SEX-SPECIFIC METABOLIC RESPONSE TO HIGH-INTENSITY INTERMITTENT SPRINT WORK

Kaitlyn J. Kielsmeier

A Thesis
Submitted to the Graduate College of Bowling Green State University in partial fulfillment of the requirements for the degree of

MASTERS OF EDUCATION

August 2015

Committee:
C. Matt Laurent, Advisor
Adam Fullenkamp
Matthew Kutz
The increased popularity of high-intensity intermittent training (HIIT) has stimulated research that seems to support the idea that a greater fatigue resistance and/or recovery ability is demonstrated in women vs. men during this mode of exercise. The purpose of this study was to identify if a sex-specific response to HIIT would influence metabolic pathway contribution between men and women when working at a similar relative intensity. Seventeen well-trained men and women performed three total trials consisting of a \( \text{VO}_2\text{max} \) test and two trials of repeated treadmill sprints at 110% \( v\text{VO}_2\max \). Both trials consisted of four sets of 4, 30-sec sprints interspersed with three minutes of passive recovery between each set. The counterbalanced trials only differed by rest period duration between sprints: 30-sec recovery (30:30 trial) and 15-sec recovery (30:15 trial). \( \text{VO}_2 \) (via indirect calorimetry) was measured during all sprints and recovery periods along with a 10-min post-exercise recovery to estimate oxidative pathway contribution during work and EPOC. The glycolytic component was measured via change in blood lactate concentration by drawing a sample of blood two minutes into the recovery stage of each set. A 2 (sex) x 4 (sprint sets) repeated measures ANOVA revealed that men significantly consumed more kCals than women in both trials \((p < 0.01)\); however, relative contribution of energy pathway (i.e., percentage of oxidative, glycolytic, and EPOC to total energy expenditure) did not reveal differences between men and women in either trial. One-way ANOVAs showed women demonstrate consistently higher heart rates and ratings of perceived exertion \((p \leq 0.03)\) throughout the trials than men. Session rating of perceived
exertion, perceived recovery status and blood lactate were not significantly different between men and women. While a metabolic pathway difference was not present between men and women in this study, women worked relatively harder from a cardiovascular and perceptual standpoint yet experienced similar metabolic strain and perceptions of recovery as men. These findings may indirectly support a greater recovery in women vs. men during HIIT.
ACKNOWLEDGMENTS

This study would not have been possible without the help of several teachers and colleagues. First and foremost, I would like to thank my thesis chair and advisor, Dr. Matt Laurent, for his guidance over the past two years. His careful critique, humble approach, and the way in which he modeled rigorous yet patient academic advising have made a lasting impression on me. My time as his student has helped develop me into the individual I aspire to be, both professionally and personally. Many thanks to my committee members, Dr. Adam Fullenkamp and Dr. Matt Kutz, for contributing their expertise and providing practical advice. As I thank my teachers, I have to express my profound gratitude for my undergraduate mentor, Dr. Heather Medema-Johnson. Her passion for teaching and exercise science is the reason I am here today. Her inspiration and belief in my abilities has led me to accomplish more than I ever thought I could.

I am indebted to many colleagues from the Kinesiology program; the success of this thesis is, in part, a product of their contributions. The close camaraderie that developed between Chris Irvine, Stephanie Douglas, and myself while spending many hours data collecting in the lab will never be forgotten. I cannot express how grateful I am for Stephanie Douglas who was a reliable companion in the lab as I pressed through the undeniable challenges of writing. The magnitude and direction we provided for each other in the program advanced into a deep friendship that I will be blessed with forever. Thanks also to Dano Tolusso for generously sharing from his own experience and thesis process; his constant moral support and assistance were invaluable from the time I started the program until the finish.

Finally, I would also like to extend a warm thanks to the people who supported and encouraged me in the everyday aspects of the last two years: my housemates, Dr. Hephzibah
Dutt and Kimberly Bright; spiritual mentor, Kathy Caperna; my sisters, Kelsie and Kami; and my beloved parents, Ken and Jodi Kielsmeier. Their unconditional love and continual encouragement were what ultimately got me to the finish line. Most importantly, I praise my Heavenly Father for the much-needed grace I was given in order to successfully complete this thesis.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER 1: INTRODUCTION</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statement of the Problem and Purpose of the Study</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CHAPTER 2: LITERATURE REVIEW</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-intensity Intermittent Training</td>
<td>5</td>
</tr>
<tr>
<td>Bioenergetics during High-intensity Exercise</td>
<td>7</td>
</tr>
<tr>
<td>Overview of Metabolic Pathways</td>
<td>7</td>
</tr>
<tr>
<td>EPOC</td>
<td>8</td>
</tr>
<tr>
<td>Fuel Usage and Energy Expenditure Estimation</td>
<td>9</td>
</tr>
<tr>
<td>Sex Differences in Fatigue during High-intensity Exercise</td>
<td>11</td>
</tr>
<tr>
<td>Proposed Mechanisms Influencing Fatigue Differences Between Sexes</td>
<td>14</td>
</tr>
<tr>
<td>Muscle Mass</td>
<td>14</td>
</tr>
<tr>
<td>Muscle Morphology</td>
<td>15</td>
</tr>
<tr>
<td>Skeletal Muscle and Substrate Metabolism</td>
<td>16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CHAPTER 3: METHODS</th>
<th>19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental Approach to the Problem</td>
<td>19</td>
</tr>
<tr>
<td>Participants</td>
<td>19</td>
</tr>
<tr>
<td>Procedure</td>
<td>20</td>
</tr>
<tr>
<td>Trial 1: VO₂peak Test and Familiarization</td>
<td>20</td>
</tr>
<tr>
<td>Trial 2: High-intensity Interval Sprints (30:30)</td>
<td>22</td>
</tr>
<tr>
<td>Trial 3: High-intensity Interval Sprints (30:15)</td>
<td>24</td>
</tr>
<tr>
<td>Calculation of Energy Expenditure</td>
<td>24</td>
</tr>
</tbody>
</table>
Aerobic Contribution ................................................................. 24
Anaerobic Contribution ............................................................... 25
EPOC Contribution ........................................................................ 26
Statistical Analysis ......................................................................... 26
CHAPTER 4: RESULTS ............................................................................. 28
Absolute EE and System Contribution to EE during 30:30 ................... 28
Absoute EE ......................................................................................... 28
System Contribution to EE ............................................................... 28
Absolute EE and System Contribution to EE during 30:15 ................... 29
Absoute EE ......................................................................................... 29
System Contribution to EE ............................................................... 29
Relative System Contribution to EE Overall and Per Set during HIIT ..... 30
30:30 ................................................................................................. 30
30:15 ................................................................................................. 31
Heart Rate Response during HIIT .................................................... 32
30:30 ................................................................................................. 32
30:15 ................................................................................................. 32
Blood Lactate Concentration during HIIT ....................................... 33
30:30 ................................................................................................. 33
30:15 ................................................................................................. 34
Rating of Perceived Exertion and Session-RPE ................................. 34
30:30 ................................................................................................. 34
30:15 ................................................................................................. 35
Perceived Recovery Status ........................................................................................... 36

30:30 ................................................................................................................ 36

30:15 ................................................................................................................ 36

CHAPTER 5: DISCUSSION ........................................................................................... 37

Limitations ................................................................................................................... 41

Future Research ........................................................................................................... 42

Conclusion ................................................................................................................... 43

REFERENCES ................................................................................................................ 45

APPENDIX A: INFORMED CONSENT ........................................................................... 54

APPENDIX B: PAR-Q ........................................................................................................ 58

APPENDIX C: MEDICAL HISTORY QUESTIONNAIRE ................................................. 59

APPENDIX D: CLASS ANNOUNCEMENT ....................................................................... 62

APPENDIX E: RECRUITMENT FLYER ......................................................................... 63

APPENDIX F: ADULT OMNI SCALE OF PERCEIVED EXERTION FOR RUNNING
(UTTER ET AL., 2004) ..................................................................................................... 64

APPENDIX G: PERCEIVED RECOVERY STATUS SCALE (LAURENT ET AL., 2011) ... 65

APPENDIX H: SESSION RPE (FOSTER ET AL., 2001) .................................................... 66
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Absolute energy expenditure (kCals) across all total sprints and the contribution of each system to total energy expenditure between men and women during HIIT 30:30 trial.</td>
<td>29</td>
</tr>
<tr>
<td>2</td>
<td>Absolute energy expenditure (kCals) across all total sprints and the contribution of each system to total energy expenditure between men and women during HIIT 30:15 trial.</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>Relative energy system contribution (%) between men and women across all sprints during HIIT 30:30 trial.</td>
<td>31</td>
</tr>
<tr>
<td>4</td>
<td>Relative energy system contribution (%) between men and women across all sprints during HIIT 30:15 trial.</td>
<td>31</td>
</tr>
<tr>
<td>5</td>
<td>Heart rate (bpm) across four sets of HIIT 30:30 sprints between men and women.</td>
<td>32</td>
</tr>
<tr>
<td>6</td>
<td>Heart rate (bpm) across four sets of HIIT 30:15 sprints between men and women.</td>
<td>33</td>
</tr>
<tr>
<td>7</td>
<td>Blood lactate concentration (mmol) across four sets of HIIT 30:30 sprints between men and women.</td>
<td>33</td>
</tr>
<tr>
<td>8</td>
<td>Blood lactate concentration (mmol) across four sets of HIIT 30:15 sprints between men and women.</td>
<td>34</td>
</tr>
<tr>
<td>9</td>
<td>Rating of perceived exertion (RPE) differences between men and women during each of four sets of 30:30 HIIT.</td>
<td>35</td>
</tr>
<tr>
<td>10</td>
<td>Differences of rating of perceived exertion (RPE) between men and women during each of four sets and Session-RPE of 30:15 HIIT.</td>
<td>36</td>
</tr>
<tr>
<td>Tables</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>1 Mean descriptive characteristics of the participants for the 30:30 trial</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>2 Mean descriptive characteristics of the participants for the 30:15 trial</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>3 Standardized warm-up protocol</td>
<td>24</td>
<td></td>
</tr>
</tbody>
</table>
High-intensity interval/intermittent training (HIIT) is a mode of exercise traditionally utilized by team-sport athletes. In addition to its place in sport, it is also becoming a popular form of exercise among the general population due to its increased effects on physical fitness (compared to traditional, continuous exercise methods) (Gaesser & Angadi, 2011). A seeming consequence of the growing popularity of HIIT has been recent studies aimed toward sex-specific responses in fatigue and recovery ability (Laurent, Green, Bishop, Sjokvist, Schumacker, Richardson, & Curtner-Smith, 2010; Mageean, Alexander, & Mier, 2011; Laurent, Vervaecke, Kutz, & Green, 2014). Thus far, the available research seems to support the notion that women tend to demonstrate a greater resistance to fatigue than men during similar exercise efforts (Hunter & Enoka, 2001; Clark, Manini, Doldo, & Poul tz-Snyder, 2003; Esbjornsson-Liljedahl, Bodin, & Jansson, 2002; Hunter, 2009). What is less clear are the precise mechanisms underlying this phenomenon, yet some research tends to suggest it stems from underlying differences in muscle mass, muscle morphology, and/or metabolic substrate utilization (Ruby, Coggan, & Zderic, 2002; Billaut, Giacomoni, & Falgai rette, 2003; Perez-Gomez et al., 2008; Laurent et al., 2010, 2014).

It is well known and commonly accepted that men present with greater absolute muscle mass and tend to yield greater absolute strength and power compared to women. It has been suggested that the consequent increased mechanical work due to differences in strength is a mitigating factor contributing to men’s expedited fatigue (Billaut & Bishop, 2012). However, with relative strength capability of muscle fibers being similar between men and women (Miller MacDougall, Tarnopolsky, & Sale, 1993; Hunter, Butler, Todd, Gandevia, & Taylor, 2006; Yoon, Schlinder-Delap, Griffith, & Hunter, 2007; Perez-Gomez et al., 2008), greater strength
SEX-SPECIFIC METABOLIC RESPONSE TO HIIT

and power typically associated with men cannot singularly explain observed differences in the rate of fatigue. While greater muscle mass/initial strength may contribute to metabolic consequences (e.g., increased blood lactate concentration – [La]) (Clark, Collier, Manini, & Ploutz-Snyder, 2005), additional metabolic consequences may also stem from muscle morphology differences between men and women.

With respect to muscle morphology, it is generally well-accepted that women tend to possess greater Type I muscle fiber per cross-sectional area than men (Simoneau & Bouchard, 1989). Type I fibers, which demonstrate an increased capacity for adenosine-triphosphate (ATP) regeneration and decreased rate of [La] production compared to Type II, are more aerobic in nature and are proposed to be a moderating factor in sex differences during high-intensity work (Esbjornsson-Liljedahl, Sundberg, Norman, & Jansson, 1999; Esbjornsson-Liljedahl, Bodin, & Jansson, 2002; Laurent et al., 2010). The contractile and metabolic properties indicate that Type I fibers are more fatigue-resistant and more efficient at energy production than Type II. Therefore, it seems that men may need to depend on carbohydrate (i.e., glycogen) for energy in association with Type II fibers. That is, men may be predisposed to rely on glycolytic pathways when performing exercise at the same relative intensity as women. Thus, women, perhaps as a result of their greater proportion of Type I fibers, tend to utilize less glycogen and may have greater fat oxidation during high-intensity activities at similarly matched efforts as men (Esbjornsson-Liljedahl et al., 1999, 2002). This, theoretically, would elicit sex-specific metabolic responses during exercise – differences in the demands placed on the glycolytic and oxidative pathways as it would relate to overall ATP production.

Indeed, when compared at similar relative intensities and when afforded similar recovery periods, women tend to have attenuated [La] compared to men during brief, high-intensity sprint
SEX-SPECIFIC METABOLIC RESPONSE TO HIIT

Accordingly, it has been reported that women utilize less glycogen for fuel compared to men and resynthesize a greater amount of ATP during recovery intervals (Esbjornsson-Liljedahl et al., 1999, 2002). These findings collectively seem to suggest women may demonstrate attenuated glycolytic activity and, instead, may exhibit a reliance on oxidative pathways during high-intensity sprint work when compared to men at matched intensities. Moreover, relative recovery ability during repeated sprints has been reported to be improved in women compared to men as indicated by a lower decrement in performance (Laurent et al., 2010); greater recovery of power output (Mageean et al., 2011); and greater cardiovascular strain, despite self-selecting lower relative velocities than men during HIIT (Laurent et al., 2014). These findings serve to further underscore women’s potential reliance on oxidative pathways, suggesting greater aerobic contribution to overall energy expenditure (EE) during high-intensity sprint exercise. While this seems plausible, the existing research has not clearly identified the precise mechanisms mediating the observed sex-specific responses. Therefore, analyzing the relative contribution of glycolytic and oxidative pathways on EE between sexes during high-intensity repeated sprints would be worthy of additional research.

Statement of the Problem and Purpose of the Study

It seems that there may be meaningful physiological and performance differences between men and women during high-intensity efforts. To that end, it seems reasonable that differences in muscle morphology and the consequent metabolic response may account for a sex-specific response in energy pathway contribution. Specifically, it seems plausible that the relative contribution of oxidative and glycolytic pathways to HIIT would influence the fatigue and recovery differences noted in the literature between men and women. It may be that the greater oxidative pathway involvement to overall work (during sprint bouts and/or recovery periods) is
SEX-SPECIFIC METABOLIC RESPONSE TO HIIT

reflective of women’s improved recovery ability compared to men. Therefore, the current study’s purpose will be to utilize two high-intensity repeated sprint protocols to identify a potential sex-specific response in the relative oxidative and glycolytic contribution to EE during HIIT. It was hypothesized that men will have a greater absolute total EE compared to women. Additionally, it was hypothesized that women will demonstrate a greater oxidative metabolic response to high-intensity repeated sprint protocols at similar relative intensities as men.
High-intensity Intermittent Training

High-intensity intermittent training (HIIT), otherwise known as interval training, is a traditional training method for most team-sport athletes and is a current fitness trend being adopted within the general population based on the appeal of its metabolic “afterburn” effect. This “afterburn” is the number of calories expended (above resting values) after an exercise bout (Vella & Kravitz, 2004). It is scientifically known as excess post-exercise oxygen consumption (EPOC), defined as the period after exercise marked by an increase in volume of oxygen consumption (VO₂) above resting levels (Gaesser & Brooks, 1984).

The general structure of HIIT consists of periods of high-intensity work paired with passive or low-intensity recovery (Kemi & Wisløff, 2010). These undulating intervals of work and recovery allow an individual to perform a greater amount of total work at a high(er) intensity than could normally be maintained during long-duration, steady-state (SS) exercise (Kemi & Wisløff, 2010). A key element prompting the sustained popularity of HIIT centers on the notion that the high-intense nature of the activity stimulates increased metabolic rates during recovery from exercise and, consequently, greater energy expenditure (EE) (Bahr & Sejersted, 1991). This, in turn, could lead to increased weight loss in those individuals utilizing HIIT as part of exercise prescription or improved training adaptations in athletes. Within those individuals utilizing HIIT for weight management, it seems likely that a mediating factor precipitating increased weight loss could be increased EPOC during recovery. Tremblay, Simoneau, and Bouchard (1994) were among the first to investigate fat loss differences of HIIT vs. continuous (i.e., SS) training. Results from their study revealed that fat loss was significantly greater with HIIT vs. continuous training following a 15-week period. Indeed, there have been numerous
SEX-SPECIFIC METABOLIC RESPONSE TO HIIT

studies confirming the positive role of EPOC on weight loss and, perhaps more importantly, fat loss as a result of HIIT (Tremblay et al., 1994; Talanian, Galloway, Heigenhauser, Bonen, & Spriet, 2007; Trapp, Chisholm, Freund, & Boutcher, 2008).

It seems the higher fat loss seen with HIIT vs. moderate-intensity, continuous training implies that following HIIT/strenuous exercise, EE is increased (Tremblay et al., 1994). The promotion of the enhancement of fat loss makes this type of training highly attractive for the goal of weight management (Gaesser & Angadi, 2011). Likewise, HIIT has also been found to increase growth hormone (stimulating muscle hypertrophy) (Gray, Telford, & Weidemann, 1993), enhance cardiovascular adaptations and function (Kemi, Haram, Loennechen, Osnes, Skomedal, Wisløff, & Ellingsen, 2005), and is a time-efficient mode of exercise (Gaesser & Angadi, 2011) compared to traditional SS exercise methods. This, obviously, is attractive among the general population, but HIIT is useful as well in sport training.

From an athletic standpoint, HIIT is similar in nature to the high-intensity intermittent work-to-rest ratios involved in many competitive team-sports. Depending on recovery interval duration, intensities near maximal or supramaximal (i.e., above maximal volume of oxygen consumption – VO2max) can be maintained throughout the periods of work. Resultant changes stemming from this type of training tend to produce increases in an individual’s lactate threshold while concomitantly enhancing an individual’s ability to recover and delay fatigue (Edge, Bishop, & Goodman, 2006). These are important factors associated with optimal performance in sport. Thus, it seems that there are positive adaptations associated with HIIT within both general population exercising for weight management as well as well-trained individuals and athletes looking to improve overall performance.
Bioenergetics during High-intensity Exercise

Overview of Metabolic Pathways

The two metabolic pathways in the body – aerobic and anaerobic – are simultaneously activated at the onset of physical activity or exercise. However, anaerobic pathways tend to be predominant during activities of high-intensity while aerobic pathways are predominant during low-intensity activities. Aerobic metabolism supplies the body with ATP (the body’s usable form of energy) in the presence of oxygen (O₂). Sufficient O₂ availability at the level of the electron transport chain is a pre-requisite for sustained utilization and predominance of aerobic metabolism (McArdle, Katch, & Katch, 2007). Under these conditions, the body is termed to be in steady-state, which is the point at which O₂ consumption meets the O₂ demand (McArdle et al., 2007). Conversely, at the onset of any activity and throughout high-intensity activities, O₂ demand exceeds O₂ consumption and, as such, the body tends to favor anaerobic metabolism for the resynthesis of ATP to sustain work. Through the processes of the ATP-PCr system, as well as glycolysis, rapid production of ATP occurs. This presents with obvious advantages in supporting high-intensity efforts; however, it forfeits the larger energy yield of the aerobic pathway and produces byproducts that negatively affect performance.

The metabolic byproducts stemming from anaerobic pathway activation (e.g., [La], H⁺, carbon dioxide [CO₂], acidosis) limit the duration for sustaining activity at this intensity and can eventually precipitate fatigue. During non-SS exercise, these metabolic byproducts are produced at rates that disallow for optimal clearance and also occur at the onset of exercise, when workloads increase. Of importance is [La], which is a known indicator of fatigue, and its accumulation is a direct consequence of anaerobic metabolism (McArdle et al., 2007). Indeed, it is known that the buffering of [La] (as well as other metabolites) is accomplished by either
decreasing intensity during exercise or through the uptake of O₂ in EPOC after the cessation of activity. Therefore, the assessment of [La] during high-intensity work could serve as an indicator of not only imminent fatigue but also could reflect the level of glycolytic activity during that period of work (Scott, 2000).

**EPOC**

The phenomenon of EPOC (increased VO₂ above resting levels post-exercise) occurs in two stages: 1) rapid phase EPOC (within the first minutes of exercise completion) and 2) prolonged EPOC (lasting multiple hours after exercise) (Lamont, Romito, & Rossi, 2009). Intensity is the primary determinant of the magnitude of EPOC incurred; duration of exercise also contributes, but to a lesser extent (Phelain, Reinke, Harris, & Melby, 1997). The rapid phase of EPOC serves to restore the body back to resting levels (e.g., lowering heart rate, respiration rate, body temperature, lactate levels; re-phosphorylating ATP levels, etc.). This rapid phase restoration is achieved via increases in VO₂ concurrent with increased EE above rest in order to restore homeostasis. However, this increased O₂ uptake is not thought to be the singular reason for the prolonged portion of EPOC.

At the start of an activity transitioning to higher intensities, the body will initially rely on anaerobic pathways to provide ATP as there is a ‘lag’ in the oxidative pathways due to insufficient supply of O₂ for the high demand of ATP. Nonetheless, depending on the target intensity, the body will tend to shift from reliance on anaerobic to aerobic metabolism (i.e, SS). This process is dependent on a number of factors that may prolong or attenuate the transition to SS (e.g., fitness level, experience, etc.). This initial period of anaerobic activity is termed the “O₂ deficit” (Krogh & Lindhard, 1919/20). Additionally, during strenuous exercise there is an
increased reliance on anaerobic metabolism, and oxidative pathways, likewise, cannot adequately supply the required ATP.

The anaerobic processes that are experienced during the initial ‘lag’ of aerobic metabolic pathway activation (i.e., O₂ deficit), or during those exercises that are of high(er) intensity in which oxidative metabolism cannot sufficiently provide ATP will require “pay back” during recovery (i.e., EPOC). This period has also been termed “oxygen debt” and “recovery energy expenditure” (Smith & Naughton, 1993). Thus, it can be surmised that HIIT, involving the activation of the glycolytic pathways, will be followed by a substantial period of EPOC (this phenomenon also known by the general population as the “afterburn” effect). The popularity of HIIT is largely based off the notion of this large EPOC and its associated large recovery EE.

Fuel Usage and Energy Expenditure Estimation

Skeletal muscle metabolism encompasses the catabolism of three different energy substrates for the synthesis of ATP – carbohydrate (CHO), fat, and to a lesser extent, protein (Zuntz & Schumburg, 1901). CHO and fat utilization are largely dependent upon the specific metabolic pathway that predominates the chosen activity (i.e., anaerobic or aerobic, respectively) and/or energy availability. The metabolic fuel being utilized will indicate the amount of heat being produced by the body as a result of performing a given task. More clearly stated, the specific metabolic substrate combusted will indicate the total amount of energy being consumed (i.e., EE) by the body during any given activity (Frayn, 1983 as cited from Lusk, 1923).

To estimate EE, indirect calorimetry is the typical technique utilized where respiratory gases are measured and analyzed. From those measurements, the ratio of CO₂ production to O₂ consumption is determined, which indicates fuel usage (Baechle, Earle, & NSCA, 2000). This is called the respiratory exchange ratio (RER). RER values tend to range from 0.69 indicating fat
utilization (i.e., predominantly oxidative processes yielding ATP) to values 1.00 or greater, which, conversely, would indicate greater CHO utilization (i.e., greater reliance on anaerobic pathways) (Zuntz & Schumberg, 1901). From the RER value, which provides information regarding macronutrient utilization, the amount of kilocalories (kCals) expended can also be estimated based upon the known O₂ necessary to combust any given ratio of fats and CHO (Baechle et al., 2000). The measurement of VO₂ estimates heat production, thus EE can be estimated per every 1 L of O₂ consumed (Scott, 2000), if the RER is known. Specifically, it seems that when CHO is combusted it yields 21.1 kJ/L O₂, whereas oxidation of fat yields 19.6 kJ/L O₂ (Scott, 2005). Therefore, it would seem that the estimation of EE at any intensity (anaerobic or aerobic) could be estimated by the known ratio: VCO₂/VO₂ (i.e., RER).

Scott (2000) proposes that an anaerobic (i.e., glycolytic) component contribution to EE above the aerobic (i.e., VO₂) component exists. For this reason, EE estimation of oxidative and glycolytic energy yield should be separated during high(er)-intensity activities since the glycolytic process does not rely on O₂ uptake to resynthesize ATP (Scott, 2005; Scott & Djurisic, 2008a; Scott, Shaw, & Leonard, 2008b; Scott & Earnest, 2011). Recent investigations have shown that EE estimated solely by VO₂ does not accurately represent total EE as it ignores specific anaerobic/glycolytic yield (Scott & Djurisic, 2008a; Scott et al., 2008b). However, it has been shown that the glycolytic component to EE can be estimated accurately through the measurement of change in [La] (Margaria, Cerretelli, & Mangili, 1964; di Prampero & Ferretti, 1999). The accumulation of [La] can serve as a marker for the level of involvement of anaerobic glycolysis. As lactate production exceeds lactate removal, glycolysis is the predominant energy pathway required to sustain work (Scott et al., 2008b). Consequently, calculating changes in [La] from resting levels could more clearly provide an estimate of glycolytic EE. Separately
estimating glycolytic EE by change in [La] has been shown to reveal significantly larger total exercise EE (blood lactate, 328 ± 74.5 kJ) as opposed to estimating EE solely by O2 uptake (271 ± 66.1 kJ) \((p = 0.03)\) (Scott et al., 2008b). Given the high-intensity nature of HIIT, the ability to estimate the glycolytic contribution to this form of work seems attractive and worthy of merit.

**Sex Differences in Fatigue during High-intensity Exercise**

The study of sex differences in fatigue and/or recovery lacks universal agreement towards mediating mechanisms ultimately involved. However, existing data show that women tend to demonstrate a greater resistance to fatigue than men during similar exercise efforts (Hunter & Enoka, 2001; Esbjornsson-Liljedahl et al., 2002; Clark et al., 2003; Hunter, 2009). The preponderance of evidence defining fatigue differences between men and women has relied on data stemming from protocols involving fatiguing isometric maximal voluntary contractions (MVC) (Maughan, Harmon, Leiper, Sale, & Delman, 1986; Miller et al., 1993; West, Hicks, Clements, & Dowling, 1995) and, to a lesser extent, dynamic muscle contractions of key muscle groups in the upper and lower limbs (Senefeld, Yoon, Bement, & Hunter, 2013). Protocols utilizing low to moderate intensity (~20-70% MVC) demonstrate increased fatigue resistance in women while higher-intensity loads (~80-90% MVC) were less likely to identify a difference between sex (Yoon, Delap, Griffeth, & Hunter 2007; Maughan et al., 1986; Miller et al., 1993). However, a more recent study observing bench press exercise found that, because of women’s enhanced recovery ability/less fatigability between sets, they were able to perform more repetitions than men at a similar relative intensity (75%1RM) (Ratamess et al., 2012). This may indicate that women require a shortened recovery interval between sets to perform the same relative work as men (Ratamess et al., 2012).
Additionally, during high-intensity dynamic performance, such as repeated sprints (i.e., HIIT), research has shown evidence that women demonstrate improved fatigue resistance and/or recovery ability compared to men (Esbjornsson-Liljedahl et al., 2002; Laurent et al., 2010; Mageean et al., 2011; Laurent et al., 2014). Studies examining sex differences in repeated sprint work have utilized protocols involving shorter sprints (≤10 sec; Billaut et al., 2003; Mageean et al., 2011; Billaut & Bishop, 2012) and longer sprints (≥30 sec; Esbjornsson-Liljedahl et al., 1999, 2002) with variable recovery intervals. In a study by Billaut et al. (2003) women were shown to recover greater power output during a 4-min recovery between two maximal 8-sec sprints despite greater loss of power during the sprint performance itself. It has also been shown that during longer sprints, lasting around 30 seconds, the production and accumulation of metabolic byproducts were attenuated in women (Esbjornsson-Liljedahl et al., 2002) even more than during a single all-out sprint (Esbjornsson-Liljedahl et al., 1999). Furthermore, there have been reports noting that during sprint bouts, women utilize less glycogen than men at similar relative intensities (indicating greater fat oxidation), and ATP resynthesis tends to occur faster in women than in men given similar recovery periods (Esbjornsson-Liljedahl et al., 2002). This data would suggest that women may be able to demonstrate lower fatigue rates and/or increased recovery ability during bouts of high-intensity work.

In a study investigating sex differences during repeated sprint performance, Laurent et al. (2010) utilized a protocol consisting of three sets of 8, 30-m sprints with 45-s of recovery between sprints. Results from this study showed that women consistently sustained a higher percentage of their maximal performance (i.e., seen by lower decrement scores) indicating less fatigue (Laurent et al., 2010). Likewise, a lower [La] was observed as well in women compared to men, which may suggest lower glycolytic activity despite similarly matched efforts. In turn, it
was concluded that at maximal relative intensity, women were able to delay the onset of fatigue and, therefore, recover faster than men. The physiological mechanisms attributed to the observed sex difference were absolute muscle mass, muscle fiber type, and associated metabolic factors (Laurent et al., 2010). The researchers, in agreement with previous sprint studies (Esbjornsson-Liljedahl et al., 1999, 2002), attributed these findings to the greater proportion of type I fibers seen in women (vs. men) which demonstrate an increased rate of ATP regeneration and decreased rate of [La] production (Laurent et al., 2010). Similarly, Mageean et al. (2011) found that men and women, matched for VO2 max relative to fat-free mass (FFM), achieved similar relative power outputs across 5, 6-sec cycling sprints (30-sec active recovery intervals). However, during a subsequent active recovery of five minutes preceding a final, all-out 30-sec sprint, women recovered a greater proportion of power output than men. While an apparent sex difference was not observed across the short repeated sprints, it was concluded in that study that there may be a sex difference seen in sprints of longer duration, hence women’s increased recovery prior to the 30-sec sprint (Mageean et al., 2011). In addition, Laurent et al. (2014) found that women will essentially “work harder”, at least from a cardiovascular standpoint, than men (evidenced by greater cardiovascular strain and greater perception of effort) despite self-selecting sprint velocities lower than men. This provides further evidence that an increased reliance on aerobic pathways vs. anaerobic pathways in women could explain the improved ability to withstand fatigue and/or recover faster when compared to men (Laurent et al., 2010, 2014). However, the precise mechanisms underlying the observed sex-specific responses in fatigue and recovery, metabolic or otherwise, have not been clearly identified in the literature.
Proposed Mechanisms Influencing Fatigue Differences Between Sexes

Processes of both the central nervous system (CNS) and within the neuromuscular system suggest multiple physiological mechanisms contribute to fatigability and performance differences between sexes. Hunter et al. (2006) have reported that supraspinal (i.e., CNS) fatigue does not explain the sex difference in muscle fatigue of maximal contractions, rather, sex differences may lay within mechanisms within the muscle itself. Within the literature, there have been three main contributory mechanisms implicated explaining the observed differences between men and women: muscle mass, muscle morphology, and metabolic substrate utilization (Ruby et al., 2002; Billaut et al., 2003; Perez-Gomez et al., 2008; Laurent et al., 2010, 2014).

Muscle Mass

It was previously hypothesized that muscle fiber size and not number of fibers primarily influenced fatigability between men and women (Miller et al., 1993). However, recent findings now seem to indicate that there are, in fact, differences influenced by the amount of muscle mass between men and women (Perez-Gomez et al., 2008). Perez-Gomez et al. (2008) found that men’s greater absolute muscle mass of the lower extremity attributed to the higher peak power output produced compared to women when performing Wingate tests. Indeed, men typically present with higher absolute muscle mass versus women and will, consequently, tend to yield greater absolute strength and power. However, it may be that these increased strength and power outputs negatively contribute to the expedited fatigue noted in the literature (Billaut & Bishop, 2012). This is because recent research has noted that there seems to be an increased fatigability associated with greater initial strength and the consequent greater mechanical work performed by men with greater muscle mass (Billaut & Bishop, 2012). Thus, the greater absolute force produced by men may elicit an increased mechanical compression of the vasculature (i.e., less
SEX-SPECIFIC METABOLIC RESPONSE TO HIIT

Muscle perfusion), causing reduced O₂ delivery and greater buildup of metabolites leading to premature fatigue (Clark et al., 2005). This sex difference in muscle perfusion, however, has only been demonstrated in certain muscle groups and, as a result, this contributory factor may be relatively task specific (i.e., sustained or intermittent contraction) (Clark et al., 2005; Parker et al., 2007). Moreover, there have been reports suggesting that during high-intensity contractions, women and men have similar blood occlusion rates (Maughan et al., 1986; West et al., 1995; Yoon et al., 2007). Parker et al. (2007) report that during dynamic contractions, greater perfusion in women (possibly due to greater vasodilation responses) could promote attenuated accumulation of metabolites, which, theoretically, could be a mechanistic factor mitigating fatigue. Importantly, strength differences between sexes cannot singularly explain the observed differences in the rate of fatigue, as relative strength capability of muscle fibers is similar between men and women (Miller et al., 1993; Hunter et al., 2006; Yoon et al., 2007; Perez-Gomez et al., 2008). However, the noted difference in muscle mass could imply that there would be differences in absolute power output which may have other implications for fatigability due to the mechanical and metabolic consequences.

Muscle Morphology

Muscle morphology refers to muscle fiber type and associated characteristics that accompany those fiber type distribution patterns. It is generally accepted that men and women possess inherent differences in their muscle morphology, with women typically possessing greater type I muscle fiber per cross-sectional area than type II (Simoneau & Bouchard, 1989). Type I fibers possess ‘slow-twitch’ or aerobic characteristics (e.g., small cross-sectional area, oxidative enzymes, low force production, high resistance to fatigue, etc.) while type II fibers tend to have ‘fast-twitch’ or anaerobic characteristics (e.g., large cross-sectional area, high force and
power production, quick to fatigue, contain a greater amount of stored phosphagens and
glycogen, etc.). Thus, type II fibers tend to be more fatigable than type I (Schiaffino &
Reggiani, 2011). Because it has been shown that women have a greater proportion of type I muscle fiber
while men have a greater proportion of type II (Simoneau & Bouchard, 1989; Esbjornsson-
Liljedahl et al., 1999; Roepstorff et al., 2006), it is proposed that this could be a mitigating factor
in sex differences in high-intensity work. Not only do type I fibers have increased capillarization
(i.e., enhanced O2 delivery), but the contractile and metabolic properties indicate that they are
more fatigue-resistant and more efficient at energy production than type II fibers, respectively
(Hunter et al., 2006; Wust, Morse, De Haan, Jones, & Degens, 2008). The differences in absolute
muscle mass and proportion of muscle fiber type seem to have a direct impact on skeletal muscle
metabolism which could offer further explanation on fatigue differences between men and
women.

*Skeletal Muscle and Substrate Metabolism*

Muscle fiber type has direct consequences on skeletal muscle metabolism. Men,
possessing a higher proportion of type II fibers, tend to be predisposed to rely preferentially on
glycolytic pathways during activities increasing in intensity when compared to women. During
glycolysis, CHO is the substrate that fuels high-energy containing fiber cells to produce the
higher power output observed in men; however, the metabolic disruption caused by a build-up of
[La] could predispose men to fatigue (Laurent et al., 2010). It has been suggested that during
HIIT, metabolic differences between men and women is not so much related to the activation of
type II muscle seen in men, rather, it could be that women, utilizing a higher proportion of type I
muscle, tend to have a higher reliance on oxidative pathways compared to men during similarly
matched efforts. The resultant metabolic implications (e.g., higher rates of [La] clearance,
increased capacity of O₂ consumption, etc.) may lead to a higher fatigue resistance/faster recovery in women compared to men (Esbjornsson-Liljedahl et al., 1999, 2002; Laurent et al., 2010).

There is considerable evidence showing that during endurance exercise women oxidize more fat and less CHO than men at the same relative intensity (Tarnopolsky, MacDougall, Atkinson, Tarnopolsky, & Sutton, 1990; Horton, Pagliassotti, Hobbs, & Hill, 1998; Roepstorff et al., 2006). However, this notion is not as clear during high-intensity activity. It has been hypothesized that at high intensities, a difference in fuel utilization between men and women may not be observed due to the presumed reliance on anaerobic pathways during these activities (Horton et al., 1998). Romijn, Coyle, Sidossis, Rosenblatt, and Wolfe (2000) found that substrate utilization during moderate and high-intensity continuous exercise showed no differences in endurance-trained men and women. However, Esbjornsson-Liljedahl et al. (2002) found that, after men and women performed repeated bouts of high-intensity cycling sprints, women were able to recover energy stores (i.e., ATP) at a higher rate between sprints which led to a higher fatigue resistance than men. Furthermore, exercise-induced glycogen reduction was attenuated in type I fibers of women (~20%) compared to men during the 2, 30-sec sprint bouts (Esbjornsson-Liljedahl et al., 2002). The findings from this study imply that there is a substrate utilization sex difference during (and after) sprints likely due to women having greater proportion of type I muscle fiber. The mechanism(s) underlying these findings are not completely clear, but it seems plausible that due to type I fibers having a smaller cross-sectional area, shorter diffusion distances could improve the ability for the transport of O₂ and substrates to oxidize cells and eliminate anaerobic byproducts (Esbjornsson-Liljedahl et al., 2002; Roepstorff et al., 2006).
This, in turn, could provide a plausible rationalization explaining the observed sex-specific responses in fuel utilization, which could influence underlying fatigue and recovery differences.

If women demonstrate a faster recovery/higher fatigue resistance than men, assumptions for similar fitness adaptations relative to men could prove inaccurate. That is, it may be that due to the proposed differences in the metabolic response to HIIT between men and women, the adaptations that are experienced by this form of training (e.g., increase of: lactate threshold, tolerance of byproduct accumulation, buffering system capabilities, etc.) may also be sex-specific. Estimating the EE of oxidative, glycolytic, and EPOC contributions to overall HIIT work may reveal a sex-specific response in energetics between men and women that would potentially contribute to differences in fatigue and recovery.
Experimental Approach to the Problem

This study aimed to examine metabolic differences between men and women during and after repeated high-intensity sprints (i.e., HIIT work-to-rest ratios of 1:1 and 2:1). Participants performed two trials of repeated sprints performed at the same relative intensity (i.e., supramaximal intensity) with different rest periods in order to examine total EE involving the exercise and the following EPOC. Oxidative and glycolytic energy contributions were separately determined by the measurement of \( O_2 \) uptake and the change in \([La]\) for accurate estimation of EE. The absolute and relative contribution of oxidative, glycolytic, and EPOC EE to the total session EE was then analyzed to determine differences between sex and across time.

Participants

Sixteen healthy, physically active men and women volunteers between 19-35 years of age were recruited to participate in this study. Altogether, sixteen participants (men, \( N=9 \); women, \( N=7 \)) completed the 30:30 trial (Table 1). The 30:15 trial consisted of the same women and men, however, three males were excluded who failed to complete the protocol resulting in thirteen total (men, \( N=6 \); women, \( N=7 \)) (Table 2). To be included in this study, participants must have been currently performing HIIT or been currently active in an intermittent-type sport (e.g., soccer, basketball, football) at least two days per week for a minimum of three months. Exclusion criteria for this study included any medical condition, orthopedic or musculoskeletal injury that would limit performance or safety of the individual, or a classification of moderate or high risk as classified by ACSM guidelines (Thompson, Gordon, & Pescatello, 2010). Prior to each testing session, participants were asked to arrive to the laboratory in a well-rested, hydrated state, be at least 4-h post-prandial, at least 4-h post-ingestion of caffeine, and at least 24-h post-
ingestion of alcohol. In addition, participants were asked to refrain from intense physical activity for 48 hours prior to performing any testing.

Participants were screened for inclusion to the study using the Physical Activity Readiness Questionnaire (PAR-Q) and a medical history questionnaire. Participants provided written informed consent after being encouraged to ask any questions regarding the study and were informed they could remove themselves from the study at any time for any reason without consequence. All procedures were approved by the local Human Subject Research Board.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Men (N = 9)</th>
<th>Women (N = 7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>24.3 ± 4.7</td>
<td>22.0 ± 1.6</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177.6 ± 6.0</td>
<td>168.5 ± 4.4</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>78.0 ± 10.4</td>
<td>64.6 ± 6.6</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>11.2 ± 3.8</td>
<td>20.6 ± 4.3</td>
</tr>
<tr>
<td>VO2peak (ml/kg/min)</td>
<td>54.9 ± 5.6</td>
<td>49.1 ± 2.3</td>
</tr>
<tr>
<td>Aerobic capacity percentile rank (%)</td>
<td>87.0 ± 10.93</td>
<td>91.4 ± 4.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Men (N = 6)</th>
<th>Women (N = 7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>23.7 ± 2.5</td>
<td>22.0 ± 1.6</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>178.6 ± 6.6</td>
<td>168.5 ± 4.4</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>81.3 ± 11.4</td>
<td>64.6 ± 6.6</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>11.2 ± 4.7</td>
<td>20.6 ± 4.3</td>
</tr>
<tr>
<td>VO2peak (ml/kg/min)</td>
<td>54.5 ± 5.4</td>
<td>49.1 ± 2.3</td>
</tr>
<tr>
<td>Aerobic capacity percentile rank (%)</td>
<td>84.8 ± 11.6</td>
<td>91.4 ± 4.8</td>
</tr>
</tbody>
</table>

**Procedure**

**Trial 1: VO2peak Test and Familiarization**

Upon arrival to the exercise physiology laboratory, participants were screened for inclusion in the study using approved procedures and were assessed for anthropometric measures prior to performing a treadmill VO2peak test. Participants’ anthropometric measures such as
height (cm) and body mass (kg) were assessed with a calibrated physician’s beam scale and stadiometer (Detecto Scale Company, Webb City, MO) along with body fat percentage estimated using the 3-site skin fold method (men: chest, abdomen, and thigh; women: tricep, iliac, and thigh; Pollack, Schmidt, & Jackson, 1980) by skinfold calipers (Lange, Cambridge, MD). A Polar heart rate monitor (Polar Electro, Kempele, Finland) to assess HR (bpm) throughout the entire trial was fitted to participants, which involves wearing a small elastic, flexible belt around the chest at the level of the sternum. A wrist-watch receiver, displaying, in real-time, HR data acquired from the belt’s transmitter signals, was monitored by the researchers throughout the testing session. Prior to beginning the maximal test, participants performed a self-selected warm-up. Participants were then fitted to a calibrated metabolic measurement system (Parvomedic TrueOne 2400, Sandy, UT) by inserting a Two-Way Non-Rebreathing T-valve (Hans Rudolf Inc., Shawnee, KS) mouthpiece and applying a nose clip in order to analyze respiratory gas exchange (i.e., indirect calorimetry). Once properly fitted to the metabolic cart, participants began the incremental maximal exertion test (Noakes, 1990) on a motorized treadmill (Truefitness, O’Fallon, MO). Participants began running at a speed of 6.2 mph with a 0% incline, and every minute thereafter, speed was increased by 0.6 mph until volitional fatigue. Metabolic measures including O₂ consumption (VO₂ L/min), carbon dioxide production (VCO₂ L/min), and RER were measured and recorded using a 5-sec average throughout the test. Additionally, HR and rating of perceived exertion (RPE) was recorded every minute before proceeding to the next stage of the test. RPE was assessed using the OMNI Scale of Perceived Exertion (Utter et al., 2004) that ranges from 0 (representing no exertion) to 10 (representing maximal exertion). The scale was explained to participants prior to the start of the test. Termination of the test was determined by participants signaling they could not continue any further or, if by the researcher’s
discretion, participants displayed signs of undue fatigue that would lead to unsafe conditions were the test to continue. After completion of the test, participants were disconnected from the metabolic cart and monitored during a self-selected cool-down until HR had returned to near resting levels. The final speed maintained for the last complete minute prior to termination of the test determined participants’ velocity at maximal oxygen uptake (vVO$_2$max). The vVO$_2$max was used to determine the workload participants would perform the subsequent experimental sprint trials.

Approximately 20 minutes following completion of the maximal treadmill test, participants performed a familiarization set of the 30:15 sprint protocol (described below). This indicated to participants their ability to perform the supramaximal protocol employed in the experimental trials, as well as acclimated them to the procedures to be followed during subsequent testing.

**Trial 2: High-intensity Interval Sprints (30:30)**

The second trial took place at least 48 hours but no longer than seven days after completion of the VO$_2$peak test. Upon arrival to the laboratory, participants donned a HR monitor and were affixed again to the calibrated metabolic measurement system (exact procedure from the maximal exertion test) in order to obtain resting metabolic measures (i.e., VO$_2$, VCO$_2$, RER). These were recorded for 5-10 minutes while participants remained seated in a chair breathing normally into the T-valve mouthpiece. Following resting EE measurement, a resting [La] (mmol) sample was taken using a calibrated, portable enzymatic lactate analyzer (Lactate Plus, Nova Biomedical Corp., Waltham, MA). This was done by the researcher performing a small ‘stick’ to a preferred fingertip with a lancet to draw a capillary sample of blood. Following the recording of resting measures, participants were disconnected from the metabolic cart and
performed a standardized warm-up described by Vetter (2007). This treadmill warm-up consisted of a 4-min walk at 3.7 mph, a 2-min run at 7.5 mph, and three rounds of a dynamic warm-up (see Table 3) performed in this specific sequence.

Following the warm-up, participants were asked to complete a high-intensity repeated sprint protocol. This consisted of four sets of 4, 30-sec sprint intervals at 110% of the participants’ predetermined vVO2max. Each 30-sec sprint was interspersed with a 30-sec passive recovery where participants were instructed to straddle the treadmill belt. At the end of each sprint, HR (bpm) was recorded, and after the 2nd and 4th sprint, OMNI scale RPE was recorded. To denote the upcoming start of the next sprint, the researcher provided a 5-sec countdown for the participants, whereupon they were instructed to return to the belt and perform a subsequent sprint. Immediately after the first set of 4, 30-sec sprints, participants were seated in a chair for a longer session of passive recovery lasting three minutes. During the 3-min passive recovery, metabolic measures continued to be recorded, and a [La] sample was taken at the 2-min mark of recovery. This process occurred for each of the four sets of sprints.

Prior to each of the four sets of sprints, a Perceived Recovery Status Scale (PRS) (Laurent et al., 2011) measure was taken to determine how well participants felt they were recovered for the next set of sprints. The PRS scale ranges from 0 (representing poorly recovered/extremely tired) to 10 (representing very well recovered/highly energetic). An explanation of the PRS scale was given to participants prior to the test. At the completion of the entire session (four sets of four sprints), participants were again seated in a chair while still connected to the metabolic cart for the recording of EPOC measures (i.e., VO2, VCO2, RER). A final [La] sample was taken at minute 2 into the EPOC measurement. This final recovery stage ended after a total of ten minutes. Approximately 20 minutes after completion of the trial (i.e.,
ten minutes after the final EPOC recovery stage), participants were asked to provide a subjective rating of the entire session’s global difficulty using the Session Rating of Perceived Exertion (S-RPE) (Foster et al., 2001). The S-RPE corresponds with the OMNI scale that ranges from 0 (representing no exertion) to 10 (representing maximal exertion).

Table 3. Standardized warm-up protocol

<table>
<thead>
<tr>
<th>Dynamic warm-up exercise</th>
<th>Repetitions</th>
<th>Cadence (reps per min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toe Raises</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>High knee lift</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Buttock kick</td>
<td>20</td>
<td>30</td>
</tr>
</tbody>
</table>


Trial 3: High-intensity Interval Sprints (30:15)

This third and final trial was identical to trial 2, but the work-to-rest ratio was 2:1 (i.e., 30-sec sprints interspersed with 15-sec passive recovery). All other measures taken and procedures were conducted in the exact same manner as trial 2. Trials 2 and 3 were counterbalanced in order to avoid any ordering effect on the outcome.

Calculation of Energy Expenditure

Aerobic Contribution

Aerobic contributions to total EE were estimated using respiratory gas exchange recorded from indirect calorimetry (i.e., VO₂ and RER). The energy expended from net VO₂, the O₂ consumed above resting levels due to exertion from exercise, was calculated through the RER equivalent (Zuntz, 1901) for every minute of the protocol. The predetermined kCals (i.e., energy expended) provided the kCals per liter of O₂ consumed (kCals/L O₂). Multiplying net VO₂ by kCals/L O₂ determined the kCals attributed to the exercise EE. An example of one set of four repeated sprints is shown below.
SEX-SPECIFIC METABOLIC RESPONSE TO HIIT

(Aerobic formula):

\[ \text{VO}_{2\text{gross}} - \text{VO}_{2\text{rest}} = \text{VO}_{2\text{net}} \]

(RER corresponds to kCals/L O\(_2\))

\[ \text{kCals/L O}_2 \times \text{VO}_{2\text{net}} = \text{kCals/min of exercise} \]

\[ 11.36 \text{ L O}_2 (\text{VO}_{2\text{gross}}) - 0.40 \text{ L O}_2 (\text{VO}_{2\text{rest}}) = 9.76 \text{ L O}_2 (\text{VO}_{2\text{net}}) \]

(associated RER = 0.90 = 4.92 kCals)

\[ 4.92 \text{ kCals} \times 9.76 \text{ L O}_2 (\text{VO}_{2\text{net}}) = 48 \text{ kCals} \]

**Anaerobic Contribution**

Anaerobic contribution to total EE was estimated using a novel method derived from Scott et al. (2008b) that utilizes the difference between resting and peak [La], calculated as the change in [La] (Δblood lactate) to estimate glycolytic contribution to EE (Scott et al., 2008b).

The O\(_2\) uptake equivalent of 1 mmoL [La] increase above rest is 3.0 ml O\(_2\)/kg of body weight and then as 1 L O\(_2\) = 21.1 kJ. Kilojoules (kJ) was further converted to kCals by dividing kJ by 4.184. An example of one set of four repeated sprints is shown below.

\[ 9.5 \text{ mmoL} ([\text{La}]_{\text{peak}}) - 1.7 \text{ mmoL} ([\text{La}]_{\text{rest}}) = 7.8 \text{ mmoL} (\Delta\text{blood lactate}) \]

\[ 7.8 \text{ mmoL} \times 3.0 \text{ ml O}_2 \times 50 \text{ kg body weight} = 1170 \text{ ml O}_2 \]

\[ 1170 \text{ ml O}_2 = 1.17 \text{ L O}_2 \]

\[ 1.17 \text{ L O}_2 \times 21.1 \text{ kJ} = 24.7 \text{ kJ/L O}_2 \]

\[ 24.7 \text{ kJ/L O}_2 / 4.184 = 5.9 \text{ kCals} \]
EPOC Contribution

Finally, EPOC contribution to total EE was calculated by measuring VO₂ during the three, 3-min passive recovery periods in between sets of sprints. In accordance with Scott, Croteau, and Ravlo (2009), gross VO₂ was converted to represent EE as 1 L O₂ = 19.6 kJ. In addition, a session EPOC was derived using similar procedures following not only each set of sprints, but following the entire session. An example of one set of four repeated sprints is shown below, as well as a summated example of total and relative EE.

\[ 6.0 \text{ L O}_2 (\text{VO}_2\text{ gross}) - 0.40 \text{ L O}_2 (\text{VO}_2\text{rest}) = 5.6 \text{ L O}_2 (\text{VO}_2\text{net}) \]

\[ 5.6 \text{ L O}_2 \times 19.6 \text{ kJ/L} = 109.7 \text{ kJ/L O}_2 \]

\[ 109.7 \text{ kJ/L} / 4.184 = \textbf{26.2 kCals} \]

Total EE

\[ \sum [\text{oxidative} = 48 \text{kCals}; \text{glycolytic} = 5.9 \text{kCals}; \text{EPOC} = 26.2 \text{kCals}] = \textbf{80.1 kCals} \]

Relative EE

Oxidative = 48/80.1 = 60%

Glycolytic = 5.9/80.1 = 7%

EPOC = 26.2/80.1 = 33%

Statistical Analysis

Absolute and relative contribution of energy system to total work during the HIIT sessions were analyzed using a series of 2 (sex) x 4 (set of sprints) repeated measures ANOVA to identify any significant main effect. When appropriate, univariate post-hoc follow-ups including 1-way ANOVA and dependent paired t-tests were performed to identify significant differences. A series of 1-way ANOVA tests determined if significant differences existed between sex regarding [La], HR, RPE, S-RPE, and PRS. An independent t-test was utilized to
assess the differences in total work performed between men and women. All data were presented as mean ± SD unless stated otherwise. Power was reported as N-β, and effect size for main effects was reported as partial eta squared (ES). Statistical significance was set at the 0.05 level, and all data was analyzed using the statistical package for social sciences (SPSS, v 22, IBM Corporation, Armonk, NY).
CHAPTER 4: RESULTS

Absolute EE and System Contribution to EE during 30:30

Absolute EE

Results from an independent t-test revealed a significant difference in overall EE (kCal) between men and women during the 30:30 HIIT trial. The overall EE was significantly greater in men vs. women (see Figure 1).

System Contribution to EE

A 2 (sex) x 4 (set of sprints) mixed model repeated measures ANOVA revealed a significant main effect of energy system contribution of kCals expended between men and women during HIIT of 30:30 (F_{3,12}=3.63; P=0.04; ES=0.47; N – B=0.64). Post-hoc measures showed significantly greater O_2 contribution to overall EE in men than in women (P<0.01) (Figure 1). Further post-hoc measures showed that men burned more kCals from oxidative pathways during set one (47.2 ± 7.4 vs. 37.1 ± 7.3; P=0.01), set two (50.9 ± 6.7 vs. 40.3 ± 5.3; P<0.01), set three (51.3 ± 6.3 vs. 40.2 ± 5.4; P<0.01), and set four (51.4 ± 5.9 vs. 40.5 ± 6.0; P<0.01). Similarly, men were shown to have significantly greater EPOC contribution to overall EE than women (P<0.01) (Figure 1). Subsequent follow-up tests identified significantly greater kCal contribution from EPOC in men (vs. women) during set one (13.7 ± 1.8 vs. 11.1 ± 1.5; P=0.01), set two (13.8 ± 1.9 vs. 11.3 ± 1.8; P=0.02), set three (14.3 ± 1.6 vs. 11.4 ± 2.0; P<0.01), and set four (14.2 ± 1.9 vs. 11.0 ± 1.9; P<0.01). There were no significant differences found in glycolytic contribution to total EE between men and women (P=0.11) (Figure 1). In addition, there was no gender by set interaction (F_{9,6}=0.70; P=0.69).
Figure 1. Absolute energy expenditure (kCals) across all total sprints and the contribution of each system to total energy expenditure between men (N=9) and women (N=7) during HIIT 30:30 trial.

**Absolute EE and System Contribution to EE during 30:15**

*Absolute EE*

Results from an independent t-test revealed a significant difference in the overall EE (kCal) between men and women during the 30:15 HIIT trial. The overall EE was significantly greater in men vs. women (see Figure 2).

*System Contribution to EE*

A 2 (sex) x 4 (set of sprints) mixed model repeated measures ANOVA revealed a significant main effect of energy system contribution of kCals expended between men and women during HIIT of 30:15 ($F_{3,9}=7.69; P<0.01; ES=0.72; N – B=0.91$). Post-hoc measures showed significantly greater $O_2$ contribution to overall EE in men than in women ($P=0.001$) (Figure 2). Further post-hoc measures showed that men burned more kCals from oxidative pathways during set one ($42.7 \pm 4.6 \text{ vs. } 31.9 \pm 2.8; P<0.001$), set two ($45.5 \pm 5.0 \text{ vs. } 34.5 \pm 3.2; P=0.001$), set three ($46.3 \pm 5.6 \text{ vs. } 34.5 \pm 3.4; P=0.001$), and set four ($46.4 \pm 5.9 \text{ vs. } 34.8 \pm 3.6; P=0.001$). Similarly, men were shown to have a significantly greater EPOC contribution to overall EE than women ($P<0.01$) (Figure 2). Subsequent follow-up tests identified significantly
greater kcal contribution from EPOC in men (vs. women) during set one (17.3 ± 2.3 vs. 13.2 ± 1.5; P<0.01), set two (18.07 ± 2.3 vs. 13.8 ± 1.7; P<0.01), set three (18.5 ± 2.5 vs. 14.0 ± 1.8; P<0.01), and set four (18.1 ± 2.3 vs. 13.9 ± 2.4; P=0.01). There were also significant differences found in glycolytic contribution to total EE between men and women (P=0.05) (Figure 2). Further measures showed that men burned more kcal from glycolytic pathways during set one (8.7 ± 2.0 vs. 6.0 ± 1.0; P<0.01) and set two (10.8 ± 1.9 vs. 8.0 ± 2.2; P=0.03). In addition, there was no gender by set interaction (F_{9,3}=1.38; P=0.43).

Figure 2. Absolute energy expenditure (kCals) across all total sprints and the contribution of each system to total energy expenditure between men (N=6) and women (N=7) during HIIT 30:15 trial.

Relative System Contribution to EE Overall and Per Set during HIIT 30:30

A 2 (sex) x 4 (set of sprints) mixed model repeated measures ANOVA identified no main effect for relative energy system contribution between men and women during HIIT of 30:30 (F_{3,12}=0.04; P=0.98) (see Figure 3). There was no gender by set interaction (F_{9,6}=0.68; P=0.71).
A 2 (sex) x 4 (set of sprints) mixed model repeated measures ANOVA identified no main effect for relative energy system contribution between men and women during HIIT of 30:15 (F3,9=0.26; P=0.85) (see Figure 4). There was no gender by set interaction (F9,3=0.80; P=0.65).
A one-way ANOVA revealed significant differences in mean HR only in set 4 (P=0.05) between men and women during 30:30 HIIT (see Figure 5). However, though not reaching statistical significance, women approached higher mean HR during set two (P=0.06) and set three (P=0.06) compared to men.

Figure 5. Heart rate (bpm) across four sets of HIIT 30:30 sprints between men (N=9) and women (N=7).

A one-way ANOVA revealed no significant differences in mean HR across sets of sprints between men and women during 30:15 HIIT (see Figure 6). However, women approached significantly higher mean HR during set two (P=0.09), set three (P=0.09), and set 4 (P=0.08) compared to men (see Figure 6).
Figure 6. Heart rate (bpm) across four sets of HIIT 30:15 sprints between men (N=6) and women (N=7).

**Blood Lactate Concentration during HIIT**

30:30

A one-way ANOVA revealed no significant differences between men and women with respect to [La] after set one (P=0.40), set two (P=0.50), set three (P=0.53), and set four (P=0.66) during 30:30 HIIT (see Figure 7).

Figure 7. Blood lactate concentration (mmol) across four sets of HIIT 30:30 sprints between men (N=9) and women (N=7).
A one-way ANOVA revealed no significant differences between men and women with respect to [La] after set one (P=0.21), set two (P=0.49), set three (P=0.83), and set four (P=0.93) during 30:15 HIIT (see Figure 8).

![Blood Lactate Concentration (mmol)](image)

Figure 8. Blood lactate concentration (mmol) across four sets of HIIT 30:15 sprints between men (N=6) and women (N=7).

**Rating of Perceived Exertion and Session-RPE**

A one-way ANOVA showed that women demonstrated significantly higher mean RPE than men during set one (P=0.03), set two (P=0.03), set three (P=0.01), and set four (P<0.01) of 30:30 HIIT (see Figure 9). However, no significant difference between men and women’s SRPE was found (6.7 ± 1.0 vs. 7.2 ± 0.9; P=0.34).
A one-way ANOVA showed that women (vs. men) demonstrated a significantly higher mean RPE during set one (P=0.02), set two (P=0.04), and set three (P=0.03); no statistical difference was found in set four (P=0.19) between sex of 30:15 HIIT (see Figure 10). There was a significant difference found between men and women’s SRPE (P=0.05) of 30:15 HIIT (Figure 10).
Figure 10. Differences of rating of perceived exertion (RPE) between men (N=6) and women (N=7) during each of four sets and Session-RPE of 30:15 HIIT.

Perceived Recovery Status

30:30

A one-way ANOVA revealed no significant differences between men and women regarding PRS during set one (8.3 ± 1.8 vs. 8.1 ± 1.3; P=0.81), set two (7.4 ± 1.6 vs. 7.4 ± 0.9; P=0.98), set three (7.0 ± 1.5 vs. 6.8 ± 0.8; P=0.82), or set four (6.6 ± 1.4 vs. 6.8 ± 1.2; P=0.78) of 30:30 HIIT.

30:15

A one-way ANOVA revealed no significant differences between men and women regarding PRS during set one (7.8 ± 2.1 vs. 6.7 ± 1.1; P=0.25), set two (6.6 ± 2.2 vs. 6.0 ± 1.2; P=0.51), set three (5.1 ± 3.5 vs. 4.4 ± 1.5; P=0.62), or set four (5.1 ± 3.0 vs. 4.7 ± 1.4; P=0.73) of 30:15 HIIT.
Previous research has suggested women may demonstrate greater aerobic reliance (vs. anaerobic reliance) than men during work matched for intensity (Esbjornsson-Liljedahl et al., 1999, 2002; Laurent et al., 2010, 2014). Indeed, this notion has been implicated in studies noting that women may fatigue less or recover faster than men, however, this has largely been associated in studies utilizing isometric or MVC protocols or SS, submaximal cardiovascular exercise (Clark et al., 2003; Hunter et al., 2002, 2009). Thus, the purpose of the current study was to compare total (i.e. kCals) and relative (i.e., percent) contribution of metabolic pathways to EE between men and women when performing HIIT at similar relative intensities utilizing two different work-to-rest ratios. Results confirm that men demonstrate greater absolute total EE compared to women in both sessions. No significant differences in relative contribution of oxidative or glycolytic pathway to total EE between men and women in either session were found. Results also show that women report significantly higher RPEs as well as significantly higher S-RPE (i.e., global difficulty) than men following the 30:15 trial. There were no significant differences in PRS values (i.e., how recovered a participant felt) between men and women within the HIIT sessions. Moreover, HR response was consistently higher in women vs. men across all sets of sprints throughout both trials, while [La] values were not significantly different suggesting similar metabolic strain.

As shown in Figures 1 and 2, men consumed greater kCals during both 30:30 and 30:15 HIIT trials compared to women. These findings were expected, as the men in this study were greater in surface area (height and weight) than the women (Table 1 and 2). While not surprising, these results provide support for Scott et al., (2008b) that also report men demonstrate greater absolute total EE than women at similar exercise intensities. In addition, Scott et al., (2008b)
SEX-SPECIFIC METABOLIC RESPONSE TO HIIT

found that men contribute a larger absolute glycolytic EE (calculated via higher changes in [La]) compared to women. The current study also found that men contributed a larger absolute glycolytic EE than women, but this was only seen in the 30:15 trial.

Figures 3 and 4 demonstrate the relative energy contribution to total EE was not significantly different from oxidative, glycolytic, and EPOC sources between men and women during 30:30 or 30:15 HIIT trials. This finding is novel as research has previously suggested that women demonstrate unique substrate utilization patterns (i.e., greater fat vs. glycogen) and, consequently, different relative contribution (i.e., greater oxidative vs. glycolytic) to overall EE (Esbjornsson-Liljedahl et al., 1999, 2002; Tarnopolsky et al., 1990; Roepstorff et al., 2006; Cheneviere, Borrani, Sangsue, Gojanovic, & Malatesta, 2011). Results from this study fail to support these findings. Scott et al. (2008b) found absolute contribution differences, however, similar to the current study, found no relative difference between oxidative, glycolytic, or EPOC contribution to overall EE between men and women. Though they utilized different methods than HIIT (i.e., 6-min of high-intensity cycling above the lactate threshold), it is the only other study that has utilized the method of using change in [La] to estimate the glycolytic component when comparing men and women’s relative contribution to EE. Thus, the current findings extend the notion of no differences in metabolic pathway contribution to repeated HIIT on a motorized treadmill.

The observed relative contribution of energy system to overall EE suggests that women and men similarly utilized fats and CHO, albeit to yield significantly different absolute EE. This may be a consequence of the intensity of the exercise session as it has been reported that substrate utilization differences tend to not be manifested during exercise at higher intensities, although the point at which intensity is too high has not been determined (Ruby & Robergs,
SEX-SPECIFIC METABOLIC RESPONSE TO HIIT

Beyond the potential influence of intensity, another factor that may have influenced the results could have been the level of cardiovascular fitness of the participants which has also been shown to influence substrate utilization (Ruby & Robergs, 1994; Marliss et al., 2000; Romijn et al., 2000).

Still, others suggest a sex difference in fat utilization does not occur, instead, women may prefer utilizing circulating blood glucose as opposed to stored glycogen per kg of FFM compared to men (Ruby et al., 2002). This would suggest that men and women would not demonstrate differences in oxidative pathway reliance vs. glycolytic pathway reliance (as shown in the current study). However, increased reliance on blood glucose (vs. glycogen) could, in part, explain women’s attenuated glycogen reduction compared to men that has been previously reported (Esbjornsson-Liljedahl et al., 1999, 2002). In turn, this theoretically could enhance their rate of recovery as seen demonstrated in previous research (Esbjornsson-Liljedahl et al., 1999, 2002). However, it is most plausible that participants in the current study, exercising at greater intensities than previously utilized protocols in the literature (i.e., single supramaximal bout or submaximal SS intensities), would exhibit no difference in substrate utilization or energy pathway preference due to required energy demands (Romijn et al., 1994, 2000).

As seen in Figures 7 and 8, blood lactate concentration was not significantly different between men and women. This is inconsistent with previous studies having shown that women have attenuated [La] when compared to men during HIIT at relative intensities (Laurent et al., 2010; Esbjornsson-Liljedahl et al., 2002). However, those studies utilized higher work-to-rest ratios than the present study which may have affected lactate clearance rates. In addition, it seems that the lower [La] in women could be attributed to a greater proportion of Type I muscle fiber (Esbjornsson-Liljedahl et al., 2002) and, as a result, women may have been exerting
themselves more to produce similar [La] to men which is in agreement with previous findings (Laurent et al., 2014). Similarly, Vincent et al. (2003) report no difference in [La] between men and women, but this followed only one Wingate test. To that end, it may be that the similar [La] levels observed between men and women in the current study is in accordance with no difference in energy system contribution.

Heart rates (Figures 5 and 6), though not always reaching statistical significance, were higher in women than in men during both sessions of HIIT. This finding, in agreement with Laurent et al. (2014), tends to indicate that women manifest higher cardiovascular strain even while performing work at lower velocities during HIIT (Laurent et al., 2014). This may indicate women attempt to maintain aerobic EE to a greater degree than men (Laurent et al, 2014). Furthermore, it seems likely that if participants in the Laurent et al., (2014) study were experiencing higher HR while at lower relative velocities than men, it stands to reason that women in the current study, running at fixed relative velocities, would also experience higher HR. Moreover, the velocities tolerated by women that elicit higher HR responses may be associated with higher in-session RPEs (discussed below), which indicate that women may incur greater physiological and perceptual strain than men despite identical relative velocity of running.

As seen in Figure 9, RPE was significantly higher in women than men during both sessions of HIIT. This finding, along with higher [La], indicates that women were not only metabolically straining themselves at least equal to men but do so at increased perceptual strain as well as cardiovascular strain (i.e., higher HR). Previous research has found similar RPEs between men and women (Laurent et al., 2014), but within that study participants utilized self-selection of velocity whereas a fixed velocity was utilized in the current study. Interestingly,
Sex-specific metabolic response to HIIT

Women have been shown to demonstrate higher RPE when performing maximal sprints of 30 meters with a 45-s recovery (Laurent et al., 2010). It is of interest that women would produce higher RPE, yet the global difficulty (i.e., S-RPE) of the 30:30 trial was no different between men and women. Laurent et al., 2010, showed that while women produced higher in-session RPE, men, in fact, reported higher S-RPE. Certainly, more research needs to be directed towards RPE and the affect it has between men and women at similar relative intensity.

Interestingly, despite significantly higher in-session RPE and in at least one S-RPE in women, PRS values were not different from men. This, despite women working harder cardiovascularly and experiencing similar metabolic strain as men, may suggest that prior to starting a new set of sprints they had “caught up” to the men in their recovery from a greater physiological disturbance from the exercise. While this is an interesting finding and one that indirectly supports the notion that women demonstrate improved recovery, further research on this topic is warranted.

Limitations

There are limitations to the current study that may have impacted findings. The HIIT protocol utilized was original in many ways. For instance, most HIIT studies and all substrate utilization difference studies observing sex differences have employed cycling as their exercise mode while the current study utilized upright treadmill sprints. The work-to-rest ratio implemented in the current study (1:1 and 2:1) was unlike most intermittent sprint studies examining sex-specific metabolic responses (i.e., all-out sprints interspersed with recovery periods long enough to elicit near to optimal performance). Important to note, exercise protocol variation complicates the comparison to existing research, as intensity and duration are
predominant factors that determine substrate utilization (Ruby & Robergs, 1994) and could impact an oxidative or glycolytic reliance.

When considering substrate utilization differences or energy pathway contribution differences between men and women, it must be known that several factors need to be accounted for such as training status of participants (Ruby & Robergs, 1994). Participants were all well-trained (≥70th percentile for VO₂max), however, they varied in the type of training they were accustomed to (e.g., some accustomed to sprints, others not) which may have an effect on energy system contribution and substrate utilization patterns. Additionally, whether the trials were conducted in the morning or afternoon (time of day staying consistent within each participant) could have an influence on substrate utilization which would affect contribution of metabolic systems to overall EE. These limitations should be taken into consideration when doing further research in the area of sex-specific metabolic responses.

**Future Research**

Since the current study was novel in protocol and technique used, there are many opportunities for future research. Controlling for variance in the sample seems to be important when assessing energy contribution differences between men and women. Perhaps doing the same HIIT protocol on participants who are all adapted to the same mode of high-intensity training would help control for some of the variance. Since lactate threshold may be a large factor in substrate utilization (Ruby et al, 2002), it could also be valuable to match participants relative to lactate threshold since this is a better indicator than VO₂max for exercise performance (Coyle, Coggan, Hopper, & Walters, 1988). Indeed, exercising at an intensity relative to the lactate threshold may prevent any discrepancies in whether participants are all working equally
to one another. Other work-to-rest ratios could also be implemented that are more intermittent in style as to mimic previous sex-specific response studies on HIIT.

**Conclusion**

The results of this study show that when men and women perform repeated sprints at similar relative intensities, men have a greater absolute EE, however, relative contribution to EE is similar. It seems that women’s greater HR and RPE may coincide with similar [La] levels as men to demonstrate women may work relatively harder from a cardiovascular and perceptual standpoint, experience similar metabolic strain, and yet feel just as recovered (i.e., PRS) when given the same amount of recovery during HIIT. These measures could be interpreted as indirect evidence that women may recover faster than men at relative intensities. The lack of differences seen from the oxidative, glycolytic, or EPOC contribution to total EE is a novel finding that may indicate a sex-specific substrate preference may have been attenuated but may be specific to the methods employed. Clearly, more research is needed in determining a sex-specific response during HIIT in the area of relative energy pathway contribution to total EE. Importantly, it does seem evident that women and men display unique physiological and metabolic differences that have, until recently, gone unnoticed in the study of exercise metabolism. While the mechanism of substrate utilization may not always present itself depending on the duration, intensity, and mode of exercise, women may demonstrate a greater ability to withstand a greater exercise-induced stress relative to men that would impact greater fatigue resistance/recover ability. Nevertheless, the findings from this study support the idea that men and women do display differences at relative intensities during HIIT. Women should be trained with a heightened awareness of safety precaution due to greater cardiovascular strain, yet it should be noted they
are able and willing to sustain performance, perhaps indirectly indicating a greater recovery relatively to men.
REFERENCES


SEX-SPECIFIC METABOLIC RESPONSE TO HIIT


APPENDIX A: INFORMED CONSENT

Informed Consent

Investigators: Chris Irvine  
Kaitlyn Kielsmeier 
Matt Laurent, Ph.D., CSCS

Phone: (419) 509-8522

Project Title: Determination of Total Energy Expenditure During and Following Repeated High-Intensity Intermittent Sprint Work

Purpose: We are Chris Irvine and Kaitlyn Kielsmeier and we are graduate students in Kinesiology at Bowling Green State University. You are being asked to participate in a study to look at total-body energy expenditure (caloric burn) during high-intensity interval sprints and during the recovery following. The purpose of the study is to estimate the “metabolic burn” or energy cost involved with high-intensity activities, which are largely unknown, therefore, many people may be misinformed. We are interested in testing men and women that are fairly well-trained and are used to performing high-intensity interval-type work. (Examples of high intensity interval-type work would be interval training as a runner or cyclist, recreational but competitive team sport participation such as soccer, volleyball, basketball would also be an example). With the rising popularity of interval-type fitness programs such as Crossfit, P90X, Insanity, and circuit training, it is important to know how much energy is being expended with these activities in order to properly train without over-working or under-working the body.

If you participate, you will be asked to complete three (3) exercise sessions on a treadmill in our laboratory. The first lab session will last approximately 45-60 minutes, and the second and third lab sessions will last approximately 60-75 minutes each for a total of approximately 2.45-3.15 hours to complete this particular study. You are welcome and encouraged to ask any questions about the study at any time if you wish. If at any time during the study you would like to stop participating, you may do so. You are not required to complete the study.

To be included in this study:
1. You must be at least 18 years of age
2. You must be younger than 35 years of age
3. You must regularly exercise a minimum of 3 times per week
4. Your exercise sessions must be at least 30 minutes in duration
5. You must participate in interval training or interval-type training
   (Examples are competitive basketball, volleyball, soccer, etc.)

Procedures:
If you are able and willing to participate, you will be asked to complete two (2) sessions of exercise tests on a treadmill. Each session is described in detail below. All testing will be conducted in the Exercise Physiology Lab in Eppler South Room 124 at Bowling Green State University.

Session 1: *Health Screening, Descriptive Data, Maximal Exertion Treadmill Testing and Sprint Familiarization. Before performing any exercise, you will be asked to come to the lab and fill out some forms about your current health status and current workout schedule. These forms will be used to make sure you can safely participate. The information you provide will be kept confidential. It is important that you answer these questions accurately and completely. Any questions you may have about your participation or the forms you
SEX-SPECIFIC METABOLIC RESPONSE TO HIIT  55

complete are welcomed and will be answered to your satisfaction. If these forms indicate it may not be safe for you to participate, you will not be allowed to continue.

After you have filled out the forms and it is determined if it is safe for you to participate you will be measured for descriptive data (age, height, weight, and percent body fat). Percent body fat will be estimated by measuring skinfold thickness; (men: chest, abdomen, and thigh; women: tricep, iliac, thigh). This process requires me to pinch your skin and use a device to measure the thickness of the pinched skin. You will then be asked to perform a maximal exertion treadmill test. During this test, you will run on treadmill for 6-12 minutes depending on your fitness. Once a standard warm-up has been completed, the maximal test will begin. The test will start at a moderate jogging speed. During exercise, we will make it more difficult by increasing the speed of the treadmill every minute. The first part of the test will be easy, but the test will get slightly harder each minute, getting very hard after several minutes. You will be encouraged to provide your best effort and continue until you feel you cannot maintain the required effort. When you let us know that you can no longer continue, the test will be stopped, and you will be monitored during a low intensity cool-down. The test may also be stopped if we feel it is not safe for you to continue. During this test you will be required to breathe through a mouthpiece and wear a nose clip, but you will be able to freely breathe room air through your mouth.

Approximately 20 minutes after the maximal exertion treadmill test, you will be asked to perform one set of four high-intensity interval sprints. The speed during the final full minute of the maximal exertion treadmill test will elicit velocity at maximal oxygen consumption (vVO₂ max). The high-intensity interval sprints will be performed at 110% of that final speed. For example, if 10 mph was the speed reached and maintained for the last full minute at maximal oxygen uptake, then running at 110% of vVO₂ max would be a speed of 11 mph.

*Maximal refers to exercise intensity. The final portion of the treadmill test will require you to exercise at your “maximal” effort (i.e., as hard as you can).

Session 2: Repeated High-Intensity Running Trial. This session will begin at least two (2) days from the maximal exertion treadmill test. You will be given at least 2 days but no more than 7 days rest between sessions. Prior to the start of the test, you will sit and have your resting energy expenditure recorded for 5-10 minutes. This requires you to sit quietly in a chair breathing through the same mouthpiece that you were wearing in session 1. You will then be asked to perform a standardized warm-up (same one as session 1). After you warm-up, the sprint intervals will be performed on a motorized treadmill where you will be asked to perform four (4), 30-second sprints with a 30-second rest period. The speed of the sprints depend on the speed that you ended with on your maximal exertion test in session 1. Simply, you will run at 110% of the velocity that you reached before termination of the maximal test. (For example, if you reached a velocity of 10 mph as the last stage of your maximal test, your sprints would be run at 110% of 10 mph, which is 11 mph). Three (3) minutes of seated rest will be given once your first set of sprints is complete. One more set of four (4), 30-second sprints will be performed after the three (3) minute rest. At the end of the fourth set of sprints, you will sit in a chair while energy expenditure is again recorded while you continue breathing through the mouthpiece until your metabolic measurements have come down to resting values (no longer than 20 minutes of seated recovery). This lab session will last about 45-60 minutes total.

Session 3: Repeated High-Intensity Running Trial. This session will begin at least two (2) days from session 2. You will be given at least 2 days but no more than 7 days rest between sessions. This session will be the same as session 2 except you will perform four sets of 4, 30 seconds sprints with a 15-second rest period. All other testing measures and procedures are the same.

Blood samples will be taken periodically throughout lab session 2 and 3. They will be taken once at the end of your resting energy expenditure measurement. Then a blood sample will be taken once during your 3 minute rest at the two minute mark, and once during the last rest session again at minute 2 for a total of five blood samples altogether. The amount of blood will equal about 2 drops per draw (total amount of blood will be less than 1 teaspoon). We will use a hand-held analyzer and disposable testing strips to analyze your blood. This process consists of a quick prick to the fingertip and is relatively painless.
Prior to beginning each sprint, you will use a Perceived Recovery Status Scale that is presented to you that lets us know how recovered you feel when you are to perform the next set of sprints. At the completion of each 30-second sprint, you will be asked to rate how you feel using the Rating of Perceived Exertion Scale provided. There is no “right” or “wrong” answer to how you feel. Approximately 20 minutes after you complete your session, you will be asked to rate the entire session using the same scale.

During both sessions you will be required to wear a heart-rate monitor around your chest near the breastbone. The monitor resembles a small belt, and it does not hurt nor stick to your skin. Also, you will be asked to wear the same mouthpiece and nose clip throughout all of session 2 that you wore during the maximal exertion treadmill test.

**Risks:** Potential risks to your health and well-being because of participation include: 1) cardiovascular injury (heart attack, stroke, and death – risk is estimated at <0.01%), 2) severe acute fatigue (100% likely) at the end of the maximal exercise test, 3) lightheadedness, dizziness, nausea - commonly experienced 4) all other possible risks associated with intense exercise. You should know that the chance of having a heart attack, stroke or other complication is possible but highly unlikely. You should understand that you will almost definitely experience fatigue during at least one of the sessions. This fatigue is similar to what you would experience during a normal, high-intensity exercise session that you would perform as a part of your training or sport participation. Some of the common side-effects associated with this type of exercise would be short periods of dizziness and in some cases lead to an upset stomach similar to when you feel sick.

If you happen to experience any of these side effects, they will most likely go away, except for a cardiovascular injury. If fatigue or sickness does happen, it will happen quickly after you stop exercising and will most likely go away within 10 – 15 minutes. If you experience any of these conditions, you will be asked to stay in the laboratory with the investigator so that you can be monitored until all symptoms have gone away and you feel better. If injury occurs, such as a heart attack or stroke, you will be provided immediate care by the investigators and emergency medical assistance will be sought when necessary. You will be responsible for paying for any emergency measures that may be required if you incur an injury due to the stated risks of participation. You are not releasing the researchers from liability. If you incur an injury due to failure of equipment or negligence of the researchers, you will not pay for your own injury.

**Benefits:** Benefits to you for participating in this research are - you will receive information regarding your fitness: VO$_{2\text{max}}$, anaerobic threshold, and percent body fat, and your rate of energy expenditure. Your VO$_{2\text{max}}$ will show you your aerobic capacity and is the gold standard for determining aerobic fitness level. Your anaerobic threshold is a useful tool in subsequent training as it is an indicator of the highest physical intensity you can maintain before experiencing premature fatigue. You can use this data to help plan your day-to-day training program if you so desire. This information will be shared with you following the second session. You are encouraged to ask questions about this data to maximize your benefits.

**Confidentiality:** After initial data collection, your name will not be associated with this data. Only the investigators and other personnel associated with this study will have access to this information, which will be kept in a locked room. No publication or other public material will carry your name as a participant.

**Voluntary Participation:** Your participation in this study is completely voluntary, and you can refrain from participating or answering any or all questions without penalty or explanation. You are free to withdraw consent and to discontinue participation in any exercises at any time. Deciding to not participate or to withdraw will not affect your relationship with BGSU.

**Contact Information:** If you have any questions or comments about this study, you can contact Chris Irvine at 419-509-8522 or cirvine@bgsu.edu, Dr. Matt Laurent at (419) 372-6904 or cmlaure@bgsu.edu, or Kaitlyn Kielsmeier at (815) 543-0943 or kkielsm@bgsu.edu. If you have questions about the conduct of this study or your rights as a research participant, you may contact the Chair, Human Subjects Review Board, Bowling Green State University, (419) 372-7716 (hsrb@bgsu.edu).
Authorization: I have read this document, and the study has been explained to me. I have had all of my questions answered. I volunteer to participate in this study.

I know that I will receive a copy of this letter.

__________________________________________  ___________
Participant’s Signature       Date
APPENDIX B: PAR-Q

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
2. Do you feel pain in your chest when you do physical activity?
3. In the past month, have you had chest pain when you were not doing physical activity?
4. Do you lose your balance because of dizziness or do you ever lose consciousness?
5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
7. Do you know of any other reason why you should not do physical activity?

**YES to one or more questions**

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.
- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

**NO to all questions**

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:
- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

**DELAY BECOMING MUCH MORE ACTIVE:**
- If you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- If you are or may be pregnant — talk to your doctor before you start becoming more active.

**PLEASE NOTE:** If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NAME ____________________________

SIGNATURE ____________________________ DATE ____________________________

SIGNATURE OF PARENT or GUARDIAN (for participants under the age of majority) WITNESS ____________________________

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

MEDICAL HISTORY QUESTIONNAIRE

All information given is personal and confidential. It will enable us to better understand you and your health and fitness habits. In addition, we will use this information to classify your health status according to the American College of Sport Medicine (ACSM) recommendations for risk stratification (ACSM, 2009). Please let us know if and when you have changed your medication (dose & type), diet, exercise or sleeping habits within the past 24 or 48 hours. It is very important for you to provide us with this information.

NAME________________________________________ AGE___________________ DATE___________________

OCCUPATION________________________________________________________________________________________

1. **FAMILY HISTORY**

Check each as it applies to a blood relative:

- **Heart Attack**
  - yes______ no______ unsure______
  - If yes, age at onset ____ yrs; relation to you __________

- **Sudden Death**
  - yes______ no______ unsure______
  - If yes, age at onset ____ yrs; relation to you __________

- **Coronary Revascularization**
  - If yes, age at onset ____ yrs; relation to you __________

Father’s Age _____ Deceased_____ Age at death_____

(*Before 55 yr. in father or first-degree male relative)

- **Tuberculosis**
  - yes______ no______ unsure______

- **Stroke**
  - yes______ no______ unsure______

- **Asthma**
  - yes______ no______ unsure______

- **High Blood Pressure**
  - yes______ no______ unsure______

- **Circulatory Disorder**
  - yes______ no______ unsure______

- **Heart Disease**
  - yes______ no______ unsure______

Mother’s Age _____ Deceased_____ Age at death_____

(*Before 65 yr. in mother or first-degree female relative)

2. **PERSONAL HISTORY**

Check each as it applies to you:

* **Age** (men ≥ 45 yr; women≥ 55 yr)  yes______ no______

* **Current Cigarette Smoking**
  - yes______ no______ unsure______

* **Sedentary Lifestyle**
  - yes______ no______ unsure______
  - Persons not participating in at least 30 min of moderate intensity physical activity on at least 3 days/wk for at least 3 months.

* **Obesity – BMI >30 kg·m⁻²**
  - yes______ no______ unsure______
  - If yes, give value: ______kg·m⁻²
  - Waist circum. > 40” men; 35” women: yes______ no______

* **High Blood Pressure**
  - yes______ no______ unsure______
  - Systolic Blood Pressure >140mmHg or diastolic >90mmHg
  - If yes, give value: ______/______mmHg.

* **Dyslipidemia**
  - yes______ no______ unsure______
  - Total Serum Cholesterol >200 mg·dl⁻¹; value: ______mg·dl⁻¹
  - LDL-C ≥ 130 mg·dl⁻¹; value: ______mg·dl⁻¹
  - HDL-C ≤ 40 mg·dl⁻¹; value: ______mg·dl⁻¹
  - On lipid lowering medication: yes______ no______ unsure______

* **PreDiabetes**
  - yes______ no______ unsure______
  - If yes, age of onset: __________ years
  - Impaired fasting glucose ≥ 100 mg·dl⁻¹; value: ______mg·dl⁻¹
  - Impaired glucose tolerance test: yes______ no______
  - (Note: values confirmed by measures on two separate occasions)

* **Negative Risk Factor:**
  - yes______ no______ unsure______
  - HDL ≥ 60 mg·dl⁻¹; value: ______mg·dl⁻¹

Have you ever had:

- **Diabetes**
  - yes______ no______ unsure______

- **Tuberculosis**
  - yes______ no______ unsure______

- **Heart Attack**
  - yes______ no______ unsure______

- **Angina**
  - yes______ no______ unsure______

- **EKG Abnormalities**
  - yes______ no______ unsure______

- **Asthma**
  - yes______ no______ unsure______

- **Emphysema**
  - yes______ no______ unsure______

- **Surgery**
  - yes______ no______ unsure______

- **Stroke**
  - yes______ no______ unsure______

- **Severe Illness**
  - yes______ no______ unsure______

- **Hospitalized**
  - yes______ no______ unsure______

- **Black Outs**
  - yes______ no______ unsure______

- **Gout**
  - yes______ no______ unsure______

- **Nervousness**
  - yes______ no______ unsure______

- **Joint Problems**
  - yes______ no______ unsure______

- **Allergy**
  - yes______ no______ unsure______

- **Convulsions**
  - yes______ no______ unsure______

- **Paralysis**
  - yes______ no______ unsure______

- **Headaches**
  - yes______ no______ unsure______

- **Depression**
  - yes______ no______ unsure______

- **Chest Pain**
  - yes______ no______ unsure______

- **Arm Pain**
  - yes______ no______ unsure______

- **Shortness of Breath**
  - yes______ no______ unsure______

- **Indigestion**
  - yes______ no______ unsure______

- **Ulcers**
  - yes______ no______ unsure______

- **Overweight**
  - yes______ no______ unsure______

- **Hernia**
  - yes______ no______ unsure______
<table>
<thead>
<tr>
<th>Condition</th>
<th>Yes</th>
<th>No</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back Pain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg Cramps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Blood Pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insomnia</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. MEDICAL HISTORY

Are you presently taking any medications? Yes_______ No_______ List name and dosage

(INCLUDING OVER-THE-COUNTER MEDICATIONS AND/OR HERBS)

Have you ever taken:

Digitalis yes______ no______ unsure______ Insulin yes______ no______ unsure______
Nitroglycerin yes______ no______ unsure______ Pronestyl yes______ no______ unsure______
High Blood Pressure Medication yes______ no______ unsure______ Vasodilators yes______ no______ unsure______
Sedatives yes______ no______ unsure______ Other yes______ no______ unsure______
Inderal yes______ no______ unsure______ If yes, list medications:

4. EXERCISE HISTORY

Do you exercise? Yes______ No______ What activity____________________________

How long have you been exercising?________________________________________

How many days do you exercise?______________ How many minutes per day?_________

What kinds of shoes do you work out in?____________________________________

Where do you usually exercise?___________________________________________

Do you monitor your pulse during your workout?______________________________

Additional information from client interview to further assess health/coronary risk status:
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

____________________________________  ______________________________________
Signature of Tester      Date  08/30/09
APPENDIX D: CLASS ANNOUNCEMENT

Dr. Matt Laurent and his graduate research assistant are in the process of conducting a study that is looking at energy expenditure (caloric burn) during and after repeated high-intensity sprint intervals. They are currently seeking healthy, trained individuals to volunteer for participation in their study. In order to volunteer, you must be at least 18 years old but not older than 35 years of age, exercise at least 3 days per week with at least one of those sessions being interval training or interval-type activity (i.e. basketball, volleyball, soccer, etc.). If you were to be selected as a participant, they would ask you to perform three (3) exercise testing sessions that would last about an hour to an hour and a half each. All trials will be conducted in the Exercise Physiology Lab in Eppler South. If you are interested in possible participation and want to set up a meeting with the investigators, please feel free to contact Dr. Matt Laurent at cmlaure@bgsu.edu Chris Irvine at cirvine@bgsu.edu for further information. By emailing Dr. Laurent or Chris, you are not agreeing to participate but are simply indicating that you are interested in hearing more about the study and the specific details concerning participation.
APPENDIX E: RECRUITMENT FLYER

INTERESTED IN EXERCISE PERFORMANCE TESTING?

A study being conducted at Bowling Green State University is in need of exercise enthusiasts to serve as volunteers to be evaluated in a research study. The study will be conducted over approximately the next 4 months and will take three (3), 30 minute to 1 hour exercise sessions on separate days for you to complete.

To qualify for the study:
1. You must be at least 18 years of age
2. You must be younger than 35 years of age
3. You must regularly exercise a MINIMUM of 3 times per week
4. Your exercise sessions must be AT LEAST 30 minutes in duration
5. You must participate in interval training or interval-type training
   (Examples are competitive basketball, volleyball, soccer, etc.)

As a result of participating you will receive a fitness evaluation (aerobic capacity, anaerobic threshold measurement and body fat percentage determination) and a training consult as a result of your participation free of charge!

LIMITED AVAILABILITY!!

If you are interested in learning more about this opportunity please contact:

Chris Irvine
Phone: 419-509-8522
Email: cirvine@bgsu.edu

Bowling Green State University
APPENDIX F: ADULT OMNI SCALE OF PERCEIVED EXERTION FOR RUNNING

(UTTER ET AL., 2004)
APPENDIX G: PERCEIVED RECOVERY STATUS SCALE (LAURENT ET AL., 2011)

**Perceived Recovery Status Scale**

10  Very well recovered / Highly energetic  
    9  Expect Optimal Performance
    8  Well recovered / Somewhat energetic
    7  
    6  Adequately recovered
    5  Expect Average Performance
    4  Somewhat recovered
    3  
    2  Not well recovered / Somewhat tired
    1  Expect Weak Performance
    0  Very poorly recovered / Extremely tired
APPENDIX H: SESSION RPE (FOSTER ET AL., 2001)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Rest</td>
</tr>
<tr>
<td>1</td>
<td>Very, very easy</td>
</tr>
<tr>
<td>2</td>
<td>Easy</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
</tr>
<tr>
<td>4</td>
<td>Somewhat hard</td>
</tr>
<tr>
<td>5</td>
<td>Hard</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Very hard</td>
</tr>
<tr>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>Maximum</td>
</tr>
</tbody>
</table>