WITHIN DAY ENERGY BALANCE IN ELITE SWIMMERS: EFFECTS ON HEALTH AND PERFORMANCE

HANNAH CANIL
SPRING 2020

A thesis
submitted in partial fulfillment
of the requirements
with baccalaureate degrees in Science and Nutritional Science
with honors in Nutritional Sciences

Reviewed and approved* by the following:

Nancy Williams
Professor of Kinesiology
Thesis Supervisor

Alison Gernand
Assistant Professor of Nutritional Sciences
Honors Adviser

* Electronic approvals are on file in the Schre yer Honors College.
ABSTRACT

Energy Balance is defined as the difference between energy intake and energy expenditure over a 24 hour period. Adequate energy balance is important for an athlete's health and exercise performance, and negative energy balance has been linked to hormonal imbalances, poor bone mass, and metabolic suppression. Energy balance is typically calculated and studied in 24 hour intervals with 24 hour energy balance as the "functional unit" of energy status. Recently however, the occurrence of negative energy balance for long periods during the day, even if the overall energy balance for the day is zero or neutral, has drawn the attention of researchers who are interested in finding whether long "within day" periods of negative energy balance are detrimental to athletes' health and performance. Within day negative energy balance has since been related to negative changes in body composition in elite athletes, and menstrual cycle disturbances in elite female athletes. The purpose of this study was to determine the effects of differences in within day energy balance on a variety of outcomes, particularly with regards to whether long periods of negative energy balance throughout the day are related to declines in athlete performance. Furthermore, it was hypothesized that in Division I swimmers, a negative correlation exists between the total number of hours spent in an energy deficit (defined as >-300 kcal for females and >-400 kcals for males) and signs of metabolic suppression including a reduced ratio of actual to predicted resting metabolic rate.

The study employed WHOOP wearable technology (WHOOP Inc., Boston, MA) and compared the resting metabolic rates (RMRs), metabolic hormone levels of total triiodothyronine (TT₃), within-day energy balance (WDEB), body composition measured by a dual energy x-ray absorptiometry (DXA) scan, performance, perceived stress, and recovery of Division 1 Penn State Swimmers to determine if signs of metabolic suppression and the results of a time trial for
swimming performance were predicted by WDEB. The findings showed that there was no statistically significant association between the number of hours spent in an energy deficit and signs of metabolic suppression, defined by TT₃ and the ratio of actual to predicted RMR. There was, however, a statistically significant positive correlation (R=0.441, p= 0.031) between the consecutive number of hours in a day spent in negative energy balance and athlete performance in a 200 yard freestyle time trial such that time in the event was slower with more hours spent in a deficit. Additionally, a statistically significant negative correlation (R= -.409, p=0.047) was found between total daily energy balance and performance in a 200 yard freestyle time trial such that the more negative the total daily energy balance, the slower the performance. Long periods of going without eating or eating very little throughout the day may be associated with poorer performance in elite collegiate swimmers.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF FIGURES</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>v</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>vi</td>
</tr>
<tr>
<td>Chapter 1 Review of Literature</td>
<td>1</td>
</tr>
<tr>
<td>Chapter 2 Introduction</td>
<td>11</td>
</tr>
<tr>
<td>Chapter 3 Materials and Methods</td>
<td>13</td>
</tr>
<tr>
<td>Chapter 4 Results</td>
<td>23</td>
</tr>
<tr>
<td>Chapter 5 Discussion</td>
<td>29</td>
</tr>
<tr>
<td>References</td>
<td>36</td>
</tr>
<tr>
<td>Academic Vita</td>
<td>41</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1 Individual Subject Average WDEB Data Example........................................22
Figure 2 Consecutive Hours in and Energy Deficit and Time Trial Performance............27
Figure 3 Total Daily Energy Balance and Time Trial Performance..............................28
LIST OF TABLES

Table 1. WDEB Variables and Considerations ................................................................. 20
Table 2 Example WDEB over 24 Hours .................................................................................. 21
Table 3 Subject Data: Demographics, Metabolism, Hormones, and WDEB Variables ............. 26
Table 4 Swimming Performance in 200 yard Time Trial and WDEB ..................................... 27
I would like to take a moment to thank all of the people who supported me in my studies, and those who helped this thesis become a reality!

Emily Lundstrom- I do not think I would have been able to write this without your help! Thank you for being a supportive graduate supervisor and basically giving me the crash-course statistics reminder I needed to analyze our data. I am glad I got to assist you in this project! Being able to observe a swim practice was pretty amazing too, so thank you for trusting me to be your assistant in this lab and for accomplishing all that you have.

Ellen Bingham- Thank you for taking me under your wing and helping me get the hang of things in the WHEL lab! I learned so much from you and will always be grateful for your role in my academic career. I will always cherish the times I had with you at Noll, thank you for all of your help!

Dr. Nancy Williams- Thank you for allowing me to work in your lab and taking a chance on me. You allowed me to pursue my passion for exercise science while I dual-majored in Biological Sciences and Nutrition, and that was an amazing opportunity to come by. I would not have had the same undergraduate thesis experience without you!

Kristen Koltun and Nicole Strock- Thank you for letting me be a fly on the wall in the graduate student offices, and for always being willing to answer my questions when they popped up! I am glad I got to see what you do at the lab, and I look forward to reading all that you publish in the future!

To the entire WHEL staff — thank you! Thank you for your support in our project and for everything you did, both seen and unseen, to help along the way.
To the Penn State Swim and Dive Team and Staff, thank you for your participation in this project! It was an honor to work with you and truly a once in a lifetime opportunity. I will never forget this experience! And thank you for letting me watch a practice for your time trials, it was amazing to see such elite athletes perform.

Dr. Alison Gernand- As my Honor’s Advisor, I would have been lost without you. You were so incredibly helpful from the moment I decided to take up a concurrent major in Nutrition, and none of it would have been the same without you. Thank you for your support and advice throughout my studies, and for seeing me through this journey!

Professor Kayla Martin- Although I only got to fully experience your class for part of the semester (thanks to the global pandemic) your Sports Nutrition course reminded me of the importance of what I was doing throughout the most difficult parts of the research process. I want to thank you for the work you are doing in your field, aided by research like this, that is making a better and healthier space for athletes everywhere.

Lastly, I would like to thank my family (with an extra thank you to my Mom, Dad, and Jillian!) and my friends for being a source of unwavering support as I took on this project. Thank you for believing in me, and for sharing me with the lab during my senior year!
Chapter 1
Review of Literature

Introduction

In the literature, energy balance has been found to relate to both an athlete's health and exercise performance. This relationship is evidenced by biomarkers such as resting metabolic rate, menstrual status, bone health, and metabolic hormone levels. Reductions in resting metabolic rate represent one initial metabolic adaptation by the body that precedes the suppression of reproductive function and decreases in bone formation. However, current research largely focuses on energy balance on a day to day basis, such that 24 hour energy balance is considered to be the "functional unit" of energy status. Gaps in the literature exist with regards to whether periods of “within day energy balance,” i.e. not simple 24-hour “blocks” are correlated with an athlete’s health and performance in the same way as overall daily energy balance. In research revisiting energy thermodynamics, Benardot (2013) highlights the importance of re-assessing the functional unit of energy balance to account for within-day energy intake and expenditure. The traditional 24-hour unit does not account for the fluctuations in meal time, exercise, or hormonal responses to caloric deficits/surpluses. For example, one could eat an 1800 kcal meal at the end of a 24-hour period and exhibit perfect energy balance if they had expended a total of 1800 kcal in that time frame. However, the 24-hour profile would not demonstrate the effect the resulting energy deficit would have throughout the entirety of the day. As the Division 1 athletic population experiences large periods of energy expenditure
throughout the day, it is important to analyze energy balance throughout the day to understand the effects it has on athlete health and performance.

**Components of Energy Balance**

Energy, as it relates to the human body, maintains the same principles as the First Law of Thermodynamics: namely that energy cannot be created or destroyed, only transferred or transformed. In the body, energy is taken in from ingested food, and is transformed to support complex physiological actions.¹ There are many components to physiologically utilized energy. Total daily energy expenditure (TEE) is the sum of these components. It is made up of exercise energy expenditure (EEE), exercise post-oxygen consumption (EPOC), diet induced thermogenesis (DIT), sleep energy expenditure (SEE), resting energy expenditure (REE), and non-exercise activity thermogenesis (NEAT).²

Exercise energy expenditure (EEE) is defined as the energy spent during purposeful exercise. In the athletic population, this component is a very large portion of total energy expenditure (15-30%), and often leaves athletes with little energy available for regulatory body functions.¹⁰,¹¹ Exercise energy expenditure is dependent on the body composition of the individual, where individuals with more lean mass would expend a higher caloric output than individuals with lower quantities of lean mass. For example, aerobic exercise such as distance running or swimming is often a more “calorically expensive” exercise as opposed to its resistance training counterparts.¹² Swimmers perform work for a longer period of time at a higher heart rate, resulting in a continuously high heart rate stimulus vs. intermittent heart rate increases. Overall, this translates to expending more calories, i.e., the direct energy expenditure of an endurance activity is higher. After an intense bout of exercise, exercise energy expenditure creates a lingering affect defined as “EPOC;” exercise post-oxygen energy consumption.
Estimates of EPOC can be derived by taking 5% of EEE during the first hour after exercise, and 3% of EEE during the second hour after exercise to account for the energy expended during recovery after the exercise bout is completed.2,13

DIT is the energy required to metabolize food. Reed and Hill (1996) studied this component of 24 hour energy expenditure and found that calories expended to metabolize food following a meal or snack decline as time passes.14 Their findings state that this effect is best categorized into the 6 hours following consumption. They developed an estimation of the pattern of energy expended after a meal where the area under the curve best represents the total DIT. The estimation is a total of 10% of TEE, distributed between 6 hours after a meal as follows: 60% of the DIT is within the first 3 hours, 78% within 4 hours, and 91% by 5 hours.14

Sleep energy expenditure is defined as 90% of the Cunningham fat-free mass (FFM) predicted resting metabolic rate (RMR). In research by Torstveit et al. (2018) studying male endurance athletes, 2 SEE differs from RMR (at 90% of this value) as RMR must still account for “awake” variables, such as higher brain metabolic tissue activity and a higher heart rate.2

Resting energy expenditure is determined by resting metabolic rate (RMR). This is a measure of energy expended when the body is completely at rest, representing 60-80% of TEE.10 This measure can be adapted by physiological stressors. In cases of high athleticism such as Division 1 collegiate athletes, it is possible that an individual’s RMR becomes suppressed in order to preserve metabolic homeostasis within the body.11 This may lead to downstream effects in hormones and neural components, as well as metabolism.11 These effects can include undesirable hormone profiles, fatigue, and a decrease in bone density in all athletes, as well as amenorrhea in female athletes.1,3,15,16
Energy Status

Energy Balance (EB) is defined as the difference between energy intake and energy expenditure over a 24 hour period. Adequate energy balance is important for sustaining life, and is also imperative in maintaining an athlete's health and exercise performance. Athletes expend a much higher amount of energy than the average human, and therefore require additional energy intake to maintain this lifestyle. If athletes do not increase their fuel intake to match their energy expenditure, they experience an energy deficit. Inversely, when athletes overcompensate with energy intake, they experience an energy surplus. Within-day negative energy balance has since been related to unfavorable changes in body composition and menstrual cycle disturbances.

EB is typically assessed in 24 hour intervals, looking at the overall difference between dietary energy intake and total energy expenditure throughout that time. However, research by Benardot et al. highlighted the failures that may result from this view of EB, as it is possible for one to appear to be in perfect EB within a 24-hour window by consuming the entirety of the dietary intake at hour 23, having spent 23 hours in an energy deficit. Bernadot et al. state that failure to pay attention to the timing of energy intake and expenditure could limit understanding of within day energy balance (WDEB). Studies by Fahrenholtz et al. and Torstviet et al. have attempted to highlight the importance of WDEB, and their research suggests that WDEB holds more physiological relevance than the traditional 24-hour EB assessment.

To date, the most research on WDEB has been conducted by Torstveit et al. A study focusing on male endurance athletes attempted to highlight the importance of WDEB. The study was composed of male cyclists, distance runners, and triathletes from 18-50 years old. Three days of data collection occurred for health and performance, as well as four consecutive days of
The study found that within-day energy deficiency was associated with a suppressed metabolic rate in this athletic population. In determining metabolic suppression, Torstveit et al. utilized the Cunningham (1980) prediction equation when calculating the RMR ratio, which was used to determine metabolic suppression. This ratio of actual measured RMR to predicted RMR (Cunningham 1980) classifies a metabolic suppression as any ratio less than 0.90.2 Research by De Souza et al. has classified another ratio marker, using a prediction equation from a dual energy x-ray absorptiometry scan that takes into account an individual’s fat-free mass and amount of highly metabolic tissue.18 This ratio has a more specific cutoff of 0.94, which may lend to a more accurate representation of metabolic suppression in subjects.18

The study employed accelerometers and heart rate monitors to gather data on non-exercise activity thermogenesis and exercise energy expenditure. It was mentioned that subjects’ use of these devices was unable to be completely controlled, so there was room for methodological error here.2 The current study aims to address this problem by utilizing the WHOOP band, which is worn on the wrist and automatically gives exercise energy expenditure data. The WHOOP band also gives a measure of total energy expenditure value, while the Torsveit study used mathematical equations to arrive at a total energy expenditure. While the WHOOP has not yet been validated against a gold standard, the technology has the potential to address the problem of accurately recording energy expenditure variables.19,20 The male study also did not link measures of WDEB to athletic performance, which will be explored in the current study. In addition, self-report diet logs were used that required subjects to weigh their food. This study will utilize a mobile application that employs barcode scanning to lessen participant burden in hopes of a more accurate self-report (Under Armour, Inc.; Baltimore, MD).
Research by Fahrenholtz et al. performed a similar assessment of WDEB in female athletes, studying the relationship of WDEB to menstrual cycle disturbances. The study also used self-report diet logs that involved the subjects weighing their own food. The study determined that those with menstrual disturbances spent more time in a catabolic state, evidenced by catabolic hormone markers and a negative WDEB. No relation to athletic performance was made in this study.

In males, a range within +/-400 kcal has been suggested as a significant range wherein energy balance is maintained. In females, that range is +/-300 kcal. These caloric values are of significant importance for the link that exists to the amount of available liver glycogen able to be metabolized from storage. The liver represents the largest glycogen storage organ, but it can only hold so much glucose in the form of glycogen. Once those stores are depleted, the body must turn to fat stores in order to oxidize fats for the process of gluconeogenesis. Further research is needed to establish a more appropriate guideline for determining a significant range within which energy balance is maintained, as these cutoffs were only utilized in two studies conducted by Fahrenholtz et al. (2018) and Torstveit et al. (2018).

A large focus and concern for athletes is the concept of energy availability (EA), defined as “the amount of dietary energy remaining after exercise training for all other metabolic processes.” To quantify EA, the accepted equation is energy intake and subtracting exercise energy expenditure, relative to an individual’s FFM [(EI- (EEE)/kg of fat free mass (FFM)]. In cases where athletes are experiencing a suppressed metabolism (determined by a decreased ratio of actual to predicted RMR), this number is typically lower. Low energy availability (low EA) can have many consequences in the athletic population. The main concern in female athletes is known as the female athlete triad, which is characterized by the following: low energy
availability, disrupted menstrual cycles, and a low bone mineral density.\textsuperscript{22} Research by Lieberman et al. has found that as EA decreases, the chance of menstrual abnormality increases as well.\textsuperscript{15} Studies in exercising non-human primates demonstrated that low EA is causally related to menstrual disturbances.\textsuperscript{16} In addition, it is has been determined that the induction of menstrual disturbances due to low EA is associated with other factors associated with one's metabolic profile, such as decreases in body weight and changes in body composition, a suppression of metabolic hormones (namely total triiodothyronine, or TT\textsubscript{3}), a high prevalence of under-eating (low energy intake), and reductions in resting energy expenditure.\textsuperscript{3,4,22} Male athletes can also experience symptoms of the triad, with associations between low EA, hypothalamic hypogonadism, and low bone mineral density.\textsuperscript{3,22} In both females and males, the triad is associated with low levels of metabolic and reproductive hormones, poor bone health, and suppressed metabolism.\textsuperscript{22} Additionally, reduced performance has been found to correlate with lower TT\textsubscript{3} levels in elite female swimmers, as athletic performance and training maladaptation occur as a result of the triad.

Research has shown that intense training in association with low EA is correlated with these detrimental symptoms of a decreased RMR, declines in metabolic and reproductive hormones, and compromised bone health. It has been speculated that monitoring these values to keep them within optimal healthy ranges will prevent athletes from fatiguing during periods of intense training, leading to better recovery and performance.\textsuperscript{11}
The Importance of Resting Metabolic Rate as an Indicator of Chronic LEA

RMR is defined as the amount of energy expended by the body to maintain homeostasis. This measurement is often predicted using a standardized equation known as the Harris-Benedict (HB) equation. This equation uses an individual’s height, weight, age, race, and sex to predict one RMR value in kcals/24hour. The dual energy x-ray absorptiometry (DXA) scan also predicts RMR using these variables, but is able to provide more specificity based on an individual’s lean mass and fat free mass, which is believed to exhibit more accuracy than the HB equation. A metabolic cart is used to measure RMR using indirect calorimetry, the “gold standard.” Using a ratio of observed to predicted RMRs, metabolic suppression can be identified and linked to energy deficiency and low serum TT3 hormones. Using the DXA predicted value for RMR, the defined RMR ratio of actual to predicted establishes a “suppressed” RMR as below the ratio cutoff of 0.94. This value was found to find the most specificity for the ratio of actual to predicted RMR in the study by De Souza at al. The study determined the significance of the DXA predicted ratios by correlating it with TT3 levels amongst exercising women grouped by categories of ovulatory, amenorrheic or those with subclinical menstrual disturbances. The value of 0.94 was determined to have more sensitivity than the 0.90 threshold commonly used in a Harris-Benedict prediction equation. A “non-suppressed” value is within the threshold of 0.94 and above. Reductions in resting metabolic rate represent an initial metabolic adaptation by the body that precedes the suppression of reproductive function and decreases in bone formation.

Elite athletes are known to have a higher RMR than the average population as a result of their increased energy expenditure and prevalence of high lean body mass. However, with increasingly high exercise energy expenditure it is often difficult for athletes to compensate for...
the caloric expenditure with their energy intake. This leads to an unfavorable RMR, as the body shuttles energy to important physiological processes necessary to maintain life.\textsuperscript{7,24}

Furthermore, it has been reported that low energy availability, which is expected to be correlated with metabolic suppression, has high significance with regards to injury and illness in athletes.\textsuperscript{9,12,17,25}

**WHOOP Wearable Device**

With the advances in wearable technology, many athletes are wearing wrist devices that monitor a variety of biological variables. The WHOOP (WHOOP Inc., Boston, MA) is commonly worn by Penn State athletes and has the capability to monitor several training related physiological variables. This device is worn on the athlete’s wrist and provides information via Bluetooth to a mobile application. The WHOOP is a multi-sensor device with 100 Hz sampling (WHOOP Inc., Boston, MA). The sensors include a tri-axial accelerometer, optical sensor, capacitive touch sensor, and ambient temperature sensor.\textsuperscript{26}

Output variables provided by the WHOOP include a measure of resting heart rate (RHR), heart rate variability (HRV), TEE, EEE, sleep hours, and recovery. HRV is defined as the fluctuation in the time intervals between consecutive heart beats.\textsuperscript{27} RHR is determined by the WHOOP during the deepest sleep and is measured as beats per minute.\textsuperscript{26} The WHOOP “recovery score” is a measure derived from HRV, RHR, sleep time and sleep quality. TEE and EEE given by the WHOOP are represented by a variable called “strain,” measured in kcals. Strain is calculated using a formula that utilizes heart rate throughout the day, including during sleep and activity.\textsuperscript{19} There is not sufficient literature to prove the WHOOP’s efficacy, however the WHOOP data has been shown by the Korey Stringer Institute to exhibit a strong correlation to expected measurements for RHR, HRV, and sleep variables in collegiate athletes.\textsuperscript{26} Further
testing against a validated measurement device is needed to provide a true validation for the wearable.20,26

**Further Directions**

A relationship has been observed between LEA, overall daily energy deficiency, and suppressed metabolic rates with indicators of triad symptoms. However, further investigation is needed to determine the relevance of within-day energy deficiency to metabolic suppression, as well as a correlation to low TT3 values. As the WHOOP is a newer device in need of validation the metrics provided by the device, such as TEE and EEE, may help in determining an athlete’s WDEB, and furthermore help predict associations with metabolic suppression and inadequate recovery. To this end, the proposed research and future research studies need to be conducted to determine if the information from this wearable technology device can be used to improve the health and performance of athletes.
Chapter 2

Introduction

Energy Balance is defined as the difference between energy intake and energy expenditure, typically measured over a 24 hour period. Adequate energy balance has been related to an athlete's health and exercise performance, as evidenced by biomarkers such as resting metabolic rate, menstrual status, bone health, and metabolic hormone levels. Reductions in resting metabolic rate represent one initial metabolic adaptation by the body that precedes the suppression of reproductive function and decreases in bone formation. However, current research largely focuses on energy balance on a day to day basis, such that 24-hour energy balance is considered to be the "functional unit" of energy status. Recently however, the occurrence of negative energy balance for long periods during the day, even if the overall energy balance for the day is zero or neutral, has drawn the attention of researchers who are interested in whether long "within day" periods of negative energy balance are detrimental to athletes' health and performance. Within day negative energy balance has since been related to negative changes in body composition and menstrual cycle disturbances. For example, gymnasts who were found to have suppressed ovulatory cycles exhibited lower energy intake and availability than their ovulatory counterparts. Furthermore, negative within day energy balance (WDEB) was found to be associated with a higher body fat percentage in female elite gymnasts and runners.

The WHOOP is commonly worn by Penn State athletes and it has the capability to monitor energy expenditure of the athlete, as well as their energy expenditure specifically related to exercise. In addition, mobile applications such as MyFitnessPal have made tracking energy
intake easier than ever, in real time. Thus, establishing a link between WDEB and changes in resting metabolism may prove useful as this measure of within day energy balance is relatively easy to acquire and does not require laboratory testing. If within day energy balance links to performance and metabolism in athletes, then future research would be directed at identifying strategies for athletes to prevent fluctuations in energy balance throughout the day so that detrimental effects could be avoided.

The purpose of this study was to determine the associations between differences in WDEB and a variety of outcomes, particularly with regards to whether long periods of negative energy balance throughout the day are related to declines in athlete performance. Furthermore, it was hypothesized that in Division I swimmers, a negative correlation exists between the total number of hours spent in an energy deficit (defined as >-300 kcal for females and >-400 kcals for males) and signs of metabolic suppression including a reduced ratio of actual to predicted resting metabolic rate.
Chapter 3

Materials and Methods

Experimental Design

This study used a cross sectional design, and the targeted population was male and female NCAA intercollegiate Division 1 swimmers prior to the “taper” or rest period of their training season. In this time period, training intensity was at its highest. There was a total of 27 individuals enrolled at the beginning of the study, consisting of 11 males and 16 females. Data collection began during the four week period prior to the athlete’s “taper” phase, before the onset of competition season. “Wave 1” consisted of 17 individuals who had completed the 2-week WHOOP calibration period prior to the data collection start date. Data collection began on the remaining individuals, “Wave 2,” two weeks after the start date, when their calibration periods were complete. All data collection and observation periods were completed prior to the onset of “taper”. All study procedures were approved by the International Review Board (IRB) at the Pennsylvania State University.

Subjects

Subjects were recruited by the Study coordinator, who spoke with the entire team to educate potential participants in detail of the research project using a script approved by the International Review Board (IRB) at the Pennsylvania State University. Inclusion criteria were as follows: 1) between the ages of 18 and 24 years; 2) a current member of the PSU Division 1 Intercollegiate Men’s and Women’s Swim team for the 2019-2020 season; 2) a consistent wearer of the WHOOP wearable technology (regularly for a minimum of 1-2 weeks); 3) must have
signed the ‘Voluntary Wearable Technology Guidelines and Consent’ Form; 4) no known heart conditions that would alter the measure of heart rate.; 5) must currently follow the training season implemented by coaches – no injuries requiring training modification or missing practices; 6) no thyroid disorders; 7) not a regular smoker/nicotine user; 8) must be in generally good health; 9) no known metabolic disorders; 10) not currently taking medications that would inhibit or alter a test of resting metabolic rate; 11) not currently pregnant or lactating; 12) must have a working cell phone with access to the internet.

**Screening Procedures**

Screening procedures began with a phone screening script. After initial recruitment, interested subjects were instructed to call or email the lab, where study personnel would provide them with the relevant information about the study and obtain verbal consent. At this point, the interested participants were asked questions regarding the inclusion criteria listed above. If they did not meet the inclusion criteria, screening ended. If the interested party was not excluded based on the inclusion criteria, they would come to the lab for an in-person informed consent appointment where they would complete a medical history questionnaire after reading an informed consent document. This was reviewed by a study team member to confirm the subjects' eligibility and entry into the study.

**Baseline**

Each participant completed a baseline period of two weeks in which it was ensured that they were properly acclimated to wearing their WHOOP wearable technology and their compliance with wearing the device could be confirmed. They confirmed their compliance with a WHOOP wear questionnaire scored to determine their consistency wearing the device. The WHOOP band technology requires a two week wear period for proper calibration to the
individual subject’s parameters, developing an individualized “baseline”. The entire study length was two to four weeks, depending on the subject’s prior WHOOP wear. A two week timeline was necessary for the subjects who had already completed the acclimation and compliance necessary for the WHOOP technology prior to the study start date. Four total weeks were needed for those subjects who still needed to complete the necessary acclimation and compliance portion before they could begin the data collection phase. This was the distinguishing factor between wave 1 and wave 2 of the study.

**Anthropometrics**

Both height and weight were measured during the in-person consent visit to the lab. Height was measured in centimeters to the nearest 0.1 cm with no shoes on. Weight was measured in kilograms to the nearest 0.01 kg on a physician’s scale (Seca Model 770; Seca, Hamburg, Germany) after the subject removed heavy clothing and shoes. Subject weight was re-recorded during the test of resting metabolism, and that weight was used in the prediction calculations for resting metabolism to compare to the value recorded by the metabolic cart during testing. Body mass index (BMI) was calculated as a ratio of weight to height, in kg/m².

During the data collection period, participants scheduled a lab visit to measure body composition using a Hologic 201331 | HORIZON-W DXA scanner (Hologic Inc., Bedford, MA) dual energy X-ray absorptiometry (DXA) test. This test exposed participants to a small amount of radiation in the form of X-Rays, and subjects were aware of this risk of exposure prior to completing the test. All female participants were required to take a pregnancy test before participating in the test. No subjects tested positive, and therefore all subjects completed the scan. A study team member who was certified by the International Society of Clinical Densitometry performed the DXA test. This test provided the following information about the
subject: lean body mass (LBM), fat free mass (FFM), % fat mass, % android fat, and % gynoid fat.

**Surveys and Questionnaires**

The following surveys and questionnaires were completed by participants at the consent period: a Three-Factor Eating Questionnaire (TFEQ) which assessed athlete eating behavior divided into categories of cognitive restraint, disinhibition, and hunger; a WHOOP wear questionnaire which assessed the athlete’s compliance with wearing the device; and a Health, Exercise, & Nutrition Survey which analyzed the athlete’s habits relating to diet history and sport. The third listed survey was edited during the course of the study, and participants answered additional questions, some male/female specific, during the rest period of their lab visits. The following surveys were added during the study, and IRB approval was granted to ask additional questions relating to eating behaviors and body image: Eating Disorder Inventory (EDI-3), which assessed athlete’s prevalence of disordered eating behaviors, Drive for Muscularity Scale, and Drive for Leanness Scale, both of which assessed an athlete’s body image perception and motivation.

Two additional questionnaires, RESTQ-52 and the Perceived Stress Scale, were used to determine participants relative stress levels, both in and outside of their sport. Participants also filled out the daily WHOOP wearable log to record all instances the strap is on, the strap is removed, or any times when the device was not charged or malfunctioned.

**Exercise Training**

The study coordinator attended all practice sessions and recorded individual participants’ training duration, and objective training volume, defined as the session yardage each athlete completed during a session. Participants were required to provide a “Rate of Perceived Exertion”
or “RPE” using the Borg modified scale (cite in your appendix) after each training session for the assigned 2-week period recorded on an iPad using the Qualtrics app. This was a subjective measure that gave insight into the perceived physical exertion each subject felt during training.

**Resting Metabolic Rate**

The two weeks of active data collection for the study participants began after the 2-week WHOOP acclimation period. During this time, the subjects completed a scheduled lab visit for a test of resting metabolic rate (RMR). All of these appointments took place between 06:00 am and 08:30 am and while the participants were in a fasted state (12 hours/overnight). The participants also refrained from both exercise and caffeine for 24 hours and did not take any metabolic-acting medications prior to the test. Participants lay supine for a 20-45 minute rest period prior to undergoing a test of indirect calorimetry with a Viasys Healthcare, Vmax Encore Metabolic Cart with a ventilated hood. During the rest period, the subjects were asked a series of questions to confirm their compliance with pre-test guidelines as previously mentioned. If they did not meet the guidelines, they were asked to reschedule the test for a future data. The test took anywhere from 20 to 60 minutes depending on how long it took to reach the predetermined criteria for achieving a steady state. During the test, the plexiglass ventilated good was placed over the subject who remained supine and unmoving for the duration of the test, with their arms resting at their sides and their legs uncrossed. Subjects were aware that if they became uncomfortable or claustrophobic during the test, the test would be stopped. Indirect calorimetry was used to measure RMR by monitoring oxygen and carbon dioxide levels throughout the test.

**Biochemical Determinations**

Following the RMR assessment, subjects completed blood sampling carried out by a trained phlebotomist to measure the metabolic hormone concentration of $TT_3$. This draw
occurred between 06:00 am and 08:30 am on the same day as the test of resting metabolism. Participants were wheeled on a gurney to the blood draw station while lying supine to allow for an accurate resting measure. Approximately 50 mL of blood was drawn from the antecubital vein using a 21 gauge blood collection needle of 0.75 inch length and 12 inch tubing (BD Vacutainer; Becton, Dickinson and Company, Franklin Lakes, NJ). After collection, samples were allowed to clot for 30 minutes at room temperature. The sample was then centrifuged (Eppendorf centrifuge 5804 R; Eppendorf, Hamburg, Germany) for 15 minutes at 3000 rpm and aliquoted for storage at -80°C until analysis. TT₃ levels were analyzed with a chemiluminescence immunoassay analyzer (Immulite; Siemens Healthcare, Erlangen, Germany). Analytical sensitivity for the TT₃ assay was 0.54 nmol/L (35 ng/dl). The intraassay CV was 13.2% and the interassay CV was 15.6%.

**WHOO Band Data**

Prior to the two week data collection phase, participants were required to wear the WHOOP device for a two week acclimation period in order to allow the device to develop a baseline of data for the user. During the two weeks of data collection, the wearable device recorded daily participant sleep (hours), recovery (on a scale of 0-100%), resting heart rate (beats per minute), heart rate variability, exercise energy expenditure, and total caloric output. These data were used in determining energy availability in the subjects, as well as within-day energy balance.

**MyFitnessPal Food Records for Assessing Dietary Intake**

Subjects were required to download and utilize the Under Armour MyFitnessPal (Under Armour Inc; Baltimore, MD) mobile application for use during three consecutive data collection days, assigned over two weekdays and one weekend day. Subjects entered all dietary intake data into the mobile application during their respective 72 hour collection window. They were
required to enter any food or calorie-containing beverage that they consumed for that time. The application provided time-stamped data, so all dietary intake was recorded within a five minute window of intake. Subjects were instructed to record their intake in real time, as they consumed it. They were also instructed to adjust the timestamp to reflect real intake time if they were not able to contemporaneously enter intake data. At the end of the three days of recording, participants emailed the exported data directly from the application to a study team member.

**Within-Day Energy Balance**

Within-day energy balance (WDEB) was determined by the WHOOP and MyFitnessPal Data. The components of this variable are the following: total energy expenditure (TEE) provided by the WHOOP exercise energy expenditure (EEE) provided by the WHOOP, exercise post-oxygen energy consumption (EPOC), defined above, hourly sleep energy expenditure (SEE), determined by taking 90% of the measured resting metabolic rate and dividing it by the total hours of sleep within the 24 hour interval given by the WHOOP, daily energy intake (EI) provided by the MyFitnessPal export, and diet-induced thermogenesis (DIT) as previously defined.

To determine the energy expenditure within hours where there was no exercise, the following equation was used: non-exercise activity thermogenesis baseline (NEAT) = [TEE-SEE-EEE-EPOC-DIT]/remaining hours with no sleep or exercise energy expenditure.

The described variables were distributed into 24 hour increments relative to the time they occurred, with intake variables being positive values and the remaining variables negative, representing energy expenditure. Each hourly energy balance is represented by the equation (Energy status from hour x-1) + (within hour x EI-SEE-EEE-EPOC-DIT-NEAT).
This allowed for a visualization of hourly energy balance within a 24 hour period. The tables below demonstrate the calculation breakdown, as well as an example of one day of subject data.

**Table 1. WDEB Variables and Considerations**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Measurement Method</th>
<th>Reference/Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>EI</td>
<td>Subjects entered time-stamped food intake into the MyFitnessPal Mobile Application (Under Armor Inc; Baltimore, MD) for 3 days. Raw time-stamped kcal information was used.</td>
<td>Subjects received one-on-one instruction on recording instructions prior to the 3 recording days</td>
</tr>
<tr>
<td>mRMR</td>
<td>Measured/actual resting metabolic rate (mRMR) was gathered by conducting a test of resting metabolism in a subject lab visit with a metabolic cart according to the methods outlined above.</td>
<td>ViaSys Healthcare, Vmax Encore Metabolic Cart</td>
</tr>
<tr>
<td>DIT</td>
<td>Represents a total of 10% of overall EI. Calculated as 10% total of each meal, and distributed in the 5 hours after a meal as following: 60% in the first 3 hours, 78% by the 4th hour, and 91% by the fifth hour.</td>
<td>Torstveit et al (2018)</td>
</tr>
<tr>
<td>TEE</td>
<td>Total Energy Expenditure was taken from the WHOOP band (cite) as the total daily strain calories</td>
<td>WHOOP Inc; Boston, MA</td>
</tr>
<tr>
<td>EEE</td>
<td>Exercise energy expenditure was taken from the WHOOP band during subject labeled exercise.</td>
<td>WHOOP Inc; Boston, MA</td>
</tr>
<tr>
<td>EPOC</td>
<td>Exercise Post-Oxygen Consumption was calculated by adding 5% of EEE to the first hour post-exercise, and 3% EEE to the second hour post-exercise for every episode of EEE.</td>
<td>Torstveit et al (2018)</td>
</tr>
<tr>
<td>NEAT</td>
<td>Working backwards from TEE, SEE, RMR, EEE, EPOC, and DIT, non-exercise activity thermogenesis was found by taking the total number of calories burned for the day and subtracting out the previous variables. That composite number was then divided by the number of hourly blocks that contained no SEE or EEE; i.e. all wakeful hours without purposeful exercise expenditure and distributed to each of those blocks.</td>
<td>See descriptions for TEE, SEE, mRMR, EEE, EPOC, and DIT</td>
</tr>
<tr>
<td>SEE</td>
<td>Sleeping energy expenditure was calculated by finding the sleeping metabolic rate (SMR) as 90% of the subjects measured RMR (kcal/day), dividing it by 24 to get an hourly sleep energy expenditure, and multiplying that number by the hours of sleep within the 24 hour window (i.e. from 00:00-24:00)</td>
<td>SMR formula was found in research by Torstveit et al (2018). mRMR was used as a more accurate predictor of SMR specified to the subject.</td>
</tr>
</tbody>
</table>

*Note* EI= energy intake, mRMR= measured (actual) RMR, DIT = diet induced thermogenesis, TEE = total energy expenditure, EEE=exercise energy expenditure, EPOC= exercise post-oxygen consumption, NEAT= non-exercise activity thermogenesis, SEE = sleep energy expenditure. This table was adapted from a study by Torstveit et al (2018):
Table 2 Example WDEB by Hour for 24 Hours

<table>
<thead>
<tr>
<th>Time Increment</th>
<th>Intake (+kcal, from MyFitnessPal)</th>
<th>Total Expenditure (-kcal)</th>
<th>Total Balance (kcal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00 - 01:00</td>
<td>0.00</td>
<td>-70.99</td>
<td>-70.99</td>
</tr>
<tr>
<td>01:00 - 02:00</td>
<td>0.00</td>
<td>-70.99</td>
<td>-141.98</td>
</tr>
<tr>
<td>02:00 - 03:00</td>
<td>0.00</td>
<td>-70.99</td>
<td>-212.97</td>
</tr>
<tr>
<td>03:00 - 04:00</td>
<td>0.00</td>
<td>-70.99</td>
<td>-283.96</td>
</tr>
<tr>
<td>04:00 - 05:00</td>
<td>0.00</td>
<td>-70.99</td>
<td>-354.94</td>
</tr>
<tr>
<td>05:00 - 06:00</td>
<td>0.00</td>
<td>-70.99</td>
<td>-425.93</td>
</tr>
<tr>
<td>06:00 - 07:00</td>
<td>0.00</td>
<td>-70.99</td>
<td>-496.92</td>
</tr>
<tr>
<td>07:00 - 08:00</td>
<td>0.00</td>
<td>-70.99</td>
<td>-567.91</td>
</tr>
<tr>
<td>08:00 - 09:00</td>
<td>0.00</td>
<td>-94.84</td>
<td>-662.75</td>
</tr>
<tr>
<td>09:00 - 10:00</td>
<td>342.50</td>
<td>-94.84</td>
<td>-415.08</td>
</tr>
<tr>
<td>10:00 - 11:00</td>
<td>240.00</td>
<td>-101.69</td>
<td>-276.77</td>
</tr>
<tr>
<td>11:00 - 12:00</td>
<td>0.00</td>
<td>-106.49</td>
<td>-383.26</td>
</tr>
<tr>
<td>12:00 - 13:00</td>
<td>390.00</td>
<td>-106.49</td>
<td>-99.74</td>
</tr>
<tr>
<td>13:00 - 14:00</td>
<td>395.00</td>
<td>-113.60</td>
<td>181.65</td>
</tr>
<tr>
<td>14:00 - 15:00</td>
<td>80.00</td>
<td>-461.47</td>
<td>-199.82</td>
</tr>
<tr>
<td>15:00 - 16:00</td>
<td>230.00</td>
<td>-140.19</td>
<td>-110.01</td>
</tr>
<tr>
<td>16:00 - 17:00</td>
<td>0.00</td>
<td>-481.89</td>
<td>-591.90</td>
</tr>
<tr>
<td>17:00 - 18:00</td>
<td>0.00</td>
<td>-463.88</td>
<td>-1055.78</td>
</tr>
<tr>
<td>18:00 - 19:00</td>
<td>1876.00</td>
<td>-154.07</td>
<td>666.15</td>
</tr>
<tr>
<td>19:00 - 20:00</td>
<td>0.00</td>
<td>-167.82</td>
<td>498.33</td>
</tr>
<tr>
<td>20:00 - 21:00</td>
<td>0.00</td>
<td>-136.07</td>
<td>362.26</td>
</tr>
<tr>
<td>21:00 - 22:00</td>
<td>1040.00</td>
<td>-134.43</td>
<td>1267.84</td>
</tr>
<tr>
<td>22:00 - 23:00</td>
<td>0.00</td>
<td>-149.40</td>
<td>1118.43</td>
</tr>
<tr>
<td>23:00 - 24:00</td>
<td>0.00</td>
<td>-116.18</td>
<td>1002.25</td>
</tr>
</tbody>
</table>

Note: This table represents the hourly caloric balance of a subject for one day.
Figure 1 Individual Subject Average WDEB Data Example

Analysis

The data were analyzed using SPSS Statistics Software (version 26 Chicago, IL). Before any data were analyzed, each variable was tested for outliers and normality. Only participants who had complete data sets were analyzed in the software. Normality was tested using the Shapiro-Wilke statistic. Outliers were located and Levene’s test was run, grouping by suppression/non-suppression of RMR. Suppressed RMR subjects were characterized as those who had actual RMR to DXA predicted RMR ratios less than 0.94, and non-suppressed subjects had a ratio of 0.94 or above. This showed that with each distribution, we could assume homogeneity of variance. A Mann-Whitney U test was used to test for differences between groups when data were non-parametric. All within day energy variables were non-parametric, and the RMR measurements and ratios demonstrated normal distributions.
Chapter 4

Results

Demographics

There were 27 individuals enrolled at the start of the study. No participants dropped out, but two subjects were excluded from analysis due to incomplete WHOOP band data during the three days of diet analysis. One additional subject was removed from analysis due to extraneous data. Of the remaining 24 subjects, 12 were characterized as having a suppressed RMR according to the ratio of actual RMR to the DXA predicted value less than 0.94. Twelve were classified as having a non-suppressed RMR by exhibiting the same ratio greater than 0.94. The demographic information of the 24 subjects is shown in Table 3. Of all subjects, there were 11 males and 13 females. Of the suppressed group (n=12), 8 individuals were male and 4 were female. Of the non-suppressed group, 3 individuals were male and 9 were female. Independent t-tests were run for the parametric variables of height, weight, BMI, fat mass, fat free mass, and lean body mass. There were no significant differences between the means of the two groups other than lean body mass, which was significantly higher (p= 0.046) in the suppressed group. A Mann-Whitney U test was run for the non-parametric variables of age and body fat percent. The only significant difference between the suppressed and non-suppressed groups was relative to body fat percent. The mean was significantly higher in the non-suppressed group (p= 0.024). This is evidenced in Table 3.
**Within Day Energy Balance in Suppressed vs. Non-Suppressed Subjects**

A Mann-Whitney U test comparing indications of within day energy balance (WDEB) across the two groups indicated that there were no differences between suppressed and non-suppressed RMR groups for any of the WDEB variables, including the number of hours spent in an energy deficit, with and without the cutoff of<-400 kcals for males and <-300 kcals for females (Table 3). Additionally, there were no significant differences between the groups in total triiodothyronine (TT₃), largest average within-day deficit, the largest within-day deficit for a single day, the average number of consecutive hours spent in an energy deficit without the cutoff of <-400 kcals for males and <-300 kcals for females, the average number of total hours spent in an energy deficit, and the average number of total hours spent in a deficit below the cutoff. An independent t-test also yielded no significant differences between the groups in, EI, DIT, EPOC, NEAT, TEE, or SEE.

**Within Day Energy Balance and Athletic Performance**

Correlations were performed to test whether any within day energy balance parameters were related to the performance in a 200 yard time trial (seconds). These results are shown in Table 4. To test our hypothesis regarding swimming performance and energy deficiency across the day, we ran a Spearman correlation test for nonparametric data on all subjects (n=24). We found a positive correlation (R= 0.441, p= 0.031) between the number of consecutive hours spent in an energy deficit, defined as <0 kcal, and subject performance in a 200 yd freestyle swim time trial (Figure 2). There was no correlation between the consecutive hours below the cutoff of <-400 kcals for males and <-300 kcals for females. Additionally, a negative correlation (R=-.409, p=0.047) was found between total daily energy balance and performance time such that the
lower the total daily energy balance, the poorer the subject performance (Figure 3). No other significant correlations were found between WDEB indices and swimming performance.
### Table 3 Subject Data: Demographics, Metabolism, Hormones, and WDEB

<table>
<thead>
<tr>
<th>Demographics</th>
<th>All (n=24)</th>
<th>Non-Suppressed RMR (n=12)</th>
<th>Suppressed RMR (n=12)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Years)</td>
<td>19.6 ± 1.1</td>
<td>19.7 ± 1.2</td>
<td>19.6 ± 1.0</td>
<td>0.799</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>180 ± 8</td>
<td>177 ± 9</td>
<td>182 ± 6</td>
<td>0.187</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>74.6 ± 10.6</td>
<td>71.4 ± 11.3</td>
<td>77.8 ± 9.2</td>
<td>0.141</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.0 ± 1.9</td>
<td>22.6 ± 2.0</td>
<td>23.5 ± 1.9</td>
<td>0.247</td>
</tr>
<tr>
<td>Body Fat % *</td>
<td>22.0 ± 5.2</td>
<td>24.4 ± 4.1</td>
<td>19.6 ± 5.2</td>
<td>0.024*</td>
</tr>
<tr>
<td>Fat Mass (kg)</td>
<td>15.7 ± 2.7</td>
<td>16.7 ± 2.0</td>
<td>14.7 ± 3.1</td>
<td>0.078</td>
</tr>
<tr>
<td>LBM (kg) *</td>
<td>54.7 ± 10.9</td>
<td>50.3 ± 10.2</td>
<td>59.1 ± 10.1</td>
<td>0.046*</td>
</tr>
<tr>
<td>FFMI (kg)</td>
<td>57.3 ± 11.3</td>
<td>52.9 ± 10.7</td>
<td>61.8 ± 10.5</td>
<td>0.051</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metabolism</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mRMR (kcal/day)</td>
<td>1589 ± 261</td>
<td>1555 ± 266</td>
<td>1623 ± 262</td>
<td>0.866</td>
</tr>
<tr>
<td>HB_prRMR (kcal/day)</td>
<td>1604 ± 114</td>
<td>1575 ± 123</td>
<td>1633 ± 99</td>
<td>0.589</td>
</tr>
<tr>
<td>dxapRMR (kcal/day)</td>
<td>1684 ± 295</td>
<td>1560 ± 262</td>
<td>1808 ± 282</td>
<td>0.787</td>
</tr>
<tr>
<td>RMRatio_hb</td>
<td>0.09 ± 0.10</td>
<td>0.98 ± 0.10</td>
<td>0.99 ± 0.11</td>
<td>0.912</td>
</tr>
<tr>
<td>RMRatio_dxapRMR</td>
<td>0.95 ± 0.07</td>
<td>1.00 ± 0.05</td>
<td>0.90 ± 0.03</td>
<td>0.384</td>
</tr>
<tr>
<td>Metabolic Hormones</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT1 ng/dL</td>
<td>91.2 ± 17.2</td>
<td>89.8 ± 18.4</td>
<td>92.8 ± 16.5</td>
<td>0.651</td>
</tr>
<tr>
<td>WDEB Variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EI (kcal/day)</td>
<td>3053 ± 960</td>
<td>2789 ± 715</td>
<td>3317 ± 1123</td>
<td>0.086</td>
</tr>
<tr>
<td>DIT (kcal/day)</td>
<td>305 ± 96</td>
<td>278 ± 72</td>
<td>332 ± 112</td>
<td>0.089</td>
</tr>
<tr>
<td>EEE (kcal/day)*</td>
<td>717 ± 272</td>
<td>680 ± 154</td>
<td>755 ± 358</td>
<td>0.001*</td>
</tr>
<tr>
<td>EPOC (kcal/day)</td>
<td>61 ± 25</td>
<td>57 ± 19</td>
<td>64 ± 30</td>
<td>0.077</td>
</tr>
<tr>
<td>NEAT (kcal/day)</td>
<td>1396 ± 312</td>
<td>1341 ± 340</td>
<td>1451 ± 284</td>
<td>0.703</td>
</tr>
<tr>
<td>TEE (kcal/day)</td>
<td>2648 ± 543</td>
<td>2558 ± 521</td>
<td>2739 ± 572</td>
<td>0.604</td>
</tr>
<tr>
<td>SEE (kcal/hour)</td>
<td>496±101</td>
<td>506 ± 108</td>
<td>486 ± 98</td>
<td>0.575</td>
</tr>
<tr>
<td>Indications of WDEB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Largest Within-Day Deficit (Average kcals)</td>
<td>-807 ± 291</td>
<td>-735 ± 236</td>
<td>-878 ± 331</td>
<td>0.291</td>
</tr>
<tr>
<td>Largest Within-Day Deficit-Single Day (Average kcals)</td>
<td>-1072 ± 479</td>
<td>-974 ± 443</td>
<td>-1170 ± 513</td>
<td>0.347</td>
</tr>
<tr>
<td>Average # consecutive hours spent in negative energy balance (Hours)</td>
<td>14 ± 5</td>
<td>14 ± 5</td>
<td>14 ± 5</td>
<td>0.843</td>
</tr>
<tr>
<td>Average # consecutive hours spent in negative energy balance below the cutoff (Hours)</td>
<td>4 ± 3</td>
<td>4 ± 3</td>
<td>4 ± 3</td>
<td>0.843</td>
</tr>
<tr>
<td>Average # hours in negative energy balance (Hours)</td>
<td>15 ± 5</td>
<td>15 ± 4</td>
<td>14 ± 5</td>
<td>0.713</td>
</tr>
<tr>
<td>Average # hours in negative energy balance below the cutoff (Hours)</td>
<td>5 ± 3</td>
<td>5 ± 3</td>
<td>5 ± 4</td>
<td>0.713</td>
</tr>
<tr>
<td>Total Daily Energy Balance</td>
<td>431 ± 651</td>
<td>259 ± 500</td>
<td>604 ± 755</td>
<td>0.190</td>
</tr>
</tbody>
</table>

**Note** WDEB= within day energy balance, BMI = Body Mass Index, LBM = lean body mass, FFM = fat free mass, mRMR= measured (actual RMR), HB_prRMR = Harris-Benedict predicted RMR, dxapRMR = DXA predicted RMR, RMRatio_hb= ratio of mRMR to harris-benedict predicted RMR, RMRatio_dxapRMR = ratio of mRMR to DXA predicted RMR, EI= energy intake, DIT = diet induced thermogenesis, EEE= exercise energy expenditure, EPOC = exercise post-oxygen consumption, NEAT = non-exercise activity thermogenesis, TEE = total energy expenditure, SEE = sleep energy expenditure, TDB = total daily energy balance. Negative energy balance is defined as below 0 kcals, while negative energy balance below the cutoff is defined by the male cutoff of below -400kcal and the female cutoff of below -300kcal. This table was adapted from Torsvei et al. (2018): *p < 0.05 independent comparison of means suppressed vs. non-suppressed RMR
Table 4 Correlations between Swimming Performance in 200 yard Time Trial and WDEB

<table>
<thead>
<tr>
<th>WDEB Indicator Variables vs. 200 yd Time Trial (seconds)</th>
<th>R value</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Consecutive Hours in a Deficit</td>
<td>.441*</td>
<td>0.031</td>
</tr>
<tr>
<td># of Consecutive Hours in a Deficit (Cutoff)</td>
<td>0.174</td>
<td>0.415</td>
</tr>
<tr>
<td>Average # of Hours in a Negative Energy Balance</td>
<td>0.367</td>
<td>0.077</td>
</tr>
<tr>
<td>Total Daily Energy Balance</td>
<td>-.409*</td>
<td>0.047</td>
</tr>
<tr>
<td>Average # Hours in a Deficit according to cutoff</td>
<td>0.186</td>
<td>0.383</td>
</tr>
<tr>
<td>Greatest # of Hours in a Deficit (cutoff)</td>
<td>0.135</td>
<td>0.528</td>
</tr>
<tr>
<td>Largest Single Day Deficit (kcals)</td>
<td>0.402</td>
<td>0.052</td>
</tr>
<tr>
<td>Largest Average Deficit</td>
<td>0.383</td>
<td>0.065</td>
</tr>
</tbody>
</table>

Note R value represents correlation between Performance in 200 yard time trial (seconds) and WDEB indicator variables

Figure 2 Consecutive Hours in and Energy Deficit and Time Trial Performance

Note This figure represents the relationship between the consecutive hours spent in a negative energy deficit (below 0 kcals) and athlete performance in a 200 yard freestyle swim
Figure 3 Total Daily Energy Balance and Time Trial Performance

Note This figure represents the relationship between total daily energy balance and athlete performance in a 200 yard freestyle swim.
Chapter 5
Discussion

Main Findings

The main findings of this study demonstrated that no relationship was found between metabolic suppression (defined by the RMR ratio of actual to measured RMR based on the DXA predicted RMR) and WDEB variables. There was, however, evidence to support the hypothesis that there was a relationship between variables of WDEB and swimming performance, with a significant positive correlation \( R=0.441, p=0.031 \) between the number of consecutive hours in a day spent in an energy deficit (below 0 kcal) and athlete performance in a 200 yard freestyle time trial. This correlation indicates that larger energy deficits were related to a longer completion time in the 200 yd trial, i.e. poorer athlete performance. Additionally, it was found that a statistically significant negative correlation \( R=-0.409, p=0.047 \) exists between total daily energy balance and athlete performance in the time trial. Data relating poorer performance and poor within day energy balance is supported by Vanheest et al., who explored ovarian suppression and performance in elite female swimmers and found a similar relationship with swimming performance. They found that the athletes (elite swimmers from 15-17 years of age) that experience ovarian suppression (as marked by hormone levels and self-reported menstrual status) who were also in an energy deficit, demonstrated poorer athletic performance. They also noted that performance continued to decline if the deficit remained. This study followed the TT3 levels of the athletes through the training season, and saw that while they were not statistically different between groups at baseline, the hormone levels decreased significantly in the ovarian
suppressed swimmers. They also observed similar EEE between the two groups, as well as EI. Additionally, they looked into the macronutrient profile of the EI and found that it was not significantly different between the two groups. These data support the findings of the current study, and prompt further investigation into the effects of a continued energy deficit in the elite collegiate athlete, as well as how the results of the Vanheest study may translate to elite male athletes.

Long periods of energy deficiency could impact performance in both physiological and psychological ways. Physiologically, this energy deficit could create low EA in the athletes, which means that the energy available for muscle repair and recovery after exercise energy expenditure would be low and have negative impacts on recovery, leading to poor performance outcome. Low EA has been found to have links to poor bone health and body composition, which could also negatively affect performance. Low EA also has a detrimental effect on metabolic and reproductive hormones, both of which could result in a decline in athlete performance. Psychologically, energy deficiency can result in a deficiency of several key nutrients that are required for neurotransmitter synthesis. Vitamin C, for example, is necessary for norepinephrine and serotonin synthesis. Norepinephrine, or “noradrenaline” is responsible for regulating the sympathetic nervous system and controls muscle fiber contraction and heart rate. It is also a precursor for epinephrine, or adrenaline, which is important for athletic performance. Adrenaline is responsible for increasing breakdown of glycogen to glucose for use in the bloodstream, and has a direct role in stimulating the heart. Serotonin is a neurotransmitter that has several behavioral effects, including sleep modulation, and deficiency has links to depression, obsessive compulsive disorder, and anxiety; all of which could have potential
negative effects on athlete performance. More research is necessary to determine the effects of low EA on hormones that may influence athletic performance.

This study is the first to look specifically at elite collegiate swimmers and examine males and females in the same study. This represents an important investigation into the effects of LEA on the health and performance of a division one program and can potentially highlight ways that athletes can better care for their health during training, while having a positive effect on performance.

It was expected that this study would yield a significant relationship between indices of WDEB and metabolic suppression. While there was no evidence to support this claim specifically, exactly half of the subjects still experienced metabolic suppression as defined by a ratio of actual to predicted resting metabolic rate. It is possible that due to the high athletic caliber of the subjects, the number of hours spent in a caloric deficit does not have the expected effect on metabolism. Additionally, it is possible that the definition of metabolic suppression used in this study is not valid for this population. Markers of TT₃ did not demonstrate a statistically significant difference between the two groups which were defined by a DXA predicted RMR ratio above or below 0.94. This is a possible indication that being below the cutoff of 0.94 is not enough to indicate metabolic suppression in this elite population. Future analyses could explore additional cutoffs with an association to reduced TT₃ levels within the subject population.

Another possibility for this outcome could be due to the number of hours subjects spent in an energy surplus during the day, in addition to the number of hours spent in an energy deficit. For example, one subject spent 9 hours in an energy deficit (according to the described cutoffs), but also spent 14 hours in energy balance between the cutoff values (+400 kcals to -400 kcals for
males, +300 kcals to -300 kcals for females) and 1 hour in energy surplus above the cutoff marker. It is possible that the magnitude of the surplus could outweigh the expected negative effect of a within day energy deficit. Another example is the subject who averaged 11 consecutive hours in an energy deficit with respect to the cutoff, but had a total daily energy balance of +234 kcals. Examining this variable in relation to other WDEB variables, particularly total energy balance, could provide insight into the effects of both an experienced within day caloric deficit and a total daily energy balance surplus.

**Study Features**

A unique component of this study was the use of MyFitnessPal (Under Armour, Inc; Baltimore, MD) rather than hand-written and subject-weighed food records. This technology allowed for simpler use and less subject burden, allowing the use of mobile technology and product barcodes to simplify the recording process. Additionally, the time-stamp feature of this application added an element of accuracy in the recording meal and snack timing. If subjects recorded their intake in real time, the application was able to represent the exact time. If subjects were not able to record in real time, there was a simple step to record the meal timing, but concurrent food recording with the application made recording timing variables very feasible. Studies that have used MyFitnessPal have shown that it exhibits reliability in portraying the raw caloric value of intake. This study supports the use of this mobile platform for subject use to lessen participant burden and improve reliability of response. In future research, subjects could also utilize a food scale in addition to the mobile data entry, as the participants in this study were given guidelines on how to enter what they were eating but were not instructed to make exact measurements to prevent participation bias.
Another important feature of this study was the utilization of the WHOOP band, as it is commonly used among the athletic population. Many Division 1 sports team at The Pennsylvania State University use the technology to gather data on the athletes. While not validated against a gold standard, the technology has been used in research for measures of sleep, HRV and heart rate and is found to be an accurate predictor of these measures. Furthermore, direct communication with John Capodilupo, co-founder and CTO of WHOOP, Inc. gave more support for the reliability of the technology. He associated the efficacy of WHOOP metrics with expected user behavior, and provided insight into research that was being conducted on the subject of efficacy. He was also willing to directly describe how the technology provides the biofeedback for HRV and RHR. Studies that have utilized the technology have approved WHOOP measures for heart rate and HRV, which are important in factors of energy expenditure. A study conducted at the University of Arizona has independently validated the data for sleep and heart rate. The WHOOP is praised for its sleep analytics, being called one of the most accurate and least invasive ways of analyzing sleep behavior. The further use of this technology could open doors with regards to energy expenditure research, as the device is non-invasive and reports via Bluetooth directly to a mobile application as well as a web browser dashboard. It could potentially revolutionize research in this area, as the only subject burden for data collection was compliance in wearing the device. Future validation of this technology against a gold standard is recommended in order for progressive research on this topic.

The results of this study should prompt investigation into the importance of the “cutoff” determined for negative energy balance (<-400 kcal for males, <-300 kcal for females). The significant results that showed a correlation between a within-day energy deficit and performance time did not consider the cutoff. No such correlation was found when it was
accounted for. The data suggest that the deficit within 0 kcals and the cutoff is important for athlete performance, and further direction should investigate this variable fully.

This research is highly important for athletes of any caliber, but especially in the elite population of Division 1 athletes. These athletes experience exceptionally high training volume, and the feedback from this study is integral not only in addressing possible improvements to performance, but additionally promotes the overall health and wellness of the athlete. It is equally important for coaching staff to be aware of the results of this study so that they can guide their athletes on the best practices both within and outside of training to help athletes reach performance and health goals. As swimming is also a physique sport, it is very important for both athlete and coach to be aware of the effects that result from caloric restriction, as this study shows that large periods of energy deficiency throughout the day, as well as overall, are correlated with athletic performance in swimmers. The results of this study are important for the athletic population to understand with regards to the effect WDEB can have on performance.

Study Limitations

There were limitations to this study that could potentially highlight more information in future studies. The study only lasted two weeks at one point during the training season, and it had a small sample size. Adding more subjects could improve outcome reliability. Additionally, this study occurred during the peak of the training season so that the subjects could be observed at the time when their bodies experience the most stress. Repeating the study at different times during the season could highlight different important components to metabolism and performance. The study also utilized the WHOOP, which made data collection on energy expenditure variables much more feasible but until it is tested against a gold standard, its reliability cannot be completely confirmed. The technology has been used in a study involving
collegiate female cross-country runners and was used to measure heart rate, HRV, and sleep metrics.26

Future Directions

Future directions for this study should be aimed at investigating the advantages/disadvantages of different macronutrient profiles of energy intake with regards to athlete performance. Carbohydrates, fats, and proteins undergo different metabolic pathways within the body, and it is possible that different ratios of macronutrients could lend to changes in athletic performance. Additionally, micronutrient deficiency in athletes who experience long periods of undereating may have a direct effect on performance. Further investigation of this issue, along with an expanded data collection period for dietary intake, could provide more information on the relationship between energy balance and athletic performance. Additionally, this study could be replicated across different elite athletic populations to observe the effects upon different training and sport styles, such as soccer or Olympic lifting. It would also be interesting to investigate potential difference in WDEB and its effects between sprint and distance runners. Effects could also be explored when repeating this study throughout an entire season to represent different training phases.
References


17. Heikura IA, Uusitalo ALT, Stellingwerff T, Bergland D, Mero AA, Burke LM. Low energy
availability is difficult to assess but outcomes have large impact on bone injury rates in elite distance athletes. *Int J Sport Nutr Exerc Metab.* 2018;28(4):403-411. doi:10.1123/ijsnem.2017-0313


26. Sekiguchi Y, Adams WM, Benjamin CL, Curtis RM, Giersch GEW, Casa DJ. Relationships between resting heart rate, heart rate variability and sleep characteristics among female collegiate


32. Smolak L, Murnen SK. Drive for leanness: Assessment and relationship to gender, gender role and objectification. doi:10.1016/j.bodyim.2008.03.004


Academic Vita

Education:
The Pennsylvania State University, University Park, PA  Projected Graduation: May 2020
Bachelor of Science: Biological Sciences and Health Professions Option
Bachelor of Science: Nutritional Sciences
  • Schreyer Honors College
The University of Sussex, Brighton, United Kingdom  January-June 2019
  • Spring semester abroad, global education experience
The Council of International Educational Exchange (CIEE)  June-August 2018
Global Leadership Internship Program
  • Completed a two-month full-time internship and online academic course equivalent to 6
    semester hours, consisting of in-person workshops, weekly internship evaluations, peer
    and workplace interviews, and a summary capstone project.
Certifications:
National Institutes of Health, Online  September 2018
  • Protecting Human Research Participants Course
Collaborative Institutional Training Initiative, Online  September-December 2018
  • Basic Course
  • Human Subjects Research
  • International Research
  • Biomedical Human Subjects Research Course
  • GCP – Social and Behavioral Practices for Clinical Research
CrossFit® Level 1 Certification  March 2018
  • Acquired knowledge reflecting proper nutrition for the person ranging from sick to
    healthy
  • Participated in hands-on workshops learning the technique to becoming a good athletic
    trainer
  • Obtained CrossFit® Level 1 Training Certificate after passing the course exam
The Phlebotomy Training Center, Pittsburgh, PA  June-August 2017
  • Phlebotomy Certification with supplemental clinical experience at LabCorp Seven Fields.
Work Experience:
Women’s Health and Exercise Lab, State College, PA  September 2018- Present
  • Volunteered as an assistant to aid the process of Penn State University Kinesiology
    Research Projects
  • Performed fecal and urine sample analyses
  • Stocked project supplies and organized participant information
CrossFit® Nittany, State College, PA  September-December 2018, August-December 2020
  • Assisted and led CrossFit® classes
Department of the Premier: Nourish to Flourish, Cape Town, South Africa  June-August 2018
  • Performed literature reviews across international databases to highlight patterns in
    employee experience regarding breastfeeding policy and administration in the workplace.
• Conducted project interviews for data collection on the experience of new mothers in the workplace.
• Developed a draft for the redesign of the Western Cape’s Strategic Framework on Food Assistance to improve government role in achieving provincial food security.
• Assimilated to a multi-cultural work environment gaining useful communication techniques.

**Bellefield Systems, LLC, Sewickley, PA**

June-August 2015, 2016, 2017

• Gained experience with computer programs such as Salesforce, Excel, and Recurly to assist with the organization of client data and subscription information.
• Handled office organization, trade show shipments, and customer contact information.
• Acquired experience in customer satisfaction phone calls and outreach.

**Leadership and Professional Experience:**

**CrossFit® Level 1 Trainer, University Park, PA**

August 2018-Present

• Instruct CrossFit® classes for members of the Penn State CrossFit® Club.
• Adapt training sessions to accommodate injury, disability, and low skill level.

**PSU CrossFit® Club THON Chair, University Park, PA**

August 2017 - Present

• Directed club involvement in Penn State University’s Dance Marathon, the world’s largest student-run philanthropy dedicated to raising money for pediatric cancer research. I communicated with businesses regarding fundraisers and initiated and ran a fundraiser with Live Lokai.
• Completed Bi-Weekly Organization Reports
• Attended Chair Workshops
• Logistics Organization

**Anatomical Presentation, University Park, PA**

August 2019

• Accepted a position in a special topics course relating to cadaver dissection and human anatomy.
• Conducted a 1 on 1 presentation with Penn State Faculty on the reproductive system.
• Developed an in-depth understanding of the human anatomical system.

**Volunteer, LifeLink PSU, University Park, PA**

September-December 2017

• Worked three days a week with a member of PSU LifeLink, an on-campus integrated special-needs program providing an opportunity for special needs students ages 18-21 to interact with students their own age in a socially and academically conducive environment.
• Directed a student’s involvement in a Kinesiology class, bringing her to and from the class as well as guiding her through it.

**Public Deliberation, Host**

February 2017

• Led a public forum debate and discussion among peers.