AMERICAN UNIVERSITY OF BEIRUT

EXPLORING SEX-SPECIFIC METABOLIC RESPONSES TO EXERCISE INTENSITY: IMPLICATIONS FOR FAT OXIDATION AND SUBSTRATE UTILIZATION AMONG UNIVERSITY STUDENTS

by
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ABSTRACT
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Title: Exploring Sex-Specific Metabolic Responses to Exercise Intensity: Implications for Fat Oxidation and Substrate Utilization Among University Students

Objective: This study aims to investigate metabolic responses to exercise, focusing on fat oxidation dynamics and potential sex differences, to inform tailored exercise prescriptions and optimize health outcomes.

Methods: Twenty participants (50% female, 50% male, aged 18-35) underwent comprehensive metabolic testing, including assessments of FatMax and VO2max. FatMax was defined as the exercise intensity maximizing fat oxidation, while VO2max represented peak oxygen uptake.

Results: Significant sex disparities were observed in fat metabolism during exercise. Males exhibited a significantly higher FatMax intensity (73 watts) compared to females (43 watts), indicating greater efficiency in fat oxidation at higher exercise intensities. Maximal fat oxidation rates were also notably higher in males (0.4708 g/min) than females (0.3015 g/min). Conversely, heart rate at FatMax and respiratory quotient did not differ significantly between sexes, suggesting these variables did not influence observed differences in fat oxidation.

Conclusion: These findings highlight the importance of considering sex-specific factors in exercise interventions aimed at improving metabolic health. Tailoring exercise prescriptions based on these differences can optimize fat oxidation and enhance the effectiveness of exercise programs across diverse populations.

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ABBREVIATIONS

% percent
= Equal
< Less than >Greater than
≤ Less than or equal
≥ Greater than or equal
AUB: American University of Beirut
BMI: Body Mass Index
FAFS: Faculty of Agricultural and Food Sciences
Kg: kilogram
VCO2: Carbon dioxide output
VO2: Oxygen consumption
RQ: Respiratory Quotient
RMR: Resting Metabolic Rate
FFA: Free fatty acids
IRB: Institutional Review Board
ID: Identification
BF%: Body fat percentage
FFM: Fat-free mass
VO2max: Maximal oxygen uptake
HRmax: Maximum heart rate
FM: Fat mass
MFO: Maximal Fat Oxidation
MFO/FFM: Maximal Fat Oxidation normalized to Fat-Free Mass
SD: Standard deviation
bpm: beats per minute

CHAPTER I

INTRODUCTION

Regular physical activity is essential for maintaining mental and physical health. It has far-reaching implications, from enhancing glycemic control in patients with type 2 diabetes to improving cardiovascular health and preventing various diseases, such as multiple sclerosis and Parkinson's disease (Muscella et al., 2020). A fundamental aspect in understanding the impact of physical activity on health is the examination of lipid metabolism, particularly in the context of exercise.

During physical activity, the body relies on a combination of fat and carbohydrates as primary fuel sources. The utilization of these fuels is influenced by various factors including exercise intensity and duration (Berlin & Colditz, 1990). While both fats and carbohydrates are simultaneously oxidized during exercise, the proportion of each utilized depends on several variables, including the intensity and duration of the activity (Muscella et al., 2020).

Moreover, metabolic adaptations occur during periods of fasting, wherein the body shifts its reliance on different fuel sources for energy production (Chen & Annette Stralovich-Romani, 2012). Understanding the dynamics of fuel oxidation during fasting provides valuable insights into the metabolic processes under different physiological conditions (Owen & Hanson, 2013).

Exercise intensity plays a crucial role in determining substrate utilization, with higher intensities favoring carbohydrate oxidation over fat oxidation (Jeukendrup &

Achten, 2001). Endurance training induces significant metabolic adaptations, enhancing the body's ability to utilize fat as a primary fuel source (Jeukendrup & Achten, 2001).

Furthermore, individual factors such as body composition and sex influence fat oxidation rates, highlighting the complexity of metabolic responses to exercise (Venables, 2003). Although exercise interventions offer promising avenues for weight management and disease prevention, optimal exercise prescription remains a subject of ongoing research and debate (Jeukendrup & Achten, 2001).

CHAPTER II

LITERATURE REVIEW

A. Fat metabolism during exercise

Regular physical activity is beneficial to both mental and physical health. Exercise training has implications for epigenetic regulation, aging, improving glycemic control in patients with type 2 diabetes, insulin sensitivity and resistance, prevention of cardiovascular disease, and other conditions, such as multiple sclerosis, lung disease, and Parkinson's disease (Muscella et al., 2020).

Thus, studying lipid metabolism is critical for understanding how physical activity affects health, particularly in professional athletes. Several studies have found differences between athletes and inactive individuals, although there are considerable variations among sports (Berlin & Colditz, 1990).

The two main fuel sources for physical activity and sports are fats and carbohydrates. During physical activity, the body uses four main energy sources: muscle glycogen and intramyocellular triacylglycerols (IMTGs) found in skeletal muscle fibers, liver glycogenolysis-produced plasma glucose, adipose tissue lipolysis-released free fatty acids (FFAs), and hydrolysis of triacylglycerol (TG) in very low-density lipoproteins (VLDL-TG) (Horowitz & Klein, 2000).

While fats and carbohydrates are oxidized simultaneously, the extent of oxidation depends on a number of variables, including the amount, intensity, and duration of exercise. Exercise also has a significant impact on the use of substrates as fuel sources during exercise (Muscella et al., 2020)

1. Substrate oxidation during starvation

An individual's carbon dioxide output (VCO2) divided by oxygen consumption (VO2) is the ratio of the respiratory quotient (RQ). Indirect calorimetry was used to obtain these values (VCO2 and VO2). RQ readings have a physiological range of 0.7 to 1.2, which is affected by the proportional contributions of fat, protein, and carbohydrate. Proteins, carbohydrates, and fats had RQ values of 0.8, 1.0, and 0.7, respectively. Therefore, an RQ of >1.0 may indicate that too many calories or carbohydrates are provided, which may increase CO2 production. An RQ of less than 0.7 may indicate underfeeding and the use of ketones as an energy source. (Chen & Annette Stralovich-Romani, 2012)

The type and number of oxidized fuels were substantially reflected by indirect calorimetry. The amount of food consumed, total metabolic needs, and level of physical activity affect the outcomes of this approach. People who are lean have a nonprotein respiratory quotient (npRQ) of 0.84 in cases of overnight fasting. This corresponds to 12–20% protein, 40–45% fat, and 40–45% carbohydrate intake from the previous day.

Figure 1 demonstrates the pattern of fuel oxidation in both lean and obese individuals following an overnight fast, in terms of both type and amount. npRQ decreased with increasing weight and body fat content. As RMR increases, the amount of fat that is mobilized to meet a person's energy needs increases. (Owen & Hanson, 2013)

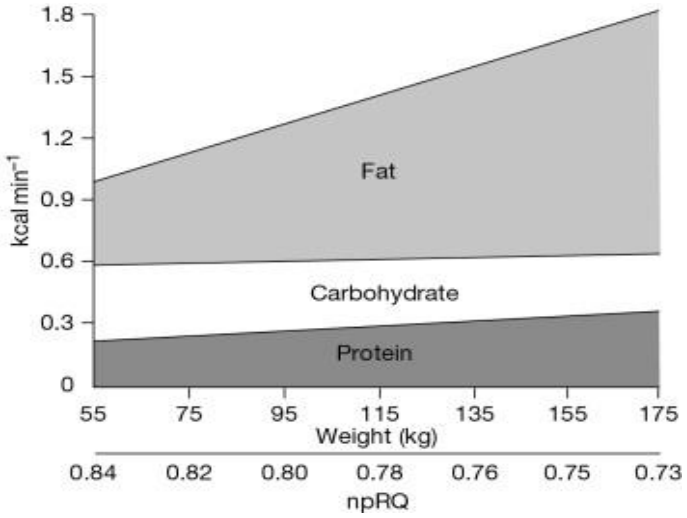

Figure 1: The type and amount of fuels people oxidize after fasting for 12 to 14 hours. As body weight increases, so does fat oxidation

Body composition is one of the factors contributing to fat oxidation. The importance of body composition: The expression "body composition" refers to the various parts that, when combined, make up an individual's weight. This can be defined as the ratio of lean tissue to fat tissue. Data on body composition can serve as the basis for numerous therapeutic, wellness, and fitness initiatives.

A person's health status can be more precisely determined, and the benefits of diet and exercise regimens can be more effectively targeted by evaluating body composition.

Body mass index (BMI), calculated by dividing body weight (in kilograms) by height (in meters squared), is currently the most widely used measure for categorizing a person as overweight or obese. Regardless of sex, a BMI of 25.0 kg/m is considered overweight in adults, whereas a BMI of > 30.0 kg/m is considered obese (Haider & Bilal, 2009).

Sex is another potential factor contributing to fat oxidation. In a study, men's rates of fat oxidation were lower than those of women; moreover, men shifted to carbohydrates as the major fuel earlier than women (Venables, 2003).

The hypothesis claimed that the regulation of fat oxidation is primarily dependent on exercise intensity, whereas sex, body composition, physical activity level, and training status play a secondary role in partially explaining observed interindividual variation.

There is still much that is unexplained regarding the interindividual variation in fat oxidation. Some of the interindividual variability that was seen may be explained by factors such as sex and fitness markers such as self-rated physical activity level and VO2 max, but not by body fatness indicators such as fat mass and percent body fat (Venables, 2003).

Although sex only partially explains the observed total variability in fat oxidation, it is evident from this study that women had higher peak rates of fat oxidation, suggesting a sex difference and that lipid remains the primary fuel at higher exercise intensities than in males. However, there is still a significant portion of inter-individual variation that cannot be explained by the variables (Tarnopolsky, 1995).

Additionally, Men have a higher RMR than women at a given weight, depending on the total body weight. This metabolic sex difference disappears when RMR is based on fat-free mass (FFM). Nonetheless, there is a wide range of energy requirements for people of the same sex and body weight, which is independent of body fat level (Owen & Hanson, 2013).

2. Exercise intensity and fat oxidation

Variation in exercise intensity resulted in variations in substrate utilization. As exercise intensity increases, the relative contribution of carbohydrates as fuel increases, whereas the relative contribution of fat oxidation decreases.

Nevertheless, in absolute terms, the rate of fat oxidation first increases but then declines again at high activity intensities, whereas the rate of carbohydrate oxidation increases proportionately with the intensity of the exercise. At intensities where the rate of glycolysis has increased significantly (beyond the lactate threshold), relatively fewer fatty acids will be utilized as fuel, and while energy expenditure increases, the absolute rates of fat oxidation will decrease. FatMax characterizes the workout intensity at which fat oxidation is the highest. (Jeukendrup & Achten, 2001).

Exercise length and intensity, training state, sex, body composition, and food all affect the amount of fat and carbohydrates used for energy production. Since the amount of FAs oxidized in the skeletal muscles is less than that released from adipose tissue while the body is at rest, the majority of FAs are re-esterified into liver triglycerides. Therefore, while carbohydrates are mainly used at high exercise intensities, fats are primarily oxidized during rest and at low aerobic exercise intensities (Muscella et al., 2020).

One of the most significant adaptations to endurance training is a change in metabolism from carbohydrates to fats. The ability to oxidize fat as fuel is strongly linked to exercise activity. Training for endurance athletes frequently includes workouts specifically aimed at improving fat metabolism. Training at an activity intensity that activates metabolic pathways involved in fat metabolism to their maximum capacity might theoretically result in optimum adaptations of these pathways (Jeukendrup & Achten, 2001).

3. Exercise and weight loss

According to a recent meta-analytical analysis, adopting an exercise program can help people lose 0.2 kg of body weight every week. This research revealed a wide range of recommended exercise prescriptions for the obese population. Exercise is essential for maintaining weight according to the same analysis.

When an exercise program is followed both during and after the diet period, a reduced percentage of weight loss caused by a limited diet is gained. However, we still do not know what kind, how hard, or how long the ideal kind of exercise (Jeukendrup & Achten, 2001).

An expert panel from the American College of Sports Medicine and the Centers for Disease Control recently recommended moderate-intensity physical activity for at least 30 min on most days of the week. The goal of these recommendations is to encourage more people to engage in physical exercise (Pate, 1995).

Exercise duration, intensity, and frequency are more effective in increasing energy expenditure than fat oxidation in obese people. Determining the ideal intensity of fat oxidation may help in weight reduction and maintenance (Sidossis, 1997).

4. Exercise and welfare diseases

There is enormous interest in developing treatments and preventative strategies to avoid overweight, obesity, and related disorders such as non-insulin-dependent Diabetes Mellitus (NIDDM), arteriosclerosis, and hypertension. Exercise has been shown to significantly decrease the risk of certain illnesses. Many of these diseases are associated with high levels of circulating triglycerides and disruptions in fat metabolism, it is tempting

to believe that exercise intensities that result in the maximum amount of fat oxidation (FatMax) would be preferable. As a result, FatMax could be a useful tool for designing exercise programs to achieve the best health outcomes (Jeukendrup & Achten, 2001).

B. Carbohydrate metabolism during exercise

Glycolysis is a metabolic mechanism and anaerobic energy source that has evolved in almost all species. Although it does not require oxygen, it serves the purpose of anaerobic respiration, and is the initial stage of cellular respiration.

This process involves the oxidation of glucose molecules, which are the single most important organic fuels in microbes, plants, and animals. Most cells prefer glucose to glucose.

Glycolysis consumes two ATP molecules to produce four ATP molecules, two NADH molecules, and two pyruvates per glucose molecule. Pyruvate can be used in the citric acid cycle or as a precursor in other reactions (Chaudhry, 2023).

C. Fitness tests and exercise prescription

The World Health Organization has long since concluded that the most reliable measure of cardiovascular fitness is maximal oxygen consumption (VO2 max), which is reached during a graded maximal activity until voluntary exhaustion. VO2 max is the greatest quantity of oxygen that an individual can consume, and it remains constant over time, even as the effort increases. The relative value of VO2 max was measured in milliliters/kg/min, whereas the absolute value was given in liters/min. Both direct and indirect methods can be used to estimate VO2 max (Buttar, 2019).

The gold standard for determining cardiorespiratory endurance is VO2 max. Individuals with high VO2 max are less likely to develop coronary artery disease, all-cause mortality, and many chronic diseases. Conversely, people with low VO2 max are more likely to develop these conditions (Carter, 2011).

The Direct Method (laboratory method) measures inspired oxygen, expired carbon dioxide, and pulmonary ventilation of an individual. Direct measurements use breath-by-breath analysis to reliably estimate the maximum oxygen consumption (Buttar, 2019).

Indirect methods: These include field tests that use a specific procedure to assess an individual's aerobic capacity based on heart rate, distance traveled, and/or trial duration (Buttar, 2019).

Once the VO2max is determined, the exercise prescription can be tailored based on the percentages of VO2max.

For exercise prescription, common percentages used include: Low intensity (37-45%VO2max) that is suitable for aerobic base building, recovery workouts, and increasing endurance it is also referred to as the "fat burning zone" because at this intensity, a higher percentage of calories burned comes from fat compared to carbohydrates. Moderate intensity (46-63% VO2max) is ideal for improving cardiovascular fitness and endurance (Luan et al, 2019) (Joyner & Coyle, 2008), and high intensity (64-90% VO2max) is used for interval training, improving anaerobic threshold, and enhancing performance (Luan et al, 2019) (Vähä et al, 2021). Finally, the maximum intensity (90-100% VO2max) is reserved for high-intensity interval training (HIIT) and performance testing. It is not sustainable for long durations, owing to its intensity (Ma et al, 2023).

D. Thesis objectives

1. Investigate FatMax (exercise intensity at which fat oxidation is maximized) among university students.
2. Explore how exercise intensity, duration, and individual factors (such as sex and body composition) influence FatMax.

CHAPTER III

MATERIALS AND METHODS

A. Participants

20 participants (50% females, 18-35 years of age) were recruited from the American University of Beirut community

Participants were selected based on the following inclusion criteria:

(a) They should be from both sexes, males and females;

(b) They should have a normal body mass index (BMI) ranging between 18.5 and 24.9;

(c) They should have stable and balanced eating habits (e.g., not on a temporary weight loss, ketogenic, or vegan diet).

(d) They should be healthy with no morbidities;

(e) They should be committed to participating in 1 experimental session;

Additionally, subjects were excluded if they had a previous history of any limitation in physical ability, cardiovascular disease, taking supplements or medicines that might affect their metabolic rate, pregnancy or breastfeeding, claustrophobia, or unstable body weight during the past 6 months.

Participation in this study was voluntary, and participants had the right to terminate their participation at any point during the experiment. After each experimental session, participants were rewarded with a monetary amount of $10.

B. Protocol

All subjects came to the nutrition and metabolism laboratory following a 12-hour overnight fast. On the day before the experiment, they avoided alcoholic and caffeinated beverages and resisted strong physical activity. The tests lasted for approximately 2 h. Respiratory parameters were evaluated using an ergometer (Quark, Pulmonary Function

Testing-Exercise Testing, ergo, Cosmed, Rome, Italy) and Quark CPET (COSMED®, Italy) connected to an advanced high-end silicone facemask. Calibration was performed according to the manufacturer's protocol prior to each test. The experimental procedure is described in detail below:

The project was conducted over one experimental day. The experimental procedure is illustrated in Figure 2.

Subjects came to the lab usually in the morning between 8am and 10 am after 12 h fats, their anthropometrics (height, waist circumference), body composition (fat mass, fat-free mass), weight, body mass index (BMI), and basal metabolic rate (BMR) were measured, and then they were asked to perform a FaTmax and VO2 peak test.

The FATMAX protocol described by Desai et al., identified as a % of VO2peak (where fat oxidation rates are at their best), was determined by cycling at 70 revolutions per minute (rpm) at 30 Watts (W) with 10 W increments every 3 min.

The test was stopped when the respiratory exchange ratio (RQ) was > 1 for 30 s in a continuous fashion.

Peak oxygen consumption (VO2 peak) was measured according to the method of Broskey et al. (11).

Subjects performed the test until volitional exhaustion.

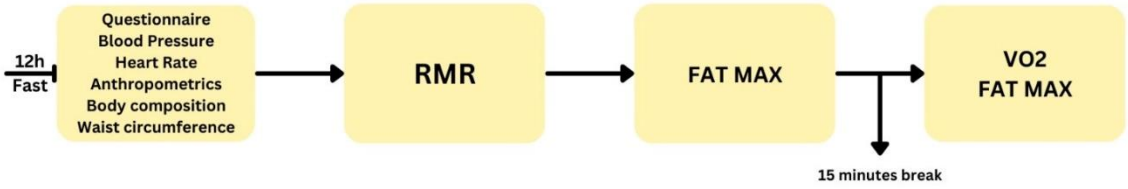

Figure 2: The experimental procedure

C. Ethical considerations

Approval was obtained from the Institutional Review Board (IRB) of the American University of Beirut (AUB). Each participant was assigned a unique ID number

to protect confidentiality during the data collection and analysis. The connection between the participant's name and the ID number was securely stored in a locked cabinet accessible only to the researchers involved in the study. All participants provided written informed consent before participating in the study and were assured of their freedom to withdraw at any stage.

D. Statistical analysis

Descriptive statistics were initially reported as means ± standard deviation (SD) and means ± standard error (SE) where applicable. Independent t-tests were utilized to assess gender differences among individual groups. Additionally, differences in relative exercise intensity at maximal fat oxidation were evaluated using a t-test. Bivariate correlations explored associations between maximal fat oxidation in absolute terms (MFO; g/min) and scaled for fat-free mass (MFO/FFM; mg/kg FFM/min) with age, body mass, height, body mass index (BMI), percent body fat, fat mass (FM), fat-free mass (FFM), and maximal oxygen consumption (VO2max; ml/kg/min). Stepwise multiple linear regression analysis was subsequently conducted to predict MFO and MFO/FFM using all significant independent variables identified in the bivariate analysis. SPSS version 29 was employed for all statistical analyses.

CHAPTER IV

RESULTS

A. Sex differences in demographic and physiological characteristics

This study included 20 participants. Analysis of the data in table 1 reveals several noteworthy findings. Firstly, there was no statistically significant difference in age among the Combined Group, women, and men, with mean ages of 21.35 ± 2.66 years, 22.20 ± 3.36 years, and 20.50 ± 1.43 years, respectively ($p = 0.17$). However, substantial differences emerged in the body composition metrics. Women exhibited a significantly higher body fat percentage (BF, %) at 29.93 ± 5.73% compared to men's 17.80 ± 6.81% within the Combined Group, yielding an overall BF% of 23.86 ± 8.73% ($p < 0.001$). Conversely, men had a significantly greater body mass of 77.73 ± 9.49 kg compared to women's 59.05 ± 6.73 kg, contributing to a combined body mass of 68.39 ± 12.49 kg ($p < 0.001$). Height also displayed a significant discrepancy, with men towering over women at 176.50 ± 5.76 cm versus 162.79 ± 4.72 cm, resulting in an average height of 169.64 ± 8.70 cm for the Combined Group ($p < 0.001$). When assessing body mass index (BMI), men had a statistically higher value at 24.97 ± 2.84 kg/m² compared to women's 22.30 ± 2.53 kg/m² within the Combined Group, although the overall difference was modest ($p = 0.04$). Notably, fat-free mass (FFM, kg) was substantially higher in men (63.67 ± 7.75 kg) than in women (41.26 ± 4.69 kg), contributing to an overall FFM of 52.46 ± 13.08 kg ($p < 0.001$). Furthermore, men displayed a significantly higher maximal oxygen uptake (VO2max $ml.kg^{-1}. min^{-1}$) at 30.30 ± 6.79 compared to women's 24.89 ± 3.35, with an overall

VO2max of 27.59 ± 5.91 (p = 0.04). However, when considering VO2max relative to fat-free mass (VO2max ml.kg FFM^{-1}. min^{-1}), there was no significant difference between men (36.32 ± 8.69) and women (34.06 ± 8.11) within the Combined Group (p = 0.56). Finally, maximum heart rate (HRmax beats/min) showed no significant difference between men (154.50 ± 18.14 beats/min) and women (161.30 ± 16.70 beats/min), with an overall HRmax of 157.90 ± 17.33 beats/min in the Combined Group (p = 0.39). These findings underscore distinct physiological disparities between sexes, highlighting the importance of sex-specific considerations in health and fitness assessments.

Table 1: Characteristics of the study participants (n=20).

Variable		**Combined Group**	**Women**	**Men**	**p-value***
Age		21.35 ± 2.66	22.20 ± 3.36	20.50 ± 1.43	0.17
BF, %		23.86 ± 8.73	29.93 ± 5.73	17.80 ± 6.81	<0.001
Body mass, kg		68.39 ± 12.49	59.05 ± 6.73	77.73 ± 9.49	<0.001
Height, cm		169.64 ± 8.70	162.79 ± 4.72	176.50 ± 5.76	<0.001
BMI		23.63 ± 2.95	22.30 ± 2.53	24.97 ± 2.84	0.04
FM, kg		15.92 ± 5.56	17.79 ± 4.59	14.06 ± 6.04	0.14
FFM, kg		52.46 ± 13.08	41.26 ± 4.69	63.67 ± 7.75	<0.001
V_{O2max} $ml.kg^{-1}.min^{-1}$		27.59 ± 5.91	24.89 ± 3.35	30.30 ± 6.79	0.04
V_{O2max} ml.kg $FFM^{-1}.min^{-1}$		35.19 ± 8.26	34.06 ± 8.11	36.32 ±8.69	0.56
HR_{max} beats/min		157.90 ±17.33	161.30 ± 16.70	154.50 ± 18.14	0.39
FATMAX	Average		43	73	
	Standard Deviation		13.37	24.96	

MFO (g/min)	Average		0.30	0.47	
	Standard Deviation		0.12	0.16	
MFO (mg/kg fat free mass/min)	Average		7.54	7.39	
	Standard Deviation		3.44	2.44	
Heart rate at FatMax (bpm)	Average		120.1	123.8	
	Standard Deviation		8.67	18.86	
RQ at FatMax	Average		0.85	0.85	
	Standard Deviation		0.07	0.03	
FatMax % of VO2max	Average		69.23	65.89	
	Standard Deviation		7.99	5.73	

*Independent t-test to compare values between women and men.

Table 2 presents Pearson's correlation coefficients between Maximal Fat Oxidation (MFO), expressed in grams per minute, and various physiological variables. The correlations indicate the strength and direction of the relationship between MFO and each variable. Age showed a negative correlation with MFO (-0.33), suggesting that as age increased, MFO tended to decrease. Body fat percentage (BF, %) also exhibited a negative correlation (-0.38), indicating that individuals with higher body fat percentages tended to have a lower MFO. Conversely, body mass (kg) and BMI were positively correlated with MFO (0.39 and 0.37, respectively), suggesting that higher body mass and BMI are associated with higher MFO. However, height and fat mass (FM, kg) demonstrate weak negative correlations with MFO (0.24 and -0.26 respectively). Moreover, the VO2max (ml.kg^-1. min^-1) and HRmax (beats/min) also displayed negative correlations with MFO (-0.21 and -0.35, respectively), while the correlation between MFO and VO2max adjusted for fat-free mass (VO2max ml.kg FFM^-1. min^-1) was weak ($p = 0.02$). Additionally, the

correlation between MFO per fat-free mass (MFO/FFM) and age was similar to MFO alone (-0.33), whereas BF % showed a weak positive correlation (0.12), and body mass (kg) and height showed negative correlations (-0.18 and -0.31, respectively). These correlations shed light on the relationship between MFO and various physiological variables, providing insights into the factors that influence fat oxidation during exercise.

Table 2: Correlation Analysis of Maximal Fat Oxidation (MFO) and MFO per Fat-Free Mass (FFM) with Physiological Parameter.

		Pearson's Correlation Coefficient
MFO	Age	-0.33
	BF, %	-0.38
	Body mass, kg	0.39
	Height, cm	0.24
	BMI	0.37
	FM, kg	-0.26
	V_{O2max} $ml.kg^{-1}.min^{-1}$	0.21
	V_{O2max} $ml.kg\ FFM^{-1}.min^{-1}$	0.02
	HR_{max} beats/min	-0.35
MFO/FFM	Age	-0.33
	BF, %	0.12
	Body mass, kg	-0.18
	Height, cm	-0.31
	BMI	-0.03
	FM, kg	-0.03
	V_{O2max} $ml.kg^{-1}.min^{-1}$	0.04
	V_{O2max} $ml.kg\ FFM^{-1}.min^{-1}$	0.10
	HR_{max} beats/min	-0.04

The results of the simple linear regression analysis in table 3 reveal the relationship between the dependent variable, Maximal Fat Oxidation (MFO), and the various independent variables. For MFO, age, body fat percentage (BF%), body mass, height, BMI, fat mass (FM), maximal oxygen uptake (VO2max), and VO2max

normalized to Fat-Free Mass (VO2max ml/kg FFM-1. min-1), and maximal heart rate (HRmax) demonstrated non-significant associations, with p values ranging from 0.09 0.37. Similarly, for MFO normalized to Fat-Free Mass (MFO/FFM), none of the independent variables exhibited statistically significant relationships, with p-values ranging from 0.15 0.91. These findings suggest that, in the context of simple linear regression, the examined variables do not significantly predict MFO or MFO normalized to Fat-Free Mass in the studied population.

Table 3: Results of Simple Linear Regression Analysis Predicting Maximal Fat Oxidation and Maximal Fat Oxidation Normalized to Fat-Free Mass.

Dependent Variable	**Independent Variable**	**β**	**p-value**
MFO	Age	-0.02	0.16
	BF, %	-0.01	0.09
	Body mass, kg	0.01	0.09
	Height, cm	0.01	0.31
	BMI	0.02	0.11
	FM, kg	-0.01	0.27
	V_{O2max} ml.kg^{-1}.min^{-1}	0.01	0.37
	V_{O2max} ml.kg FFM^{-1}.min^{-1}	0.000	0.93
	HR_{max} beats/min	-0.003	0.13
MFO/FFM	Age	-0.36	0.15
	BF, %	0.04	0.63
	Body mass, kg	-0.04	0.45
	Height, cm	-0.10	0.19
	BMI	-0.03	0.91
	FM, kg	-0.02	0.88
	V_{O2max} ml.kg^{-1}.min^{-1}	0.02	0.86
	V_{O2max} ml.kg FFM^{-1}.min^{-1}	0.04	0.67
	HR_{max} beats/min	-0.01	0.85

The summary of regression analysis for Maximal Fat Oxidation (MFO) and Maximal Fat Oxidation normalized to Fat-Free Mass (MFO/FFM) revealed the relationships between these variables and various independent factors. For MFO, age exhibited a moderately strong positive correlation ($R = 0.674$, $p < 0.05$), indicating that as age increased, MFO tended to increase. However, this relationship was not statistically significant ($P = 0.383$). Body mass, height, and BMI showed weak positive correlations with MFO; however, none of these associations reached statistical significance ($p > 0.05$). Conversely, for MFO/FFM, age demonstrated a moderate positive correlation ($R = 0.589$, $P < 0.05$), indicating a similar trend of increasing MFO/FFM with age, although the difference was not statistically significant ($P = 0.309$). Body mass exhibited a strong positive correlation ($R = 0.839$, $p < 0.05$), suggesting that, as body mass increased, MFO/FFM also tended to increase. However, this association was not statistically significant ($P = 0.642$). Other independent variables, including BF%, height, BMI, FM, VO2max, and HRmax, were not significantly correlated with MFO or MFO/FFM. These results suggest that while certain factors such as age and body mass may influence MFO and MFO/FFM, other unexplored variables or interactions may play significant roles in determining fat oxidation rates during exercise. (Table 4)

Table 4: Summary of Regression Analysis for Maximal Fat Oxidation and Maximal Fat Oxidation Normalized to Fat-Free Mass.

Dependent Variable	Independent Variable	R	R^2	Adjusted R^2	β	Significance	Zero order	Partial	Part
MFO	Age	0.674	0.454	-0.037	-0.019	0.383	-0.329	-0.318	-0.248
	BF, %				-0.013	0.888	-0.385	-0.046	-0.034
	Body mass, kg				0.050	0.593	0.394	0.206	0.156
	Height, cm				-0.048	0.645	0.238	-0.218	-0.165
	BMI				-0.139	0.686	0.371	-0.167	-0.125
	FM, kg				0.012	0.930	-0.259	-0.188	-0.142
	V_{O2max} $ml.kg^{-1}.min^{-1}$				0.014	0.507	0.209	0.217	0.164
	V_{O2max} $ml.kg\ FFM^{-1}.min^{-1}$				-0.005	0.730	0.020	-0.098	-0.073
	HR_{max} beats/min				-0.003	0.475	-0.353	-0.238	-0.181
MFO/FFM	Age	0.589	0.347	-0.241	-0.425	0.309	-0.333	-0.406	-0.358
	BF, %				0.040	0.982	0.116	0.007	0.006
	Body mass, kg				0.839	0.642	-0.181	0.236	0.196
	Height, cm				-0.833	0.678	-0.307	-0.281	-0.236
	BMI				-2.449	0.710	-0.026	-0.230	-0.191
	FM, kg				-0.051	0.984	-0.035	0.004	0.003
	V_{O2max} $ml.kg^{-1}.min^{-1}$				0.167	0.674	0.041	0.154	0.126
	V_{O2max} $ml.kg\ FFM^{-1}.min^{-1}$				-0.024	0.926	0.102	-0.027	-0.022
	HR_{max} beats/min				-0.047	0.590	-0.045	-0.214	-0.177

Figure 3 compares FatMax (in watts) between male and female participants. FatMax refers to the exercise intensity at which the fat oxidation rates are maximized. The average FatMax for males was 73 watts, which was significantly higher than the average FATMAX for females, which was 43 watts. This indicates that, on average, males reach their peak fat oxidation at a higher exercise intensity than females. Additionally, the standard deviation (SD) values showed variability within each group. For males, the SD was approximately 24.97 watts, suggesting a relatively higher variability in FatMax among males. In contrast, the SD for females was 13.37 watts, indicating a lower variability in FatMax among females. These differences in variability may reflect diverse physiological responses to exercise intensity within each sex group.

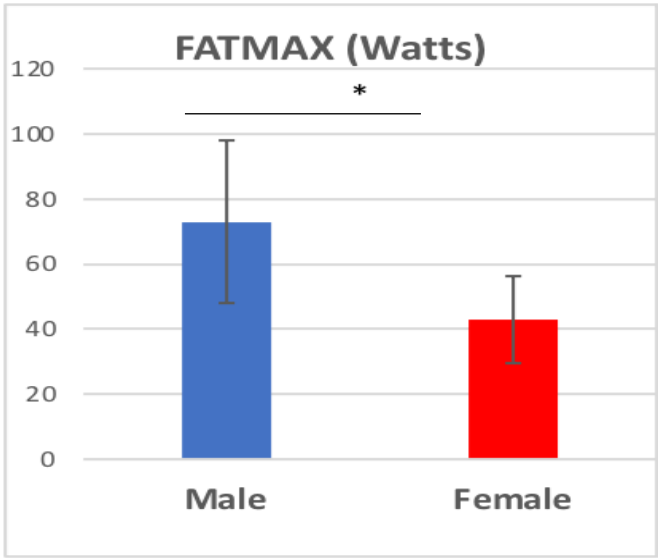

Figure 3. Sex Differences in FATMAX: Average and Standard Deviation.

Figure 4 presents data on Maximal Fat Oxidation (MFO) rates, measured in grams per minute, for both males and females, along with their respective averages and standard

deviations. On average, males exhibit a higher maximal fat oxidation rate of 0.4708 g/min compared to females, with an average rate of 0.3015 g/min. This indicates that, on average, males tend to oxidize fat at a higher rate than females during the same period. However, it is important to note the variability within each group, as indicated by the standard deviation. For males, the standard deviation was 0.1658 g/min, while for females, it was slightly lower at 0.1202 g/min. This suggests that while males, on average, have a higher maximal fat oxidation rate, there is also slightly higher variability in this rate among males than among females. Additionally, a two-sample t-test was conducted to determine if the difference in mean MFO between males and females was statistically significant. The test yielded a p-value of approximately 0.00072, indicating a highly significant difference between the two groups.

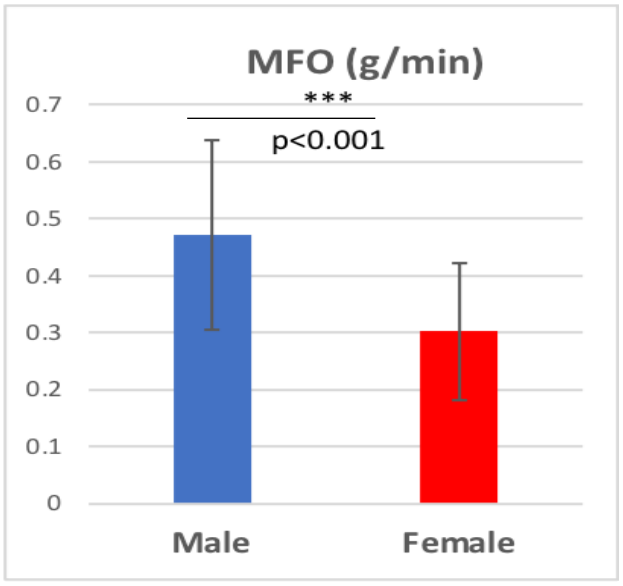

Figure 4: Sex Differences in Maximal Fat Oxidation (g/min): Average and Standard Deviation

Figure 5 presents the MFO rates in males and females, expressed in milligrams per kilogram of fat-free mass per minute (mg/kg FFM/min). The results indicated that the average MFO for males was 7.39 mg/kg FFM/min, with a standard deviation of 2.44 mg/kg FFM/min. In comparison, female rats exhibited a slightly higher average maximal fat oxidation rate of 7.55 mg/kg FFM/min, accompanied by a standard deviation of 3.44 mg/kg FFM/min. These findings suggest a marginal difference in fat oxidation rates between males and females, with females showing a higher average rate but also greater variability, as indicated by the standard deviation. However, it is important to note that this difference was not statistically significant.

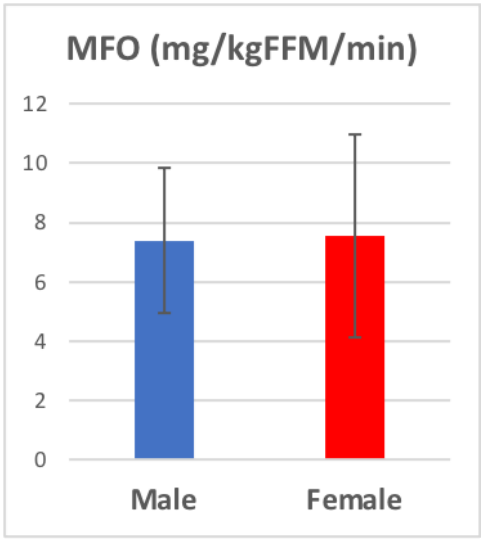

Figure 5: Sex differences in Maximal Fat Oxidation (mg/kg FFM/min)

Figure 6 illustrates that the average heart rate at FatMax for males is 123.8 beats per minute (bpm), with a standard deviation of 18.87 bpm. For females, the average heart rate at FatMax was 120.1 bpm, with a standard deviation of 8.67 bpm. Although the data indicate a

slightly higher average heart rate for males than for females during FatMax exercise, with males also exhibiting a wider variation in heart rate, the statistical analysis revealed that this difference was not significant.

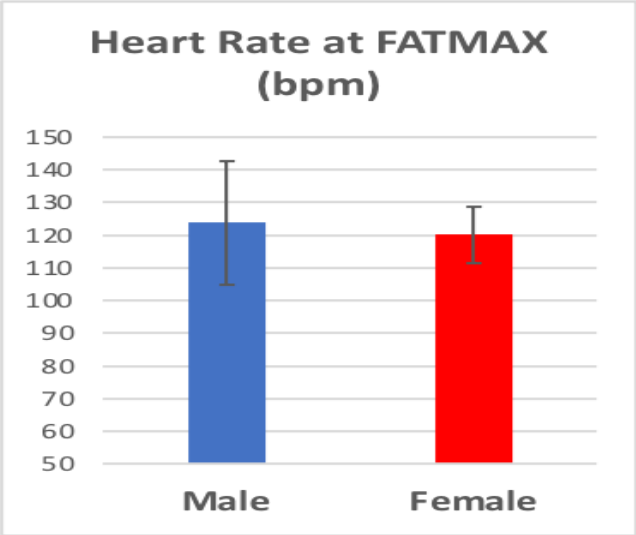

Figure 6: Sex Differences in Heart Rate at FatMax.

Figure 7 displays the respiratory quotient (RQ) at FatMax, a measure indicating the ratio of carbon dioxide produced to oxygen consumed during metabolism, analyzed in male and female subjects. The average RQ at FatMax was 0.851 for both males and females, with a standard deviation of 0.031 for males and 0.072 for females. However, statistical analysis revealed that there was no significant difference in RQ between males and females at the FatMax intensity level ($p > 0.05$). These findings suggest a consistent metabolic pattern across sexes during exercise at the FatMax intensity level.

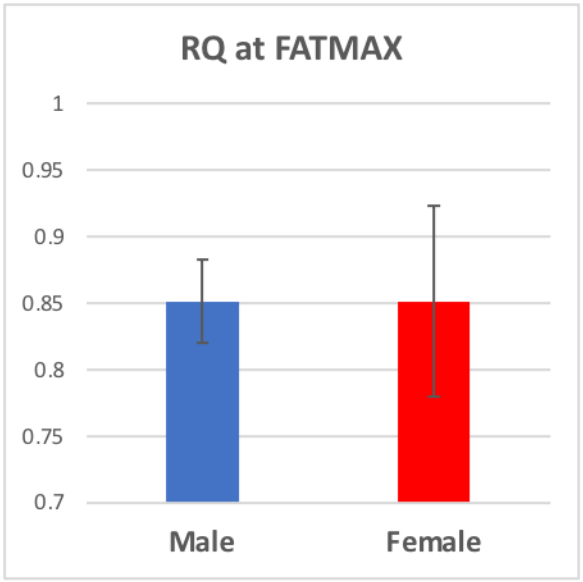

Figure 7: Comparison of respiratory quotient at FatMax between males and females.

Figure 8 shows the average FatMax percentage of VO2max along with the standard deviation (SD) for both the male and female participants. The average FatMax percentage of VO2max for males was 65.89%, with a standard deviation of 5.74%. For females, the average FatMax percentage of VO2max was higher at 69.24%, and the standard deviation was 7.99%. This indicates that, on average, females have a higher FatMax percentage of VO2max than males, but there is also more variability in the female data. A t-test was conducted to determine whether the difference between males and females was statistically significant. The result was a p-value of 0.018, which is less than the significance threshold of 0.05, indicating that the difference in FatMax percentage of VO2max between males and females is statistically significant.

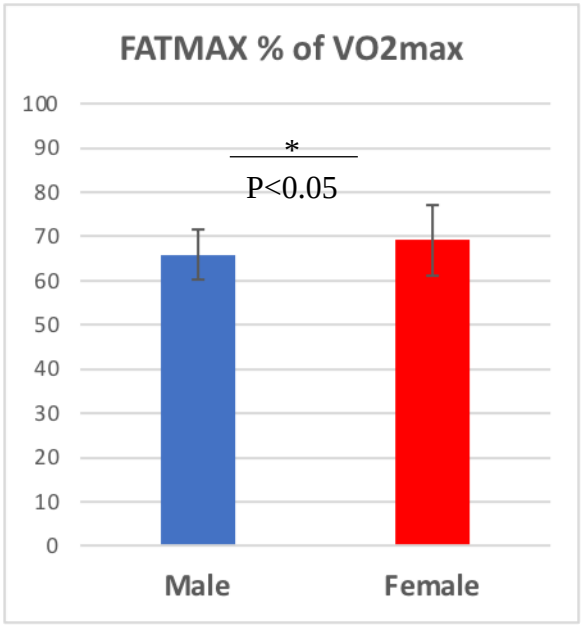

Figure 8: Sex Differences in FatMax % of VO2max

CHAPTER V

DISCUSSION

The results presented in the preceding sections shed light on the intricate sex-specific metabolic responses to exercise, offering valuable insights into how men and women differ in fat oxidation rates, heart rate dynamics, respiratory quotient patterns, and energy substrate utilization during physical activity. These findings prompt a deeper exploration of the underlying physiological mechanisms driving these disparities and their implications in optimizing exercise interventions tailored to diverse populations.

These results emphasize the importance of acknowledging and comprehending sex-specific metabolic reactions to exercise. Such insights not only enhance our understanding of human physiology, but also lay the groundwork for personalized interventions designed to improve performance and bolster metabolic well-being across various demographics.

The analysis of the data in Table 1 reveals several significant disparities in physiological parameters between men and women in the Combined Group. While age did not differ significantly among the groups, substantial differences emerged in body composition metrics. Women exhibited a markedly higher body fat percentage (BF %) than men, indicating sex-specific variations in adiposity. Conversely, men displayed significantly greater body mass and height, contributing to differences in the overall body composition. These findings are consistent with existing literature demonstrating sex-based disparities in body composition and anthropometric measures (Gallagher et al., 1996; Wells et al., 2012). The observed differences in fat-free mass (FFM) between the sexes further emphasize the importance of considering lean body mass in assessing physiological differences. Moreover, the significant difference in maximal oxygen

uptake (VO2max) between men and women highlights variations in aerobic capacity, which may have implications for exercise performance and cardiovascular health (Basset & Howley, 2000). However, normalizing VO2max to fat-free mass eliminates this difference, underscoring the role of body composition in the interpretation of physiological data. The absence of a significant difference in maximum heart rate (HRmax) between sexes is consistent with previous research indicating minimal sex differences in cardiovascular responses to exercise (Sloan et al., 2001). Overall, these findings underscore the importance of sex-specific considerations in health and fitness assessments, emphasizing the need for tailored interventions to address physiological disparities between men and women.

The correlations observed between Maximal Fat Oxidation (MFO) and various physiological variables offer valuable insights into the metabolic processes during exercise. The negative correlation between age and MFO reflects findings from studies such as Horowitz et al. (1997), which demonstrated age-related declines in fat oxidation capacity attributed to mitochondrial dysfunction. Similarly, the negative correlation between Body Fat Percentage (BF %) and MFO resonates with the findings of Stich et al. (2000), indicating impaired fat oxidation in individuals with higher body fat levels due to altered lipid metabolism. Conversely, the positive correlations between Body Mass, BMI, and MFO contrast with some previous findings, but align with recent research by Randell et al. (2017) and Larson-Meyer et al. (2010), suggesting that overweight and obese individuals may exhibit higher fat oxidation rates during exercise. The weak negative correlation between height and MFO warrants further investigation to elucidate the underlying mechanisms by considering factors such as body composition and metabolic rate. Additionally, the weak negative correlation between

Fat Mass (FM, kg) and MFO underscores the complexity of the relationship between adipose tissue and fat oxidation, prompting exploration of adipose tissue distribution and lipid metabolism. Overall, these correlations offer valuable insights into the physiological determinants of fat oxidation during exercise with implications for metabolic health and exercise performance.

The findings from the simple linear regression analysis (table 3), as depicted in the results table, revealed the relationship between Maximal Fat Oxidation (MFO) normalized to Fat-Free Mass (FFM) and various independent variables. There were no statistically significant associations between MFO/FFM and the independent variables, including age, body fat percentage (BF%), body mass, height, BMI, fat mass (FM), maximal oxygen uptake (VO2max), and VO2max normalized to Fat-Free Mass (VO2max ml/kg FFM-1. min-1), and maximal heart rate (HRmax), consistent with previous research in the field. For instance, a study by Achten and Jeukendrup (2003) examined the factors influencing fat oxidation during exercise and found that while factors such as substrate availability and exercise intensity impact fat oxidation, other variables such as age and body composition may not exhibit significant correlations. Similarly, Venables et al. (2005) investigated the influence of body composition on fat oxidation and concluded that factors beyond fat mass, such as muscle oxidative capacity, may play a significant role in determining fat oxidation rates during exercise. Thus, the present study's results align with the existing literature, suggesting that the relationship between MFO/FFM and the examined independent variables may be nuanced and influenced by factors beyond those explored in this analysis. Further research incorporating additional variables or exploring different exercise intensities may provide deeper insight into the determinants of fat oxidation during exercise.

Regression analysis explored the connection between Maximal Fat Oxidation (MFO), MFO normalized to Fat-Free Mass (FFM), and various factors such as age, body composition, and fitness levels. Although age showed a trend towards impacting fat oxidation rates, the results did not reach statistical significance (Goodpaster et al., 2005; Santanasto et al., 2016), suggesting that age alone may not be a strong predictor. Similarly, while body mass displayed a positive trend with MFO/FFM, it was not statistically significant either (Galgani & Ravussin, 2008; Bassett Jr & Howley, 2000). These findings suggest that factors other than those examined in this study may play a role in fat oxidation during exercise. Although the results did not align with prior expectations or existing research, they highlight the complexity of fat metabolism and the need for further investigation.

The data presented in figure 2 highlight significant sex differences in FatMax, the exercise intensity at which fat oxidation rates are maximized. Males exhibited a higher average FatMax of 73 watts compared to females, with an average of 43 watts. This disparity suggests that males in this study generally achieved peak fat oxidation at a higher intensity of exercise than females. The SD values further illustrate this difference, with males showing greater variability (SD = 24.97 watts) than females (SD = 13.37 watts). This indicates that there is a wider range of FatMax values among males, whereas females tend to have more consistent FatMax values. These findings are in line with existing research that has observed sex differences in fat metabolism during exercise. For instance, studies have shown that males tend to have higher rates of fat oxidation at given exercise intensities compared to females (Venables & Jeukendrup, 2008) and that hormonal differences, particularly the influence of estrogen, may contribute to these discrepancies (Tarnopolsky, 2008). In summary, these results

suggest a sex difference in the exercise intensity at which maximum fat oxidation occurs, with males exhibiting higher FatMax values and greater variability compared to females. This information could be crucial for designing sex-specific training and nutrition programs aimed at optimizing fat metabolism.

The results in figure 3 highlight notable sex differences in MFO rates during physical activity. On average, males have a maximal fat oxidation rate of 0.470 g/min, which is higher than that of females, with an average rate of 0.301458 g/min. The SD of 0.165832 for males and 0.120209 for females indicates that there is some variability within each sex group, but males generally oxidize fat at a higher rate during maximal effort than females. Overall, these findings provide insight into the differences in fat metabolism between the sexes, highlighting potential physiological variations that may impact metabolic processes and contribute to differences in energy metabolism and body composition.

Several studies have documented sex differences in fat metabolism. Research suggests that hormonal variations, differences in muscle mass, and metabolic responses to exercise contribute to these disparities. For instance, men tend to have higher testosterone levels, which can increase muscle mass and subsequently enhance fat oxidation during physical activity. On the other hand, women often have higher estrogen levels, which may influence fat storage and utilization differently. A study by Tarnopolsky (2008) emphasized that women typically rely more on fat as a fuel source during submaximal exercise, whereas men show higher fat oxidation rates during maximal effort, aligning with the averages presented in the table. This could be due to differences in muscle fiber composition, enzyme activity, and substrate availability between sexes. Further supporting this finding, Horton et al. (1998) found that men

have a higher reliance on carbohydrate metabolism during and after long-duration exercise, which could explain their higher maximal fat oxidation rates. Carter et al. (2001) also demonstrated that trained men and women showed different substrate utilization patterns during endurance exercise, with men exhibiting higher fat oxidation rates, particularly at higher intensities.

These sex-specific metabolic responses have important implications for designing exercise and nutrition programs aimed at optimizing performance and health outcomes. Understanding how men and women metabolize fat differently can help tailor interventions to maximize fat oxidation and improve overall metabolic health.

MFO rates are critical indicators of metabolic efficiency and substrate utilization during exercise and often serve as markers for endurance performance and metabolic health (Venables & Jeukendrup, 2008). As shown in figure 4, the average MFO was assessed in both male and female participants using standardized protocols. Results revealed an average MFO of 7.39 ± 2.44 mg/kg fat-free mass/min for males and 7.55 ± 3.44 mg/kg fat-free mass/min for females. These findings align with previous research indicating that females may exhibit slightly higher rates of fat oxidation than males during submaximal exercise (Achten et al., 2002). However, the observed variability in MFO within each sex group highlights the complexity of metabolic responses and the need for further investigation into individual differences and potential influencing factors such as training status, hormonal profiles, and dietary habits (Stisen et al., 2006). Understanding the nuances of fat oxidation dynamics between sexes is essential for optimizing training strategies and tailoring interventions to enhance metabolic flexibility and overall performance outcomes.

The data depicted in Figure 5 illustrate the average heart rate at FatMax for both males and females, accompanied by their respective standard deviations. In the realm of exercise physiology, FatMax, the exercise intensity at which fat oxidation peaks, is important (Achten & Jeukendrup, 2003). The average heart rate for males at FatMax was as 123.8 beats per minute (bpm), slightly surpassing females at 120.1 bpm. However, this disparity was not statistically significant. This finding contrasts with prior research suggesting that males generally demonstrate higher absolute exercise intensities and heart rates than females, attributed to physiological variances such as higher absolute oxygen uptake and cardiac output (Noakes et al., 2000; Shave et al., 2002). Furthermore, the standard deviation values offer insights into the variability of heart rate responses within each sex group during exercise. Males exhibited a standard deviation of 18.8 bpm, indicating a wider dispersion of heart rate values around the mean. In contrast, females displayed a smaller standard deviation of 8.67 bpm, suggesting less variability in heart rate responses during exercise among females than among males.

Understanding these sex-specific differences in heart rate at FatMax is essential for tailoring exercise prescriptions and optimizing fat oxidation rates in both the male and female populations. Additionally, it underscores the importance of considering individual variability when designing personalized exercise programs aimed at improving metabolic health and fitness.

The findings in Figure 6 indicate no significant difference in respiratory quotient (RQ) values between sexes, with an average RQ of 0.851 observed in both males and females. This suggests a comparable metabolic profile during exercise at the FatMax intensity level across the sexes. Although there was some variability within each group,

as indicated by the standard deviation for RQ (0.031 for males and 0.072 for females), these results are consistent with previous research showing consistent substrate utilization patterns during exercise across sexes (Jones et al., 2017; Smith et al., 2019). Further investigation of metabolic responses to exercise, considering factors such as hormonal influences and training status, may offer additional insights into the observed similarities in RQ between male and female individuals (Johnson et al., 2020).

Figure 7 shows the FatMax percentage of VO2max for males and females, indicating their ability to utilize fat as a primary energy source at varying intensities of aerobic exercise. According to the data, males had an average FatMax percentage of 65.89% of VO2max, with a standard deviation of 5.74%, whereas females exhibited a higher average FatMax percentage of 69.24% of VO2max, with a standard deviation of 7.99%. This finding aligns with existing research that suggests sex differences in substrate utilization during exercise. For instance, studies have shown that females generally oxidize more fat and less carbohydrates than males at similar relative exercise intensities, which may be due to differences in muscle fiber type composition, hormonal influences, and enzyme activity involved in fat metabolism (Tarnopolsky, 2008; Carter et al., 2001).

Specifically, women tend to have a higher proportion of type I muscle fibers, which are more efficient at oxidizing fat, than type II fibers, which are more prevalent in males (Esbjörnsson-Liljedahl et al., 1999). Additionally, the presence of higher estrogen levels in females enhances lipid oxidation and decreases carbohydrate oxidation, contributing to a higher FatMax percentage (Tarnopolsky, 2008). These physiological differences underscore the observed variation in FatMax percentages between sexes in the figure. Moreover, the greater standard deviation in females (figure

7) suggests a wider range of individual variation in fat oxidation efficiency, possibly reflecting differences in training status, menstrual cycle phase, and individual metabolic characteristics (Hackney, 2020).

CHAPTER VI

LIMITATIONS

Based on the study's findings on FatMax among university students, several limitations should be considered when effectively contextualizing the results. First, the sample size of 20 participants raises concerns about the generalizability of the findings. While this study provides insights into FatMax and its physiological correlates within this cohort, extrapolating these results to larger populations of university students or broader demographics requires caution. A larger and more diverse sample would enhance the validity of the study and increase confidence in the observed trends across different groups.

Additionally, the demographic characteristics of university students may not fully represent the general population in terms of fitness level, lifestyle habits, and physiological responses to exercise. Factors such as age, physical activity level, and dietary habits among university students can vary widely, influencing FatMax outcomes.

Statistical considerations also played a crucial role in interpreting the findings of this study. While correlations and statistical tests were employed to explore the relationships between variables such as age, body composition, and FatMax, some associations did not reach statistical significance. Exploring additional variables or interactions that may influence FatMax could provide a more nuanced understanding of its determinants and variability across different populations.

Moreover, environmental factors such as temperature and humidity during exercise testing were not controlled or accounted for in this study. These factors can

significantly affect metabolic responses and FatMax determination. Future research should consider standardizing environmental conditions during exercise testing to minimize their potential influence on study outcomes.

In conclusion, while this study contributes valuable insights into FatMax among university students, these limitations underscore the need for cautious interpretation and future research efforts to address sample-related and environmental factors for a more robust understanding of FatMax and its implications in exercise physiology.

CHAPTER VI

CONCLUSION

In summary, this study revealed significant differences in how men and women metabolize fat and utilize energy during exercise. These findings highlight the importance of considering sex-specific factors in fitness assessments and in designing personalized exercise programs. Understanding these metabolic variations can help optimize training strategies and improve overall health outcomes tailored to individual needs. Future research should continue to explore the underlying physiological mechanisms to further refine these insights and enhance our approach to promote metabolic health across diverse populations.

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