

2014

THYROID HORMONES, PERFORMANCE, AND PSYCHOLOGICAL CHANGES ON OVERTRAINING IN FEMALE DISTANCE RUNNERS

Justin Nicoll

University of Rhode Island, justin_nicoll@my.uri.edu

Follow this and additional works at: <https://digitalcommons.uri.edu/theses>

Terms of Use

All rights reserved under copyright.

Recommended Citation

Nicoll, Justin, "THYROID HORMONES, PERFORMANCE, AND PSYCHOLOGICAL CHANGES ON OVERTRAINING IN FEMALE DISTANCE RUNNERS" (2014). *Open Access Master's Theses*. Paper 342.
<https://digitalcommons.uri.edu/theses/342>

This Thesis is brought to you by the University of Rhode Island. It has been accepted for inclusion in Open Access Master's Theses by an authorized administrator of DigitalCommons@URI. For more information, please contact digitalcommons-group@uri.edu. For permission to reuse copyrighted content, contact the author directly.

THYROID HORMONES, PERFORMANCE, AND
PSYCHOLOGICAL CHANGES ON OVERTRAINING IN
FEMALE DISTANCE RUNNERS.

BY

JUSTIN NICOLL

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

IN

KINESIOLOGY

UNIVERSITY OF RHODE ISLAND

2014

MASTER OF SCIENCE

OF

JUSTIN NICOLL

APPROVED:

Thesis Committee:

Major Professor Disa L. Hatfield

Deborah Riebe

Kathleen J. Melanson

Nasser H. Zawia

DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND

2014

ABSTRACT

Statement of the Problem: Overtraining (OT) is common in endurance sports.

Perturbations in the hormonal milieu are common throughout OT literature. Thyroid hormones (TH) are altered by energy imbalances, and these imbalances are often present in female endurance athletes. Thyroid hormones also regulate metabolism, energy production, and therefore they may play a role in commonly cited symptoms of OT in these athletes. Alterations in TH status often occur slowly, and research

investigating TH and their relationship in overtrained athletes is sparse. **PURPOSE:**

The purpose of this study was to investigate relationships in TH and commonly cited symptoms of OT in collegiate track and field (T&F) endurance runners. **METHODS:**

Sixteen female track and field middle (MD; n=9; age: 20.21 ± 1.49 yrs; height: 167.86 ± 5.04 cm; body mass: 57.97 ± 5.05 kg; VO_{2MAX} : 53.62 ± 6.04 ml/kg/min) and long

(LD; n=7; age: 20.47 ± 1.53 yrs; height: 162.48 ± 6.11 cm; body mass: 56.15 ± 5.99 kg; VO_{2MAX} : 61.94 ± 3.29 ml/kg/min) distance runners participated in a 14 week

descriptive study. Thyroid stimulating hormone (TSH), triiodothyronine (T3), and

thyroxine (T4), were collected at the beginning of the indoor T&F (PRE) and end of

the outdoor T&F season (POST). Dietary intake and vertical jump power (VJP) were

tested at PRE, MID, and POST season. A fatigue scale was administered weekly, and

percent change (ΔRT) in race time (season best v.s. championship performance) was

calculated. Wilcoxon-sign ranked tests were used to determine changes in hormonal,

dietary, and performance measures over time. Spearman's rho correlation coefficient

was used to determine relationships between thyroid hormones, dietary intake,

performance variables, and commonly cited symptoms of overtraining. Statistical

significance was set at an alpha level of $p \leq 0.05$. **RESULTS:** Fatigue was significantly lower at week 2 compared to MID season ($p=0.016$), week 12 ($p=0.018$) and POST ($p=0.007$). There was a significant correlation between fatigue at week 12 and running performance at the end of the season ($\rho = -0.741$, $p= 0.004$). Vertical jump power significantly increased PRE to MID season in MD and LD. Power significantly decreased MID to POST in MD. There were no significant changes in TSH, T_3 and T_4 from PRE to POST. There were significant correlations between total caloric intake at POST and peripheral hormones (T_3 POST; $\rho = 0.900$, $p= 0.037$. T_4 POST; $\rho= 0.667$, $p= 0.050$). The percent change (Δ) in T_3 from PRE to POST was significantly correlated with running performance at the end of the season ($\rho=-0.700$, $p=0.036$). Most of the subjects fell below current the RDA for carbohydrates and protein at PRE and POST. There was a significant relationship between caloric intake relative to lean body mass ($\text{kcal} \cdot \text{kgLBM}^{-1}$) at PRE and fatigue at week 1 (PRE) ($\rho= -0.521$, $p=0.046$). **CONCLUSION:** There were no significant differences between PRE and POST thyroid hormone concentration. Thyroid hormones are related to other variables of important in assessing the overall training state of the endurance athlete. Resting thyroid hormone concentrations may change too slowly to be a frequently used marker of monitoring overtraining status. Using weekly fatigue scales, monitoring dietary intake, and the utilization of VJP may be more readily available markers to assess overtraining and overall training status of collegiate female endurance runners.

ACKNOWLEDGMENTS

I would like to express sincere gratitude to all those who have supported and inspired me during my graduate career at the University of Rhode Island. First, I would like to thank my undergraduate and graduate advisor, Dr. Disa L. Hatfield. Your guidance and expertise in the field inspired me to think critically about physiology as it relates to athletic performance. Thank you for all of your hard work guiding me in becoming the best researcher I can be. Surely this thesis is a testament to that.

Thank you to my committee members, Dr. Deborah Riebe and Dr. Kathleen Melanson, for development of the study design, and helping make the study stronger with their multidisciplinary expertise. Thanks to my Chair, Dr. Skye Leedahl for taking the time out of her schedule to be a part of my defense.

I would like to thank all of the professors at URI for enhancing my graduate experience. School became a home away from home that I enjoyed coming to everyday because of all of you. I would particularly like to thank Dr. Thomas Manfredi for his insightful comments on my manuscript when I was preparing for my thesis defense.

I would particularly like to thank the Women's Track and Field Team here at URI. Without your persistence and participation this project would not have been possible. Hopefully the results of this project can direct your training programs to help you attain the peak performances all of you strive to achieve.

I would like to thank the graduate/research assistants Samantha Marks, Chelsey Da Silva, Dave Sanders, Lisa Vincent-Horta, Ryan Keith, Stephen Maris, Mike

Babatunde, Cortney Armitano, and Andy Procopio for your teamwork and friendship here at URI. Part of what made “the room with no windows” so great was having all of you there in the pursuit of knowledge with me.

I would like to thank Alyssa Guastella and Kelly Murphy for keeping me sane during these past two years, especially during the many all-nighters balancing research and coursework. These past two years would not have been as fulfilling and gratifying without the two of you. I look forward to performing collaborative research with you in the future.

I would like to thank my partner Humberto Rodriguez for his support through these trying times, but more importantly listening to my crazy theories about science even when it didn't make complete sense to me sometimes.

Lastly, I would like to thank my loving grandmother Eleanor Edmonds to whom I dedicate this thesis. It was through your loving support and encouragement of my aspirations through the years, whether athletic or academic, that shaped who I am today.

PREFACE

This thesis is written to comply with the University of Rhode Island graduate school Manuscript Thesis Format. This thesis contains one manuscript: *Thyroid Hormones, Performance, and Psychological Changes on Overtraining in Female Distance Runners*. This manuscript has been written in a form suitable for publication in the *Medicine & Science in Sport & Exercise*.

TABLE OF CONTENTS

ABSTRACT.....	ii
ACKNOWLEDGEMENTS.....	iv
PREFACE.....	vi
TABLE OF CONTENTS.....	vii
LIST OF TABLES.....	viii
LIST OF FIGURES.....	ix
MANUSCRIPT: Thyroid Hormones, Performance, and Psychological Changes on Overtraining in Female Distance Runners.....	1
Abstract.....	2
Introduction.....	4
Methodology.....	9
Results.....	14
Discussion.....	17
Conclusion.....	27
References.....	28
Tables.....	33
Figures.....	36
APPENDIX A: Review of Literature.....	47
APPENDIX B: Literature Review Matrix: Thyroid Hormones and Exercise.....	80
APPENDIX C: Informed Consent.....	84
APPENDIX D: Energy Metabolism Lab Food Log.....	89
APPENDIX E: Fatigue Scale.....	95

LIST OF TABLES

TABLE	PAGE
Table 1. Study Timeline.....	33
Table 2. Subject Characteristics.....	34
Table 3. Dietary Intake.....	35

LIST OF FIGURES

FIGURE	PAGE
Figure 1. TSH at Beginning and End of Track & Field Season.....	36
Figure 2. Thyroxine at Beginning and End of Track & Field Season.	37
Figure 3. Triiodothyronine at Beginning and End of Track & Field Season.	38
Figure 4. T ₃ Versus End of Season Race Time.....	39
Figure 5. Total Caloric Intake and Peripheral Thyroid Hormones at Post Season.	40
Figure 6. Change in TSH and Lean Body Mass From PRE to POST.....	41
Figure 7. Week 12 Fatigue and End of Season Performance.....	42
Figure 8. Changes in Fatigue Throughout the Track & Field Season.....	43
Figure 9. Vertical Jump Power During Season.....	44
Figure 10. Lean Body Mass.	45
Figure 11. Lean Body Mass Change and Vitamin D Intake	46

MANUSCRIPT

Publication Status

This manuscript was formatted and prepared for publication in the journal *Medicine & Science in Sport & Exercise*

ABSTRACT

Overtraining (OT) is common in endurance sports. Thyroid hormones (TH) regulate metabolism, mood, and energy production, and may play a role in OT of endurance athletes. **PURPOSE:** The purpose of this study was to investigate relationships in TH and symptoms of OT in track and field endurance runners (ER). **METHODS:** Sixteen female track and field middle distance (MD; n=9; age: 20.21±1.49yrs; ht:167.86 ± 5.04 cm; body-mass: 57.97±5.05 kg; VO_{2MAX}:53.62±6.04 ml/kg/min) and long distance (LD; n=7; age: 20.47±1.53yrs; ht:162.48±6.11 cm; body-mass: 56.15±5.99 kg; VO_{2MAX}: 61.94±3.29 ml/kg/min) ER participated in a 14-week descriptive study. Thyroid-stimulating hormone (TSH), triiodothyronine (T3), and thyroxine (T4), were collected at pre-(PRE) and post-season (POST). Dietary intake (DI) and vertical jump power (VJP) were tested PRE, MID, and POST season. A fatigue scale (FS) was administered weekly, and percent change (Δ RT) in race time (season best v.s. championship performance) was calculated. Wilcoxon-sign ranked tests and Spearman's rho correlations were used to determine changes and relationships between thyroid hormones, DI, and performance variables, Significance was set at $p \leq 0.05$. **RESULTS:** There were no significant changes in TSH, T₃ and T₄ from PRE to POST. There were significant correlations between total kcals at POST and TH (T₃ POST; $\rho=0.900, p=0.037$. T₄ POST; $\rho=0.667, p=0.050$). There was a significant correlation between fatigue at week 12 and running performance at the end of the season ($\rho=-0.741, p=0.004$). VJP significantly increased PRE to MID (2046±213W vs 2227±269W) and significantly decreased MID to POST (2227±269W vs

2102±220W). **CONCLUSION:** TH may be valuable in assessing the overall training state of ER. TH concentrations change too slowly to be a frequent marker of monitoring OT but are related to markers of decreased performance. Monitoring dietary intake, fatigue and power may be predictive markers to assess OT and training status of female ER.

INTRODUCTION

To be successful in sport, athletes must balance energy intake and energy expenditure, however not all athletes achieve energy balance (34) and may be subject to overtraining. Works by Kreider et al. define overtraining (OT) as “an accumulation of training and/or non-training stress resulting in long-term decrement in performance capacity with or without related physiological and psychological signs and symptoms of maladaptation in which restoration of performance may take several weeks or months (26). In addition to negatively affecting performance, a chronic negative energy balance can affect reproductive and skeletal health. Thyroid hormones (TH) are involved in these systems, regulated by nutritional intake, and are key regulators in metabolism, growth, recovery, and mood. The relationship between thyroid hormones and overtraining however, has not been studied extensively.

Overtraining is common in endurance sports. The mechanisms responsible for OT are difficult to identify, however energy imbalance, hypothalamic imbalances, and autonomic neuromuscular fatigue are important factors (25). Iron deficiency may contribute to OT in some female athletes. In this case, athletes may be supplemented with more iron, however this additional supplementation may elude the deeper cause of this deficiency, which is most likely poor dietary intake and energy imbalance (37). Many hormones such as TH, growth hormone (GH) and cortisol (C) are influenced by energy balance and therefore play a key role performance and recovery in the overtraining status of an athlete.

Appropriate macronutrient intake is essential to elicit positive adaptation to training and to meet the intense energy demands during competition (21). Due to the large amount of energy expenditure associated with endurance training (42), it may be difficult for these athletes to consume the necessary amount of calories to maintain energy balance. Some female athletes may feel like they have to force-feed themselves to compensate for energy expenditure. Female athletes may believe that a lower weight is the primary predictor of performance, however in high intensity and long duration sports the limiting factor of performance is often energy intake (34). Furthermore, a particular concern for collegiate athletes is that while they may be able to consume the necessary amount of total calories, the recommended intake of macronutrients may be inadequate (7). Inadequate dietary intake during training, post-exercise recovery, and preparation for competition may initiate physiologic processes of underperformance and overtraining. Thyroid hormones have been shown to be substantially lower in female athletes with negative-energy balance induced amenorrhea (31, 18). Given that thyroid hormones regulate metabolism and growth, this can have deleterious effects on athletic performance and recovery (19).

Hormonal fluctuations are common in overtrained athletes (39). Triiodothyronine (T_3), thyroxine (T_4), and thyrotropin (thyroid stimulating hormone; TSH) have been shown to influence metabolism and growth (6). Thyroid hormone concentrations are reduced with increased exercise training, due to negative energy imbalances and reduced energy availability (32). The concept of energy availability is defined as dietary energy intake minus exercise expenditure (32), suggesting energy that is normally used to maintain bodily functions is instead used for exercise

expenditure. Dietary intake is an essential mediator of T_4 to T_3 conversion in the body's circulation, with T_3 being the most biologically active form of TH. During carbohydrate deficiency T_3 secretion is suppressed, which may negatively affect metabolism and recovery. A euthyroid state of T_3 regulates protein synthesis and some proteolysis (35). However, in both hyper and hypothyroid conditions, T_3 's influence on muscle may potentiate atrophy. Dietary and energy balance dysregulation of TH is of importance, as low TH may negatively affect GH secretion.

Thyroid hormones are also stimulators of mitochondrial biogenesis, energy metabolism, and energy transfer in the cell. A study by Ciloglu et al. provided evidence that thyroid hormones are altered after maximal aerobic exercise. During that study TSH and T_4 concentration continued to rise during testing when exercising at 90% of their heart rate (HR) maximum with a concomitant decrease in T_3 and free T_3 (f T_3) (5). Repeated bouts of maximal aerobic exercise are of occurrence in regular practice and competitive meets. However, some research suggests TSH and f T_3 were shown to be decreased after a prolonged, intense training cycle. Interestingly, these decreases remained lower long after the intensified training was reduced (1). These responses should be taken into consideration by coaches and athletes when designing training programs. Thyroid hormone responses to exercise may contribute to, and even exacerbate metabolism and recovery dysfunction in athletes with OT symptoms and energy imbalances. Previous work (28) investigating TH in relation to overtraining have done so over the course of several weeks, and therefore the results of TH must be interpreted cautiously as changes in resting thyroid hormone levels occur slowly, and the process of overtraining may take many months to develop.

Additionally, the relationship of TH to OT has not been studied exclusively during longitudinal studies and therefore more research is needed in this area.

Psychological status in the athlete is of utmost importance, however psychological well being may be reduced when athletes participate during periods of intense training (14) or overtraining (41). Profile of mood states is an accurate and valid test to assess changes or disturbances in mood and vigor (38), however more readily available and faster methods of assessment are needed. Overtrained athletes have decreased motivation, confidence, and vigor (43). Overtrained athletes also have higher ratings of fatigue, depression, anger and compromised concentration (43). Some of these mood changes have been theorized to be due to endocrine changes (13). Depression is a commonly cited symptom in hypothyroid individuals and even apparent in subclinical hypothyroid subjects (17). Some investigators suggest the fatigue and depression during overtraining closely resembles symptoms of subclinical hypothyroidism (48). Given the high incidence of depression in OT athletes and altered thyroid function in energy deficient athletes, further investigating TH and psychological status are important factors to consider in monitoring OT.

Given these personal observations and lack of literature specifically addressing TH and OT, it is important to investigate the mitigating factors associated with impaired athletic performance and fatigue experienced by these female endurance athletes. Few studies have investigated multiple variables associated with overtraining concurrently in a longitudinal study such as this one. Therefore the purpose of this study was to monitor and describe relationships between thyroid hormones, commonly cited symptoms of overtraining (e.g. fatigue, energy imbalance, and performance

decrements) over a track season in female collegiate endurance athletes. A secondary aim of this study was to determine if the use a simple fatigue scale and assessment of vertical jump power could be potential indicator of overtraining or staleness in middle and long distance runners.

METHODOLOGY

Subjects

Sixteen female mid- and long-distance runners who were part of the University of Rhode Island Track and Field, Indoor Track, and Cross Country Teams participated in the study. Mid-distance runners were considered athletes whose main running event was the 800-meter run. Long distance runners were considered athletes whose main running event was 1500-meters or more. Subjects were informed of the risks and benefits of participating in the study. Written informed consent (Appendix C) was obtained from all of the participants prior to the start of the study. The Institutional Review Board at the University of Rhode Island approved all study procedures and protocols. The subjects participated in their normal practice and competition schedule throughout the study. Exclusions criteria included under age 18, pregnancy, lactation, and taking medications or supplements that would interfere with the measurements.

Measures

This descriptive study followed the subjects across the spring 2013 track and field season. Measurements were taken on the following various schedules: 1) preseason only (PRE); 2) pre-season and post-season (POST); 3) Pre-season, mid-season (MID), and post-season; or 4) weekly. See Table 1 for the timeline of study measurements.

Anthropometric Measures: Height was measured in centimeters (cm) using a Seca 216 stadiometer (Hanover, MD). The measurement was taken from the floor to

the top of the head, with the feet together and flat on the floor. The participant's head, shoulders, buttocks, and heels were in contact with the stadiometer. The participant was asked to inhale and hold her breath while the measurement was taken.

Measurements were taken in duplicate and averaged provided both were within one-half centimeter of one another.

Weight was measured in kilograms (kg) with a Tanita scale (Tanita Corporation, Japan). The scale was calibrated, and participants were weighed on the center of the scale with shoes and excess clothing removed. Duplicate measurements to the nearest tenth of a kilogram were averaged and recorded.

Body Composition: Body composition was assessed via dual-energy x-ray absorptiometry (DXA) by whole body scans using a fan-beam densitometer with accompanying software (Lunar iDXA, GE Medical Systems, USA). Total body estimates of total body mass (TBM), percent fat (BF%), total fat mass (TFM), and non-bone lean tissue (LBM) were determined using manufacturer described procedures and supplied algorithms.

Blood Profiles: All venipuncture blood draws were obtained by a trained clinician. Blood draws were obtained in a fasted state in the morning to account for potential diurnal influences. Whole blood was collected and transferred into appropriate tubes in order to obtain serum and plasma. Blood was centrifuged at 1500 g for 15 min at 4° C. Resulting serum and plasma were aliquoted and stored at -80° C for analysis. Serum thyroid stimulating hormone (TSH), thyroxine (T₄), and triiodothyronine (T₃) were analyzed using standard enzyme-linked immunosorbent

assay (ELISA) kits (Phoenix Pharmaceuticals; Burlingame, CA). Intraassay coefficients of variation were 11%, 9%, and 12% respectively.

Power Testing: Vertical jump power (VJP) was assessed using a force plate and associated software (Accupower, Advanced Mechanical Technologies Inc., Watertown, MA). After familiarization, subjects were asked to place their hands on their hips and jump as high as they could for 3 subsequent repetitions. Subjects were asked to repeat this test two more times, with 2-3 minutes of rest between each set. The highest force, power, and jump height in the three sets were recorded.

Performance Analysis: Performance was assessed by reviewing personal race times during the track season. The investigators reviewed the race times of the athletes after each meet, and the athlete's best race time was deemed as "*season best*". Race times that were run during the championship season (final two weeks of outdoor track season) were collected and deemed "*championship time*". To determine if there were improvements or impairments in running performance at the end of the season, a percent delta (Δ) change was calculated, such that $[(\textit{championship time} - \textit{season best time}) \div \textit{season best time}] \times 100$ indicates the percent increase or decrease in championship race time. All positive numbers indicate an increase in race time during the championship season, and therefore an impairment in running performance (subjects ran slower). All negative numbers indicate a decrease in race time during the championship season and therefore an improvement in running performance (subjects ran faster).

Maximal Aerobic Capacity Testing (VO_{2max}): All subjects performed a maximal aerobic capacity test on a Marquette Series 2000 treadmill utilizing a modified Costill and Fox treadmill protocol to measure maximal oxygen consumption. The test protocol required subjects to run at 6-8 mph for 4 minutes at a 0% grade. After 4 minutes, the grade was increased to 4% for 2 minutes. The grade was then increased 2% every 2 minutes until the subject reached volitional exhaustion. Maximal efforts were determined by having achieved at least two of the following criteria: a plateau in the rise of oxygen consumption with a further increase in work, a respiratory exchange ratio value of 1.1 or higher, heart rate within +/- 10 beats per minute of age predicted maximum or an RPE value of 17 or greater.

Dietary Intake: Subjects were instructed on how to complete an accurate 3-day (2 weekdays and 1 weekend day) food log, and carried this form with them to fill out the foods and beverages they consume. Upon submission a nutrition graduate student reviewed the food log with the subject to assure accuracy and thoroughness. Dietary intake from food logs were entered into the Food Processor SQL Database (Salem, OR) to assess macronutrient, micronutrient, and dietary content. Total calorie consumption (kcal), carbohydrate (CHO), protein (PRO), dietary fat (FAT), and vitamin-D intake (VDI) were used for data analysis. See Appendix D for a copy of the Food Log.

Fatigue: Fatigue ratings were obtained using a standard visual analog scale from 1 to 10 with standard psychometric tags ranging from 0 – no fatigue, 3 moderate fatigue, 5 – heavy fatigue, 10 – maximal fatigue. See Appendix E for Fatigue scale.

Statistical Analysis: Normality was tested with the Shapiro-Wilk test. Since the data of the primary outcome variables (thyroid hormones) were not normally distributed, non-parametric statistics were implemented for analysis. Wilcoxon-sign ranked tests were used to determine changes in hormonal, dietary, and performance measures over time. Spearman's rho correlation coefficient was used to determine relationships between thyroid hormones, dietary intake, performance variables, and commonly cited symptoms of overtraining. Delta (Δ) and percent delta ($P\Delta$) were calculated for all thyroid hormones, body composition, and performance measures. Previous work (33) determined that an n of 20 was adequate to defend the 0.05 alpha level of significance with a Cohen probability level of 0.8 (G-Power software, version 3.1.3, Kiel University, Germany) using T_3 as our primary outcome variable. Data are reported as mean and standard deviation ($M \pm SD$) unless otherwise stated. Statistical significance was set at an alpha level of $p \leq 0.05$.

RESULTS

Demographics

Subject characteristics are presented in Table 2.

Thyroid Hormones:

There were no significant changes in TSH, T₃, or T₄ from PRE to POST season (Fig. 1-3). No significant relationships between TSH and peripheral hormones (T₃ and T₄) were observed at PRE or POST season.

There were significant correlations between total caloric intake at POST and peripheral hormones (T₃ POST; $\rho = 0.900$, $p = 0.037$. T₄ POST; $\rho = 0.667$, $p = 0.050$) (Fig. 5). Triiodothyronine at PRE was significantly correlated with PRO intake at PRE ($\rho = -0.604$, $p = 0.029$). Thyroxine (T₄) POST was significantly associated with total caloric intake relative to lean body mass ($\text{kcal} \cdot \text{kgLBM}^{-1}$) at POST ($\rho = 0.786$, $p = 0.021$). The Δ in TSH from PRE to POST was significantly correlated with PRO intake at POST ($\rho = -0.929$, $p = 0.001$).

The Δ in TSH from PRE to POST was significantly correlated with a Δ LBM from PRE to POST ($\rho = 0.571$, $p = 0.041$) (Fig. 6).

The percent change ($P\Delta$) in T₃ from PRE to POST was significantly correlated with running performance at the end of the season ($\rho = -0.700$, $p = 0.036$) (Fig. 4).

There was a non-significant relationship between TSH POST and fatigue POST, although there was a trend ($\rho = 0.491$, $p = 0.063$).

Fatigue:

Fatigue was significantly lower at week 2 compared to MID season ($p=0.016$), week 12 ($p=0.018$) and POST ($p=0.007$) (Fig. 8). Fatigue was not statistically different between MID season, week 12 and POST season ($p=0.404$). There was a significant correlation between fatigue at week 12 and running performance at the end of the season ($\rho= -0.741$, $p= 0.004$) (Fig. 7).

Vertical Jump Power:

Vertical jump power significantly increased from PRE to MID in both the middle distance ($p=0.036$) and long distance runners ($p=0.046$). However only the middle distance runners significantly decreased power from MID to POST ($p=0.018$) (Fig. 9).

There was a significant relationship between lean body mass (PRE and POST) and vertical jump power at PRE ($\rho= 0.572$, $p=0.026$) and POST season ($\rho=0.802$, $p=0.001$) respectively.

Dietary Intake:

Total caloric intake (kcal) increased from PRE to POST (PRE: 1838 ± 687 kcal vs POST: 2484 ± 654 kcal; $p=0.012$). At PRE more than 50% of the athletes were not meeting the current RDA for protein intake ($1.2 \text{ g}\cdot\text{kgBM}^{-1}$) for endurance athletes (Median: $1.14 \text{ g}\cdot\text{kgBM}^{-1}$). At POST 75% of athletes were meeting current recommendations, however 25 % fell below or were just meeting the current RDA (lower 25%: $1.28 \text{ g}\cdot\text{kgBM}^{-1}$) (Table 3). At PRE 75% of the athletes in the current study were not meeting the minimum current RDA of carbohydrate intake (6-10

$\text{g}\cdot\text{kgBM}^{-1}$) for endurance athletes (75%: $4.7 \text{ g}\cdot\text{kgBM}^{-1}$). At POST 50% of athletes were just meeting (Median: $6.5 \text{ g}\cdot\text{kgBM}^{-1}$) the current recommendations (Table 3).

There were no significant changes in vitamin D (IU) intake at PRE and POST ($p= 0.857$). All athletes (100%) were below the current RDA of 200 IU per day at PRE (Maximum: 148 IU; Mean: 57 ± 43.39 IU) and POST (Maximum: 190 IU; Mean: 56 ± 61.50 IU) (Table 3). Fatigue at POST season was significantly correlated with vitamin D intake at POST ($\rho= -0.667$, $p= 0.05$). Δ LBM from PRE to POST was significantly related to Δ vitamin D intake from PRE to POST ($\rho= 0.738$, $p= 0.037$) (Fig. 11).

There was a significant relationship between caloric intake per kg of lean body mass ($\text{kcal}\cdot\text{kgLBM}^{-1}$) at PRE and fatigue at week 1 (PRE) ($\rho= -0.521$, $p=0.046$). Total caloric intake (kcal) at PRE was not significantly correlated with fatigue at week one, although there was a trend for a relationship ($\rho= -0.509$, $p= 0.053$)

Body Composition:

There were no significant changes in body composition from PRE to POST season in the runners overall (Table 2). However, upon further investigation the middle distance runners significantly lost LBM ($p=0.028$) from PRE to POST (Fig. 10). There were no significant changes in body composition in the long distance runners.

DISCUSSION

The results of this study indicate there were increases in commonly cited symptoms of OT such as decreased anaerobic performance, increased fatigue, and changes in body composition. Additionally, changes in TH were associated with decreased running performance and caloric intake. Thyroid hormones may change too slowly to be used as a convenient and readily available marker of overtraining. However, monitoring TH may provide valuable information about the training status of an endurance athlete, such that relative decreases or clinically low values may indicate preparedness for competition in championship races at the end of the season. The use of a weekly fatigue scale and monitoring vertical jump power could be a useful and readily available tool to monitor competitive readiness of an endurance athlete, and therefore may be a promising tool as an early indicator of overtraining. To our knowledge, this is the first study to use an anaerobic test of vertical jump power as a marker of overtraining in endurance runners.

Mean values of thyroid hormones TSH, T₃, and T₄ did not significantly change over the course of this study. This response was similar to a previous study by Hohtari et al. who investigated changes in thyroid hormones in runners and joggers over the fall and spring training seasons (22). Thyroid stimulating hormone in the aforementioned study did not significantly differ between training seasons. Similarly, an increase in running volume of 30km per week did not significantly alter resting concentrations of TSH or T₄ (3). In contrast, Boyden et al. provided evidence that TSH was shown to be higher after an increase in running volume from 48km per week

to an increase in 80km per week (2). Interestingly, decreases in T_3 were evident in runners after an increase in running volume of 48km (from baseline) per week, however there were no further decrements in T_3 when increasing running volume to 80km per week (from baseline) (2). Although the current study did not control running mileage throughout the study, most track and field athletes go through a taper (reduction in training volume) at the end of the season to promote an increase in running performance during important competitions. The biological impact of a taper has been noted elsewhere (36) and can significantly improve running performance. Although the runners most likely reduced running volume towards the end of the study, many of the runners participated in cross-country running in the fall. Therefore, when thyroid hormone values were collected at the beginning of indoor season (PRE), decreases and possible increases in thyroid hormones (2) relative to the start of cross country season may have already occurred. The current data suggest that distance runners do not experience thyroid hormone changes during the indoor or outdoor season. Although statistical analysis revealed no differences in hormone concentrations from PRE to POST, the relationship of thyroid hormones to other markers of athletic performance are markedly apparent. This data is of clinical importance since the values of T_3 our subjects (PRE: 1.37 ± 0.5 nmol/L; POST: 1.34 ± 0.5 nmol/L) were in the lower range of normal (1.1-2.9 nmol/L) (27) and T_4 values were in the higher range (PRE: 126 ± 24 nmol/L; POST: 119 ± 33 nmol/L) of normal (64-154 nmol/L) (27). Decreased T_3 levels had a significant relationship with running performance at the end of the season (Figure 6). This might be expected as T_3 is the biologically active form of thyroid hormone (47) and has potent effect on metabolism

and energy production (4). While it is unclear at the present time if relative decreases in T_3 are responsible for decreases in running performance, it does provide evidence indicating the overall training status of an endurance athlete and readiness to perform well during important times of the season.

Thyroid hormones have been shown to be regulated by energy availability (32) (31). Figure 4 presents data that provide strong evidence to this theory. At the end of the season, lower caloric intake was significantly associated with peripheral thyroid hormone concentrations of T_3 and T_4 , such that the athletes who had consumed more calories also had higher resting levels of thyroid hormones. Furthermore, this relationship was more pronounced when taking into account caloric intake relative to lean body mass ($\rho = 0.786$, $p = 0.021$). Thyroxine at POST was significantly associated with total kcals ($\text{kcal} \cdot \text{kgLBM}^{-1}$) consumed at the end of the season and provides further evidence that circulating thyroid hormones are influenced by not only total calories consumed, but also the consumption relative to lean mass. If relative low availability of energy is one of the primary variables influencing thyroid hormones this may explain the relationship between changes in TSH and changes in LBM (Figure 5). The strong association between T_4 and caloric intake ($\text{kcal} \cdot \text{kgLBM}^{-1}$) may influence feedback mechanisms in the hypothalamus to alter thyroid hormone secretion. The relationship seen in Figure 5 indicates that an increase in TSH is associated with an increase in LBM, and a suppression of TSH secretion was seen in those athletes with losses in LBM. It is unclear which order of events are related to the decrease in LBM: decrease in kcal availability; leads to a decrease in T_4 ; which signals the hypothalamus to decrease TSH; therefore conserving energy by further

reducing metabolic rate (10) and peripheral hormones to attenuate losses in LBM. Alternatively, a decrease in kcal availability; could signal the hypothalamus to decrease TSH; which leads to a decrease in T₄; therefore conserving energy by further reducing metabolic rate (10) and peripheral hormones to attenuate losses in LBM. More research is needed to elucidate regulating mechanisms behind these relationships, but it is clear that nutritional intake and thyroid hormones are strongly implicated in an endurance athlete's performance and body composition at the end of a track and field season.

Intakes of some selected nutrients in these athletes were substantially below current recommendations for endurance athletes (44). Although the athletes were meeting recommended macronutrient ratios for exercise (PRE: protein: 15%, carbohydrate: 56%, fat: 30%; POST: protein: 16%, carbohydrate: 54%, fat: 30%), the total caloric intake recommended for their sporting activity was below optimal. It is important to note that in energy deficient states the importance of protein intake increases possibly by increasing availability circulating amino acids (16) for fuel as opposed to initiating gluconeogenesis from valuable muscle tissue. This evidence corroborates previous work that female athletes are in a state of chronic energy deficiency (34) and may increase the risk of developing amenorrhea . Amenorrhea is a common problem in highly active females and is an important cofactor in the female athlete triad (39). The cessation of menstrual function may be a potential indicator of overtraining and decrements in athletic performance (10). An increasing body of evidence suggests energy imbalance may play a significant role in menstrual dysfunction in exercising female athletes (10). While total caloric intake increased

from PRE to POST the athletes were not consuming energy intakes to meet the demands of their sport. Carbohydrate intake is one of the most important macronutrient involved in endurance exercise. Increasing carbohydrate intake has also been shown to decrease the severity of overtraining symptoms but not delay its onset of development (18). This is of particular concern for the middle distance runners in our study. There was a significant relationship between caloric intake ($\text{kcal}\cdot\text{kgLBM}^{-1}$) at PRE and fatigue at week 1. The individuals who were consuming more calories relative to their size had lower ratings of fatigue. This may be expected as higher energy intake during an intense training period can reduce feelings of fatigue (18). There were significant correlations between vitamin D intake at POST and fatigue at POST. In addition, there was a significant relationship between Δ LBM and Δ vitamin-D intake from PRE to POST. Increasing evidence suggests the importance of vitamin-D intake in athletic populations (40). A recent study found similar results of low vitamin-D intake in a young healthy population (12). Lewis et al. investigated the effect of season-long supplementation of vitamin-D in swimmers (30). While vitamin-D status was not correlated with inflammatory cytokines (possible indicator of overtraining; for review see (46)), it was positively associated with increases in mineral-free mass (LBM-bone mineral content) and 77% of reported injuries also coincide with reduced vitamin-D status. Together, these results indicate the vitamin-D status is an important factor associated with some variables implicated in overtraining (fatigue, LBM changes, injury). Future research should investigate possible mechanisms this vitamin may have in energy imbalance and overtraining.

Vertical jump power increased from PRE to MID in the long and middle distance runners. However power only significantly decreased from MID to POST in the middle distance runners. The increase in power from PRE to MID was expected as this was most likely from increases in performance from athletic training. The decrease in VJP at POST was unexpected. Considering that the runners had already finished their taper, an increase or negligible change in VJP was expected. Causes of the decreased power output may have been due to an ineffective taper, changes in LBM, or overtraining. An effective taper not only decreases running time in trained endurance runners, it also increases muscular power and shortening velocity (36) which is important for stride frequency and strategic positioning during endurance races. Research has shown that athletic training has an impact on vertical jump and power-time curves (8). Furthermore reduced amortization phase of the stretch shortening cycle is related to power output, and more importantly that sprint power activities are important in endurance performance and should be incorporated into endurance training programs (20). Research has also shown that measures of anaerobic performance (vertical jump power) and aerobic capacity (VO_{2MAX}) together can influence time to exhaustion in distance runners and that anaerobic jumping power is a vital aspect of endurance performance (23). The impairments in VJP over the course of the season occurred when changes in T_3 and running performance were negatively associated (as T_3 decreased runners ran slower), fatigue was high, and running performance decreased. The use of a simple test such as VJP may be a useful tool to monitor training adaptations and overtraining status in endurance athletes. The use of this methodology warrants further investigation. Due to minute testosterone

concentrations in women, GH is one of the most important hormones promoting growth and maintenance of muscle tissue and health (9). Secretion of GH may be impaired with OT (49). Growth hormone regulates muscle growth primarily through feedback mechanisms that stimulate the secretion of insulin-like growth factor-1 (IGF-1) from the liver. The production of IGF-1 from the liver is dependent on the presence of T₃ (35) Hepatic IGF-1 modulates type-1 skeletal muscle fiber maintenance and genomic expression. Endurance training primarily utilizes type-1 fibers due to their high glycolytic capacity, resistance to fatigue, capillary and mitochondrial density (24). While type-1 fibers may be more sensitive to TH, the exposure of TH to type-II skeletal muscle fibers results in a stronger, faster and more glycolytic muscle (48). Monitoring TH in relation to skeletal muscle performance, recovery, and body composition is important to understanding their role in overtrained athletes as well. In our investigation, the middle distance runners significantly lost LBM, decreased VJP, and also had stale performance at the end of the season. Monitoring anaerobic power may be a useful tool when monitoring performance and overtraining in middle distance runners.

Fatigue was higher at the end of the season than at the beginning. This cohort had previously complained of “dead legs” and high fatigue during past seasons as well as during the season this investigation took place. Elevations in fatigue are expected when training loads are increased (15). Statistical analysis indicated there were no differences in fatigue during the final 4-5 weeks of the season. While there were no differences between these weeks it is important to note that the mean fatigue scores varied between 3.5 (moderate fatigue) and 5 (heavy fatigue). Some of the athletes

maintained moderate to heavy fatigue during the final 5 weeks of the season, which also happened to be the most important because of conference and regional championships during that time. Intensification of fatigue was also evident despite the coach implementing a taper at the end of the season. These data indicate that persistent feelings of fatigue can also exist despite a taper. This may have been caused by inadequate dietary intake by the athletes, and performing at a high intensity with poor nutritional intake most likely contributed to their feelings of fatigue. Increasing the frequency and duration of exercise for an extended period of time more so than intensity of exercise has been indicated as a cause of OT symptoms in endurance athletes (29). High fatigue for an extended period of time and a concomitant stagnation or decrease in performance (Fig. 2) potentially indicates that these athletes may have been in a state of nonfunctional overreaching (stagnancy/decrease in performance with planned recovery) and quite possibly overtraining, considering they were participating in a relatively low volume of training during that time. It is possible these decrements in performance and high fatigue are related to impaired thyroid physiology. Previous work by Dunn et al. (11) demonstrated mitochondrial disruption and decreased mitochondrial (a possible reduced capacity for energy production) number in patients with subclinical hypothyroidism. These patients also had myofibrillar disarray, atrophy of Type-II muscle fibers, and complaints of fatigue and lethargy. Findings by Dunn et al. (11) found similar results of impaired muscle quality and structure in a longitudinal study of hypothyroidism in Alaskan sled dogs, which reported reduced energy metabolism, decreased Type-II fibers, and exercise

intolerance (45). The runners in our study had similar symptoms of fatigue and may be related to the aforementioned consequences of reduced TH concentration.

Limitations

In the current investigation there were several limitations. Not obtaining a third measurement of thyroid hormones at MID was a limitation. It is well accepted that resting levels of thyroid hormones change slowly and do not occur frequently. Obtaining a thyroid data from the middle of the season may have provided more clues to the relationship TH contribute to other OT symptoms in between indoor and outdoor season. Additionally, it would have been useful since dietary data, power, and fatigue scales were also obtained at MID and may have shed more light on the change in the relationships of thyroid hormones and overtraining symptoms. Secondly, overtraining is hard to definitively diagnose, and is quite difficult to induce in the laboratory. Conducting more frequent exercise tests or training workouts in the lab may have been more optimal to control intensity and volume over the course of the season. However, the subjects were competing Division 1 NCAA track and field athletes. Intentionally inducing overtraining in competing athletes is unethical. This study was conducted because this cohort, collectively had been experiencing symptoms of fatigue, burnout, and OT during the end of the season for the past few years. The current research team was approached by the track team's sports medicine physician to elucidate some of the causes of their chronic underperformance the runners were experiencing year after year. This opportunity provided a natural observance of a group predisposed to OT. Furthermore, allowing the development of

OT to occur naturally and monitoring commonly cited symptoms allow for a greater comprehension of factors involved in the onset of its development. The inclusion of an athletic but non-competing control group may have been useful in differentiating athletic and academic stressors at the end of the season.

CONCLUSION

In conclusion, the results of this study provided evidence that impairments of athletic performance in endurance runners were related to inadequate nutritional intake, thyroid hormone status, and fatigue. Although there were no significant differences between PRE and POST thyroid hormone concentration, they appear to be quite valuable in terms of assessing the overall training state of the endurance athlete. Resting thyroid hormone concentrations change too slowly to be a frequently used marker of monitoring overtraining status. Alternatively, it appears using weekly fatigue scales, monitoring and improving dietary intake via food logs, and the utilization of VJP may be more readily available and predictive markers to assess overtraining and overall training status of collegiate female endurance runners.

REFERENCES

1. Baylor LS, Hackney AC. Resting thyroid and leptin hormone changes in women following intense, prolonged exercise training. *Eur J Appl Physiol* 2003;88(4-5):480–4.
2. Boyden TW, Pamerter RW, Rotkis TC, Stanforth H P, Wilmore JH. Thyroidal changes associated with endurance training in women. *Med Sci Sport Exerc* 1984;16(3):243–6.
3. Boyden TW, Pamerter RW, Stanforth P, Rotkis T, Wilmore JH. Evidence for mild thyroidal impairment in women undergoing endurance training. *J Clin Endocrinol Metab* 1982;54(1):53–6.
4. Cheng S-Y, Leonard JL, Davis PJ. Molecular aspects of thyroid hormone actions. *Endocr Rev* 2010;31(2):139–70.
5. Ciloglu F, Peker I, Pehlivan A, et al. Exercise intensity and its effects on thyroid hormones. *Neuroendocrinol Lett* 2005;26(6):830–4.
6. Cioffi F, Senese R, Lanni A, Goglia F. Thyroid hormones and mitochondria: with a brief look at derivatives and analogues. *Mol Cell Endocrinol* 2013;379(1-2):51–61.
7. Clark M, Reed DB, Crouse SF, Armstrong RB. Pre- and post-season dietary intake, body composition, and performance indices of NCAA division I female soccer players. *Int J Sport Nutr Exerc Metab* 2003;13:303–19.
8. Cormie P, McBride J, McCaulley G. Power-time, force-time, and velocity-time curve analysis of the CMJ: impact of training. *J Strength Cond Res* 2009;23(1):177–86.
9. Deschenes MR, Kraemer WJ. Performance and physiologic adaptations to resistance training. *Am J Phys Med Rehabil* 2002;81(11 Suppl):S3–16.
10. Dueck CA, Manore MM, Matt KS. Role of energy balance in athletic menstrual dysfunction. *Int J Sport Nutr* 1996;6(2):165–90.
11. Dunn ME, Hennessey J V, Cosmas AC, Lamont LS, Manfredi TG. Clinical Case Report : Ultrastructural Evidence of Skeletal Muscle Mitochondrial Dysfunction in Patients With Subclinical Hypothyroidism. *Thyroid Sci* 2009;4(5):1–8.

12. Forney L, Earnest C, Henagan T, Johnson L, Castleberry T, Stewart L. Vitamin D status, body composition, and fitness measures in college-aged students. *J Strength Cond Res* 2014;28(3):814–24.
13. Fry RW, Grovet JR, Edd ARM, Hons PMZ, Hons SG, Keast D. Psychological and immunological correlates of acute overtraining. *Br J Sports Med* 1994;28(4):241–6.
14. Fry RW, Grovet JR, Mortont AR, Zeronit PM, Gaudieri S, Keast D. Psychological and immunological correlates of acute overtraining. *Br J Sports Med* 1994;28(4):241–6.
15. Fry RW, Morton AR, Garcia-Webb P, Crawford GPM, Keast D. Biological responses to overload training in endurance sports. *Eur J Appl Physiol Occup Physiol* 1992;64(4):335–44.
16. Gaine PC, Pikosky M a, Bolster DR, Martin WF, Maresh CM, Rodriguez NR. Postexercise whole-body protein turnover response to three levels of protein intake. *Med Sci Sports Exerc* 2007;39(3):480–6.
17. Gold MS, Pottash L, Extein I. Hypothyroidism Evidence From. *JAMA* 1981;245(19):1–4.
18. Halson SL, Lancaster GI, Achten J, Gleeson M, Jeukendrup AE. Effects of carbohydrate supplementation on performance and carbohydrate oxidation after intensified cycling training. *J Appl Physiol* 2004;97(4):1245–53.
19. Harber VJ, Peterson SR, Chillibeck PD. Thyroid Hormone Concentrations and Muscle Metabolism in Amenorrheic and Eumenorrheic Athletes. *Can J Appl Physiol* 1998;23(3):293–306.
20. Harrison AJ, Keane SP, Coglan J. Force- velocity relationship and stretch-shortening cycle function in sprint and endurance athletes. *J Strength Cond Res* 2004;18(3):473–9.
21. Hawley J a, Dennis SC, Lindsay FH, Noakes TD. Nutritional practices of athletes: are they sub-optimal? *J Sports Sci* 1995;13 Spec No:S75–S81.
22. Hohtari H, Pakarinen a, Kauppila a. Serum concentrations of thyrotropin, thyroxine, triiodothyronine and thyroxine binding globulin in female endurance runners and joggers. *Acta Endocrinol (Copenh)* 1987;114(1):41–6.
23. Houmard JA, Costill DL, Mitchell JB, Park SH, Chenier TC. The role of anaerobic ability in middle distance running performance. *Eur J Appl Physiol* 1991;62:40–3.

24. Hunter GR, Harris RT. Structure and function of the muscular, neuromuscular, cardiovascular, and respiratory systems. In: Baechle TR, Earle RW, editors. *Essentials of strength and conditioning*. Champaign (IL): Human Kinetics; 2008 p. 4–20.
25. Kreher JB, Schwartz JB. Overtraining syndrome: a practical guide. *Sports Health* 2012;4(2):128–38.
26. Kreider R, Fry A, O’Toole M. Overtraining in sport: terms, definitions, and prevalence. In: Kreider R, Fry A, M O, editors. *Overtraining In Sport*. Champaign (IL): Human Kinetics; 1998 p. VII–IX.
27. Larsen PR, Davies TF, Schlumberger MJ, Hay ID. Thyroid physiology and diagnostic evaluation of patients with thyroid disorders. In: Larsen PR, Kronenberg HM, Melmed S, Polonsky KS, editors. *Williams textbook of endocrinology*. Philadelphia, PA: Saunders; 2003 p. 331–73.
28. Lehmann M, Gastmann U, Petersen KG, et al. Training - overtraining: performance, and hormone levels, after a defined increase in training volume versus intensity in experienced middle- and long-distance runners. *Br J Sp Med* 1992;26(4):233–42.
29. Lehmann M, Gastmann U, Peterson K, et al. Training-overtraining: performance, and hormone levels, after a defined increase in training volume versus intensity in experienced middle- and long-distance runners. *Br J Sports Med* 1992;26(4):233–42.
30. Lewis RM, Redzic M, Thomas DT. The effects of season-long vitamin d supplementation on collegiate swimmers and divers. *Int J Sport Nutr Exerc Metab* 2013;23(5):431–40.
31. Loucks A, Callister R. Induction and prevention of low-T3 syndrome in exercising women. *Am J Physiol* 1993;264(33):R924–30.
32. Loucks A, Heath E. Induction of low-T3 syndrome in exercising women occurs at a threshold of energy availability. *Am J Physiol* 1994;266(3 Pt 2):R817–23.
33. Loucks A, Laughlin G, Mortola J, Girton L, Nelson J, Yen S. Hypothalamic-Pituitary-Thyroidal Function in Eumenorrheic and Amenorrheic Athletes. *J Clin Endocrinol Metab* 1992;75(2):514–8.
34. Loucks AB. Energy balance and body composition in sports and exercise. *J Sports Sci* 2004;22(1):1–14.
35. Loucks AB. The Endocrine System: Integrated Metabolism, Growth, and Reproduction. In: Farrell PA, Joyner MJ, Caiozzo VJ, editors. *ACSM’s*

Advanced Exercise Physiology. Philadelphia, PA: Lippincott, Williams & Wilkins; 2012 p. 467–506.

36. Luden N, Hayes E, Galpin A, et al. Myocellular basis for tapering in competitive distance runners. *J Appl Physiol* 2010;108:1501–9.
37. Malczewska J, Raczynski G, Stupnicki R. Iron status in female endurance athletes and in non-athletes. *Int J Sport Nutr Exerc Metab* 2000;10(3):260–76.
38. McKenzie DC. Markers of Excessive Exercise. *Can J Appl Physiol* 1999;24(1):66–73.
39. Meeusen R, Duclos M, Foster C, et al. Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Med Sci Sports Exerc* 2013;45(1):186–205.
40. Ogan D, Pritchett K. Vitamin D and the athlete: risks, recommendations, and benefits. *Nutrients* 2013;5(6):1856–68.
41. Purvis D, Gonsalves S, Deuster P a. Physiological and psychological fatigue in extreme conditions: overtraining and elite athletes. *PM R J Inj Funct Rehabil* 2010;2(5):442–50.
42. Rapoport BI. Metabolic factors limiting performance in marathon runners. *PLoS Comput Biol* 2010;6
43. Ratamess NA. Adaptations to Anaerobic Training Programs. In: Baechle TR, Earle RW, editors. *Essentials of strength training and conditioning*. Champaign (IL): Human Kinetics; 2008 p. 94–119.
44. Rodriguez NR, DiMarco NM, Langley S. American College of Sports Medicine position stand. Nutrition and athletic performance. *Med Sci Sport Exerc* 2009;41(3):709–31.
45. Rossmeisl JH, Duncan RB, Inzana KD, Panciera DL, Shelton GD. Longitudinal study of the effects of chronic hypothyroidism on skeletal muscle in dogs. *Am J Vet Res* 2009;70:879–89.
46. Smith LL. Cytokine hypothesis of overtraining : a physiological adaptation to excessive stress? *Med Sci Sport Exerc* 2000;(317):317–31.
47. Song Y, Yao X, Ying H. Thyroid hormone action in metabolic regulation. *Protein Cell* 2011;2(5):358–68.

48. Steinacker J, Brkic M, Simsch C, et al. Thyroid hormones, cytokines, physical training and metabolic control. *Horm Metab Res* 2005;37:538–44.
49. Urhausen A, Gabriel H, Kindermann W. Blood Hormones and Markers of Training Stress and Overtraining. *Sport Med* 1995;20(4):251–76.

TABLES

Table 1. Timeline

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Height and Weight	X														X
VO₂max	X														
Anthropometrics	X														X
Body Composition	X														X
Blood Collection	X														X
Power Testing	X								X						X
Fatigue Rating Scale	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Race Times	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Food Records	X														X

Table 2. Subject Characteristics

<u>Descriptive Statistics</u>		<u>PRE</u>	<u>POST</u>
		Mean ± SD	Mean ± SD
<u>Age (yrs)</u>		20.34 ± 1.47	
<u>Height (cm)</u>		165.17 ± 6.08	
<u>Total Body Mass (kg)</u>	<u>Total</u>	57.06 ± 5.44	55.45 ± 5.59
	<u>Middle Distance (n=9)</u>	57.97 ± 5.06	56.11 ± 5.15 *
	<u>Long Distance (n=7)</u>	56.15 ± 5.99	54.79 ± 6.35
<u>Percent Body fat (%)</u>	<u>Total</u>	23.43 ± 4.18	23.17 ± 3.90
	<u>Middle Distance (n=9)</u>	21.1 ± 3.70	21.3 ± 4.34
	<u>Long Distance (n=7)</u>	25.77 ± 3.35	25.04 ± 2.43
<u>VO₂MAX ml•min⁻¹•kg⁻¹</u>		58.24 ± 5.924	

*; Indicates significantly different from PRE. p≤0.05

Table 3. Dietary Intake

Descriptive Statistics	Mean ± SD PRE (n=16)	Percentiles PRE			Mean ± SD POST (n=9)	Percentiles POST		
		25th	50th (Median)	75th		25th	50th (Median)	75th
Total Calories (kcal)	1838 ± 687	1470	1696	1908	2484 ± 654 *	2003	2392	2795
Total kcal • kg body mass ⁻¹	31.73 ± 12.07	26.21	29.91	31.98	46.55 ± 11.67	35.81	46.72	50.51
Total kcal • kg lean body mass ⁻¹	43.04 ± 16.27	35.64	40.82	42.27	61.96 ± 13.12	49.49	62.6	68.76
Carbohydrates (g)	257.67 ± 101.30	186.92	241.17	307.21	337.60 ± 83.30	276.18	359.96	399.96
Carbohydrates (g • kg body mass ⁻¹)	4.38 ± 1.69 §	3.38 §	4.13 §	4.72 §	6.26 ± 1.69 §	4.91 §	6.57	7.3
Protein (g)	67.81 ± 16.12	55.19	65.22	76.96	97.81 ± 35.89	70.14	92.53	129.69
Protein (g • kg body mass ⁻¹)	1.19 ± 0.31 †	0.887 †	1.14 †	1.46	1.85 ± 0.74	1.28	1.68	2.27
Vitamin D (IU)	57.07 ± 43.39 ‡	21.95 ‡	44.7 ‡	87.6 ‡	56.09 ± 61.50 ‡	5.92 ‡	52.06 ‡	85.305 ‡

†; Indicates value below current RDA for protein (g • kg body mass⁻¹) in endurance athletes

§; Indicates value below current RDA for carbohydrates (g • kg body mass⁻¹) in endurance athletes

‡; Indicates value below current RDA for vitamin D (IU) in general population

*; Indicates significantly different from PRE. p<0.05

FIGURES

Figure 1.

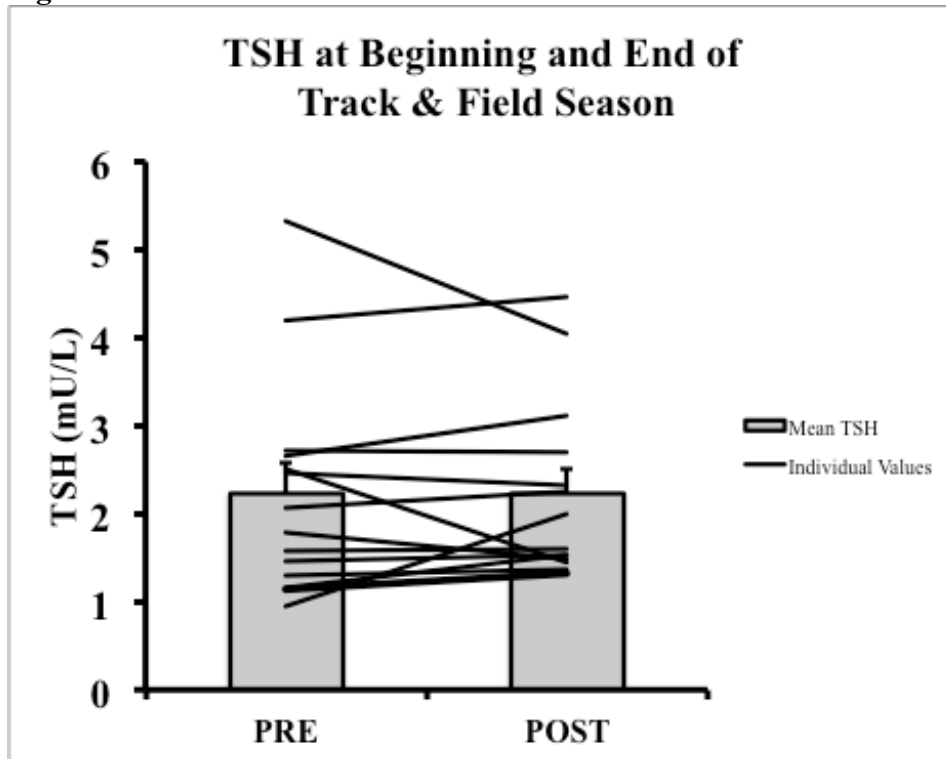


Figure 1. Changes in TSH at PRE and POST. No significant difference between time points $p \geq 0.05$. $n=14$

Figure 2.

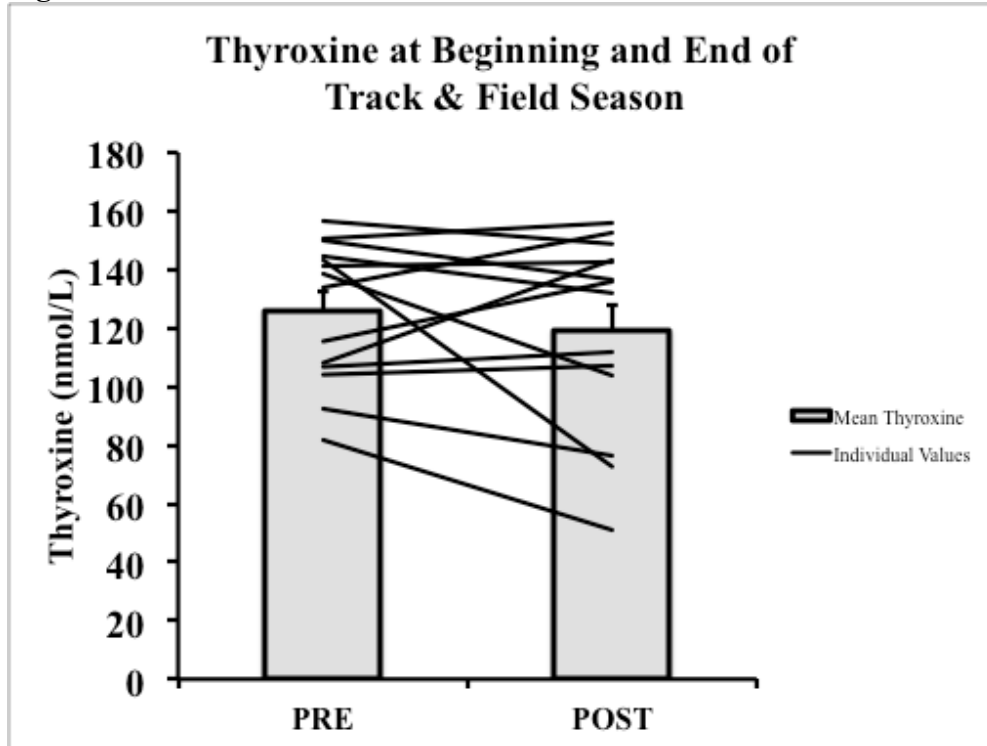


Figure 2. Changes in T_4 at PRE and POST. No significant difference between time points $p \geq 0.05$. $n=14$

Figure 3.

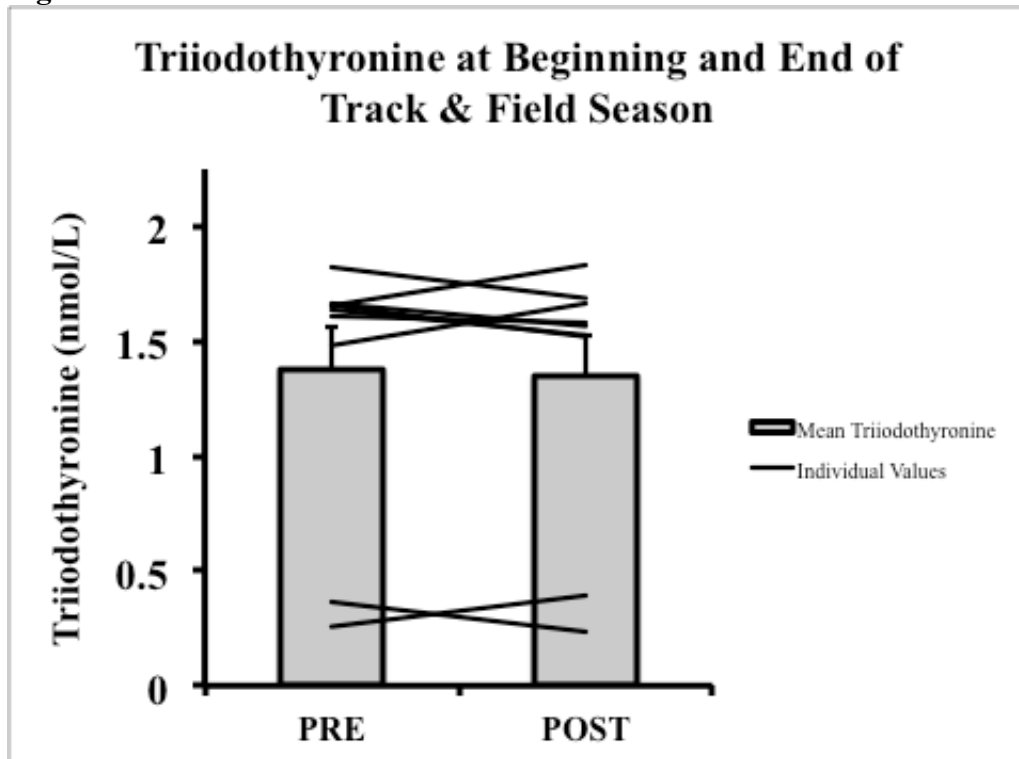


Figure 3. Changes in T_3 at PRE and POST. No significant difference between time points $p \geq 0.05$. $n=10$

Figure 4.

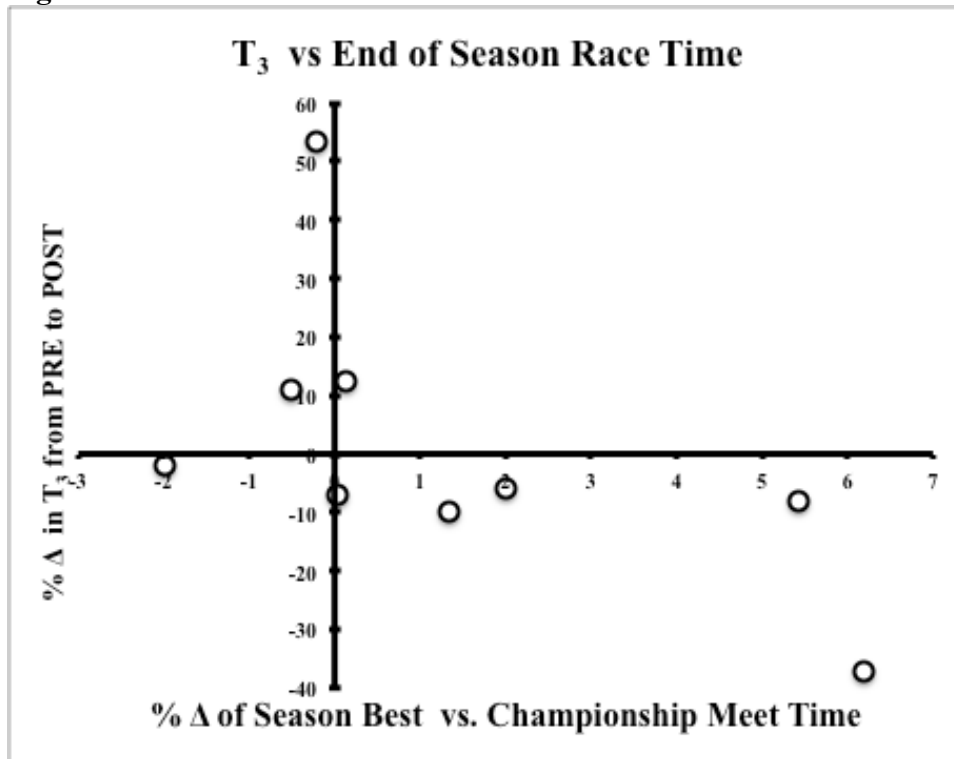


Figure 4. Correlation of Percent Change in T₃ and Percent Change in race time at end of season
 $\rho = -0.700$, $p = 0.036$, $n = 9$

Figure 5.

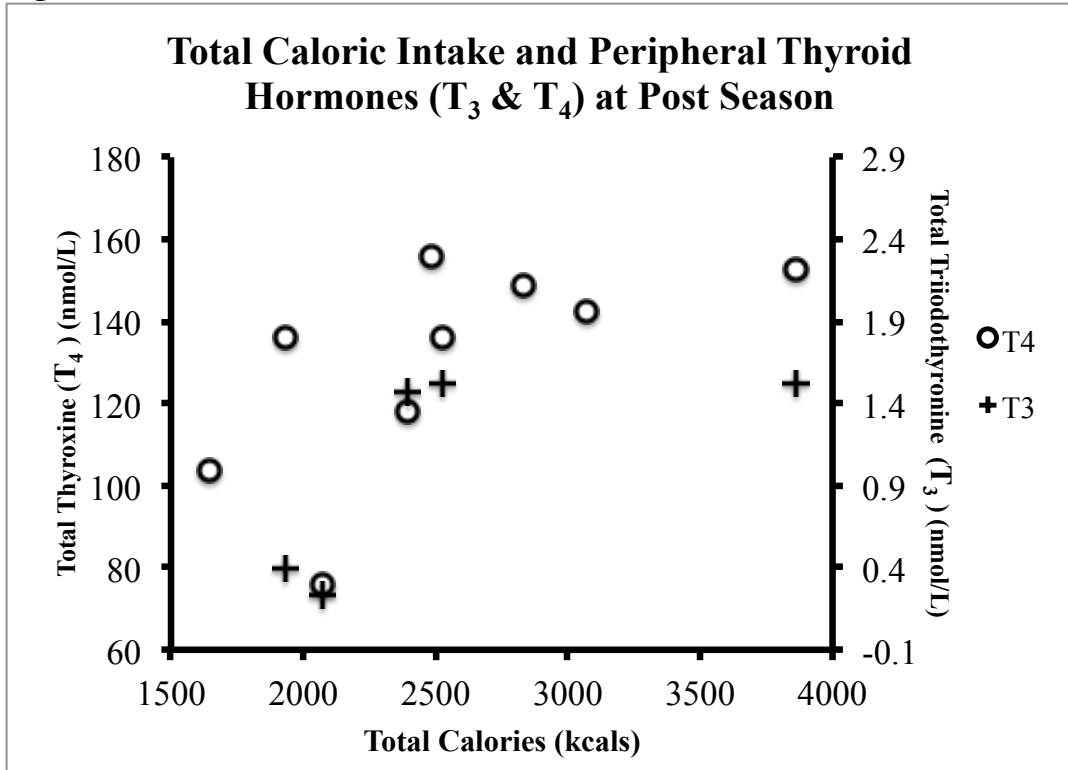


Figure 5. (○) Correlation between Total Calories (kcal) at POST and T4 POST; $\rho = 0.667$, $p = 0.050$. $n = 9$
(+) Correlation between Total Calories (kcal) at POST and T3 POST; $\rho = 0.900$, $p = 0.037$. $n = 5$

Figure 6.

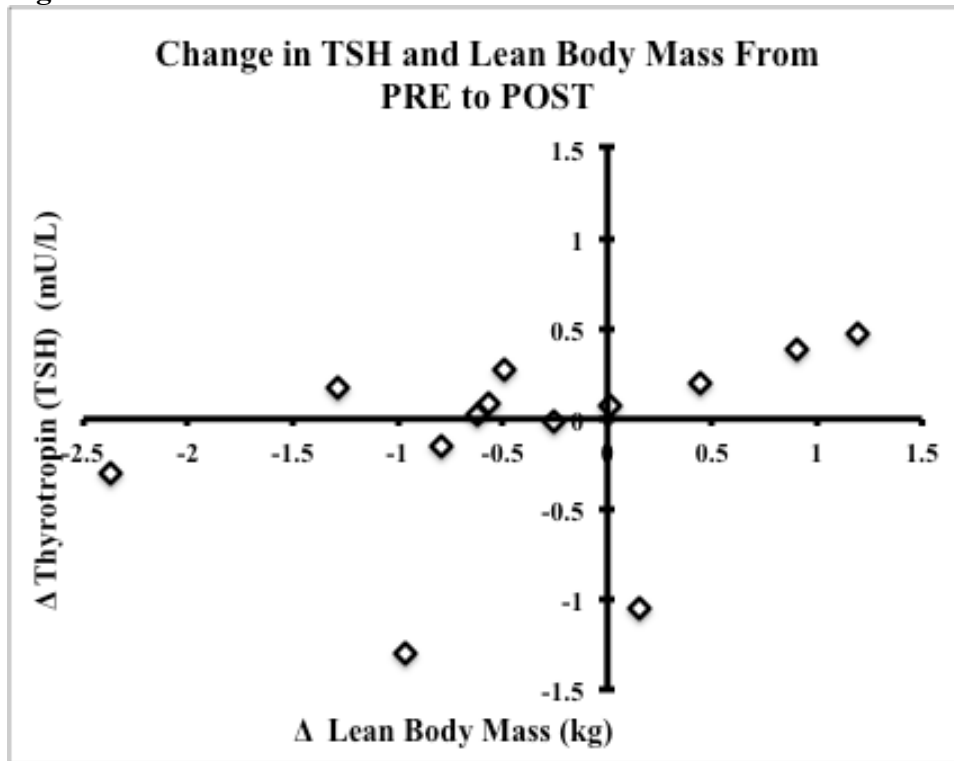


Figure 6. Change in thyrotropin and lean body mass from PRE to POST $\rho=0.571$, $p=0.041$
 $n=13$

Figure 7.

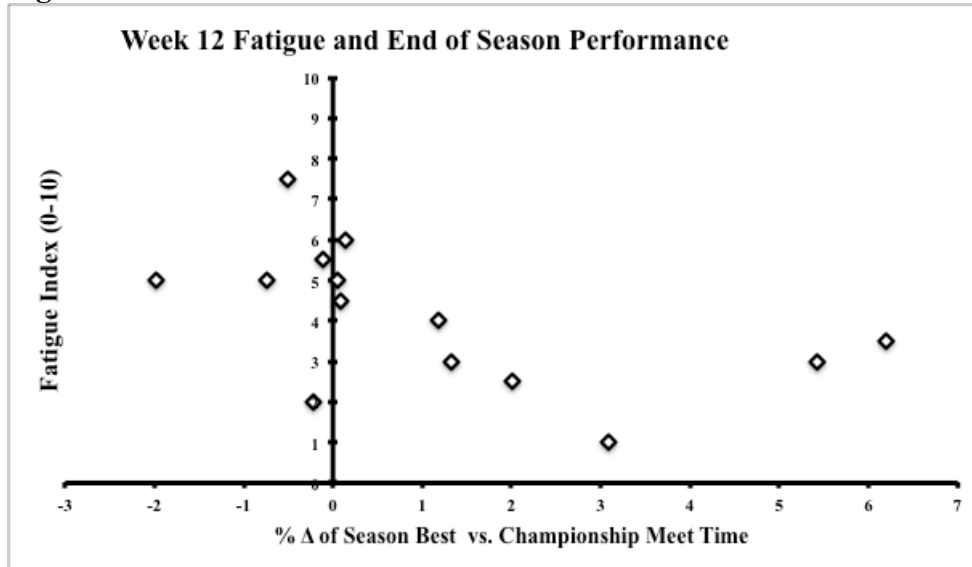


Figure 7. Correlation between fatigue at week 12 and running performance at the end of the season $\rho = -0.741$, $p = 0.004$
 $n = 14$

Figure 8.

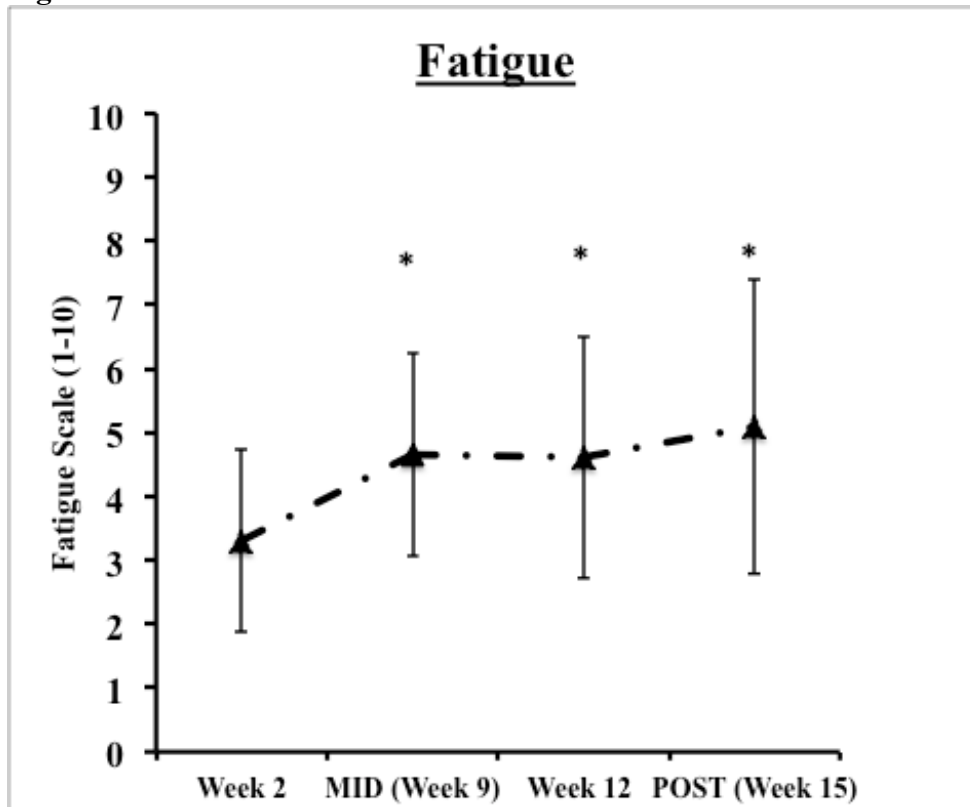


Figure 8. Perceived fatigue over the course of a track and field season. *; Indicates significantly different from Week 2. $p \leq 0.05$. $M \pm SD$. $n=13$

Figure 9.

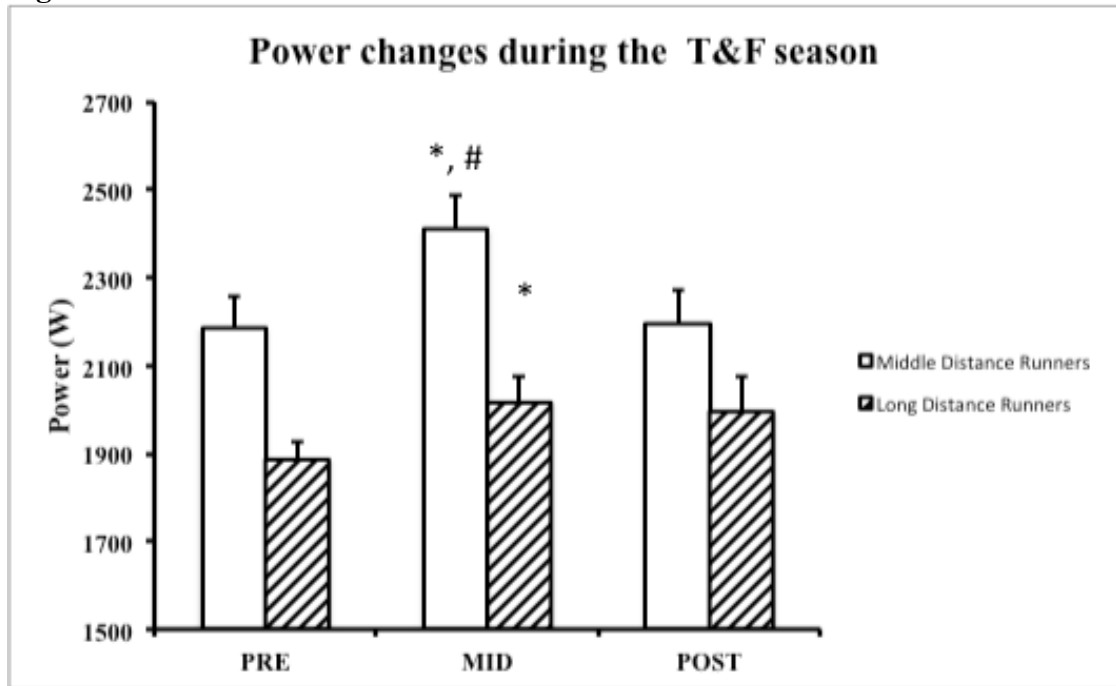


Figure 9. *; indicates significantly different from PRE in corresponding group. $p \leq 0.05$
#; indicates significantly different from POST in corresponding group. $p \leq 0.05$
Middle Distance Runners $n=7$, Long Distance Runners $n=6$.

Figure 10.

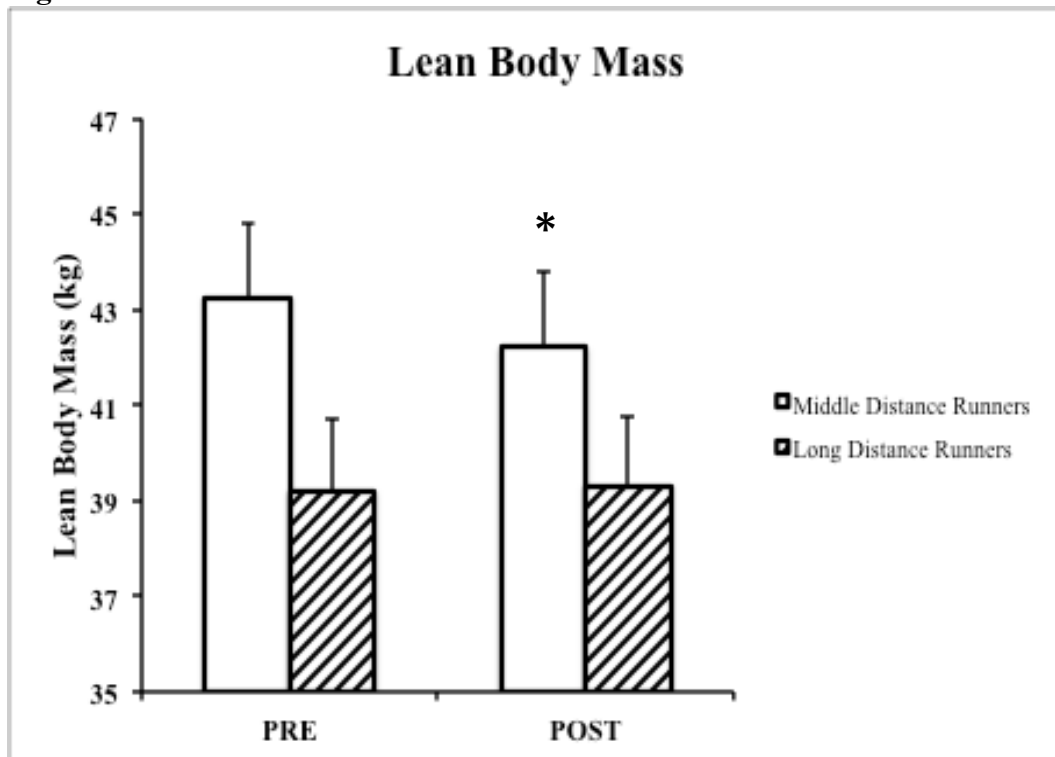


Figure 10. *; Indicates significantly different from PRE in corresponding group. $p \leq 0.05$
Reported as $M \pm SE$. Middle Distance Runners: $n=7$. Long Distance Runners: $n=7$.

Figure 11.

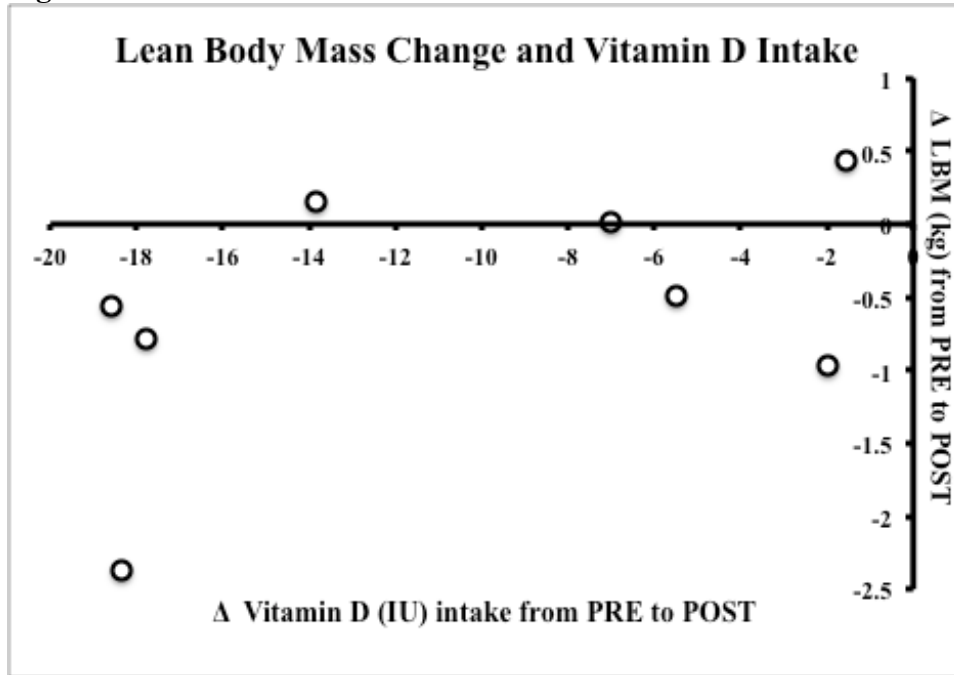


Figure 11. Change in lean body mass and vitamin-D intake from PRE to POST $\rho=0.738$, $p=0.037$
 $n=8$

APPENDIX A

REVIEW OF LITERATURE

Introduction to overtraining

Scope

The goal of athletic training is to improve athletic performance. Athletes train over many weeks or months to elicit sport specific changes and improve performance. This relationship of duration and intensity exist upon a continuum such that too high of an intensity for too long a duration, without an appropriate amount of rest may lead to increased fatigue and decreased performance of an athlete. Conversely, exercise that does not meet sufficient intensity or duration will not result in physiologic changes to improve sport performance. Athletes and coaches design training programs to prepare athletes to attain peak performances in competition many weeks or months in the future. However, the exercise variables of the training paradigm must be meticulously coordinated according to the athletes' goals and recovery status.

Overtraining syndrome (OTS) in athletes, is often described as decreased performance, hypothalamic imbalances, high fatigue, depression, and altered energy consumption (63). Often times many weeks or months of recovery are needed to see improved performance (78). Research on overtraining has sought to determine the primary causes of this syndrome, so changes in training can be made before the syndrome occurs in the athlete. The problem with overtraining research is that there are a plethora of factors involved in athletic performance (40), and pinpointing the exact cause often leads researchers with more questions than answers in elucidating

this phenomenon. Methodological differences may be the underlying cause of the inconsistent results in research studies such as intensity and volume range to induce an overtraining state. Additionally, the terminology of overtraining is varied throughout literature as the development of clinical symptoms of overreaching (OR), overtraining (OT) and overtraining syndrome (OTS) largely depend on individual phenotype, and multifactorial training or non-training stressors alike (49).

Relevance

Monitoring and preventing overtraining is clinically relevant as up to 64% of elite runners report of experiencing at least one episode of OTS at some point in their careers (39, 41, 42). The prevalence of OTS in younger athletes is also of concern. A recent survey in three-hundred young English athletes indicated that 29% had experienced a period of OT during training, and the athletes most affected were females, elite level, and individual sport athletes (47). The athletes surveyed represented athletes from various levels of athletic talent and development. These results indicate that 1) even at a young age overtraining may develop, and 2) those athletes participating in individual sports and female athletes in particular may be at an increased risk for the development of OTS. Even more importantly, the results of these studies suggest the necessity of further elucidating the causes and pathology of overtraining. The psychological impact of overtraining in the young athlete may deter them for pursuing athletics after underperformance and burnout in their sport. Additionally, many coaches and athletes train almost year round to prepare for peak condition in competition that may only last a few weeks.

Purpose

Evidence suggests that the development of OTS may develop during at least one point in 60% of female endurance athletes' career (54). The importance of identifying early markers of overtraining remains paramount in the literature. Currently, commonly cited symptoms of overtraining include decreased performance, reduced hunger and energy imbalance, changes in body composition, increased fatigue, and alterations of hormonal status in the hypothalamic-pituitary-axis. Thyroid hormones have received less attention in the role of hormonal alterations specifically related to overtraining. Contrary to the lack of research on overtraining, thyroid hormones have profound effects on physiology, metabolism, and athletic performance. Therefore, the purpose of this literature review is to thoroughly examine the topics of nutritional intake, fatigue, and body composition, which are strongly associated with overtrained status endurance athletes. Furthermore, this review will highlight the role thyroid hormones contribute to the aforementioned topics and their potential implications these hormones may contribute in overtraining and performance.

Terminology

One of the problems with the diagnosis of overtraining is the terminology to assess or describe certain states of this syndrome. Additionally, much of the confusion about properly assessing a state of overtraining is that an athlete may show different symptoms of overtraining at varied points of its onset, and these symptoms may not always follow the time course usually presented in the literature (49). With over 80 cited symptoms related to overtraining the decision of when to diagnose overtraining

can be a perplexing one. For the purpose of this literature review, the definitions of overreaching and overtraining will be referred to the works of Kreider et al. (38).

Overreaching (OR)—an accumulation of training and/or non- training stress resulting in short-term decrement in performance capacity with or without related physiological and psychological signs and symptoms of maladaptation in which restoration of performance capacity may take from several days to several weeks.

Overtraining (OT)—an accumulation of training and/or non- training stress resulting in long-term decrement in performance capacity with or without related physiological and psychological signs and symptoms of maladaptation in which restoration of performance capacity may take several weeks or months

Furthermore, it is important to differentiate between the different uses of these definitions (49). Both overreaching and overtraining are the end result of training, such that the intensified training is considered the process (or one of them) by which OR and OT develops (28). The processes of development in different states of OR are important to distinguish. Terminology by Meeusen et al. will be used for the purpose of this literature review (50).

Functional Overreaching (FOR) is used for a temporary decrease in performance following overload training. This overload is used by athletes in order to reach an increase in sports specific performance after a short recovery period.

Non-Functional Overreaching (NFOR) occurs when the overload training has detrimental effects in the long term, and full recovery does not happen during the pre-planned recovery period.

Overtraining Syndrome (OTS) takes the definition of OT further and incorporates “syndrome,” by emphasizing that chronic underperformance is a multifactorial etiology and that the exercise training is not necessarily the only contributory factor of the syndrome (49).

Nutrition

Energy Balance

Nutritional intake is an integral piece of sports training that must be consistently monitored and adjusted in order to achieve training goals, as well as optimal performance during competition (9). Appropriate macronutrient intake is essential to elicit positive adaptation to training and to meet the intense energy demands during competition (29). While endurance performance primarily utilizes aerobic metabolism to meet the demands of exercise, there are situations in long distance events where anaerobic metabolism is necessary to perform optimally (9). The consumption of CHO during exercise is dependent on the intensity of the exercise being performed (67). As the intensity of exercise increases, the demand for CHO in energy production increases concomitantly (36). When muscle glycogen and circulating blood glucose are diminished, glucose is synthesized from non-CHO sources via gluconeogenesis. Although rare, in such a case, amino acids can be catabolized from lean tissue (36). The use of amino acids for energy is not optimal to maintain and improve performance, and in the long-term will result in the degradation of valuable muscle tissue. For this reason appropriate carbohydrate (CHO), protein

(PRO), and lipids must be carefully attuned for each athlete such that energy balance is sustained.

Energy balance is when energy expenditure is equal to energy intake. Due to the large amount of energy expenditure associated with endurance training (62), it may be difficult for these athletes to consume the necessary amount of calories to maintain energy balance. Furthermore, a particular concern for collegiate athletes is that while they may be able to consume the necessary amount of total calories, the recommended intake of macronutrients may be inadequate (15). Indeed, Drenowatz et al. (18) investigated dietary intakes of 15 male endurance athletes during two non-consecutive weeks of high and low volume training. The results of that study indicated that there was no change in energy intake during a high-volume training period, such that energy intakes during the two training periods were similar. Since there were no changes in body composition, the investigators attributed the reported decreased energy intake during the high-volume training as underreporting. One week of increased volume may not be long enough to see significant changes in body composition. Despite the suspected underreporting, the investigators did note that carbohydrate intake was substantially lower than the current recommendations. A review by Hawley et al. (29) suggested that many athletes have carbohydrate deficient diets. The review went on to state that males generally consume enough calories to meet total energy expenditure; females on the other hand consume less energy than what is required from their training. In an excellent review of energy balance in sport and exercise by Loucks, she supported the conclusion that despite the common underreporting by female athletes, females participating in sport are chronically energy deficient (43).

Considering that some theories of the initiation of overtraining stems from energy imbalance or carbohydrate deficiency, the remaining information in this section will review research in investigations related to nutritional intake and overtraining/overreaching.

Carbohydrates

Prolonged training can result in decreased muscle glycogen levels after successive exercise sessions (16). Recently, it is thought that the fatigue and impaired performance from overtraining may originate from chronically low muscle glycogen (69), however this theory has yet to be fully elucidated in practice. The importance of carbohydrate consumption has been shown to influence the symptoms of overtraining. Halson et al. had endurance cyclists undergo one week of normal training, eight days of intensified training, and two weeks of recovery training on two occasions in a cross over design. In one trial period subjects consumed a 6% carbohydrate solution before and during training, and a 20% solution after training (H-CHO). On the other occasion subjects consumed a 2% carbohydrate solution (L-CHO) at all time points. The results showed that a significant decrease in maximal power output and an increase in mood disturbances occurred after intensified training. However the decrease in performance was significantly worse in the L-CHO trial compared to the H-CHO. Furthermore the increase in mood disturbance was significantly higher in the L-CHO trial and remained higher during the recovery period compared to the H-CHO trial. These results indicate that carbohydrate intake is critical to the development of classic

symptoms of overtraining (attenuates performance decrements and fatigue), however they cannot prevent the development altogether.

Protein

Protein is an essential component of an athlete's diet. Running involves an eccentric component of muscle action that results on the damage of muscle tissue and delayed onset muscle soreness (DOMS) (65). Protein is a necessary component involved in the repair of muscle tissue, and therefore subsequent training bouts (46). The current recommended daily allowance for non exercising individuals is 0.8g/kg of body weight (70). However for athletes, and particularly endurance athletes this recommendation is not adequate to maintain nitrogen balance (72). Thus, higher intakes of protein by endurance athletes are necessary to maintain performance and positive adaptation to training. Increased energy expenditure by endurance athletes provides an opportunity for a state of energy imbalance to occur, particularly during periods of high training volume or intensity (18). It is widely accepted that post-exercise nutrition is essential for positive adaptation and forthcoming performances in both endurance and strength athletes (70). As demonstrated in the previous section, adequate carbohydrate intake is essential for endurance performance. Acknowledging that information, more importance on increasing protein consumption should be emphasized as well and the importance of "making room" for protein in endurance athletes' diet warrants further discussion (64).

Protein synthesis is strongly associated to the recovery period that is allotted to the athlete post exercise. Aerobic exercise increases protein turnover by the

degradation and synthesis of muscle proteins during the recovery of exercise (66). Although there is some debate as to the inclusion of protein to CHO training supplements (3), the importance of consuming protein post-exercise is widely accepted (70) to repair damaged muscle tissues and possibly the increased preparation for subsequent bouts of exercise (21). Considering many endurance athletes may not be attaining optimal energy balance during the course of training, physiological mechanisms of adaptation may be impaired due to inadequate protein consumption.

Gaine et al. (25) investigated whole-body protein turnover response to three different levels of protein intake. In a randomized repeated measures study, 5 highly trained male runners consumed three levels of protein ($.8\text{g/kg}\cdot\text{BM}^{-1}$, $1.8\text{g/kg}\cdot\text{BM}^{-1}$, or $3.6\text{g/kg}\cdot\text{BM}^{-1}$) for four weeks. Protein turnover was assessed using a 75 minute run at 70% of their $\text{VO}_{2\text{peak}}$. After a washout period the runners crossed into the remaining conditions. The results of this study concluded that differing levels of protein turnover was altered depending on the amount of dietary protein consumed. The authors suggested that there was an increased reliance of amino acids for fuel during exercise on the 1.8 and 3.6 $\text{g/kg}\cdot\text{BM}^{-1}$ protein diets, which possibly had a glycogen sparing effect on the muscle. Conversely in the 3.6 $\text{g/kg}\cdot\text{BM}^{-1}$ intervention the authors suggested that the relatively low CHO intake may have impacted the glycogen stores, and possibly impacted the oxidation of amino acids for fuel during exercise. However, in the $.8\text{g/kg}\cdot\text{BM}^{-1}$ diet leucine rate of appearance (indicator of protein breakdown) and leucine oxidation was lower compared to the high protein diet (3.6 $\text{g/kg}\cdot\text{BM}^{-1}$). In this case if the endurance athlete is not incorporating more than the $.8\text{g/kg}\cdot\text{BM}^{-1}$ or protein in their diet and in a situation of energy deficiency, this would

result in a chronic state of nitrogen imbalance and therefore insufficiently replacing the protein that is degraded during exercise.

Supporting the previously mentioned theory, Pasiakos et al. (58) investigated the effects of muscle protein synthesis and signaling proteins under an acute bout of energy deprivation. The investigators measured muscle fractional synthetic rate in physically active adults over a twenty-day diet intervention. Ten days consisted of the participants being in a weight maintenance diet and then crossed over into a 10 day energy deficient diet (~ 80% of required estimated energy) with protein (1.5g/kg•BM¹) and fat (30% of total energy) held constant during both diet interventions. The results indicated that even while protein and fat were constant in both diets, muscle fractional synthetic rate was decreased 19% with as little as a 20% decrease in total energy intake over ten days. The down regulation of muscle fractional synthesis rate and signaling proteins provide evidence that being in a state of energy deficiency will also reduce the athlete's ability to repair and synthesize muscle tissue in vivo. Even athletes with 60% of daily required energy intake have been shown to attenuate losses in lean muscle tissue by increasing the proportion of protein in the diet (51).

Considering that many endurance athletes are in a state of energy deficiency it is important for coaches and athletes to ensure that they are meeting energy requirements from training, and to emphasize the importance of appropriate protein intake.

Furthermore, those athletes who are in energy balance and acquiring protein intakes above the RDA of .8g/kg•BM¹ but within the macronutrient range will gain an added benefit of training as increased protein intake also utilized for energy to maintain

blood glucose if the athlete does not consume appropriate amounts of CHO for a given training session (57).

While whole body protein turnover is not necessarily predictive of protein turnover in the exercising muscle, Bolster et al. (4) set out to examine if post exercise skeletal muscle protein synthesis was different depending on various amounts of habitual protein intakes in the diet. Five endurance trained male runners consumed an $.8\text{g/kg}\cdot\text{BM}^{-1}$, $1.8\text{g/kg}\cdot\text{BM}^{-1}$, or $3.6\text{g/kg}\cdot\text{BM}^{-1}$ of protein for four weeks. All diets were eucaloric and only CHO and protein content was different between the diets. After four weeks on the diet the runners performed an endurance run at 75% of $\text{VO}_{2\text{Peak}}$. Muscle biopsies were taken immediately after exercise and 180 minutes post exercise (~3 hours). Contrary to the investigators' hypothesis the results of this study revealed that the highest protein diet intervention ($3.6\text{g/kg}\cdot\text{BM}^{-1}$) had decreased muscle fractional synthesis rates post exercise. There was also a significant negative correlation between plasma concentrations of branched-chain amino-acids (BCAAs) and muscle fractional synthesis rate. The researchers suggested that an increase in protein intake was reducing the exercise induced proteolysis of skeletal muscle, therefore reducing the magnitude of anabolic response to exercise. Corroborating these findings, although acutely and post-exercise, Nelson et al. (55) provided evidence that a protein post exercise supplementation increases plasma BCAA concentration and nitrogen balance, thus reducing tissue damage from the exercise bout and enhancing recovery. The importance of ingesting protein post-exercise is well noted in literature and research suggest the importance of post-exercise protein consumption.

The evidence regarding the effect of protein ingestion, and more importantly the maintenance of appropriate protein in the diet is apparent. Bearing in mind that many endurance athletes lose lean muscle tissue throughout the duration of the season, evidence does suggest the importance of increased intakes of protein above the RDA of $.8\text{g}/\text{kg}\cdot\text{BM}^{-1}$. Not only does the increase in protein support important physiologic functions such as increase protein synthesis (31), and has also been hypothesized to possibly have a glycogen sparing effect as well (25). There is still inconclusive evidence that protein intake has a direct role on the development of overtraining, however some studies suggest prolonged decreases in amino acid availability may be related to persistent fatigue and sickness in elite athletes (35). Interestingly, Petibois et al. (61) monitored substrate utilization in a group of 15 rowers. Two of the rowers had been diagnosed as overtraining after 10 weeks, and this diagnosis was clinically evident only after alterations in protein metabolism were present. The investigators proposed that while the technology used to determine substrate usage was relatively new, a common pattern suggested that the differences between overreaching and overtraining most likely occurred when alterations in carbohydrate and lipid metabolism manifested. In such a case the chronic use of protein catabolism and amino acids for energy may have reduced other essential functions of proteins thereby affecting the overtraining athlete. The investigators stated that it was only after the alterations in protein utilization that the rowers clinically diagnosed as overtrained and presented classical symptoms of overtraining such as reduced sleep, depression, and the inability to maintain previously accomplished workload. If endurance athletes are in a state of energy deficiency, particularly in carbohydrates, other sources of fuel such

as protein may be used for energy. Considering that the amount of protein consumption impacts muscle tissue damage, and the degree of protein synthesis post exercise, macronutrient content should be carefully attuned to maintain the important physiologic function of protein in the recovering endurance athlete.

Hormonal Imbalance

Overtraining is common in endurance sports. The mechanisms responsible for overtraining are difficult to identify, however energy imbalance, hypothalamic imbalances, and autonomic neuromuscular fatigue are important factors (37). Hormonal factors are one of the most frequently investigated variables in discourse of overtraining (22). However, thyroid hormones receive less attention when investigating the development of overtraining, possibly because they are tightly regulated and resting levels don't often change acutely. Thyroid hormones may play an important role in the overtraining process because of their role in regulating metabolism, mood, and recovery.

Thyroid Hormones

The hypothalamic-pituitary axis is often understood as a system regulating homeostasis in the human body. Thyroid hormones are peptide hormones responsible for growth and metabolism. The release of thyroid hormones are under a negative feedback loop. The hypothalamus secretes thyrotropin-releasing hormone (TRH), which stimulates the pituitary gland to secrete thyrotropin or thyroid stimulating hormone (TSH). The release of TSH from the pituitary then targets the thyroid gland.

Once at the thyroid gland, TSH signals the thyroid to release thyroxine (T_4), and to a lesser degree, triiodothyronine (T_3). When the levels of T_4 and T_3 in circulation reach a threshold, the secretion of TRH from the hypothalamus subsides and therefore halts the release of TH from the thyroid (20).

While T_4 is produced in much greater quantities than T_3 , T_3 is considered more biologically potent (1) because it has a higher affinity of binding with thyroid receptors (TR). Thyroxine is considered a pro-hormone, such that T_4 is necessary for the production of T_3 , and also a storage form of the biologically active T_3 . Circulating thyroid hormones are bound by thyroxine-binding globulin (TBG) or un-bound in the form of free thyroxine ($f T_4$) and free triiodothyronine ($f T_3$). Though the thyroid gland is able to produce both T_4 and T_3 , much of the conversion of T_4 to T_3 takes place in peripheral circulation. The conversion of T_4 into the more active T_3 is under the control of enzymes known as iodothyronine deiodinases. The expression of deiodinases determine the level of TH activity within the cell (77). Deiodinases type 1 (D1) and type 2 (D2) activates the deiodination of T_4 into T_3 (1). A third type (D3) of deiodinase is generally seen as an inactivating enzyme that inactivates iodothyronines, such that the deiodination of T_4 by D3 results in the synthesis of reverse T_3 (rT_3). No metabolic effects have been cited in reference to $r T_3$, therefore many consider that $r T_3$ is an inactive metabolite (59), although this is still under some debate (77). Since the conversion of T_4 to T_3 can occur in in central and peripheral systems, and is under regulation of specific enzymes and receptors, the control of thyroid hormones represents a tightly regulated system. Because of this, the activity of T_3 , and thus TH

signaling, can be mediated within localized tissues and cells, independently of circulating T₃ levels (77).

Thyroid hormones have a profound effect on the growth and metabolism of human physiology. In particular, THs have been shown to influence the rate of heat production, cellular respiration, and metabolic rate via mitochondria, muscle fiber type synthesis and differentiation. While some of the previously mentioned characteristics of TH action have been known for quite some time, new technology and research techniques have shed light on some of the proposed mechanisms of action in these hormones (73).

Mitochondria

Adenosine tri-phosphate (ATP) is the form of energy that sustains life, and is required for almost all of aspects of physiology such as cell signaling, human locomotion, energy production. Mitochondria produce ATP through the oxidative phosphorylation of various metabolic fuels and substrates (13). Up to 90% of the energy contributed to the cells are produced by the mitochondria. In addition, these organelles are the powerhouses to many of the essential mechanisms that are required during metabolism (14). Because of altered metabolism frequently seen in hypothyroid and hyperthyroid individuals, thyroid hormones became implicated in their role in regulating metabolism and mitochondrial function. Today, it is well known that one of the effects of TH is mitochondrial biogenesis, thereby increasing the number of mitochondria in the cell and increasing the amount of ATP capable of being produced. The mechanisms behind the increase, and the effects TH have on

energetics still require more research to be fully understood (13). However, it is believed T_3 may regulate transcriptional pathways of mitochondria, which would harmonize the production of additional mitochondria and events taking place at the nucleus of the cell (14).

Metabolic rate

The proton flux across the inner mitochondrial membrane usually results in the synthesis of ATP. However, this event is never perfect and protons that go un-coupled during phosphorylation across the membrane are dissipated as heat. Through this process, it is believed that basal metabolic rate (BMR) and thermogenesis are regulated (34). Un-coupling proteins were first discovered in brown adipose tissue (BAT). These proteins increase the permeability of the inner mitochondrial membrane and allow protons to escape the gradient and go un-coupled, thus leading to an increase in heat production (7). Brown adipose tissue is abundant in un-coupling protein-1 (UCP-1), and the discovery was made that the activation of these proteins were amplified when stimulated by THs (77). A third type of un-coupling protein (UCP-3) was found predominantly located in muscle and may have implications in human performance (17). Given that muscle is highly active, and the discovery of this protein in the muscle, this has led researchers to consider this an alternative mediator of metabolic rate through thyroid hormones (14). While data does support the role thyroid hormones play in metabolic rate, much of the research on this area is done in hypothyroid, and hyperthyroid human and animal models. There is still some debate in

the degree each of these components play in overall metabolic rate in euthyroid individuals (34).

Fiber-type distribution

Evidence suggests THs are important and potent mediators of muscle development and myogenesis (11). Several studies in animal models have provided evidence of the influence TH have in muscle fiber-type differentiation (10, 11, 12). The plasticity of muscle fiber types being augmented through exercise is well known (23). The exact mechanisms however, remain to be elucidated. Due to the diverse effects THs have in various tissues, animal models provide the opportunity to control for confounding factors that contribute to muscle fiber adaptations, particularly in humans. Slow (type-1) and fast (type-2) twitch muscle fibers possess distinct metabolic and contractile properties that exist along a continuum. Slow twitch fibers are low force producing fibers but are highly resistant to fatigue, predominantly due to their high capillary density, mitochondrial content, and glycolytic enzymes (32). Fast twitch fibers are high force producing fibers, but fatigue quickly. Casas et al. provided evidence that THs influence fiber-type expression at the mitochondrial membrane. The investigators overexpressed the mitochondrial T_3 receptor p43 on the mitochondrial membrane in genetically modified mice. The results of that study indicated that at the overexpression of these receptors and T_3 stimulated mitochondrial activity the fibers containing the overexpression and had transitioned to more oxidative slow type fibers (12). The increased receptor content transition was due to amplified mitochondrial biogenesis, respiration, and body temperature in the affected

mice. Conversely, Larsson et al induced hyperthyroidism in mice with repeated administration of T_3 (39), and induced increases in a transition from slow twitch fibers to fast twitch fibers. The researchers concluded that four weeks of T_3 administration reduced contraction time and relaxation times by up to 57% and decreased type-1 fibers by up to 77% in the soleus muscle in experimental condition rats. Together these results indicate that THs can change muscle fiber types radically. Although the methodology between the two studies are different, practically these results may have implications in athletic performance due to the necessity of muscle and metabolism to meet the sport specific demands during exercise and competition.

These diverse actions of THs on metabolism, and muscle may have an important association with athletes undergoing intense training. Practically, for endurance runners the increase in mitochondrial density, and activity offer promising mechanisms for beneficial adaptations for training. Additionally, changes in fiber type in the either direction may improve athletic performance. If an increase in type-1 fibers occurs, this could prove beneficial for endurance athletes, as it may be more beneficial in energy production. Increases in type-2 fibers may improve components of endurance performance where anaerobic metabolism is important such as sprinting for position during a race and to the finish line, as well as up hill running. Changes in metabolic rate can have direct consequences concerning energy balance and the determination of appropriate energy consumption.

Elaborating upon the previous statement, energy balance is often cited as an important potential contributor to the onset of overtraining. Athletes in a state of energy imbalance have been shown to have alterations in thyroid hormone status.

Research on thyroid hormone status and overtraining is lacking, most likely because chronic changes in TH occur in a slow process. Despite this, alterations in do occur TH during acute and chronic exercise. The exact relationship intensity and volume have in altering these hormones are still of some debate, but are important to understand the relationship they may play in the overtraining status of an endurance athlete.

Thyroid Hormones and Exercise: Descriptive Studies

The influence of thyroid hormones on metabolism and mitochondrial function is widely recognized. Variations in thyroid status have been reported in runners (5, 6) and some suggest that the complaint of fatigue and decreased performance may present a sign of subclinical or overt thyroid disease (20). To compare thyroid hormone status in runners and recreational athletes Hohtari et al. investigated changes in TSH, T₄, f T₄, T₃, and TBG (thyroxine binding globulin) in female runners vs controls, and joggers vs controls. The investigators wanted to determine if changes in thyroid status and reproductive function was altered during light (autumn) and hard (spring) training seasons. The results of the study concluded that TSH was not different between runners or joggers and their controls. Although TSH did not differ between runners and controls, there were significant differences in f T₄, T₄, and T₃ between groups. The runners had significantly lower concentrations of T₄, f T₄, and T₃ compared to controls. Joggers had less pronounced changes in thyroid hormones such that only fT₄ was decreased compared to their controls. The authors concluded that moderate exercise does not seem to alter thyroid function in exercising women,

and that changes during strenuous exercise seem to come from reduced capacity of TBG. Although a relatively novel at the time, the investigation did not directly compare thyroidal changes between the runners and joggers, only to their controls. Additionally, the authors did not account for dietary intake during light and hard training seasons. Since thyroid hormone status is suppressed during energy restriction this is a major limitation in this study. However, in general the study does provide evidence that there are impairments in serum thyroid hormone concentrations in exercising compared to non-exercising women.

Conversely, Perseghin et al. investigated changes in thyroid function and free leptin index in highly trained athletes (60). The investigators explored these resting differences between highly trained male athletes (n=27) and sedentary controls (n=27). In this study TSH was significantly lower in athletes compared to controls. The although total T₃ was not different between athletes and controls, leptin and the TSH/f T₃ ratio was reduced in highly trained athletes, an indication that feedback mechanisms and regulation of other metabolism hormones influence the availability and relationship of thyroid hormone secretion and activity (60). Again, this study did not screen for dietary intake, and as such, these data must be interpreted cautiously.

A multitude of studies have investigated thyroid hormones in relation to amenorrhea (30, 41, 42), the cessation of menstrual function may be a potential indicator of overtraining and decrements in athletic performance (19). An increasing body of evidence suggests the energy balance plays a significant role in menstrual dysfunction in exercising female athletes (19). Thong et al. (75) investigated circulating thyroid hormones in elite female athletes and recreational athletes taking

and not taking oral contraceptives. Elite athletes with amenorrhea had significantly lower T_3 and T_4 compared to eumenorrheic athletes and recreational athletes. Elite amenorrheic athletes also had lower caloric and nutritional fat intakes and lower levels of the energy sensing adipocyte leptin. There was no difference in T_3 or T_4 between elite and recreationally active cyclic athletes. Although not of high magnitude, there was a significant relationship between leptin and thyroid hormones, therefore indicating that caloric intake and energy sensing mechanisms may play a role in thyroid and menstrual status in the exercising female athlete. Similarly, Loucks et al. (42) investigated differences in thyroid hormones in cyclic menstruating athletes, amenorrheic athlete, and cyclic menstruating sedentary females. In this study, although the athletes were about 20 times more active than sedentary females, their overall energy intakes were similar. Only T_4 was significantly lower in cyclic menstruating athletes compared to sedentary controls. All thyroid hormones (T_4 , T_3 , fT_4 , fT_3 , rT_3) except TSH were significantly lower in athletes with amenorrhea compared to sedentary controls. The researchers concluded chronic exercise is associated with reduced concentrations of T_4 , without alterations in the hypothalamic-pituitary- thyroid axis (42). There were however, larger aberrations in thyroid hormones in athletes with amenorrhea. Interestingly, fT_3 and fT_4 were significantly lower in the amenorrheic athletes compared to cyclically menstruating athletes indicating an impaired availability of freely circulating unbound thyroid hormone.

Clearly changes in the resting hormonal profile occur in athletes. In general, it appears there are few changes in TSH in athletes, however bound (T_3 , T_4) and unbound (fT_3 , fT_4) peripheral hormone concentrations are significantly altered.

Whether it be training, or inadequate dietary intake, alterations in these hormones occur in athletes and therefore may influence performance and subsequent overtraining. The culmination of acute training responses eventually leads to chronic adaptations in the training athlete. Therefore, the effect of an acute response of exercise on thyroid hormones requires further discussion.

Prolonged Training and Exercise on Thyroid Hormones

Repeated bouts of maximal aerobic exercise are of occur in regularly practice and competitive meets. Thyroid hormones may be altered by repeated bouts of exercise and subsequent recovery periods. Some research suggests TSH and fT_3 were shown to be decreased after a prolonged (10 weeks), intense training cycle. Interestingly, these decreases remained lower long after the intensified training was reduced (2). Additionally the changes in thyroid hormones were not present in all the athletes and the investigators indicated that there were responders and non-responders in those that were subject to the intensified training period. These responses should be taken into consideration by coaches and athletes when designing training programs. These TH responses to exercise may contribute to, and even exacerbate metabolism and recovery dysfunction in athletes with overtraining symptoms and energy imbalances. Furthermore, this study provides evidence that not all athletes respond similarly to a given training program and that there is a large variability in hormonal response to such paradigms. Such variability may be due to current training status, and genetic factors.

In regards to genetic factors, Tremblay et al. investigated determinants of resting metabolic rate (RMR) with constant energy intake in monozygotic (identical) twins after 93 days of bi-daily cycle ergometer exercise. There was a decrease in resting metabolic rate without a change in lean mass, and the thyroid hormones T_3 , T_4 , and fT_3 were lower after the 93-day training period, while no changes were notable for fT_4 . The authors noted there was less variation of T_4 within twin pairs than there were between, indicating a strong potential genetic role in the response of thyroid hormone to exercise. Therefore large variations in RMR and thyroid hormones are primarily due to genetic influences. Prolonged training seems to result in decreased levels of T_3 (76) and fT_3 (68) possibly as an energy sparing mechanism (71), with negligible effects on fT_4 levels (2, 55, 64).

Body Composition

A euthyroid state of triiodothyronine regulates protein synthesis and some proteolysis (44). However, in both hyper and hypothyroid conditions, T_3 's influence on muscle causes atrophy. Dietary and energy balance dysregulation of TH is of importance, as low TH may negatively affect growth hormone and insulin-like growth factor 1 (IGF-1) secretion (33). The dysregulation of this axis has been shown to result in delayed developmental growth and possibly increased rates of skeletal and muscle injury (33).

Thompson et al. screened highly trained male endurance athletes for dietary habits and measures of energy expenditure (74). Ten athletes met the criteria to be considered weight stable with a low dietary intake (LOW; n=6) or consumed an

adequate amount of dietary intake to meet energy needs (ADQ; n=4).

Triiodothyronine levels were not different between the low dietary group and adequate intake group, however $f T_4$ levels were significantly lower in the LOW group compared to ADQ group. The investigators suggested that athletes who do not consume enough calories to meet energy demands can maintain body weight, in part, because of lower sedentary 24 hour energy expenditure. Additionally, Thompson et al. suggested a possible mechanism of lower energy expenditure during sedentary activity was due to lower levels of free thyroxine. This may be a plausible mechanism behind the lower energy expenditures in the low dietary intake group considering the effects T_4 and T_3 have on metabolism. The authors note that more research is needed investigating energy expenditure between low and balanced energy intake athletes, as the sample size in the present study (N=10) and more specifically the ADQ (n=4) were low. Although Thompson et al (74) had a small sample size, their study provides valuable insight regarding the influence of dietary intake, chronic exercise, and alterations in hormonal and physiologic function.

Fatigue

Psychological status in the athlete is of utmost importance (63). The profile of mood states (POMS) is an accurate and valid test to assess changes or disturbances in mood and vigor (48). Overtrained athletes have decreased motivation, confidence, and vigor (63). On the contrary, overtrained athletes also have higher ratings of fatigue, depression, anger and compromised concentration (63). Some of these mood changes have been theorized to be due to endocrine changes. O'Conner et al. (56) found that depression and cortisol elevation were highly correlated in overtrained

female swimmers however this theory has yet to be fully elucidated. Fatigue and lethargy were experienced by athletes after 10 consecutive days of treadmill exercise to exhaustion (24). Decreases in time to exhaustion and increases in feelings of fatigue and lethargy persisted 5 days after a reduction in exercise and administration of active recovery. Given the influence intensive training programs have on fatigue, mood, and hormonal milieu, employing an effective taper in endurance performance is important for peak performances (79). Similarly recent research has suggested improvements in type II fiber diameter and peak shortening velocity and power after an effective taper without any adverse influences on aerobic capacity (45) indicating potential mechanisms for improved running performance. Increases in fatigue and concomitant decreases in performances are often observed in overreaching, overtraining, and overtrained athletes (27). Monitoring mood states and fatigue may be a useful tool in monitoring training status of athletes, however their reliability of predictive value in forecasting overtraining has yet to be fully elucidated. Increased incidence of depression and fatigue and depression are often observed in overtrained athletes (8). In addition, depression is a commonly cited symptom in hypothyroid individuals and even apparent in subclinical hypothyroid subjects (26). Given the high incidence of depression in OT athletes and altered thyroid function in energy deficient athletes, further investigating TH and psychological status are important factors to consider in monitoring OT.

Conclusion

The multifactorial contributions that nutrition, exercise duration & intensity, and hormonal response provide to the development of overtraining are widely accepted. Thyroid hormones have diverse effects on growth, metabolism, and recovery. These effects can take place in almost every tissue of the body, independent of centrally regulating mechanisms. Changes in thyroid hormones are often investigated in relation to energy balance and athletic amenorrhea, and not exclusively researched in relation to overtraining. Therefore, information regarding these hormones, athletic performance, and potential early indicators of overtraining requires more thorough elucidation, and their contribution to the development of overtraining warrants further investigation.

REFERENCES

1. Arrojo E Drigo R, Bianco AC. Type 2 deiodinase at the crossroads of thyroid hormone action. *Int J Biochem Cell Biol* 2011;43(10):1432–41.
2. Baylor L, Hackney A. Resting thyroid and leptin hormone changes in women following intense , prolonged exercise training. *Eur J Appl Physiol* 2003;88:480–4.
3. Betts J a, Stevenson E. Should protein be included in CHO-based sports supplements? *Med Sci Sports Exerc* 2011;43(7):1244–50.
4. Bolster DR, Pikosky M a., Gaine PC, et al. Dietary protein intake impacts human skeletal muscle protein fractional synthetic rates after endurance exercise. *Am J Physiol - Endocrinol Metab* 2005;289(4 52-4):E678–E683.
5. Boyden TW, Pamenters RW, Rotkis TC, StanforthH P, Wilmore JH. Thyroidal changes associated with endurance training in women. *Med Sci Sport Exerc* 1984;16(3):243–6.
6. Boyden TW, Pamenters RW, Stanforth P, Rotkis T, Wilmore JH. Evidence for mild thyroidal impairment in women undergoing endurance training. *J Clin Endocrinol Metab* 1982;54(1):53–6.
7. Brand M. The efficiency and plasticity of mitochondrial energy transduction. *Biochem Soc Trans* 2005;33:897 – 904.
8. Budgett R. Fatigue and underperformance in athletes: the overtraining syndrome. *Br J Sports Med* 1998;32(2):107–10.
9. Burke LM, Millet G, Tarnopolsky M a. Nutrition for distance events. *J Sports Sci* 2007;25(S1):S29–S38.
10. Caiozzo VJ, Baker MJ, Baldwin KM. Novel transitions in MHC isoforms: separate and combined effects of thyroid hormone and mechanical unloading. *J Appl Physiol* 1998;85(6):2237–48.
11. Carnac G, Albagli-curiel O, Pinset C, et al. 3,5,3'-Triiodothyronine Positively Regulates both MyoD1 Gene Transcription and Terminal Differentiation in C2 Myoblasts. *Mol Endo* 1992;6(8):1185–94.
12. Casas F, Pessemesse L, Grandemange S, et al. Overexpression of the mitochondrial T3 receptor p43 induces a shift in skeletal muscle fiber types. *PLoS One* 2008;3(6):e2501.

13. Cheng S-Y, Leonard JL, Davis PJ. Molecular aspects of thyroid hormone actions. *Endocr Rev* 2010;31(2):139–70.
14. Cioffi F, Senese R, Lanni A, Goglia F. Thyroid hormones and mitochondria: with a brief look at derivatives and analogues. *Mol Cell Endocrinol* 2013;379(1-2):51–61.
15. Clark M, Reed DB, Crouse SF, Armstrong RB. Pre- and post-season dietary intake, body composition, and performance indices of NCAA division I female soccer players. *Int J Sport Nutr Exerc Metab* 2003;13:303–19.
16. Costill DL, Bowers R, Branam G, Sparks K. Muscle glycogen utilization during prolonged exercise on successive days. *J Appl Physiol* 1971;31:834–8.
17. Dhamrait SS, Williams AG, Day SH, et al. Variation in the uncoupling protein 2 and 3 genes and human performance. *J Appl Physiol* 2012;112(7):1122–7.
18. Drenowatz C, Eisenmann JC, Carlson JJ, Pfeiffer K a., Pivarnik JM. Energy expenditure and dietary intake during high-volume and low-volume training periods among male endurance athletes. *Appl Physiol Nutr Metab* 2012;37(2):199–205.
19. Dueck CA, Manore MM, Matt KS. Role of energy balance in athletic menstrual dysfunction. *Int J Sport Nutr* 1996;6(2):165–90.
20. Duhig TJ, McKeag D. Thyroid disorders in athletes. *Curr Sports Med Rep* 2009;8(1):16–9.
21. Ferguson-Stegall L, McCleave E, Ding Z, et al. Postexercise carbohydrate–protein supplementation improves subsequent exercise performance and intracellular signaling for protein synthesis. *J Strength Cond Res* 2011;25(5):1210–24.
22. Fry A, Steinacker J, Meeusen R. Endocrinology of Overtraining. In: Kraemer W, editor. *The Endocrine System in Sports and Exercise*. London: Blackwell Scientific; 2005 p. 578–99.
23. Fry AC. The role of resistance exercise intensity on muscle fibre adaptations. *Sport Med* 2004;34(10):663–79.
24. Fry RW, Grovet JR, Mortont AR, Zeronit PM, Gaudieri S, Keast D. Psychological and immunological correlates of acute overtraining. *Br J Sports Med* 1994;28(4):241–6.

25. Gaine PC, Pikosky M a, Bolster DR, Martin WF, Maresh CM, Rodriguez NR. Postexercise whole-body protein turnover response to three levels of protein intake. *Med Sci Sports Exerc* 2007;39(3):480–6.
26. Gold MS, Pottash L, Extein I. Hypothyroidism Evidence From. *JAMA* 1981;245(19):1–4.
27. Halson SL, Bridge MW, Meeusen R, et al. Time course of performance changes and fatigue markers during intensified training in trained cyclists. *J Appl Physiol* 2002;93(3):947–56.
28. Halson SL, Jeukendrup AE. Does overtraining exist? An analysis of overreaching and overtraining research. *Sport Med* 2004;34(14):967–81.
29. Hawley J a, Dennis SC, Lindsay FH, Noakes TD. Nutritional practices of athletes: are they sub-optimal? *J Sports Sci* 1995;13 Spec No:S75–S81.
30. Hilton LK, Loucks a B. Low energy availability, not exercise stress, suppresses the diurnal rhythm of leptin in healthy young women. *Am J Physiol Endocrinol Metab* 2000;278(1):E43–9.
31. Hulmi J, Tannerstedt J, Selanne H, Kainulainen H, Kovanen V, Mero A. Resistance exercise with whey protein ingestion affects mTOR signaling pathway and myostatin in men. *J Appl Physiol* 2009;106:1720–9.
32. Hunter GR, Harris RT. Structure and function of the muscular, neuromuscular, cardiovascular, and respiratory systems. In: Baechle TR, Earle RW, editors. *Essentials of strength and conditioning*. Champaign (IL): Human Kinetics; 2008 p. 4–20.
33. Jahreis G, Kauf E, Frohnert G, Schmidt HE. Influence of Intensive Exercise on Insulin-like Growth Factor I, Thyroid and Steroid Hormones in Female Gymnasts. *Growth Regul* 1991;1:95–9.
34. Kim B. Thyroid Hormone as a Determinant of Energy Expenditure and Basal Metabolic Rate. *Thyroid* 2008;18(2):141–4.
35. Kingsbury KJ, Kay L, Hjelm M. Contrasting plasma free amino acid patterns in elite athletes: association with fatigue and infection. *Br J Sports Med* 1998;32(1):25–32; discussion 32–3.
36. Kraemer WJ, Fleck SJ, Deschenes MR. Bioenergrtics and Meeting the Metabolic Demand for Energy. In: *Exercise Physiology: integrating theory and apploication*. Philadelphia, PA: Lippincott, Williams & Wilkins; 2012 p. 27–63.

37. Kreher JB, Schwartz JB. Overtraining syndrome: a practical guide. *Sports Health* 2012;4(2):128–38.
38. Kreider R, Fry A, O’Toole M. Overtraining in sport: terms, definitions, and prevalence. In: Kreider R, Fry A, M O, editors. *Overtraining In Sport*. Champaign (IL): Human Kinetics; 1998 p. VII–IX.
39. Larsson L, Li X, Teresi a, Salviati G. Effects of thyroid hormone on fast- and slow-twitch skeletal muscles in young and old rats. *J Physiol* 1994;481 (Pt 1):149–61.
40. Lehmann M, Foster C, Keul J. Overtraining in endurance athletes: a brief review. *Med Sci Sport Exerc Sport Exerc* 1993;25(7):854–62.
41. Loucks A, Heath E. Induction of low-T3 syndrome in exercising women occurs at a threshold of energy availability. *Am J Physiol* 1994;266(3 Pt 2):R817–23.
42. Loucks A, Laughlin G, Mortola J, Girton L, Nelson J, Yen S. Hypothalamic-Pituitary-Thyroidal Function in Eumenorrheic and Amenorrheic Athletes. *J Clin Endocrinol Metab* 1992;75(2):514–8.
43. Loucks AB. Energy balance and body composition in sports and exercise. *J Sports Sci* 2004;22(1):1–14.
44. Loucks AB. The Endocrine System: Integrated Metabolism, Growth, and Reproduction. In: Farrell PA, Joyner MJ, Caiozzo VJ, editors. *ACSM’s Advanced Exercise Physiology*. Philadelphia, PA: Lippincott, Williams & Wilkins; 2012 p. 467–506.
45. Luden N, Hayes E, Galpin A, et al. Myocellular basis for tapering in competitive distance runners. *J Appl Physiol* 2010;108:1501–9.
46. Lunn WR, Pasiakos SM, Colletto MR, et al. Chocolate milk and endurance exercise recovery: protein balance, glycogen, and performance. *Med Sci Sports Exerc* 2012;44(4):682–91.
47. Matos NF, Winsley RJ, Williams C a. Prevalence of nonfunctional overreaching/overtraining in young English athletes. *Med Sci Sports Exerc* 2011;43(7):1287–94.
48. Mckenzie DC. Markers of Excessive Exercise. *Can J Appl Physiol* 1999;24(1):66–73.
49. Meeusen R, Duclos M, Foster C, et al. Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College

of Sport Science and the American College of Sports Medicine. *Med Sci Sports Exerc* 2013;45(1):186–205.

50. Meeusen R, Duclos M, Gleeson M, Rietjens G, Steinacker J, Urhausen A. The Overtraining Syndrome – facts & fiction. *Eur J Sport Sci* 2006;6(4):263–263.
51. Mettler S, Mitchell N, Tipton KD. Increased protein intake reduces lean body mass loss during weight loss in athletes. *Med Sci Sports Exerc* 2010;42(2):326–37.
52. Morgan W, O'Connor P, Ellickson K, Bradley P. Personality structure, mood states, and performance in elite male distance runners. *Intern J Sport Psychol* [date unknown];19::247–63.
53. Morgan W, O'Connor P, Sparling P, Pate R. Psychological characterization of the elite female distance runner. *Int J Sport Med* [date unknown];8(Suppl 2):124–31.
54. Morgan W, O'Connor P, Sparling P, Pate R. Psychological characterization of the elite female distance runner. *Int J Sport Med* 1987;8(2 suppl):124–31.
55. Nelson AR, Phillips SM, Stellingwerff T, et al. A protein-leucine supplement increases branched-chain amino acid and nitrogen turnover but not performance. *Med Sci Sports Exerc* 2012;44(1):57–68.
56. O'Connor PJ, Morgan WP, Raglin JS, Barksdale CM, Kalin NH. Mood State and Salivary Cortisol Levels Following Overtraining in Female Swimmers. *Psychoneuroendocrinology* 1989;14(4):303–10.
57. Pasiakos SM, Martin WF, Sharma CS, et al. Level of dietary protein intake affects glucose turnover in endurance-trained men. *J Int Soc Sports Nutr* 2011;8(1):20.
58. Pasiakos SM, Vislocky LM, Carbone JW, et al. Acute energy deprivation affects skeletal muscle protein synthesis and associated intracellular signaling proteins in physically active adults. *J Nutr* 2010;140(4):745–51.
59. Pedrelli M, Pramfalk C, Parini P. Thyroid hormones and thyroid hormone receptors : Effects of thyromimetics on reverse cholesterol transport. *World J Gastroenterol* 2010;16(47):5958–64.
60. Perseghin G, Lattuada G, Ragogna F, Alberti G, La Torre A, Luzi L. Free leptin index and thyroid function in male highly trained athletes. *Eur J Endocrinol* 2009;161(6):871–6.

61. Petibois C, Cazorla G, Poortmans J, Déléris G. Biochemical aspects of overtraining in endurance sports. *Sport Med* 2002;33(2):83–94.
62. Rapoport BI. Metabolic factors limiting performance in marathon runners. *PLoS Comput Biol* 2010;6
63. Ratamess NA. Adaptations to Anaerobic Training Programs. In: Baechle TR, Earle RW, editors. *Essentials of strength training and conditioning*. Champaign (IL): Human Kinetics; 2008 p. 94–119.
64. Rodriguez NR. Making room for protein in approaches to muscle recovery from endurance exercise. *J Appl Physiol* 2009;106(4):1036–7.
65. Scott KE, Rozenek R, Russo AC, Crussemeyer J a, Lacourse MG. Effects of delayed onset muscle soreness on selected physiological responses to submaximal running. *J Strength Cond Res* 2003;17(4):652–8.
66. Seene T, Kaasik P, Alev K. Muscle protein turnover in endurance training: a review. *Int J Sports Med* 2011;32(12):905–11.
67. Sherman WM, Jacobs KA, Leenders N. Carbohydrate Metabolism During Endurance Exercise. In: Kreider R, Fry A, O'Toole M, editors. *Overtraining In Sport*. Champaign (IL): Human Kinetics; 1998 p. 289–307.
68. Simsch C, Lormes W, Peterson K, et al. Training Intensity Influences Leptin and Thyroid Hormones in Highly Trained Rowers. *Int J Sports Med* 2002;23:422–7.
69. Snyder AC. Overtraining and glycogen depletion hypothesis. *Med Sci Sport Exerc* 1998;30(7):1146–50.
70. Stand P. Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and Athletic Performance. *J Am Diet Assoc* 2009;109(3):509–27.
71. Steinacker J, Brkic M, Simsch C, et al. Thyroid hormones, cytokines, physical training and metabolic control. *Horm Metab Res* 2005;37:538–44.
72. Tarnopolsky MA, Macdougall JD, Atkinson SA. Influence of protein intake and training status on nitrogen balance and lean body mass. *J Appl Physiol* 1988;64(1):187–93.
73. Tata JR. The road to nuclear receptors of thyroid hormone. *Biochim Biophys Acta* 2013;1830(7):3860–6.

74. Thompson JL, Manore MM, Skinner JS, Ravussin E, Spraul M. Daily energy expenditure in male endurance athletes with differing energy intakes. *Med Sport Sci* 1995;27(3):347–54.
75. Thong FS, McLean C, Graham TE. Plasma leptin in female athletes: relationship with body fat, reproductive, nutritional, and endocrine factors. *J Appl Physiol* 2000;88(6):2037–44.
76. Tremblay A, Poehlman ET, Despres JP, Theriault G, Danforth E, Bouchard C. Endurance training with constant energy intake in identical twins: changes over time in energy expenditure and related hormones. *Metabolism* 1997;46(5):499–503.
77. Warner A, Mittag J. Thyroid hormone and the central control of homeostasis. *J Mol Endocrinol* 2012;49(1):R29–35.
78. Winsley R, Matos N. Overtraining and elite young athletes. *Med Sport Sci* 2011;56:97–105.
79. Zehsaz F, Azarbaijani MA, Farhangimaleki N, Tiidus P. Effect of tapering period on plasma hormone concentrations, mood state, and performance of elite male cyclists. *Eur J Sport Sci* 2011;11(3):183–90.

APPENDIX B

Author	Participants	Protocol, Methods	Sampling	Outcomes	Results	Conclusions
Hackney et al. 2012	highly trained males (n=15)	Intense Interval vs Steady State	Immediate post, 12hrs post	ft4, ft3, cortisol, rT3	ft4,ft3, rT3 ↑ post Intense ex ↑ 12hrs post vs SS and Con	Intense interval EX suppresses peripheral conversion of T4 to T3 compared to SS, a longer recover from intense ex might be needed.
Baylor & Hackney 2003	Collegiate athlete females (n=17) Sedentary controls (n=4)	Resting concentrations after 20 weeks of EX (intense wk1-9) (wk5 regeneration) (moderate wk10-20)	Responders (↓ in TH, n=10) Non-responders (↔ in TH, n=7)	ft3, ft4, TSH, Leptin	ft3 = ↓wk5 &wk10 vs BL BL Returned towards BL during moderate training (wk20 vs BL) ft4= no sig change in any group TSH= ↓ from BL to wk5, wk10. Returned towards BL during moderate training (wk20 vs BL)	Lowered Leptin, TSH, ft3 during a period of intense prolonged training. Speculated the decrease was due to low HTP action as a means of energy conservation through leptin. Must interpret cautiously as is only casual relationship
Ciloglu et al. 2005	Well trained male athletes (n=60)	Acute aerobic EX, bicycle ergometer at 45%, 70%, and 90% of HRmax (Carvonen meth)	Every three min fro total of 9min of EX. 45%, 3; 70%, 3; 90%, 3.	T4, T3, ft3, TSH	TSH= sig ↑to 90% T4=↑ from 70-90% vs 45% ft4=↑ from 70-90% vs 45% T3=↑ from 45%-70% Then ↓from 70-90% ft3=↑ from 45%-70%	There is an increase in TSH during moderate and max intensity acute EX. TSH levels may rise to supply exercise needs for TH in peripheral system
Harber et al 1998	Eumenorrhic Athletes (n=11) Amenorrhic Athletes (n=8) Eumenorrhic Athletes (n=13)	Graded unilateral plantar flexion exercise.	20, 30, 40, 100% peak work rate	T3, T4, inorganic Phosphate, PCr,	T3 and T4 declined across all groups (non-athletes > eumenorrhic endurance-trained > amenorrhic endurance-trained -PCr recovery was significantly faster in Eumenorrhic compared to AA and SED	Amenorrhic athletes have slower PCR recovery after exercise. Further exercise should examine if decreased rate is due to reduced T3/T4 concentration.
Loucks & Callister 1993	Sedentary women (n=46)	Randomly assigned 3X2 aerobic exercise (zero, low, high intensity) And diet treatments (balanced, deficiency)	After 4 days on treatment resting THs were assessed	T4, ft4, T3, ft3, rT3, TBG	T3=↓ all energy deficient groups; ↔ in Balanced groups ft3=↓ energy deficiency T4=↑ energy deficiency rT3=↑ energy deficiency	Thyroid metabolism is controlled by the concept of energy availability not necessarily dietary intake. T4 rise in response to decreased T3 in low energy groups.
Perseghin et al. 2009	Highly trained male athletes (n=27) Sedentary men (n=27)	Descriptive	Resting	TSH, ft4, ft3, TSH/ft3 ratio, RQ, Leptin, Adiponectin, sOB-R	TSH=↓ in athletes TSH/ft3 ratio=↓ in athletes ft3=↔ no difference ft4=↔ no difference RQ=↓ in athletes sOB-R=↑ in athletes Adiponectin=↑ in athletes Leptin =↓ in athletes	Leptin bioavailability rather than crude serum concentration is involved in the adaptive response of thyroid function in professional athletes.

Author	Participants	Protocol, Methods	Sampling	Outcomes	Results	Conclusions
Smallridge et al. 1985	Sedentary men (n=20) Joggers (n=22) Marathoners (n=18)	Bruce Protocol	Before; Immediately POST; 1hr POST;	T4, T3, rT3, TSH, prolactin	No Sig change in any of the TH parameters	TSH secretion and serum TH concentrations are unaltered by maximal treadmill EX or Phys Cond.
Sander et al. 1988	Well-trained male runners (n=16)	Marathon race	Before; immediately POST; 1hrPOST; 22hrsPOST	TSH, T4, T3, rT3, fT4, T3uptake,	TSH increased after race T3 Decreased after race	
Thong et al. 2000	Female athletes (N=39) Elite Non-Cyclic (n=5) Elite Cyclic (n=8) Rec Cyclic (n=13) Rec Contraceptive (n=13)	Descriptive Study	Descriptive	T3, T4	T4=EAA ↓ vs RCA,ECA,ROC T3= EAA ↓ vs RCA,ECA,ROC ↔ dif in T4,T3 between RCA vs ECA -Energy availability was 50% kcal day / LBM the intake compared to elite intake. -Sig correlation between leptin and TH	
Hackney & Dobridge. 2009	Male endurance trained athletes (n=22)	Prolonged treadmill run @ VT until exhaustion	BL, Exhaustion, 30, 60, 90 min recovery, and 24 hrs post EX	fT3, fT4, TSH, cortisol, prolactin	TSH=↑at exhaustion; ↓at 24hr vs BL fT4=↑at exhaustion fT3=↑at exhaustion; ↓at 24hr vs BL Cortisol=↑at exhaustion, 30, 60 min post ↓ at 24hr vs BL Prolactin=↑at exhaustion, 30, 60 min post Cortisol @ exhaustion and TSH, fT3 24hrs	-Sig reduction in key TH after exhaustive exercise 24 hrs post. The reduction in TH are negatively related to the elevations in cortisol and are temporally delayed -Men participating in endurance training may need longer than 24hrs to completely recover from demanding exercise
Simsch et al 2002	Well trained male rowers (n=6)	3wks heavy RT, 1 wk R (1) crossover to 3weeks ET, 1 wk R (2)	Taken at BL, after RT, R1, ET, R2	TSH, fT3, fT4, Cortisol, Leptin	TSH= ↓ after RT ↓ after R1 ↑at start of ET ↑from ET-R2 fT3= ↓ after ET fT4= ↔ no change Leptin=↓ after RT and into R1	Leptin ↓ during the high intensity RT. Speculated the ↓ in TSH and peripheral TH due to lower HTP hormones and is related to lowered leptin levels as a energy saving mechanism.
Hohtari et al. 1987	Female runners (n=18) Controls (n=12) Female joggers (n=13) Controls (n=11)	Descriptive Determine seasonal variation in TH, Luteal phase, and light and hard training season	Autumn, Spring	TSH, T4, fT4, T3, TBG	TSH=↔ no change between runners & controls during seasons. It was ↑in spring than autumn T4=↓ runners vs Controls fT4=↓ runners vs Controls T3=↓ runners vs Controls	Exercise does not alter TSH, However does lower T4, and therefore slight function of thyroid gland. In spring pituitary axis function was activated.

Author	Participants	Protocol, Methods	Sampling	Outcomes	Results	Conclusions
Loucks et al. 1992	Female Cyclic athletes (n=9) Amenorrhea Athletes (n=9) Cyclic Sedentary (n=9)	Descriptive	Fasting, Resting samples	T4, fT4, T3, fT3, rT3, TBG, TSH	T4=↓ in AA vs CS; =↓ in CA vs CS T3=↓ in AA vs CS fT4=↓ in AA vs CS&CA fT3=↓ in AA vs CS&CA rT3=↓ in AA vs CA TBG=↔ no change between groups TSH= was not different	Athletes with amenorrhea all TH were lower than controls. In CA only T4 was lower than Control. Chronic exercise associated with low T4 levels without changes in H-P-T axis. However, a reduction of all circulating thyroid hormones in women athletes with amenorrhea
Roemmich & Sinning 1997	9 adolescent wrestlers 7 rec. active controls	Descriptive effect of dietary restriction on growth related hormones	Pre-season, Late season, 3.5 months after post season	T4, T3	No difference in TH between controls and wrestlers or over time	Under nutrition may alter GH-IGF-1 axis, but in this study so difference in TH
Hesse et al. 1989	3 long distance runs. 75km run n=13 45km run n=41 marathon n=9	Descriptive Between different runs	Before, and Within 10 of end of run	TSH, T3, T4, rT3	TSH ↓ after 45 km run ↔ after marathon T4 ↑ in 75 km & marathon ↓ after 45 km run T3 ↔ in 75 km & marathon ↓ after 45 km run	The stressful stimulus of the longer runs resulted in increased T4, and no change in TSH and T3. Authors noticed a sig association of TH and age, such that increased age resulted in lower levels of TH. Possible a reduction in training adaptation due to age.
Tremblay et al 1997	7 pairs of sedentary monozygotic twins	93 day exercise protocol 2 cycle ergometer sessions per day at 50-55% of VO2 max for 93 days	Before and After	T4, fT4, T3, fT3, RMR	T4 ↓ after 93 days T3 ↓ after 93 days fT3 ↓ after 93 days fT4 ↔ after 93 days Less variation within twin pairs vs between in T4	RMR can decrease despite no decreases in lean mass. The decrease is associated with a decrease in TH. There substantial variations in this response, primarily do to genetic influences.
Lucia et al. 2001	9 professional road cyclists	20 min cycle ergometer test at 80% of VO2max	Before and After	TSH, T3, T4	Plasma T3 and T4 were inversely correlated with a change in slow component VO2	During sub-maximal exercise the magnitude of slow component VO2 decreases with increased levels of TH.
Steinacker et al. 2005	Review	Review Considering the huge storage capacity for T, and T4 In the body, it is clear that these peripheral hormones change slowly and are not Metabolism and Thyroid Hormones sensitive enough for monitoring of training	Review The down regulation of the thyroid axis, a shortage of fT3 develops, which saves energy.	Review This effect on thyroid hormones may have an impact on skeletal muscle, and thereby on muscular training response	Faster, stronger and glycolytic type of muscle. In general, TH, increases muscular contractility and forced generation of muscle. In hypothyroidism, muscles are weak, while reflex activity and neuromuscular function are depressed. There has been some discussion as to whether the weakness reported during overtraining partly resembles hypothyroidism.	Thyroid hormones and the thyroid hormone receptors are strongly involved in the training process and related catabolic processes in skeletal muscle and fat tissue; however, many questions remain as to which should be examined in further studies

Author	Participants	Protocol, Methods	Sampling	Outcomes	Results	Conclusions
Schmid et al. 1982	14 runners. 20 divers	Maximal treadmill an bike test., sub-max test only in divers	Before, Post, 15 min Post	TSH, T3, rT3, fT4	TSH ↓ Post, ↓ 15post BL T3 ↑Post, (did not increase in ergometry) ↓ 15post BL rT3 ↔ fT4 ↓ Post, ↓ 15post BL Sub max= TSH ↑during EX, T3 ↓15 min Post	The rise in T3 in MPE may be due to hemococoncentration, And decrease in f4 due to cellular utilization
Boyden et al. 1984	17 recreationally active women	Increased running from 48 km (8.5 mo of training) for 2 weeks; again 80km (13.5mo of training above BL for 2 weeks	Baseline 8.5 mo, and 13.5 mo	T3 T4 rT3, TSH	T4 ↑ from 48km-80km rT3 ↑ from 48-80km TSH ↑from 48km-80km	Important diff between prolonged stress and other stress conditions assoc. with iodothyronine changes
Lee et al. 2009	Untrained Male participants (n=9)	Examine the effect of a 12 wk endurance training program on RMR.	Before and After	VO2, RMR, T4, fT4	T4 no change fT4 decreased after training	The ↓ in fT4 observed in the Exercise group did not seem to affect RMR.
Thompson et al. 1995	10 highly trained endurance male athletes. (6 low energy intake, 4 adequate intake)	Screened for dietary habits. Daily energy Expenditure. (24hr, resting, sleeping)	Descriptive	T3, fT4, EE	T3 no sig difference between groups fT4 levels were sig lower in Low dietary group compared to ADQ.	-LOW athletes maintain BM on ↓ than energy intakes due, in part, to a ↓ sedentary 24-h EE. -Possible mechanisms of ↓ 24-h EE in LOW athletes ; ↓ fT4, genetics, and ↓ TEF.

- Baylor L, Hackney A. Resting thyroid and leptin hormone changes in women following intense , prolonged exercise training. *Eur J Appl Physiol* 2003;88:480-4.
- Boyden TW, Pamerter RW, Rotkis TC, StanforthH P, Wilmore JH. Thyroidal changes associated with endurance training in women. *Med Sci Sport Exerc* 1984;16(3):243-6.
- Ciloglu F, Peker I, Pehlivan A, et al. Exercise intensity and its effects on thyroid hormones. *Neuroendocrinol Lett* 2005;26(6):830-4.
- Hackney AC, Dobridge JD. Thyroid hormones and the interrelationship of cortisol and prolactin: influence of prolonged, exhaustive exercise. *Polish J Endocrinol* 2009;60(4):252-7.
- Hackney AC, Kallman A, Hosick KP, Rubin D a, Battaglini CL. Thyroid hormonal responses to intensive interval versus steady-state endurance exercise sessions. *Hormones* 2012;11(1):54-60.
- Harber VJ, Peterson SR, Chillibeck PD. Thyroid Hormone Concentrations and Muscle Metabolism in Amenorrheic and Eumenorrheic Athletes. *Can J Appl Physiol* 1998;23(3):293-306.
- Hesse V, Vilser C, Scheibe J, Jahreis G, Foley T. Thyroid Hormone Metabolism under Extreme Body Exercises. *Exp Clin Endocrinol* 1989;94:82-8.
- Hohtari H, Pakarinen a, Kauppila a. Serum concentrations of thyrotropin, thyroxine, triiodothyronine and thyroxine binding globulin in female endurance runners and joggers. *Acta Endocrinol (Copenh)* 1987;114(1):41-6.
- Lee M-G, Sedlock D a, Flynn MG, Kamimori GH. Resting metabolic rate after endurance exercise training. *Med Sci Sports Exerc* 2009;41(7):1444-51.
- Loucks A, Callister R. Induction and prevention of low-T3 syndrome in exercising women. *Am J Physiol* 1993;264(33):R924-30.
- Loucks A, Laughlin G, Mortola J, Girton L, Nelson J, Yen S. Hypothalamic-Pituitary-Thyroidal Function in Eumenorrheic and Amenorrheic Athletes. *J Clin Endocrinol Metab* 1992;75(2):514-8.
- Lucia A, Hoyos J, Perez M, Chicharro JL. Thyroid Hormones May Influence the Slow Component of VO2 in Professional Cyclists. *Jpn J Physiol* 2001;51:239-42.
- Perseghin G, Lattuada G, Ragona F, Alberti G, La Torre A, Luzi L. Free leptin index and thyroid function in male highly trained athletes. *Eur J Endocrinol* 2009;161(6):871-6.
- Roemmich JN, Sinning WE. Weight loss and wrestling training: effects on growth-related hormones. *J Appl Physiol* 1997;82(6):1760-4.
- Sander M, Röcker L. Influence of marathon running on thyroid hormones. *Int J Sports Med* 1988;9(2):123-6.
- Schmid P, Wolf W, Pilger E, et al. TSH, T3, rT3 and fT4 in Maximal and Submaximal Physical Exercise. *Eur J Appl Physiol* 1982;48:31-9.
- Simsch C, Lormes W, Peterson K, et al. Training Intensity Influences Leptin and Thyroid Hormones in Highly Trained Rowers. *Int J Sports Med* 2002;23:422-7.
- Smallridge RC, Whorton NE, Burman KD, Ferguson EW. Effects of exercise and physical fitness on the pituitary-thyroid axis and on prolactin secretion in male runners. *Metabolism* 1985;34(10):949-54.
- Steinacker J, Bricic M, Simsch C, et al. Thyroid hormones, cytokines, physical training and metabolic control. *Horm Metab Res* 2005;37:538-44.
- Thompson JL, Manore MM, Skinner JS, Ravussin E, Spraul M. Daily energy expenditure in male endurance athletes with differing energy intakes. *Med Sci Sport Exerc* 1995;27(3):347-54.
- Thong FS, McLean C, Graham TE. Plasma leptin in female athletes: relationship with body fat, reproductive, nutritional, and endocrine factors. *J Appl Physiol* 2000;88(6):2037-44.
- Tremblay A, Poehlman ET, Despres JP, Theriault G, Danforth E, Bouchard C. Endurance training with constant energy intake in identical twins: changes over time in energy expenditure and related hormones. *Metabolism* 1997;46(5):499-503.

APPENDIX C

Initial _____ Date _____ Page 1 of 4

The University of Rhode Island
Department of Kinesiology, 25 West Independence Square, Suite P, Kingston, RI
02881
Department of Nutrition and Food Science, 112 Ranger Hall; Kingston, RI 02881

Energy Balance, Health, and Performance in URI Endurance Athletes

CONSENT FORM FOR RESEARCH

You are invited to take part in a research study. The researcher will explain the project to you in detail. You should feel free to ask questions. If you have more questions later, Dr. Hatfield (phone: 401-874-5183), or Ryan or Justin (Phone: 401-874-2980), from the Department of Kinesiology, or Dr. Kathleen Melanson (Office Phone: 401-874-4477), from the Department of Nutrition and Food Sciences, the individuals mainly responsible for this study, will discuss them with you. You must be between 18 and 28 years old to be in this research project.

Description of the project:

You have been asked to take part in the study that will attempt to identify and integrate many factors that influence 'calories-in and calories-out' during your regular training and competitive season. The purpose of the study is to understand how this calorie balance might impact health and performance. Tests include blood collection, treadmill exercise testing, daily physical activity, body composition, questionnaires and nutritional factors. The specific objective of the study is to compare your calorie balance and things that might influence it during the early, mid-, and late seasonal phase.

Exclusion criteria:

Taking drugs that act as performance enhancers or interfere with the validity or reliability of information collected in this study will exclude participation in the study. Pregnant women or nursing will also be excluded for participation.

What will be done:

If you decide to take part in this study here is what will happen:
Some tests will be conducted at all three phases of the season, and some only during early and late phases.

The following tests will be conducted during a visit at early phase only.

- VO₂max (~20-30minutes)- For this test we will ask you to run on a treadmill at 6-8 mph for 4 minutes at a 0% grade. After 4 minutes, the grade will be increased to 4% for 2 minutes. The grade will then be increased 2% every w minutes until the you can't run and more.

The following tests will be conducted during a visit at early and late phases only. For these visits you will need to abstain from eating and exercising for 12 hours, and report to the Human Performance Laboratory (Suite P, Independence Square) in the morning:

- Blood Collection (~5 minutes) - Approximate 30 ml of blood (approximately 2 tablespoons of blood) will be collected during each of the 3 to 5 visits. A certified health professional will take a blood sample. The blood sample will be used to assess iron levels and some hormones associated with calorie balance (thyroid, cortisol, growth hormone).
- Body Composition (20-30 minutes) – Following a height, weight, and waist circumference measurements, your body fat and muscle content will be determined using dual-energy x-ray absorptiometry (iDXA) using fan-beam technology (GE Lunar iDXA, Madison, WI) operated by a certified health professional. DEXA uses two low energy x-rays which scan the body and determine body composition, including bone mineral density. Even though the DEXA uses two x-rays the energy of the x-rays is very low, and radiation exposure is significantly lower than a typical x-ray. The amount of radiation you will be exposed to on each visit is comparable to visiting New York City for a day, and is slightly less than a normal chest x-ray. Even though the DEXA emits only small amounts of radiation, as a precaution often used with x-ray testing, women who are pregnant may not participate to prevent harm to the fetus. For that reason, we have to ask you to give us a urine sample in the lab to do a pregnancy test, even if you don't think you need one.

For the DEXA scan, you will be asked to change into a set of medical scrubs, and lay flat on the DEXA panel. A strap will be placed around your ankles to aid in maintaining proper body position during the scan. You will lay as still as possible while an arm which emits the x-rays passes over your body and scans it. A typical DEXA scan lasts approximately 10 minutes.

The following tests will be conducted at all three phases (early, mid, late):

- Vertical Jump (10 minutes): We will want to measure how high you can jump. Before you do these exercises, you can warm-up on a stationary bike and do some dynamic stretches. To measure jump height and power, we will ask you to perform 3 jumps in a row as high and as fast as you can on a platform that will record your power and jump height. We will ask you to do that 3 times, resting in between each 3-jump set, so we can use your best scores.
- Assessment/Survey Forms – You be asked to complete the following forms:
 - *Food Record* – You will be instructed on how to complete an accurate food record, and take with you a 3-day dietary record (2 weekdays and 1 weekend day) form, used to fill out the foods and beverages that you consume. Each 3-day dietary record should take a total of approximately 10 minutes a day.

- *Fatigue, stress, and sleep quality questionnaires* – you will be asked to fill out questionnaires that attempt to determine your levels of fatigue, stress, and sleep quality. These questionnaires take between 8 – 12 minutes to complete.
- Physical Activity - You will be asked to wear a monitor (accelerometer) to measure physical activity during waking hours for 5-7 days. You will record when you wore it in your exercise diary.

The following tests will be conducted at various times throughout the study:

- Training & Performance Log – The training diary will be used to track your workouts and competitions. For any meets you compete in you will record the events you participated in and your times. You can fill this out at home, during the competitions or at the workouts. The activity log takes 5 – 10 minutes each time you fill it out.
- Body temperature and heart rate (5 minutes): We are going to ask you to take your temperature with an oral thermometer (which we will give you) and your heart rate (beats per minute) for 30 seconds measured by wrist palpitation first thing in the morning. We will ask you to do this before you get out of bed, so it is as close to resting measurements as possible. We will ask you to do these measurements for the duration of the study. After you take these measurements, we will ask you to write them down in a log for us.
- Fatigue, stress, and sleep quality questionnaires: You will be asked to fill out questionnaires that attempt to determine your levels of fatigue, stress, and sleep quality once a week. These questionnaires take between 8 – 12 minutes to complete.
- Phone Calls – Prior to each visit you will receive phone calls from a researcher who will set up your assessment date and agenda.

Risks or discomfort:

No known risks or discomforts have been identified for responding to the questionnaires, measuring height, weight, body temperature, heart rate, diet or physical activity.

There are some risks to having bone density tested because a DEXA uses a similar kind of radiation that an x-ray does. Total radiation exposure for the whole study (one DEXA before and after the study) is almost the same as one and a half chest x-rays or four cross-country flights

The blood draw uses a sterile technique performed by an experienced clinician. However, there are a few risks with a blood draw that include bruising, formation of a clot, infection, and discomfort from the needle. Fainting is also considered a risk factor during blood collection.

As with regular exercise, there is a slight risk of muscular injury in performing the vertical jump test and VO_{2max} tests. However, these risks are minimal, and are not greater than what would incur during your normal training routine.

Benefits of this study:

You will gain general knowledge regarding nutrition, sleep patterns, body composition, and physiological and blood measurements that affect performance. You will also gain

knowledge about your diet and nutrition, body composition, blood and physiological and blood measurements that, blended with the general knowledge may benefit your performance. In addition, you will not be charged for any of the tests that we ask you to perform.

Confidentiality:

Your participation in this study is confidential. None of the information will identify you by name. Your name will not be linked to any study data or anyone except the principal investigators of this study. None of the study data will be known to anyone except the primary investigators (Dr.'s Hatfield, Melanson, Reibe and Justin and Ryan). All study data and consent forms will be kept in a locked file cabinet in the Kinesiology suite (Independence Square building, Suite P, room 221).

Computer-based data will be kept on a password-protected computer (Independence Square building, Suite P, room 221). The researchers will be the only people who have access to these records.

In case there is any injury to the subject:

If this study causes you any injury, you should write or call the principal investigators, Drs. Disa hatfield (401) 874-5183, or Kathleen Melanson (401) 874-4477. You may also call the office of the Vice President for Research, 70 Lower College Road, University of Rhode Island, Kingston, Rhode Island; telephone: (401) 874-4328.

Decision to quit at any time:

The decision to take part in this study is entirely of your own volition. You do not have to participate in this study. If you decide to take part in the study, you may quit at any time. Withdrawing from the study will not affect your status on the University of Rhode Island's Track or Cross Country Team. Whatever you decide you will in no way be penalized. If you wish to quit, simply inform Justin or Ryan (401) 874-2980 or Dr. Hatfield at (401) 874-5183 of your decision.

Rights and Complaints:

If you have any questions about your rights as a research subject, you may call Drs. Disa Hatfield (401) 874-5183, or Kathleen Melanson (401) 874-4477, anonymously, if you choose. In addition, you may contact the office of the Vice President for Research, 70 Lower College Road, Suite 2, University of Rhode Island, Kingston, Rhode Island, at (401) 874-4328.

You have read and understood the information above in the Consent Form and have been given adequate opportunity to ask the investigators any questions you have about the study. Your questions, if any, have been answered by the investigators to your satisfaction. Your signature on this form means that you understand the information and you agree to voluntarily participate in this study.

Signature of Participant

Signature of Researcher

Typed/printed Name

Typed/printed name

Date

Date

Blood Sample Collection

By signing below you understand that your blood sample and information derived from it may be stored for up to 5 years and may be used for potential future studies by the principal investigators Dr's Hatfield, Melanson, and Reibe, but only in research studies that examine health in endurance athletes. There will be no expected benefit to you from this analysis since you will not be provided with any result or information from your blood test. If any of your blood chemistries are reported to be out-of-normal range, you will be promptly notified.

Signature of Participant

Signature of Researcher

Typed/printed Name

Typed/printed name

Date

Date

Please sign both consent forms and keep one for yourself

APPENDIX D

ENERGY METABOLISM LAB FOOD RECORD

NFS Department, University of Rhode Island

Accurately determining portion sizes and amounts

The most accurate way to determine portion size is to weigh and measure foods and beverages using measuring cups and spoons. The following guidelines will assist you in choosing how to describe and measure portion sizes.

Guidelines for describing and measuring foods

<u>FOODS</u> <u>WITH:</u>	<u>MEASURE & DESCRIBE</u>
Vegetables, fruit cup, pasta, rice, casseroles, ice cream, pudding, margarine, and all liquids including beverages, soups, gravies, salad dressing	measuring cups (c) teaspoons (tsp) Tablespoons (Tbs)
Any solid food such as meat, cheese or (oz) frozen entrees	weight in grams (gm) or ounces
Pie, cantaloupe, other melons melon)	fraction of the whole (Ex: 1/8 of 9" pie, 1/4 of 6"
Liquids	Fluid ounces or cups

I. "Guesstimating" Guidelines

Since measuring is not always possible or practical, there are times when "guesstimating" will suffice. Use the following guidelines to help you determine portion sizes when you're not able to weigh or measure.

- A woman's fist is about a cup.
- A man's fist is about 1-1/2 cups.
- The cupped palm of an adult's fist holds about one-half cup.
- 3 ounces of cooked meat is similar in size to a standard deck of cards.
- A one-ounce meatball is approximately the size of a golf ball.
- A McDonald's plain hamburger patty is 2 ounces of cooked meat.
- The average cooked chicken breast weighs between 3 and 4 ounces.
- A Kraft American single is a one-ounce slice of cheese.
- The standard slice of bologna is one ounce.
- A package of peanuts that you'd get on an airplane is a one-ounce package.
- A frozen Lender's bagel is two ounces. Most other bagels are three to four ounces.

Measurement conversion information

Common household measures

3 teaspoons = 1 Tablespoon

tsp

4 Tablespoons = 1/4 cup

Tbsp

5-1/3 Tablespoons = 1/3 cup

8 Tablespoons = 1/2 cup

oz

10 2/3 Tablespoons = 2/3 cup

oz

12 Tablespoons = 3/4 cup

16 Tablespoons = 1 cup

gm

1/2 fluid ounce = 1 Tablespoon

1 fluid ounce = 2 Tablespoons

2 fluid ounces = 1/4 cup

4 fluid ounces = 1/2 cup

6 fluid ounces = 3/4 cup

8 fluid ounces = 1 cup

16 fluid ounces = 2 cups

2 cups = 1 pint

1 ounce (oz.) = 28.4 grams

1 pound (lb.) = 16 ounces

1/4 pound = 4 ounces

Abbreviations

teaspoon =

Tablespoon =

cup = C

ounce =

fluid ounce = fl

pound = lb

grams =

FOOD INTAKE RECORD FORM *EXAMPLE*

Name: Volunteer Date: 10/04/09, Thursday Visit: 1 (circle)

Time	Amount	Full Description of Food or Beverage Consumed
7:10 am	8 fl-oz	Orange juice, from frozen concentrate, prep
	1 cup	Kellogg's Crispix cereal
	1/2 cup	2% milk (vitamin A & D fortified)
	2 teaspoons	sugar
	1 cup	Black coffee
10:00am	12 fl-oz can	Diet Coke
12:15pm	2 slices	Pepperidge Farm whole grain oatmeal bread
	2 leaves	Iceberg lettuce
	1 tablespoon	Mayonnaise, Cain's regular
	1 medium	Fresh pear
	1 cup	2% milk (vitamin A & D fortified)
2:30 pm	12 oz can	Orange Fanta, regular
6:30pm	6 oz	Pork chop, broiled
	1 medium	Baked potato
	2 tablespoons	Margarine, Blue Bonnet Soft, Low-Sodium
	5 inner leaves	Romaine lettuce
	4 slices	Fresh red tomato (1/4" thick)
	2 tablespoons	Ranch Dressing, Hellman's Creamy Lite
	1/2 cup	Frozen peas, cooked in microwave (Shaw's)
	1 cup	Whole milk (vitamin A, D & calcium fortified)
	1/8 of 9" diam.	Homemade cherry pie
9:10 pm	1 large	Fresh Granny Smith Apple
	1 -12 ounce glass	Mineral water, Adirondack Sparkling
	1 each	Bagel, plain (3 oz-wt size)

Name: _____ Date: _____ Day: _____ 1 2 3 4
5 (circle)

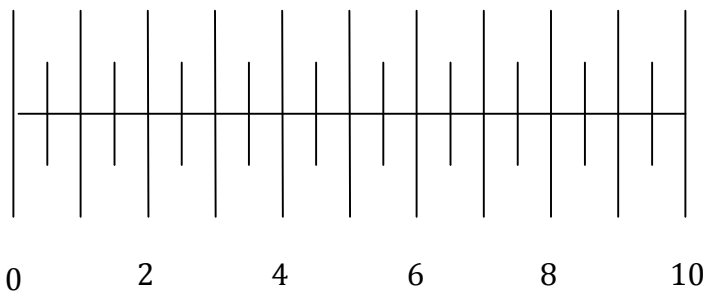
Time	AMOUNT	Complete <i>DESCRIPTION</i> of food/beverage

APPENDIX E

Subject Number:

Date:

Instructions: Place a vertical mark on the horizontal visual analog scale below and circle a number on the categorical scale. The number does not have to be one of the whole numbers already written, you can write in a more accurate number that corresponds to your fatigue/soreness. In addition, magnitude estimation above 10 is possible if you feel that your fatigue/soreness is beyond what you have experienced before.

Fatigue Rating Scale							
							
0	2						
4	6						
8	10						
No fatigue	Maximal fatigue						
<div style="border: 1px solid black; padding: 5px;"><table border="0" style="width: 100%;"><tr><td style="padding: 2px 5px;">1- Very light fatigue</td></tr><tr><td style="padding: 2px 5px;">2- Light (weak) feelings of fatigue</td></tr><tr><td style="padding: 2px 5px;">3- Moderate fatigue</td></tr><tr><td style="padding: 2px 5px;">5- Heavy (strong) feelings of fatigue</td></tr><tr><td style="padding: 2px 5px;">7- Very heavy feeling of fatigue</td></tr><tr><td style="padding: 2px 5px;">10- Maximal fatigue</td></tr></table></div>		1- Very light fatigue	2- Light (weak) feelings of fatigue	3- Moderate fatigue	5- Heavy (strong) feelings of fatigue	7- Very heavy feeling of fatigue	10- Maximal fatigue
1- Very light fatigue							
2- Light (weak) feelings of fatigue							
3- Moderate fatigue							
5- Heavy (strong) feelings of fatigue							
7- Very heavy feeling of fatigue							
10- Maximal fatigue							