physical fatigue interacts with exercise. More specifically, these results are helpful in understanding physical fatigue as a factor regulating, or limiting, physical activity participation in this population (Sadja et al., 2012). In this investigation, participants were not fatigued enough to elicit decrements in cognition or performance, although their perceptions of physical capacity was affected (as per anecdotal reports). Similarly, research has shown that individuals newly engaged in physical activities demonstrate the tendency to underestimate their ability to perform and tolerate physical exercise. This leads to lower intensity levels of exercise when self-paced, and poor physical activity adherence (Rhodes & Fiala, 2009; Williams, 2008). As a result of the limited work using recreational exercisers, it is difficult to implement a training protocol that is at a high enough intensity to achieve the goals of the investigation; yet, not too high in intensity or load that it will expose participants to injury.

To elicit the level of physical fatigue needed in the present investigation, a number of recommendations can be made for consideration in future research designs. First, the training volume and/or the training intensity must be increased (Lehmann et al., 1997; Meeusen et al., 2010). If participants were exercising at near-maximal intensity, an increase in load is needed specifically. As such, an important recommendation would be to implement an additional training session for each day (e.g., a morning training session, with an addition of an afternoon training session). This protocol would be more similar to the protocol implemented by Bredin and Warburton in endurance-trained athletes.

To use physical performance as a performance capacity measurement, participants' performances must be truly maximal (Dupuy et al., 2012). Participants were not endurance-trained cyclists, and their performances showed changes (non significant) throughout the week, suggesting that they were acquiring pacing strategies or familiarization with the task. Indeed, as shown in Figure 5.14, the participant's performances were not stable. Within the training group, all participants improved their time to complete the distance over 2 or more sessions during the training. In fact, 66% (4 out of 6) participants anecdotally reported trying out various strategies to improve their time-trial performances throughout the week. This observation leads us to believe that: (1) before using a time-to-completion measure in recreational exercisers, participants should engage in practice trials, to familiarize themselves with the requirement of the exercise, and (2) participants in the training group were not truly exercising to their maximal capacity, which limited the extent to which the training protocol affected them.

5.7 Strengths and Limitations of the Investigation

This is, to our knowledge, the first randomized control investigation monitoring the cognitive performance during a fatigue inducing training protocol, in recreational exercisers. Another strength of this investigation is the use of a Cogstate test battery that has been investigated for its reliability, prior to the main investigation of this thesis. This prior methodological investigation allowed us to better understand the cognitive performances of a normal and healthy population as it relates specifically to the Cogstate test battery.

This investigation had several limitations. First, the training protocol used was not sufficient to induce extreme conditions of fatigue in the participants, possibly because of an insufficient training volume. As such, we were not able to examine the time course of cognitive and physical decrements in human performance. At this time, we are unable to make evidence-based recommandations regarding use of the Cogstate test to predict the onset of physical performance decrements.

Second, including participants who are not familiar with the specific demands of a 20 km time-trial increased the variability of the results. Indeed, participants learned pacing strategies, as shown by 73% of participants (8 out of 11) who decreased their time-to-finish between their first and second performances. Again, the variability in physical performance results makes it difficult to draw clear conclusions regarding physical performance. To prevent such limitations in the future, implementing practice trials of the 20 km time-trial performance prior to the training week is a recommended strategy. Differently, an additional training week (5 more days of training) could potentially lead to greater physical fatigue: recreational exercisers tend to perform the 20 km at lower intensity; therefore, increasing the training volume could by a sufficient stressor to induce physical fatigue.

5.8 Conclusion

In conclusion, the training stressor was not sufficient to induce levels of extreme fatigue as measured by no physical performance decrements. Therefore we could not document cognitive changes in relation to physical changes. During the training, participants reported symptoms of discomfort associated to the training load, although this discomfort did not in fact lead to adverse effects on both cognitive and physical performance. It is well documented that recreational exercisers misconceive their adaptive abilities to physical training, which is thought to be linked with poor physical activity adherence (Rhodes & Fiala, 2009). Future research documenting cognitve changes in relation to physical performance decrements is needed to deepen our understanding of the mind-body interaction, and how it affects recreational exercisers as well as athletes. The critical factor in conducting these types of research investigations is to implement training protocols that is sufficient in training and/or intensity to induce physical fatigue. We recommend planning practice trials for the time-trial performance prior to the start of the investigation to ensure that intensity is close to maximal during testing. In addition, we recommend doubling the training load by adding one more training session daily. For example, one session in the morning and one session in the evening.

6 CHAPTER SIX: Conclusion

This chapter will conclude the thesis document. The main findings of the two investigations presented will be discussed in relationship to the current literature regarding the use of a cognitive test battery to predict the onset of physical performance decrements. Recommendations regarding findings applicable to athletes and non-athletes will be presented. The contribution of this work to the literature will also be highlighted, and future research directions will be discussed.

6.1 Inducing Physical Performance Decrements in a Group of Recreational Exercisers

In our investigation we failed to elicit physical performance decrements in a group of active male recreational exercisers. Specifically, a one-week, once a day, 20 km time-trial was not sufficient to demonstrate decrements in performance. One approach for modifying future research design is to incorporate practice trials for the physical performance, especially in the case of a time-trial, where pacing strategies can be developed. Indeed, adding practice time-trials would ensure that participants are exercising at near-maximal capacity throughout the exercise, as per the training plan. This strategy would not be needed in a group of endurance-trainde cyclists who are accustomed to the demands of a time-trial, and aware of optimal pacing strategies. We also speculate that an additional daily training session would increase the training load sufficiently to induce the appropriate level of physical fatigue required for an investigation of this nature in a group of recreational exercisers. Implementing such a protocol would be more similar to the testing protocol implemented by Bredin and Warburton in endurance-trained athletes. Adding a second daily time-trial appears to be a better strategy than doubling the distance in a single daily bout of exercise. A 40 km time-trial would increase the variability in performance within participants, as they learn the demands of such performance, as well as pacing strategies. Also, a 40 km time-trial performed by a non-experienced cyclist can increase risk for injuries associated to inappropriate posture caused by short-term fatigue during the training.

During this investigation, we assessed cognitive performances prior to and immediately following the training session, in an attempt to identify a specific time where cognition would be impaired. An important factor in such a design is the delay between a training session and administration of the cognitive test. It has been well documented that physical exercise has short-term effects on cognition, whereby cognition is improved (Joyce, Graydon, McMorris, & Davranche, 2009). This short-term positive effect on cognition can also mask more detrimental, longer-term effects caused by the training load that may manifest several hours following the training. We attempted to capture possible longer-term detrimental effects of fatiguing exercise by assessing cognition 24 hours later, prior to the start of each testing session. However implementing hourly testing sessions following a training session could reveal more precise information regarding the time-frame of a cognitive decrement. As such, it may be beneficial to perform the post-exercise cognitive testing 60 minutes following the completion of the exercise, as Joyce et al. (2009) reported short-term positive effects on cognition up to 52 minutes following exercise.

6.2 Use of the Cogstate Test Battery

According to the systematic review conducted in this thesis (Chapter 3) several psychomotor tests have been employed in the literature: the Stroop Colour-word test, the Vienna Determination test, and the Finger pre-cuing test (Dupuy, Renaud, Bherer, & Bosquet, 2010; Hynynen, Uusitalo, Konttinen, & Rusko, 2008b; Nederhof, Lemmink, Zwerver, & Mulder, 2007a; Nederhof, Zwerver, Brink, Meeusen, & Lemmink, 2008a; Rietjens et al., 2005). We utilized a select battery of cognitive tests designed by CogState Research. (CogState, CT, USA). CogState Research software (CogState, CT, USA) includes tests assessing information processing speed, and learning capacities, and has been shown to be sensitive to mild cognitive impairment (Collie et al., 2003). To our knowledge this test battery had not been used in the present context. Moreover, the reliability of a Cogstate battery when administered more than 4 times had not been investigated to-date (Collie et al., 2003; Falleti et al., 2006). As presented in Chapter 4, we investigated the reliability of a selected CogState test battery under conditions of repeat testing and under different testing schedules. Our findings demonstrated that in tasks like the detection task and the identification task, only one test session is needed to establish a baseline measure of reaction time. In contrast, the continuous paired associate learning task (a matching task) requires 3 practice trials before collecting baseline measures. Stated more simply, it is recommended that the fourth measurement be used as a participant's baseline measure.

6.3 Is this Line of Investigation Important To Continue?

Although the training protocol implemented in the main investigation of the thesis was limited in achieving its intended objectives, it is a line of investigation that is important to continue. It is suggested that cognitive impairment associated to physical performance decrement relates to the development of central fatigue. As physical fatigue occurs, the demand on the central nervous system is increased to maintain physical performance of the task. As a result, cognitive performance is adversely affected (Lorist et al., 2002), wherein attentional resources are invested in maintaining physical performance rather then invested in the performance of a cognitive task.

Another research direction to examine relates to the autonomic balance of the central nervous system. It is suggested that an imbalance between stressors and recovery during the development of an overtrained state leads to an imbalance within the autonomic nervous system (Lehmann, Foster, Dickhuth, & Gastmann, 1998b). It is unclear how the sympathetic and the parasympathetic branches of the autonomic nervous system are affected when overtraining occurs (Hynynen, Uusitalo, Konttinen, & Rusko, 2008a; Lehmann, Foster, Dickhuth, & Gastmann, 1998b); however it has been proposed there is an interaction between autonomic control and cognitive performance. Specifically, reduced excutive function may be associated with the imbalance between stress and recovery typical of overtraining (Dupuy et al., 2012; Thayer, Hansen, Saus-Rose, & Johnsen, 2009).

Identifying an early marker of physical fatigue, as an indicator of overtraining is needed. Improving our knowledge of the timing of the development of adverse consequences of an overtrained state would improve the way we plan training schedules. A training plan closely associated to each athlete's adaptive abilities would result in an improved administration of training stressors and recovery time, possibly leading to improved training capacity, and performance gain (Kellmann, 2010). In addition, documenting cognitive changes in relation to physical fatigue in a non-athletic population would help to further our understanding of the development of physical and central fatigue. This understanding is important to gain knowledge on basic motor behaviour principles, physical fatigue as an indicator of an overtrained state, and as a barrier to physical activity.

The presented investigation makes a contribution to the literature. From a more general perspective, this topic is an important area of investigation for a deepened understanding of the principles regulating cognitive and physical capacity, and their relationship in the presence of physical fatigue. Another area benefiting from this research is the high performance domain, as well as for long-term athlete development across the life span. Early identification of physical performance decrements as an indicator of overtraining and the development of tools to assist in early detection can facilitate the prevention of aggravated states that not only hinder the training and performance of the individual; but also prevent adverse training-related effects on his or her short- and long-term health and well-being.

6.4 Future Research Directions

With respect to cognitive function, work is still needed to examine the effects of different cognitive tests. Thus far, cognitive tests have mainly focused on speed of information processing (Hynynen, Uusitalo, Konttinen, & Rusko, 2008c; Jeukendrup, Hesselink, Snyder, Kuipers, & Keizer, 1992; Nederhof, Lemmink, Zwerver, & Mulder, 2007b; Nederhof, Zwerver, Brink, Meeusen, & Lemmink, 2008b; Rietjens et al., 2005; Schmidt, 1982). Other aspects of cognitive function, or more specifically executive cognitive functions, such as attention, decision making, and working memory should be investigated. Future investigations should also focus on females, and on populations of various levels of fitness (low active population to elite athletes) to examine the mind-body interaction as a basic principle of motor behaviour.

6.5 Conclusion

In this work, we have shown that there is some evidence in the literature supporting the use of a psychomotor tool to identify the onset of physical fatigue; however, the research in this area is sparse. We also have demonstrated that the Cogstate test battery is a reliable tool to use in multiple testing sessions and under different testing schedules. Although we failed to elicit the level of physical fatigue needed in recreational exercisers for our present investigation, we have put forward recommendations for future research directions, addressing the limitations of the current (and exploratory) research protocol that was employed.

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APPENDIX A : Delayed Onset of Muscle Soreness Scale

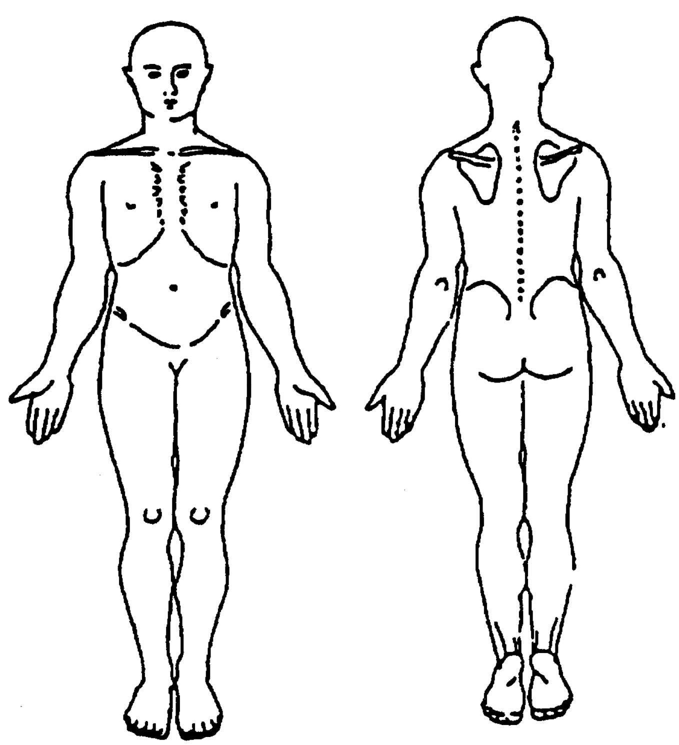
Muscle Soreness

Prior to this task, sit and rest in a chair for 5 minutes.

Put a mark on the line at the point that best describes how much **<u>muscle soreness</u> you are having right now** as you lower yourself from standing to sitting in a chair without using your arms.

no soreness worst soreness ever felt

On the diagram below, **mark the areas on your <u>legs</u> where you feel <u>muscle soreness</u>** as you lower yourself from standing to sitting in a chair without using your arms.



Pre Test ☐
Post Test ☐

APPENDIX B : Recovery-Stress Questionnaire for athletes (RestQ-Sport)

The Recovery-Stress Questionnaire
RESTQ Sport (52 items)

This questionnaire consists of a series of statements. These statements possibly describe your psychic or physical well-being or your activities during the past few days and nights.

Please select the answer that most accurately reflects your thoughts and activities. Indicate how often each statement was right in your case in the past days.

The statements related to performance should refer to performance during competition as well as during practice.

For each statement there are seven possible answers.

Please make your selection by marking the number corresponding to the appropriate answer.

Example:

In the past (3) days/nights

... I read a newspaper

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In this example, the number 5 is marked. This means that you read a newspaper very often in the past three days.

Please do not leave any statements blank.

If you are unsure which answer to choose, select the one that most closely applies to you.

Please turn the page and respond to the statements in order without interruption.

In the past (3) days/nights

1) … I watched TV

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

2) … I laughed

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

3) … I was in a bad mood

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

4) … I felt physically relaxed

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

5) … I was in good spirits

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

6) … I had difficulties in concentrating

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

7) … I worried about unresolved problems

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

8) … I had a good time with my friends

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

9) … I had a headache

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In the past (3) days/nights

10) … I was dead tired after work

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

11) … I was successful in what I did

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

12) … I felt uncomfortable

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

13) … I was annoyed by others

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

14) … I felt down

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

15) … I had a satisfying sleep

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

16) … I was fed up with everything

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

17) … I was in a good mood

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

18) … I was overtired

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In the past (3) days/nights

19) … I slept restlessly

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

20) … I was annoyed

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

21) … I felt as if I could get everything done

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

22) … I was upset

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

23) … I put off making decisions

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

24) … I made important decisions

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

25) … I felt under pressure

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

26) … parts of my body were aching

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

27) … I could not get rest during the breaks

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In the past (3) days/nights

28) … I was convinced I could achieve my set goals during performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

29) … I recovered well physically

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

30) … I felt burned out by my sport

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

31) … I accomplished many worthwhile things in my sport

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

32) … I prepared myself mentally for performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

33) … my muscles felt stiff or tense during performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

34) … I had the impression there were too few breaks

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

35) … I was convinced that I could achieve my performance at any time

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

36) … I dealt very effectively with my teammates' problems

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In the past (3) days/nights

37) … I was in a good condition physically

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

38) … I pushed myself during performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

39) … I felt emotionally drained from performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

40) … I had muscle pain after performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

41) … I was convinced that I performed well

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

42) … too much was demanded of me during the breaks

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

43) … I psyched myself up before performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

44) … I felt that I wanted to quit my sport

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

45) … I felt very energetic

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

In the past (3) days/nights

46) … I easily understood how my teammates felt about things

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

47) … I was convinced that I had trained well

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

48) … the breaks were not at the right times

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

49) … I felt vulnerable to injuries

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

50) … I set definite goals for myself during performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

51) … my body felt strong

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

52) … I felt frustrated by my sport

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

53) … I dealt with emotional problems in my sport very calmly

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

APPENDIX C : Groningen Sleep Questionnaire

The Groningen Sleep Quality Scale

1. I had a deep sleep last night
2. I feel that I slept poorly last night
3. It took me more than half an hour to fall asleep last night
4. I woke up several times last night
5. I felt tired after waking up this morning
6. I feel that I did not get enough sleep last night
7. I got up in the middle of the night
8. I felt rested after waking up this morning
9. I feel that I only had a couple of hours' sleep last night
10. I feel that I slept well last night
11. I did not sleep a wink last night
12. I did not have trouble falling asleep last night
13. After I woke up last night, I had trouble falling asleep again
14. I tossed and turned all night last night
15. I did not get more than 5 h' sleep last night

All items are scored true/false

APPENDIX D: The Physical Activity Readiness Questionnaire for Everyone

PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

Regular physical activity is fun and healthy, and more people should become more physically active every day of the week. Being more 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)?	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition?	☐	☐
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.	☐	☐
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 Canada's Physical Activity Guidelines for your age (www.csep.ca/guidelines).
- You may take part in a health and fitness appraisal.
- If you have any further questions, contact a qualified exercise professional such as a Canadian Society for Exercise Physiology - Certified Exercise Physiologist® (CSEP-CEP) or a CSEP Certified Personal Trainer® (CSEP-CPT).
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional (CSEP-CEP) before engaging in this intensity of activity.

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

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever - 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 qualified exercise professional (CSEP-CEP or CSEP-CPT) before continuing with any physical activity program.

PAR-Q+

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 Heart Disease or Cardiovascular Disease?** *This includes Coronary Artery Disease, High Blood Pressure, Heart Failure, Diagnosed Abnormality of Heart Rhythm* If the above condition(s) is/are present, answer questions 3a-3e	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 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** ☐
3e.	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 any Metabolic Conditions?** *This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes* If the above condition(s) is/are present, answer questions 4a-4c	If **NO** ☐ go to question 5
4a.	Is your blood sugar often above 13.0 mmol/L? (Answer **YES** if you are not sure)	**YES** ☐ **NO** ☐
4b.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, and the sensation in your toes and feet?	**YES** ☐ **NO** ☐
4c.	Do you have other metabolic conditions (such as thyroid disorders, pregnancy-related diabetes, chronic kidney disease, liver problems)?	**YES** ☐ **NO** ☐
5.	**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 5a-5b	If **NO** ☐ go to question 6
5a.	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** ☐
5b.	Do you **ALSO** have back problems affecting nerves or muscles?	**YES** ☐ **NO** ☐

PAR-Q+

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 (e.g., a CSEP-CEP or CSEP-CPT) 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 (CSEP-CEP) 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 (CSEP-CEP) to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever - 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 (CSEP-CEP) 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 PAR-Q+ Collaboration, the Canadian Society for Exercise Physiology, and their agents assume no liability for persons who undertake physical activity. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- 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 they maintain the privacy of the information and do 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 or
Canadian Society for Exercise Physiology
www.csep.ca

Citation for PAR-Q+
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The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or BC Ministry of Health Services.

Key References
1. [illegible]
2. [illegible]

01-11-2011

PAR-Q+

6.	**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 6a-6d	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.	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** ☐
6c.	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** ☐
6d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	**YES** ☐ **NO** ☐
7.	**Do you have a Spinal Cord Injury?** *This includes Tetraplegia and Paraplegia*	
	If the above condition(s) is/are present, answer questions 7a-7c	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.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	**YES** ☐ **NO** ☐
7c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	**YES** ☐ **NO** ☐
8.	**Have you had a Stroke?** *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*	
	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 have any impairment in walking or mobility?	**YES** ☐ **NO** ☐
8c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	**YES** ☐ **NO** ☐
9.	**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 9a-9c	If **NO** ☐ read the Page 4 recommendations
9a.	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** ☐
9b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	**YES** ☐ **NO** ☐
9c.	Do you currently live with two or more medical conditions?	**YES** ☐ **NO** ☐

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

