EVALUATION OF A 3-BOUT EXERCISE LABORATORY PROTOCOL IN DEVELOPMENT OF PSYCHOPHYSIOLOGICAL MARKERS OF TRAINING STRESS INDICATIVE OF FUNCTIONAL OVERREACHING

by

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STATEMENT OF THESIS APPROVAL

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ABSTRACT

The prevalence of overtraining (OT) may vary anywhere from 10-60%, depending on the sport and athletic level. OT poses many problems to coaches, teams, and athletes as it leads to performance decrements, injury, and lost playing time. The physiological development of OT is not well understood and coaches lack affordable and easy-to-use tools that can be used for the early detection of OT, aside from psychometric tests. The purpose of this pilot study was to develop a protocol that could be used to examine the early psychophysiological development of OT, or functional overreaching (FOR) in order to better identify tools for the early detection of OT. Ten age-group cyclists completed 3 40k cycling time trials (TT) on 3 consecutive days with a 48-hour follow-up period to try to elicit a FOR response. Five measurements were used in this study to examine neuromuscular fatigue, changes in mood, affect, and perceived muscle pain and fatigue. Despite signs of acute fatigue, there were no changes in performance ($p > 0.582$) or in neuromuscular fatigue ($p > 0.360$) from one TT to the next. There was, however, a significant decrease in heart rate ($p < 0.005$) and changes in mood and affect indicative of some cumulative fatigue. The Fatigue subscale of the Profile of Mood States increased and remained elevated across three pre-TT time points, and positive affect (Positive and Negative Affect Schedule) decreased across two time points ($p < 0.05$ and 0.02, respectively). While these results do not support the conclusion that FOR was achieved in these age-group cyclists according to the definition provided by Meeusen et

al., the significant increases in cumulative fatigue suggest that psychological stress and fatigue may be preliminary signs to even the first and earliest stage of OT, FOR. Therefore, future research should expand on the current study in order to develop a protocol that elicits a FOR response in the majority of subjects.

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CHAPTER I

INTRODUCTION

Overtraining (OT) is a complex multidimensional construct encompassing alterations in biochemistry, physiology, and mental states. OT is defined as a maladaptive response to an imbalance of training stress and recovery (Meeusen et al., 2013). An overtrained athlete may experience a variety of symptoms including increased fatigue perception, and negative affect along with altered physiological characteristics that significantly impair performance for an extended period of time (Kreher & Schwartz, 2012).

There are three recognized stages in the OT process, identified by the severity of performance changes and time to recover: functional overreaching (FOR), nonfunctional overreaching (NFOR), and overtraining syndrome (OTS), with each stage more severe than the last (Meeusen et al., 2013). Most athletic training schedules involve periods of intensified training (IT) followed by a period of recovery. Coaches intentionally use these periods of IT to disrupt the stress/recovery balance, creating FOR, for the purpose of inducing positive physiological adaptations (a.k.a. supercompensation). However, it is possible for the stress/recovery imbalance to be too great for some athletes following these training schedules, leading to development of NFOR or OTS. As a result, athletes lose valuable training time, suffer severe performance decrements, and are at an increased risk for injury and illness (Matos, Winsley, & Williams, 2011; Vetter & Symonds, 2010).

There still exists some ambiguity regarding the physiological development of OT as many theories currently exist. In one review of these existing theories on the most severe form of OT, OTS, Kreher and Schwartz (2012) conclude that OTS is caused by an inflammatory process that impacts other systems such as the neurohormonal axis, altering immune function and mood. However, more recently Meeusen and colleagues (2013) in their consensus statement affirm that OTS is a multidimensional construct and that development involves multiple body systems and processes. Additionally, the symptomatology of OT varies greatly and may be similar to those of other conditions. As a result, the current medical recommendation is to rule out other possible conditions, such as anemia, before diagnosing OTS in athletes presenting symptoms of OT (Kreher & Schwartz, 2012; Meeusen et al., 2013). The complex nature of OTS has made it difficult to identify tools to efficiently diagnose OTS, let alone identify and prevent OT in the FOR stage as the differences between the stages are subtle and diagnostic criteria have yet to be developed.

FOR is seen as the first stage in the OT process and is considered to be a healthy or positive response to training stress when accompanied by the appropriate amount of recovery. FOR has been characterized by temporary decrements in performance, increased sense of effort, and increased fatigue (Halson et al., 2002; Le Meur et al., 2013; Schmikli, Brink, Vries, & Backx, 2011). As the first stage of the OT process, it would be practical for coaches and trainers to be able to identify FOR and differentiate it from the more severe forms in athletes in order to better prevent OTS from developing. However, there are no diagnostic tools available to coaches or trainers that allow for a comprehensive, yet quick assessment of OT. Part of this is due to the fact that many symptoms of FOR are not unique to OT, and could be caused by a myriad of other conditions or problems, such as the flu. Consequently, it is difficult for athletes and coaches to determine appropriate training loads in order to enhance performance without risking OT. Therefore, it is important to better understand the physiological process of OT in the early stages in order to identify tools that can help separate OT-related symptoms from other conditions as well as help in the proper diagnosis and prevention of more severe forms of OTS.

Several psychometric tests have been used in the OT literature, including the Profile of Mood States (POMS). The POMS has provided insight into characterization of mood states in healthy and overtrained athletes and has been shown to be fairly reliable in tracking OT, particularly OTS (Achten et al., 2008; Goss, 1994; Kellman et al., 2001). Although the POMS is effective in detecting changes in protocols that last over a few weeks or months, the relative stability of mood states could be a limitation for use over a shorter time frame (less than a week). Affect, on the other hand, has been shown to be much more susceptible to moment-to-moment changes; therefore, a tool such as the Positive and Negative Affect Schedule (PANAS) may be a useful measure to assess acute psychological fluctuations associated with early OT. Additional psychological changes due to OT (aside from mood disturbances) should also be considered as potential tools for assessing the development of OT. Some professionals consider OT to be part of the etiology of burnout and, therefore, a scale such as the Athlete Burnout Questionnaire (ABQ) may provide additional insight into psychological changes of the early stages of OT (Lemyre et al., 2007; Silva, 1990).

While the assessment of mood and other psychological changes has been valuable in characterizing OT, these changes in mood could be caused by a variety of stressors other than training, such as school stress. Identification of an objective measure of fatigue-related changes associated with the early development of OT would be useful in separating other life stressors from training stress. Neuromuscular function (NMF) is one such measurement. It has been shown that chronic stress produced by high-intensity resistance training alters NMF in a manner similar to what could be expected during FOR (Maffiuletti et al., 2006; Zory et al., 2010). Additionally, Amann et al., (2011) showed that there was a significant amount of neuromuscular fatigue associated with a single bout of exhaustive endurance cycling exercise. While NMF testing has not been used in OT research for endurance training, the studies by Amann (2011), Maffuletti (2006), and Zory indicate that it may have potential to track and monitor exercise-related fatigue both acutely and cumulatively across a training protocol. A particularly valuable function of NMF is that it could be used to determine adequate recovery duration following IT bouts.

One challenge in the current research is the development of a research design that would allow researchers to test the type of measurements described previously. The complexity of the athletic setting makes it difficult to test measurements. Uncontrollable factors, such as training and competition schedules, as well as the variable length of time leading to FOR, are major challenges to the study of FOR in a natural athlete environment. Therefore, a time-efficient and well-controlled laboratory protocol for inducing FOR is proposed. A laboratory model of FOR could be used for the testing and validation of measurements that could better explain and predict the early OT process, thereby preventing the more severe forms of OT.

Therefore, the purpose of this pilot study was to determine if a repeated 40k cycling time trial (TT) model would elicit characteristics of FOR (Meeusen et al., 2013), as evidenced by a decrement in performance, along with increased perceptions of fatigue in age-group cyclists. In addition, the utility of NMF assessments along with the POMS, ABQ, and PANAS will be examined as viable tools for early detection of OT.

We hypothesized that over the course of the 3 TTs, there would be a significant decrease in performance as indicated by an increased time to completion of the 40k TT from TT1 to TT3. Furthermore, we hypothesized that there would be significant acute (post TT) increases in muscular and perceived fatigue. We also hypothesized that there would be a long-lasting fatigue (both muscular and perceived) that is greater at TT2 and TT3 as compared to TT1, which will result in an increase in negative mood and affect.

CHAPTER II

METHODS

Participants

Participants were healthy, age-group cyclists and triathletes (*n* = 12, 7 male, 5 female). The mean age was 33.8 (9.9) years and VO_{2peak} were 49.4 (7.02) - $mL.kg^{-1}.min^{-1}$. The self-reported average hours per week of participation in cycling training and competition during the 2013 season (including mountain biking, road biking, and triathlon) was 7.8 (4.42) hours. The study was approved by the Institutional Review Board of the University of Utah and written informed consent was obtained from all participants.

Protocol Overview

Design

The study was a repeated measures design composed of a baseline assessment, 3 consecutive 40k TT, performed over 3 days, and 24-hour (24HR) and 48-hour (48HR) follow-up periods. The study protocol is detailed in Figure 1.

Baseline

During this initial session, participants were screened for participation according to their physical fitness (VO_{2peak} and physical activity questionnaire) and the criteria established by the NMF assessment. Each participant filled out a physical activity questionnaire that assessed cycling history and confirmed whether they abstained from participating in strenuous exercise during 48 hours before coming in to the lab. Psychometric assessments were administered first, followed by NMF and VO_{2peak} testing. If all criteria were met, participants were given instructions regarding the repeated TT protocol, dietary, and hydration control measures (see below) and were scheduled to return to the lab within 2-14 days. Additionally, participants were asked to refrain from all forms of other exercise during the study.

TT1-TT3

Each 40k TT was conducted according to the same schedule as seen in Figure 1. All other assessments were scheduled around the TT in standardized order. According to research done by Amman and colleagues (2011), the acute effect of intense exercise on NMF starts to diminish within 3 minutes post exercise; therefore, the protocol required that the participant transfer from the cycle ergometer to the NMF testing station immediately following each TT. Numeric rating scale (NRS) and PANAS measurements were the only tests used both before and after each TT, due to their sensitivity to acute changes.

24 and 48 Hour Follow-Up

During the follow-up period, participants were required to abstain from all exercise (excluding light stretching) until their last appointment at 48HR. During both 24 and 48HR all of the psychometric and NMF tests were repeated. Both hydration status and caloric intake were monitored at each appointment as described below.

Instrumentation

VO_{2peak}

During baseline, a graded maximal cycling test was used to determine participant fitness levels. The test was conducted on an electronically braked cycle ergometer (Velotron, Elite Model Racer Mate, Seattle, WA, USA) using a standardized protocol where males began at 100 watts (W) and females at 50 W and resistance was increased by 25 W increases every minute until volitional exhaustion. Gas exchange was measured using a True One System 2400 (ParvoMedics, Sandy, UT, USA).

Time Trials

Forty-k TT were conducted on the Velotron cycle ergometer. Participants were encouraged to give each TT a “race like” effort with the goal to complete the TT as fast as possible. Work rate, heart rate, cadence, and rating of perceived exertion (RPE) were recorded during each time trial at 5k intervals.

Neuromuscular Function (NMF)

Setup

Participants were tested in a semirecumbent position with the right leg in 90° flexion with the right ankle attached to a calibrated load cell (Interface, Model SM 1000, Scottsdale, AZ, USA) using a noncompliant strap just above the malleoli. A magnetic stimulator with a 70 mm double coil magnet (MagStim 200, The MagStim Company Ltd., UK) was used to supramaximally stimulate the femoral nerve to evoke quadriceps twitch forces (Q_{tw}). For a full explanation of the protocol, please see the papers by Amman and colleagues (2011).

Motor Recruitment Curve

During their baseline visits, a one-time neuromuscular recruitment curve of consisting of 3 unpotentiated Q_{tw} forces at 60, 70, 80, 85, 90, 95, and 100% of maximal stimulator output were obtained to ensure that supramaximal stimulation of the femoral nerve was possible. Two participants did not reach a plateau in force production and consequently were not eligible to continue in the study.

NMF Testing

Testing was done before and 3 minutes post TT as well as during the 24 and 48HR follow-up visits. Participants were asked to perform six, 5-second maximal voluntary contractions (MVC) against a static load cell. During the 3rd second of each MVC, a supramaximal femoral nerve stimulation was applied to obtain superimposed twitch force (SIT). Approximately 5 seconds post MVC, with the leg relaxed, another supramaximal femoral nerve stimulation was applied to assess potentiated twitch force ($Q_{tw \cdot pot}$). Peak forces for MVC, SIT, and $Q_{tw \cdot pot}$, for each contraction were assessed on saved data, with the average of the last 4 trials reported. These measures provide an indication of the degree of central vs. peripheral fatigue caused by acute exercise.

<u>POMS</u>

The POMS has been shown to be valid in diagnosing mood changes that characterize OT (Bresciani et al., 2011; Goss, 1994; Halson et al., 2002). The POMS is a 65 item survey with 6 subscales; anxiety, depression, anger, vigor, fatigue, and confusion (McNair, Lorr, & Droppleman, 1971). Changes in total mood disturbances (TMD) were calculated by adding the negative subscales, subtracting vigor, and adding 100. Additionally, each subscale was averaged independently for comparison.

PANAS

Affect, similar to mood, is a subjective measurement that indicates the overall negative or positive affect of an individual. The PANAS is a 20 item survey with 2 subscales: positive and negative affect. Positive and negative affect scales are summed separately and used on independent bipolar scales.

ABQ

The ABQ is a 15 item survey with 3 subscales relating to the athlete's feelings regarding their sport: reduced sense of accomplishment (RA), devaluation of sport (DS), and Exhaustion (Exh).

Perceived Exertion and Fatigue

Perceived exertion of each TT was measured using Borg's Rating of Perceived Exertion scale, using the 6-20 scale (Borg, 1998). Perceptions of physical pain and fatigue were recorded using a numeric rating scale (NRS) of 0-100, where 0 indicated the absence of either pain or fatigue and 100 was the worst possible pain, soreness, or complete exhaustion, respectively. Lastly, in order to better understand changes in mood during each TT, two items from the PANAS (one positive and one negative), "enthusiasm" and "distress" were used to track subjective mood every 10k during each TT.

Diet and Hydration

During the study protocol, diet and hydration were controlled using a dietary log and food tracker (www.myfitnesspal.com). Participants were instructed to eat a similar diet in caloric and macronutrient content each day during the testing period in order to mitigate the potential effect of glycogen depletion as a rival hypothesis for any changes in performance (Dunford & Doyle, 2012). It was prescribed that their diets had a minimum of 5g/kg carbohydrate (CHO). Additionally, participants were required to consume approximately 1.5g/kg body of CHO extra after each TT and prior to leaving the lab. Pre and post exercise weights were also collected, and 1.5 L water/1 kg body weight of water lost after exercise was prescribed for maintaining euhydration.

Data analysis

Data were analyzed using IBM SPSS (v17) data analysis software. Four repeated measures ANOVA (RMANOVA) analyses were used in this study. TT performance used a 1 x 3 model for time to completion, work rate, HR, and RPE. A 3 (TT) x 4 (time) model was used to examine Enthusiasm and Distress ratings at 10, 20, 30, and 40k during each TT. Acute fatigue from pre to post TT was a 2 x 3 design with NMF, PANAS, and NRS data. Lastly, accumulated or residual fatigue was assessed using a 1 x 3 (TT only) and 1 x 5 design with NMF, POMS, PANAS, ABQ, and NRS. Where appropriate, planned contrasts were built into the RM model to compare time 1 (baseline) to all other time points. Alpha was set at $p<0.05$. Data are expressed as means and standard deviations. The data from baseline and the first TT (TT1) were averaged to create a more reliable baseline, leaving 5 time points (TT1, TT2, TT3, 24HR, and 48HR). Results will be separated by performance, acute (pre/post) and OT changes (OT indicating long-lasting changes).

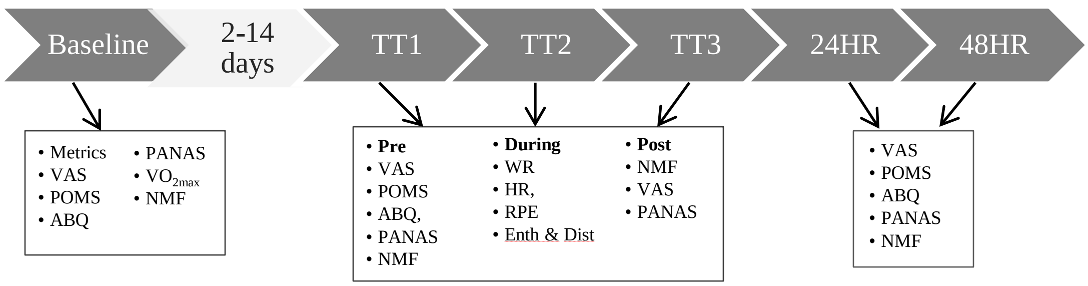


Figure 1: Study protocol including measurement testing order.
VAS = Visual Analogue Scale, POMs= Profile of Mood States, ABQ= Athlete Burnout Questionnaire, PANAS= Positive and Negative Affect Schedule, NM= Neuromuscular testing, Enth & Dist= Enthusiasm & Distress scales from the PANAS, WR = Work Rate, HR= Heart Rate, & RPE= Borg's Rating of Perceived Exertion

CHAPTER III

RESULTS

Performance

There were no significant differences across TTs for time to completion, work rate, or RPE (see Table 1). However, HR was significantly lower at TT2 and TT3 as compared to TT1 (p = .003, .005, respectively). Distress was significantly higher at 20k, 30k, and 40k as compared to the first 10k for all trials (see Figure 2). However, the Enthusiasm subscale did not significantly change at any time point for any trial (p = 0.695 and 0.530, respectively).

Acute Changes

Significant increases in acute fatigue were detected in both physiological and psychometric measures. MVC and $Q_{tw \cdot pot}$ both significantly decreased from pre to post for all TT ($p = 0.038$ and $p < 0.001$, respectively). However, there were no acute changes in SIT; see Figure 3. Subjective Pain and Fatigue as measured by the NRS were both significantly increased from pre to post for all TT ($p > 0.001$). There were no significant acute changes in positive or negative affect as indicated by the PANAS. See Figure 4 for acute NRS and PANAS results.

Cumulative/OT Changes

To determine if any cumulative change or if FOR had occurred as a result of the 40k TTs, scores were analyzed before each TT and at 24 and 48HR. Data representing the cumulative changes for each variable discussed below can be found in Table 2.

Analysis found little support for cumulative muscular fatigue. While there were significant decreases in MVC and $Q_{tw \cdot pot}$ acutely, there were no lasting changes between trials ($p > 0.40$). However, several measures of pain, fatigue, and mood showed significant changes.

The three psychometric tests used in this study, POMS, PANAS, and ABQ, each found interesting residual changes of fatigue on mood, affect, and psychological motivation. The POMS was analyzed as a summed score of all subscales (TMD) as well as an averaged score for each subscale. Compared to TT1, TMD was significantly higher at TT3 ($p = 0.033$). The Fatigue subscale significantly increased from TT1 at TT2, TT3, and the 24-hour follow-up (p = 0.049, 0.017, and 0.037, respectively. Interestingly, the Anxiety and Depression subscales were significantly lower at TT2 (p = 0.027 and 0.015, respectively) from TT1. Refer to Appendix C for further discussion on the POMS data.

From the PANAS, only positive affect had any cumulative response. Positive affect was significantly lower at both TT2 and TT3 as compared to TT1 (p = 0.010 and 0.017). Negative affect remained consistent across all TTs ($p = 0.396$). NRS data showed that there was long-lasting muscular pain or soreness as indicated by significantly higher pain scores at TT3 and 24HR as compared to baseline (p = 0.005 and 0.015, respectively) and fatigue ratings were significantly higher at TT2 and TT3 (p = 0.045 and 0.033, respectively); 24HR was borderline significant ($p = 0.065$). Refer to Figure 5 for

Table 1: Performance data measured during each time trial

	TT1	TT2	TT3	*p*
Time (mins)	73.38 (06:59)	74.12 (07:09)	73.48 (06:48)	0.582
40k WR (W)	202 (52.4)	201 (51.9)	201 (49.6)	0.928
Final 2k WR (W)	242 (76.3)	228 (72.8)	239 (75.5)	0.290
HR (bpm)	168 (9.7)	164 (10.0)*	163 (7.5)*	0.003
RPM	94 (7.2)	91 (7.8)	92 (7.4)	0.074
RPE	16 (1.1)	16 (0.8)	16 (1.0)	0.640

Performance variables that were measured during each TT. Work rate (WR) is expressed as an average for the distance specified. Except for Time, all variables are shown as mean (±*SD*).
* significantly different from TT1

information regarding these changes in PANAS and NRS.

Interestingly, while there was some doubt whether ABQ would be useful in this study, there was a significant decrease in Sense of Accomplishment at TT2 from TT1 ($p = 0.001$), which trended towards significance at TT3 ($p = 0.077$).

Table 2: Trends of cumulative fatigue and OT in 5 measurements

	Pre TT1	Pre TT2	Pre TT3	24HR	48HR
NMF					
MVC	45.9 (10.60)	44.8 (10.01)	43.6 (9.95)	46.7 (10.90)	45.6 (7.29)
SIT	3.0 (0.97)	3.2 (1.33)	3.0 (1.21)	4.1 (2.19)	4.1 (2.92)
$Q_{tw\cdot pot}$	14.6 (5.29)	14.6 (4.76)	14.0 (5.74)	15.3 (5.30)	15.1 (4.62)
POMS					
Anx-Tens	12.4 (3.15)	10.2 (2.70)*	12.8 (3.49)	13.5 (5.96)	10.7 (2.65)
Dep-Dej	14.6 (1.91)	12.7 (1.06)*	14.8 (1.14)	15.0 (4.56)	14.9 (1.45)
Ang-Host	12.8 (1.80)	13.7 (1.34)	14.3 (2.21)	14.8 (3.46)	14.3 (1.73)
Vig-Act	26.3 (5.22)	25.5 (3.90)	23.9 (5.22)	24.4 (5.15)	25.8 (5.33)
Fat-Exh	8.7 (1.67)	10.1 (2.68)*	13.1 (4.31)*	13.2 (5.74)*	11.0 (4.00)
Conf-Bew	9.0 (1.75)	8.8 (1.87)	9.1 (1.66)	10.6 (4.39)	9.1 (2.32)
Total Mood Disturbances	131.1 (8.85)	130.0 (7.70)	140.2 (11.55)*	140.2 (21.67)	134.2 (12.50)
PANAS					
Pos	34.8 (6.1)	30.6 (5.0)*	30.0 (5.8)*		
Neg	12.6 (1.9)	12.7 (2.4)	12.6 (2.3)	31.7 (5.4)	33.9 (6.3)
				12.6 (5.2)	11.1 (1.4)
ABQ					
ACC	2.7 (0.4)	2.4 (0.5)**	2.4 (0.65)		
				2.6 (0.78)	2.5 (0.68)
Dev	1.9 (0.6)	2.0 (0.7)	1.9 (0.66)	2.2 (0.78)	2.0 (0.81)
Exh	2.0 (0.7)	2.1 (0.7)	2.2 (0.67)	2.2 (0.67)	2.2 (0.75)
NRS					
Pain	6.2 (7.9)	10.5 (8.6)	23.5 (15.5)*	23.8 (14.8)*	14.1 (15.5)
Fatigue	9.8 (7.7	16.8 (6.5)*	27.8 (15.8)*	29.4 (21.2)	16.9 (19.3)

Neuromuscular Function (NMF), Profile of Mood States (POMS), Positive and Negative Affect Schedule (PANAS), Athlete Burnout Questionnaire (ABQ), and the Numeric Rating Scale for Pain and Fatigue were all used to record and track cumulative fatigue to indicate the OT process. Values are means (± *SD*).
As compared to TT1; $p >$ * 0.05 and ** 0.01

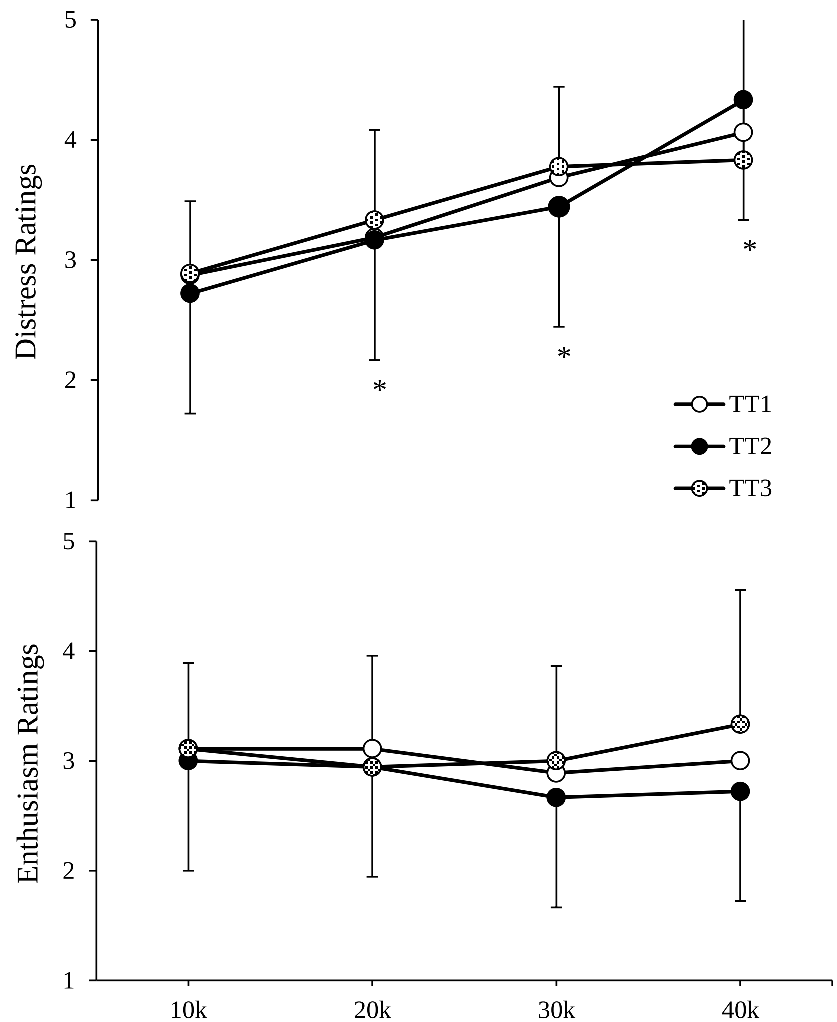
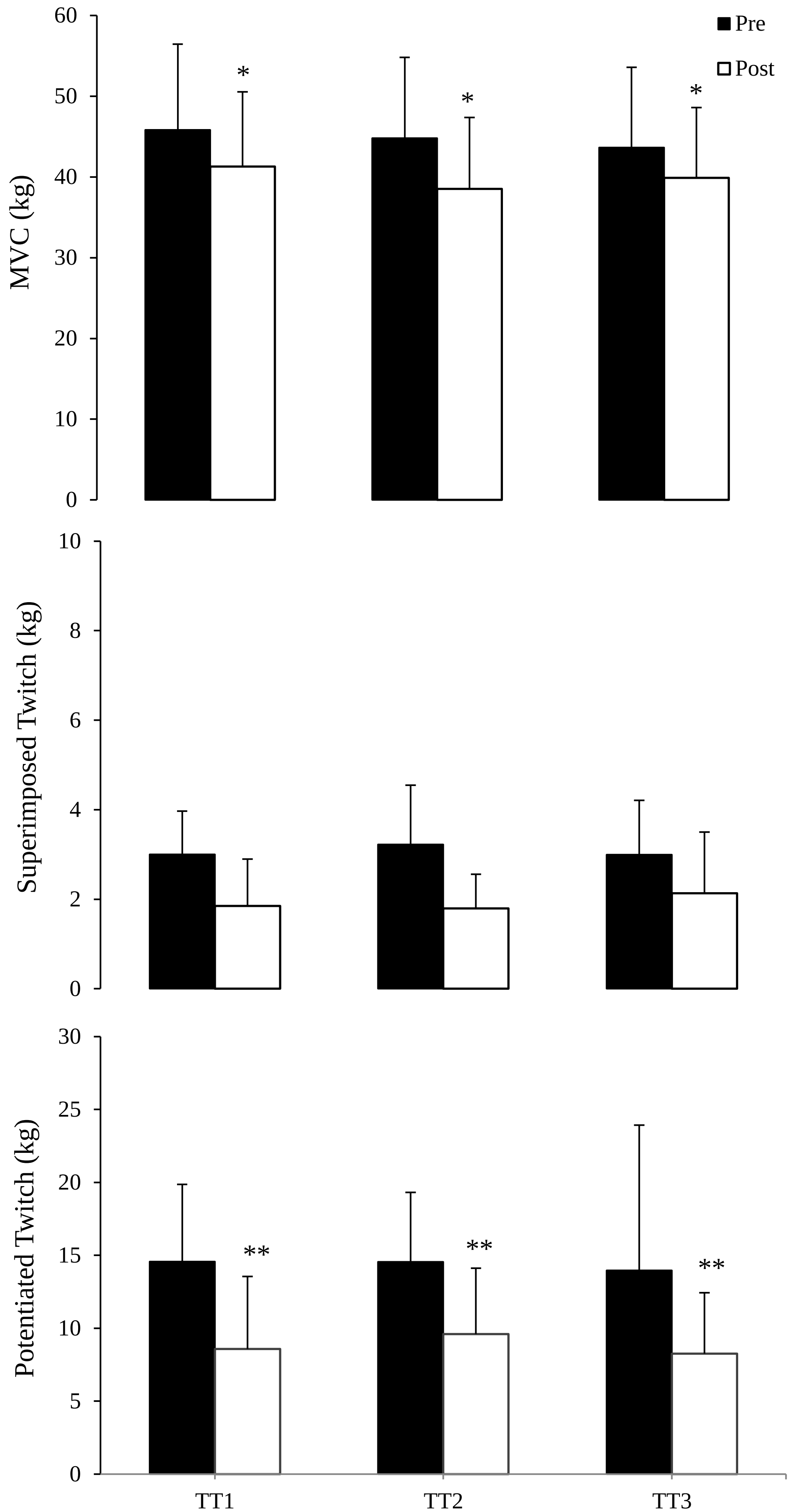


Figure 2: Distress and Enthusiasm ratings taken at 10k intervals during all 3 time trials. Distress and Enthusiasm are items borrowed from the PANAS. Distress is from the negative subscale and Enthusiasm from the positive. Values are means (± *SD*).
* significant overall time effect was noted for Distress for all groups as compared to 10k time point ($p < 0.0001$)

Figure 3: Acute neuromuscular fatigue developed from pre to post 40k time trial (TT). Values are means (± *SD*). Maximum Voluntary Contractions (MVC) is the average of 4 measurements, Superimposed Twitch forces during each MVC, Potentiated Twitch forces immediately following each MVC. A significant overall time (pre/post) effect was noted for MVC ($p = 0.038$) and $Q_{tw \cdot pot}$ ($p < 0.001$).
* significantly different than pre values for all groups ($p < 0.05$)
** significantly different than pre values for all groups ($p < 0.001$).



MVC (kg)
0
10
20
30
40
50
60
Pre
Post
*
*
*
Superimposed Twitch (kg)
0
2
4
6
8
10
Potentiated Twitch (kg)
0
5
10
15
20
25
30
**
**
**
TT1
TT2
TT3

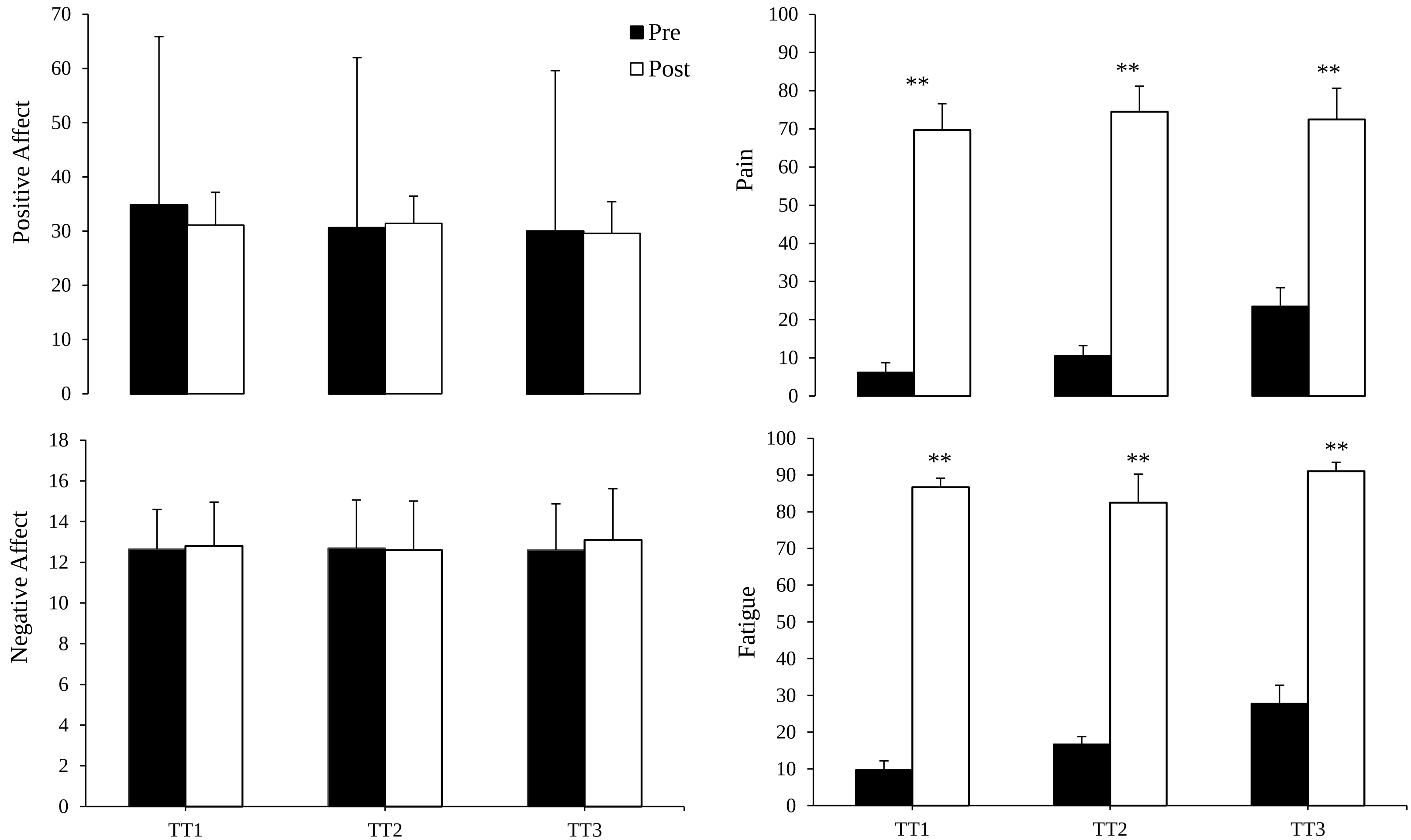


Figure 4. Acute fatigue as represented by the PANAS and NRS for pain and fatigue scores for pre-post time trials. NRS scores range from 0-100. PANAS scores range from 0-50. Values are mean (±*SD*).
** Significantly different from pre-TT value at $p \leq 0.001$

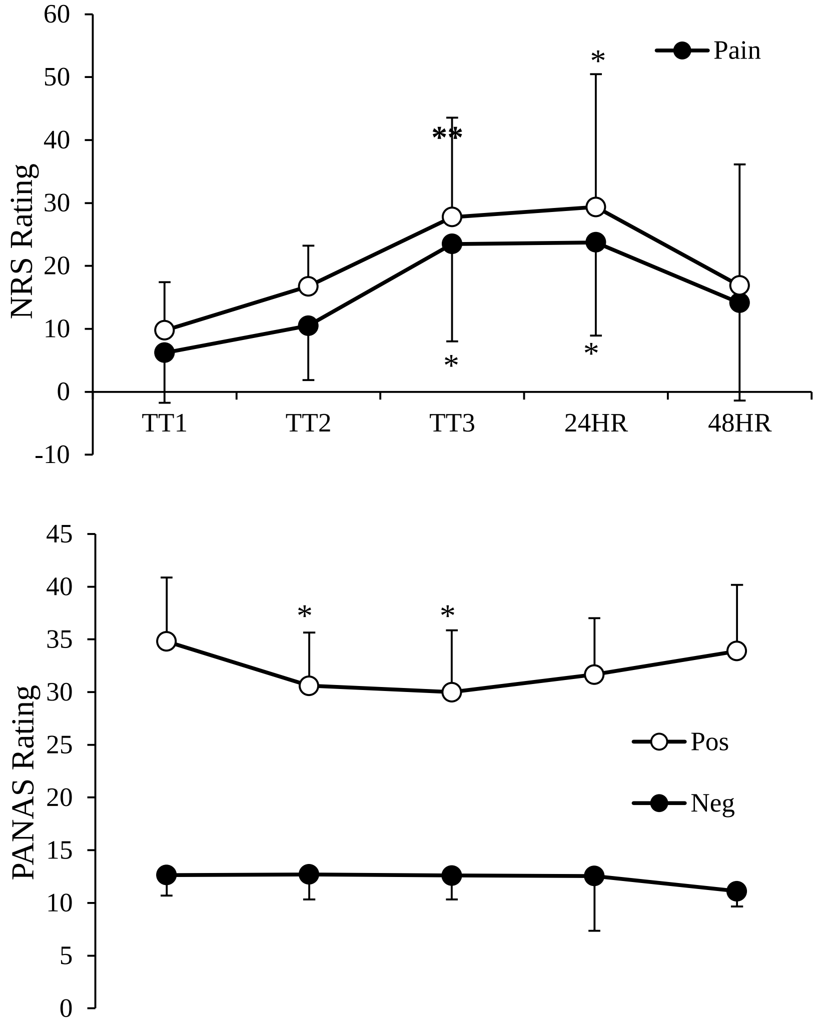


Figure 5: Cumulative changes in fatigue across the 3 time trials and 2 follow-up periods for the PANAS and NRS for pain and fatigue. NRS scores range from 0-100. PANAS scores range from 0-50. Values represent means (±*SD*).

* significantly different than TT1 ($p < 0.05$)

** significantly different than TT1 ($p < 0.001$)

CHAPTER IV

DISCUSSION

The primary purpose of this study was to determine whether a time-efficient, repeated 40k TT protocol could provide enough training stress to induce FOR, an adaptive stage of OT. The second purpose of this study was to determine if the measurements NMF, PANAS, and/or ABQ could be used as tools for better understanding the process of developing FOR as well as tracking and monitoring athletes for the early detection of OTS.

FOR is characterized by significant performance decrements accompanied by increased perceptions of fatigue (Meeusen et al., 2013). Most research to date has focused on more severe forms of OT and therefore, there is a limited understanding of the physiological process that leads to FOR and eventually to NFOR and OTS. This study sought to add insight into this process through the introduction of the aforementioned measurements conducted in a controlled environment.

Contrary to what was hypothesized, there were no significant decrements in performance variables. While there was a significant change in HR, in a meta-analysis of HR as a measure for predicting OT, Bosquet and colleagues (2008) determined that the HR changes were too small to be clinically useful, and therefore is not a reliable measure for tracking overtraining alone. However, using HR in conjunction with other measures could prove more useful. For example, Le Meur and colleagues (2013) found that HR along with blood lactate accounted for over 89% of variance in OR athletes during a graded maximal test. Nonetheless, using the standardized definition provided by Meeusen and colleagues (2013), a state of FOR was not achieved using this model.

Results from this study support that a 40k TT (race-like effort) is intense enough to cause acute stress and fatigue as indicated by significant decrements in MCV and $Q_{tw \cdot pot}$, along with increases in pain and fatigue. However, the lack of performance decrements and NMF alterations from trial to trial indicate that the protocol was not rigorous enough. Most studies done on FOR or OT used longer (2+ weeks) protocols such as one conducted by Halson and colleagues (2002). In this particular study, they found that there were signs of OT within the first week. While there was no significant change in performance, and FOR was not achieved, the insights in this study can be used to direct future research.

Of particular value to this study was the use of NMF testing as it helped quantify muscular fatigue. In previous research using this technique, Amann and colleauges (2006) saw reductions of around 10% in MVC and about 34% in $Q_{tw \cdot pot}$ data after about a single bout of exercise (placebo conditions). In the present study, we found similar reductions after each acute bout of exercise. MVC decreased approximately 9.9% in TT1, 14% in TT2, and 8.5% in TT3. Likewise, $Q_{tw \cdot pot}$ decreased approximately 41%, 34%, and 41%, respectively. The similar results of each pre-TT value indicate that the muscles recovered in between each time trial, thus suggesting that the protocol was not strong or intense enough to elicit a state of FOR. NMF could still prove to be a useful tool for monitoring and quantifying physiological changes due to OT and should be considered in future research.

Psychological changes are also an important part of the OT process. Measurements of fatigue and stress, like the POMS, have been used in many studies to detect OT and diagnose OTS (Achten et al., 2008; Goss, 1994; Kellman et al., 2001). See Appendix C for more information on using POMS for detecting OT. In the present study, TMD trended up, with TT3 being significant higher from TT1. Furthermore, Fatigue was significantly higher at 3 time points (see Table 2). One theory that explains these and other changes seen in subjective data (see NRS data in Table 2) is that the psychological stress response precedes physiological stress response in the OT development process. However, this theory does not account for the drop in feelings of anxiety and depression. One explanation is that participants felt less stress as they knew what to expect on the second TT, but the stress returned as fatigue increased from trial to trial. Future research should focus on manipulating the intensity, volume, and/or trial type (a.k.a. constant workload vs. constant distance) in order to find a protocol that will elicit an OT response that can be used to study the process and determine tools and measures for the prevention and diagnosis of OT.

PANAS was another novel measure in this study and added a few interesting insights into early OT. Affect, while similar to mood in some ways, is unique in that positive affect and negative affect are not seen as opposites of each other. In other words, it is possible for a person to have low positive affect and low negative affect simultaneously. In this present study, at baseline, individuals reported a high positive affect and low negative affect. From TT1 to TT2 and TT3, positive affect decreased significantly while negative affect remained the same. Participants experienced possible decreases in energy levels or ability to concentrate; however, they did not experience any increases in anger, frustration, and were relatively calm and serene (as indicated by a low negative affect score). Interestingly, on the last day of the study, 48HR follow-up, participants' negative affect score actually dropped significantly, indicating they may have felt an increase in calmness or sense of relief. This response may have been due to the decreased stress from the last day of study participation.

The ABQ looks at three constructs of sport psychology. sense of accomplishment, value of sport participation, and exhaustion. These constructs are indicators of stress, amotivation, and burnout (Raedeke & Smith, 2001). Several researchers have indicated that burnout is closely connected with OT (Lemyre et al., 2007; Silva, 1990). While most who are OT still maintain some motivation, it is not unreasonable to suspect that it would decrease as OT increases (Goodger et al., 2008). In this study, Sense of Accomplishment decreased significantly at TT2. When viewed in combination with the POMS data where anxiety and depression were also significantly increased at TT2 but not TT3, these data become more meaningful. Most would suspect that their TT3 would elicit the greatest change in negative mood or affect. One possible explanation is that because the participants were asked to perform 3 consecutive days of hard work. After the first day, participants would be more familiar with the amount of work and stress and it is possible that there was apprehension of repeating the TT. These feelings would then be mitigated on the third day by the knowledge that it was their last TT and they would soon be done with the study.

A limitation to this study was the large variability in the fitness and performance ability of the participants compared to the number of participants. The time to completion ranged from 1:02-1:22 and average 40k power varied from 143 – 301 (see Table 1 for more performance descriptives). As a result, it is difficult to tell whether the protocol could have been better suited to more highly trained individuals as compared to those who are less well trained or vice versa. In future, better matching of the protocol to the level of the participants or creating more homogeneity of test subjects may allow for greater effect. Another limitation to this study was the lack of statistical power. Several measures were nearing significance at different time points; for example, changes in fatigue, anger, and SIT across time points had significant levels of $p < 0.100$. However, other variables such as work rate and time to completion were very consistent from trial to trial. It is possible, despite receiving instructions regarding the expected maximal effort of the test, that participants consciously or subconsciously reserved energy from trial to trial in self-preservation. This theory is supported by the fact that at the end of each TT, participants had conserved enough energy to produce a significant increase in power output during the last 1-3k (see Table 1). Another possible explanation is that the protocol did not cause enough stress to the physiological system. Adding high-intensity intervals or increasing the volume may have led to the desired FOR.

In conclusion, while this study was not able to determine a time-efficient model for the development of FOR, it is possible that insight was gained into the early signs of OT starting with psychological fatigue and stress. Future research should use this information to build a protocol that will better stimulate the stress and demands of a high stress athletic training program in order to better prevent severe OT and better inform coaching practices.

APPENDIX A

REVIEW OF LITERATURE

In order to improve fitness, systematic overload must be applied. The overload principle of training states that an unaccustomed training stress is necessary to produce desired training adaptations. However, in order for the adaptations to be positive (beneficial), an adequate recovery period must follow. When the overload stimulus is great enough over an extended period of time, without allowing for adequate recovery, the athlete is said to be "overtraining" (Meeusen et al., 2006). Overtraining (OT) is a complex multidimensional construct encompassing alterations in biochemistry, physiology, and mental states. As a result, the athlete experiences a variety of symptoms including increased fatigue perception, decreased motivation, and negative affect along with altered physiological characteristics that significantly impair performance for an extended period of time (Kreher & Schwartz, 2012).

Severe forms of chronic overtraining are given a medical diagnosis of overtraining syndrome or, in the most severe cases, burnout. Overtraining syndrome (OTS) is defined as chronic overtraining, combined with other nontraining stress, that results in chronic fatigue, deleterious physical and mental adaptations, and significant decrements in performance that may persist for a few months up to a year before recovery (Meeusen et al., 2013). Furthermore, chronic overtraining may contribute to athlete burnout, which is characterized as mental and physical exhaustion that may result in premature retirement from sport (Goodger, Goreley, Lavalle, & Harwood, 2007). Both OTS and burnout typically result in severe setbacks for athletes including poor performance, lost playing time, loss of sponsorships/scholarships, injury, and premature retirement (Vetter & Symonds, 2010).

Athlete surveys have indicated that the incidence of OTS varies with sport and competition level. The prevalence of OTS at some point in an athlete's career has been found to be as high as 30% in young elite athletes, 60% in elite runners, and as high as 30% in nonelite runners (Matos, Winsley, & Williams, 2011; Meeusen et al., 2013). The majority of athletes will never develop OTS; however, research suggests that those who do may have an increased risk of developing it again (Meeusen et al., 2013).

OT and OTS have been identified as a concern for athletes at all levels of competition (Hollander, Meyers, & LeUnes, 1995; Matos et al., 2011). Because of this, researchers have sought to understand the etiology and symptomatology of OT. In 2006 and again in 2013, Meeusen and his colleagues wrote a position statement regarding the current understanding of OT-related conditions. This position statement laid a theoretical framework that operationalized the progressive symptomatology and apparent time course of chronic OT (see Figure 6). Meeusen's timeline of stages includes (from least to most severe) acute fatigue, overreaching (OR), which can be subdivided into functional (FOR) and nonfunctional overreaching (NFOR), and overtraining syndrome (OTS). While acute fatigue and FOR may appear to be adaptive responses to overload, NFOR and OTS should be avoided as they offer no benefits and lead to severe consequences for the performance and health of the athlete. NFOR and OTS are typically grouped together as they are very difficult to distinguish from each other prerecovery (Kreher & Schwartz, 2012). Of note, while burnout is not included on this continuum, some researchers and professionals would still include burnout as the most severe form of mental and physical exhaustion resulting in part from overtraining (Hollander et al., 1995; Lemyre, Roberts, Stray-Gundersen et al., 2007; Silva, 1990).

The symptomatology of each level of these disorders is difficult to distinguish. Studies have varied greatly in their design, which has made it difficult to substantiate particular results. For example, some studies have used field models where they tracked athletes over a season at various intervals measuring only psychological markers (Goss, 1994; Kellman, Altenburg, Lormes, & Steinacker, 2001; Lemyre, 2007). Conversely, Meeusen et al., (2010) developed a two-bout protocol in order to differentiate athletes who have NFOR from OTS, and Halson et al., (2002) used a 2-week overreaching protocol that involved supervised and unsupervised training time. Furthermore, in order to predict the development of or to diagnose overtraining disorders, researchers have examined a variety of physiological markers including blood lactate, heart rate variability, cytokines, growth hormone, and others (Halson et al., 2002; Meeusen et al., 2011; Slivka, Hailes, Cuddy, & Ruby, 2010). Although certain variables have been examined repeatedly, such as blood lactate levels, heart rate, and cortisol, no conclusive physiological markers of OT have been elucidated. In 2002, Urhausen and Kinderman compiled the existing body of overtraining research in an attempt to identify consistent measurements that could be viable tools for diagnosing OTS. Unfortunately, they were unable to identify any tool that had the potential of becoming the gold standard due to inconsistencies in study designs and outcomes. More recently, several other compendiums have been compiled with only slightly better conclusions (Kreher &

Schwartz, 2012; Meeusen et al., 2006, 2013). Kreher and Schwartz (2012) and Meeusen and colleagues (2013) noted two things: First, several markers in conjunction might be helpful to diagnose OTS, but no single marker has been shown to consistently identify or predict OTS. Meeusen et al. (2013) posited that in order for a diagnostic tool to be a viable measurement, it must be easy to use, cost effective, and readily accessible. Unfortunately, none of the identified physiologic markers met all of these criteria. Secondly, it was acknowledged that the only consistent measures of OT that are also viable are changes in psychological parameters such as stress and mood. Particularly, the Profile of Mood States (POMS) has been found to be very consistent at detecting OT due to the relative stability of mood states (Goss, 1994; Kellman et al., 2001). Nonetheless, because OTS manifests both psychologically and physiologically it is important that tools predicting both of these consequences of OT be assessed.

NFOR and OTS have been difficult to study in the field, and almost impossible to induce or replicate in a laboratory design. One of the major problems for researchers is the low incidence of NFOR/OTS, which prevents researchers from studying it as it naturally occurs during a training season. Furthermore, it would be difficult and unethical to recruit athletes for a study that would lead to such serious consequences as long-term decrements in performance. Although there is little research on FOR compared to that of OTS, FOR may be a viable area of investigation because it shares similar characteristics to NFOR and OTS, although less severe. It would be much more time efficient to induce FOR in a well-controlled laboratory experiment, as it may not take as long to achieve a FOR state as it would NFOR or OTS. One study estimated that it may take as little as 3 days to induce OR in a moderately trained athlete (Halson et al., 2002). Additionally, the reduced time to recover along with decreased severity of symptoms may reduce the burden of participation in the study. While FOR may not provide the same degree of dysfunction as NFOR or OTS, a laboratory-based model for studying FOR would be useful in understanding the performance, physiological, and psychological changes that occur during the development of OT.

Consequently, researchers have attempted to use precursors of OTS such as functional overreaching (FOR) in order to better understand chronic overtraining and to identify markers for preventing OTS. FOR has been defined as an increased training and/or nontraining stress that results in fatigue-related performance decrements and temporary psychophysiological alterations that may take anywhere from a few days to a few weeks from which to recover (Meeusen et al., 2006, 2013). However, research on FOR is still limited. Thus far, FOR has been characterized by small decrements in performance, increased sense of effort, increased sensitivity to fatigue, and possible shifts in mental motivation and mood consistent with increased stress and fatigue. Some studies have also shown physiological changes such as increased blood lactate, blunted cortisol response, decreased maximum power, decreased force production, and a decrease in maximal and submaximal heart rate (Halson et al., 2002; Le Meur et al., 2013; Schmikli, Brink, Vries, & Backx, 2011).

Unfortunately, the current body of literature on FOR is small. One reason for the lack of progress is the difficulty of developing an efficient, inexpensive, well-controlled protocol that can be easily replicated in order to allow for more reliable examination of the OT process. Another possible reason is that a significant number of studies use elite or well-trained, highly competitive athletes who may be more resistant to developing

OTS over relatively short periods of time (e.g., a single season; Lemyre et al., 2007; Moore & Fry, 2007). However, a study conducted by Halson et al., (2002) successfully induced FOR in moderately trained cyclists during a 2-week experimental protocol. The present study will attempt to overcome the above-mentioned challenges by using a short, time-efficient model of FOR in age-group cyclists. Additionally, this study will add to the body of knowledge by employing three tools that, to our knowledge, have not been examined within the context of OT and FOR. These measurements will both add to the current body of knowledge by examining new dimensions (neuromuscular dysfunction and the relationship of OT and burnout) as well as provide new insights in already examined dimensions (time course of mood and affect).

As previously mentioned, the POMS is a valuable tool, as it is one of few measurements to consistently identify OT (Achten et al., 2008; Goss, 1994). Furthermore, the POMS has provided insight into characterization of mood states in healthy and overtrained athletes. However, while POMS has been successfully used with protocols that last more a few weeks or months, the relative stability of mood states could be a potential limitation for use over a shorter time frame (less than a week). Affect, on the other hand, has been shown to be much more susceptible to moment-to-moment changes; therefore, a tool such as the Positive and Negative Affect Schedule (PANAS) may be a useful supplemental measure to assess fluctuations in affect. Additional psychological changes due to OT (aside from mood disturbances) should also be considered as potential tools for assessing the development of OT. As previously discussed, some professionals in the field consider OT to be part of the etiology of burnout (Lemyre et al., 2007; Silva, 1990). Yet, to our knowledge, no research has determined if there are similar psychological characteristics that are shared between the two. As such, the Athlete Burnout Questionnaire (ABQ) will also be employed in this study.

A novel extension of past research will be to examine neuromuscular effects of the overreaching model. Specifically, the degree of peripheral fatigue over the course of the protocol will be quantified through changes in quadriceps force in response to supramaximal magnetic femoral nerve stimulation ($\Delta Q_{tw \cdot pot}$). This technique has been used in a variety of study designs previously (Amann et al., 2009; Maffiuletti et al., 2006; Zory, Jubeau, & Maffiuletti, 2010) but has never been used as a diagnostic tool for OT disorders. Amann et al., (2009) showed that there was a significant amount of neuromuscular fatigue associated with a single bout of exhaustive cycling exercise and Maffiuletti et al., (2006) and Zory et al., (2010) both found that there were atypical neuromuscular function adaptations associated with long-term electrical stimulation resistance training. Based on these results, it stands to reason that this technique might be useful in understanding and detecting OT disorders.

PROCESS	TRAINING (overload)	INTENSIFIED TRAINING		
OUTCOME	ACUTE FATIGUE	FUNCTIONAL OR (short-term OR)	NON-FUNCTIONAL OVERREACHING (extreme OR)	OVERTRAINING SYNDROME (OTS)
RECOVERY	Day(s)	Days – weeks	Weeks – months	Months - …
PERFORMANCE	INCREASE	Temporary performance decrement (e.g., training camp)	STAGNATION DECREASE	DECREASE

Figure 6: Possible framework of the stages of OT in order of severity with their effects on recovery and performance. Borrowed from Meeusen et al., 2013.

APPENDIX B

POMS AND THE ICEBURG PROFILE

Results from the POMS can be utilized through a few different means. The first is through the previously mentioned TMD scores. TMD represent global changes in perception and feelings without offering insight into how mood is changing. In the present study, TMD scores were used to determine if there was significant alterations in mood resulting from each TT. In the present study, TMD data were represented in Table 2. However, Figure 7 is a graphic portrayal that better illustrates the upwards trend in global mood changes across TT1, 2, 3 and 24HR resulting from the 3 40k TTs. While only TT3 was significant, it is possible with greater statistical power that additional time points would become significant as well.

Another method for interpreting POMS results is by comparing the profile made when each subscale is averaged and graphed to that of a typical healthy athletes' Iceberg Profile (Goss, 1994). The iceberg profile is considered a healthy mood state profile for an athlete as vigor is high and the negative mood states are low. Flattening of the profile has been used as a criterion for OT whereas a flipping of the iceberg profile indicates severe OT such as OTS (see Figure 8; Achten et al., 2008; Goss, 1994). In the present study, there was a slight elevation of the profile due to increases of fatigue, but as can be seen in Figure 8, the Iceberg Profile remains predominate.

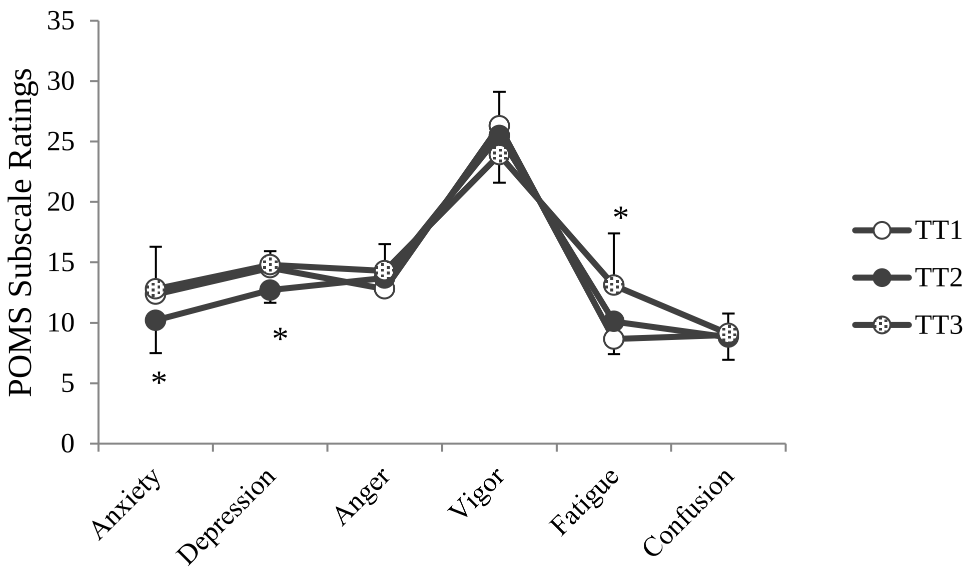


Figure 7: The POMS Iceberg profile as depicted when graphing the averages of each subscale from the Profile of Mood States. The name is given by the shape taken using the results from a healthy athletes' assessment. When the athlete is said to be healthy, Vigor will be rated high with each of the 5 other subscales rated low.

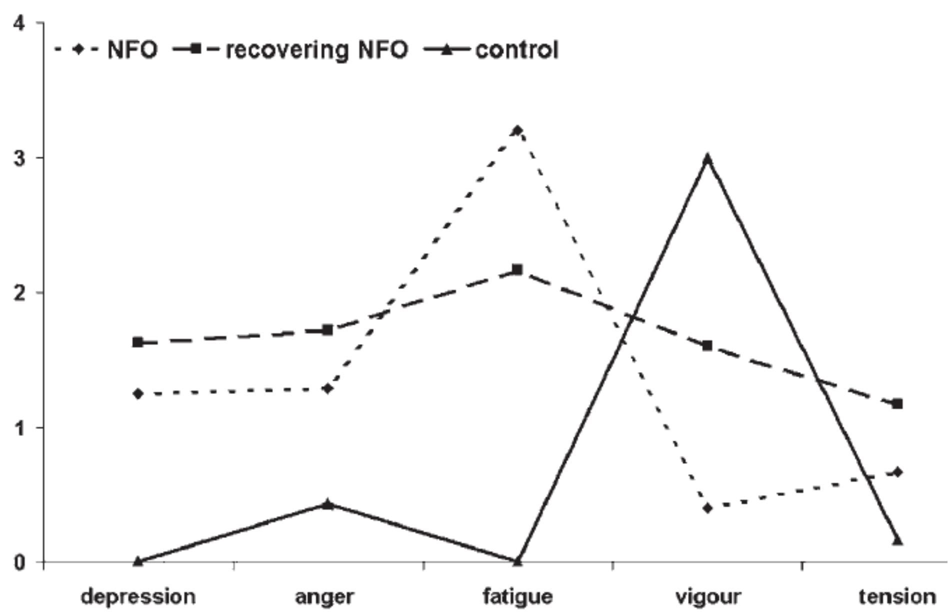


Figure 8: Profile of Mood States of 3 athletes, an athlete currently nonfunctional overreached (NFO/R), an athlete recovering from NFOR, and a healthy control athlete. Notice the iceberg profile of the healthy athlete vs. the NFOR athlete. Borrowed from Nederhof, Zwerver, Brink, Meeusen, & Lemmink, 2008

APPENDIX C

RECRUITMENT CURVES

At the baseline visit, each participant completed a recruitment curve (RC) protocol to ensure that it was possible to stimulate the femoral nerve supramaximally during NMF testing. The RC was completed only one time and it was done prior to any other testing. The procedure went as follows. While lying semirecumbent in the previously discussed setup (see NMF setup in Methods chapter), each participant was stimulated 3 times at 70, 80, 85, 90, 95, and 100% of stimulator intensity. Elicited forces were then averaged for each intensity and plotted. Participants who did not exhibit a plateau in force were excluded from the study (see Figure 9).

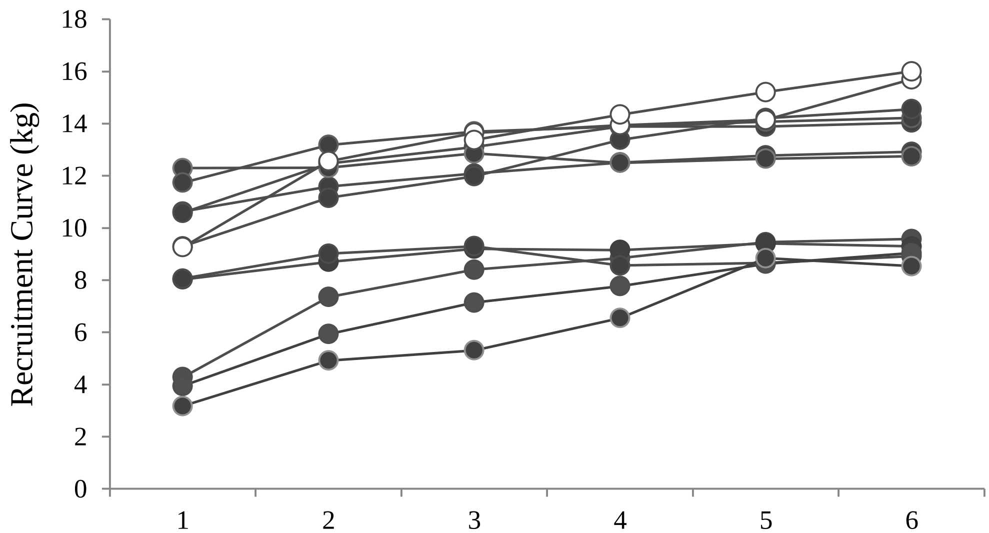


Figure 9: Recruitment curve (RC) profile for all 12 study participants. The object of the RC was to eliminate subjects whose force production did not plateau. Closed circles represent the 10 subjects who were accepted into the study based on this criterion.

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