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CONTEXTUALIZING THE ACUTE RESPONSES TO ARM CYCLING

by

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ABSTRACT

The prescription of aerobic exercise modalities engaging the arm musculature have the potential to extend the reach of physical activity and promote cardiorespiratory fitness in individuals with lower body impairment due to excessive body mass, and among individuals seeking to complement and diversify standard leg training. This study compared the acute cardiopulmonary responses obtained during arm cycling and leg cycling performed at different intensities among lean and average (LA) and overfat and obese individuals (OFO). Participants were 37 young and relatively healthy adults. They were tested for mode-specific peak power output and work rate at ventilatory threshold during two randomized maximal incremental protocol tests. The experiments were four randomized constant work rate isocaloric protocols for arm cycling and leg cycling performed at heavy and moderate exercise intensities based on participants' ventilatory threshold and peak power output obtained from the maximal incremental protocol tests. All experiments were matched for the same caloric expenditure of 100 kcal. Cardiopulmonary parameters and the time to expend 100 kcal ($Tkcal_{100}$) were recorded. $Tkcal_{100}$ was increased for the OFO in comparison to the LA group. Among the cardiopulmonary parameters measured in this study, only oxygen uptake relative to body mass was significantly different between groups; however, differences were no longer evident when oxygen uptake values were considered relative to fat-free mass. Furthermore, cardiopulmonary variables are more affected by exercise intensity than exercise mode, while responses to different intensities are not necessarily proportional. Young adults with excess body fat appear to respond less favorably to acute exercise when compared to lean and average body composition individuals, as evidenced by a longer $Tkcal_{100}$.

To my parents, Hilda and Jose Paulo,
who have given me unconditional love
and support every step of the way.

To my wife Fernanda and my daughter Eva,
who inspire me to be a better person.

To my family, friends, and colleagues,
who have helped me to get here where I am today.

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CHAPTER ONE: INTRODUCTION

Walking, running, and cycling are standard modes of exercise that have been extensively studied because of their popularity, familiarity, and relatively simple movement patterns. Intriguingly, all of these exercises primarily involve the lower body musculature. The prescription of aerobic exercise modalities engaging the arms have the potential to extend the reach of physical activity and promote cardiorespiratory fitness in individuals with lower body impairment due to excessive body mass, and among individuals seeking to complement and diversify standard leg training. Alternatives utilizing the upper limb musculature include swimming, rowing, and arm cycling; however, arm cycling uniquely limits the involvement of the lower body musculature. Swimming and rowing require a certain level of fitness and technical skills that are arguably above the novice training/experience level. Arm cycling involves a lever-like movement pattern and controlled range of motion that can be performed in the seated or standing position. Despite its simplicity and easy application, this modality does not share the same popularity or familiarity as other exercise modes.

Arm cycling featuring stationary ergometers have been historically applied in a variety of settings, although the most conspicuous application of this exercise modality has been to serve as a surrogate for lower body exercises due to temporary or permanent injury (Knechtle et al., 2003; Miles et al., 1989; Olivier et al., 2008). Nonetheless, upper body aerobic exercise can produce localized physiological adaptations that are more beneficial than exercising the lower limbs alone (Magel et al., 1978; Ranadive et al., 2012). The potential for limb-specific adaptations is congruent with the principle of training specificity (Boushel et al., 2014; Saltin et al., 1976). Although the systemic changes that occur during aerobic exercise enhance whole-body physiological function, the magnitude of selective muscle metabolic adaptations is far greater (Ahlborg et al., 1975; Boushel et al., 2014; Franklin, 1989; Saltin et al., 1976).

Despite the dissimilarity of physiological responses resulting from upper and lower body aerobic exercise, it is accepted that greater absolute performance outcomes can be achieved by the larger musculature of the lower limbs (Larsen et al., 2016; Miles et al., 1989; Sawka, 1986). A series of interrelated factors have been suggested to explain the reduced efficiency of aerobic exercise using the upper limbs. These include larger hydrostatic forces (Bhambhani et al., 1998), lower vascular conductance (Garten et al., 2019), lower vascular capillary bed and higher cellular hypoxia (Jensen-Urstad et al., 1993; Sawka, 1986), differences in fiber types and the patterns of motor unit recruitment (Sawka, 1986), decreased rate of energy production via oxidative pathways (Shephard, Bouhlel, et al., 1988), and the most frequently mentioned, the innate lower physical activity level and aerobic training status of the upper limbs (Larsen et al., 2016; Miles et al., 1989; Sawka, 1986). Whether or not these are exclusive contributors, upper body aerobic exercise training has great potential to promote aerobic adaptations in the short (La Monica et al., 2019, 2020) and long term (Hettinga et al., 2016; Schoenmakers et al., 2016), and in some cases, more so than lower body exercise (Zinner et al., 2016). Recently, arm cycling has been shown to positively impact postprandial blood glucose and insulin in a sample of sedentary obese individuals (McCarthy et al., 2017, 2020).

Studying the magnitude of mode-specific differences has an important public health consideration, as the development of mode-specific guidelines may help reduce the medical burden of obesity and inactivity.

Physical inactivity and obesity are significant contributors to all-cause mortality and are among the most critical public health problems of the 21st century (Gibson et al., 2019). Currently, nearly 70% of the U.S. population is either overweight or obese (CDC, 2021a). Preventable obesity-related cardiometabolic and renal conditions continue to lead the main causes of premature death in the United States (CDC, 2021a). Obesity also imposes a tremendous economic burden among taxpayers and has been estimated to cost an additional $1,429 in medical spending compared to normal-weight individuals (Finkelstein et al., 2009). Physical activity and exercise play a critical role in weight management and can drastically reduce the progression of disease indicators in overweight and obese individuals (CDC, 2021b). Increased energy expenditure via moderate physical activity, between 90-110 kcal/day, may considerably reduce the risk of all-cause mortality (Ekelund et al., 2015). It has been estimated that as little as 15 minutes a day of moderate activity could avert one in every nine deaths caused by being physically inactive (Wen et al., 2011).

The second edition of “The Physical Activity Guidelines for Americans” proposed that adults should regularly engage in moderate, vigorous, or a combination of moderate and vigorous-intensity of aerobic exercise such as walking and dancing (Powell et al., 2019). Although the range of time per week spent in moderate and vigorous exercise intensities has been well established to provide positive metabolic adaptations, little is known about the substitution of upper body aerobic exercise for typical lower body modalities, which may be a preferred or more feasible option for obese populations and/or those with mobility issues (i.e., lower-body injury, higher relative effort while walking). As an inverse relationship between BMI and ambulatory activity has been shown in obese individuals (Tudor-Locke et al., 2001), arm cycling could be an alternative for obese individuals not meeting their minimal physical activity levels and potentially increase adherence to future exercise programs (McCarthy et al., 2017, 2020).

The impact of modifiable factors such as body composition, training status, exercise volume and intensity, and exercise mode has become instrumental in understanding various populations' metabolic and performance characteristics (King et al., 2007). Therefore, this area of research has the potential to highlight population-related metabolic differences and inform aerobic exercise prescription for health and performance. Although considerable research has been devoted to understanding the acute and chronic responses to upper and lower body cycling exercise, rather less attention has been paid to the effect that body composition and fitness may have on metabolism using primarily the upper body musculature. First, it is essential to note that leanness and aerobic fitness have an important role in metabolic capabilities during exercise (Kelley, 2005); yet some research shows that weight loss alone may not be sufficient to promote these changes in metabolism (Simoneau et al., 1999). Secondly, excess body fat may also affect oxidative energy production (Abdul-Ghani et al., 2009). Third, obesity causes alterations in the respiratory system's structure and function that could be exacerbated during upper body exercise because of the increased torso stabilization required by this modality (Casaburi et al., 1992; Li et al., 2001; Whipp & Davis, 1984). Taken together, body composition, physical activity level, and aerobic fitness should also be considered when assessing individuals during arm and leg cycling.

Purpose

1. The primary purpose of this study was to evaluate the time taken to expend 100 kcal (Tkcal$_{100}$) during arm and leg cycling performed at moderate and heavy intensities between lean–average weight and overweight–obese individuals.

2. A secondary purpose was to evaluate the cardiopulmonary responses of arm and leg cycling performed at moderate and heavy intensities between lean–average weight and overweight–obese individuals. The cardiopulmonary variables evaluated included oxygen uptake ($\dot{V}O_2$), respiratory exchange ratio (RER), ventilation (V_E), tidal volume (V_t), respiratory frequency (f_R), and heart rate (HR).

Hypotheses

Primary purpose

a) The time taken to expend 100 kcal (Tkcal$_{100}$) during leg cycling would be shorter than arm cycling.
b) The time taken to expend 100 kcal (Tkcal$_{100}$) during exercises performed at heavy exercise intensities would be shorter than exercises performed at moderate exercise intensities.

c) The time taken to expend 100 kcal ($Tkcal_{100}$) during arm cycling at heavy exercise intensities would be shorter than leg cycling at moderate exercise intensities.

d) The time taken to expend 100 kcal ($Tkcal_{100}$) during arm or leg cycling performed at moderate or heavy exercise intensities would be shorter for the lean–average weight group than the overweight–obese group.

Secondary purpose

a) Cardiopulmonary responses during leg cycling would be greater than arm cycling

b) Cardiopulmonary responses during exercises performed at heavy intensities would be greater than exercises performed at moderate intensities.

c) Cardiopulmonary responses during arm cycling at heavy would be greater than leg cycling at moderate intensities.

d) Cardiopulmonary responses during arm or leg cycling performed at moderate or heavy intensities would be greater for the lean–average weight group than the overweight–obese group.

CHAPTER TWO: REVIEW OF LITERATURE

Introduction

The study of cardiopulmonary responses of arm versus leg cycling ergometry date back to early work by Collett & Liljestrand, (1924), aiming to establish the influence of arm work on ventilation and cardiovascular responses in healthy individuals. Since then, a series of studies have addressed physiological differences between modes, and a few reviews of the literature have been published to summarize those findings (Franklin, 1985; Miles et al., 1989; Sawka, 1989). There has been a renewed surge in interest in the topic over the past few years, with a systematic review and meta-analysis being performed on the difference in maximal oxygen uptake achieved during arm cycling (AC) and leg cycling (LC) (Larsen et al., 2016).

Most of the published peer-reviewed literature comparing AC and LC has been concerned with maximal exercise responses. However, deepening the understanding of submaximal exercise responses to AC may assist future investigations aiming to implement this exercise mode in specific populations. The broad methodological approach and results reported in the current literature require careful consideration. A scoping review of the body of literature, in this case, can be of particular use since the relative impact of performing AC on cardiopulmonary parameters remains to be fully explored.

Therefore, this scoping review aims to systematically map the body of literature and present findings and an overview and recommendations for future research.

Therefore, the specific objectives are to: (1) review the literature, (2) summarize the available studies, (3) examine and report the main results, and (4) propose recommendations for advancing the study of AC and LC.

Research Question

This scoping review is guided by the question, "What are the cardiopulmonary responses and range of methodologies used in studies comparing arm and leg cycling during submaximal exercise?". The methodological approaches used to compare cycling exercises involving AC and LC are discussed within each section of the review. Physiological and conceptual discussion is conducted on the absolute (i.e., total) and relative measurements expressed relative to body mass and the interrelationships between cardiopulmonary variables measured during acute exercise. Specifically, noninvasive measurements of cardiopulmonary exercise testing, including cardiovascular, ventilatory, and pulmonary and metabolic gas exchange measurements were evaluated (Figure 1). Interrelated variables, such as external load (i.e., work-rate, power output) and internal load (i.e., subjective ratings of feelings and perceived exertion), were also discussed. When appropriate, the invasive measurement of lactate production was considered.

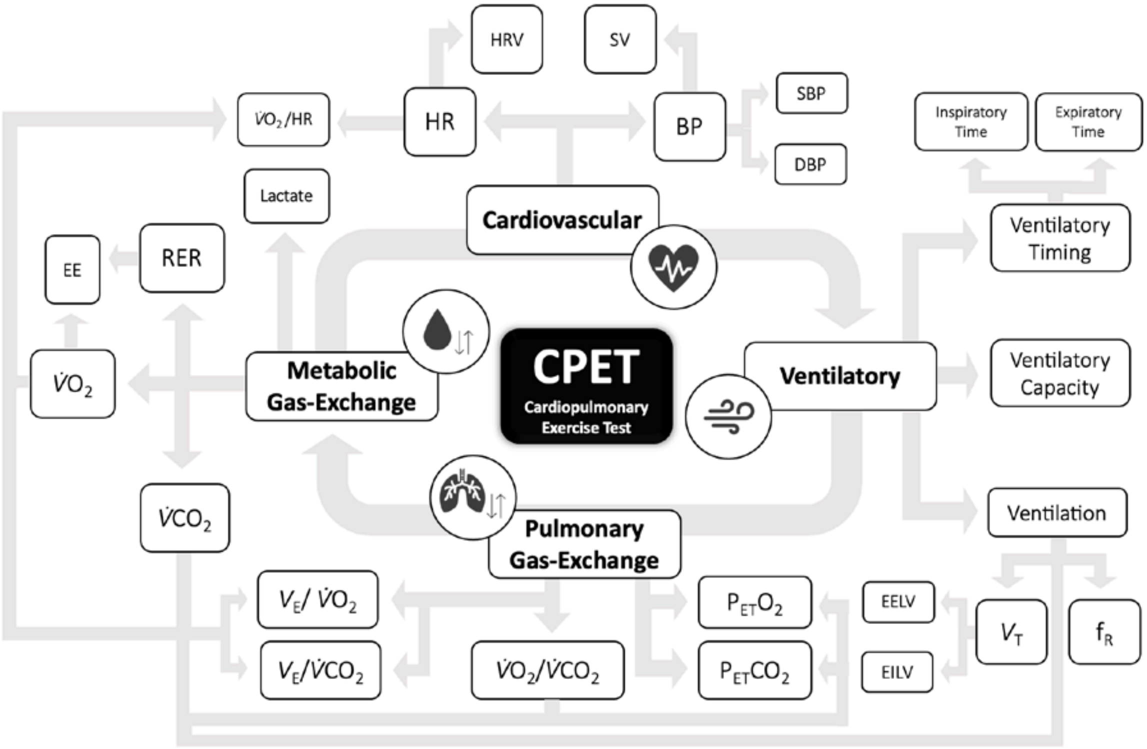


Figure 1. Main cardiopulmonary exercise test outcomes

Notes: *Cardiovascular*: BP = blood pressure, SBP = systolic blood pressure, DBP = diastolic blood pressure, SV = stroke volume, HR = heart rate, HRV = heart rate variability; *Ventilatory*: f_R = respiratory frequency, V_T = tidal volume, EELV = end-expiratory lung volume, EILV = end-inspiratory lung volume; *Pulmonary Gas Exchange*: $P_{ET}O_2$ = end-tidal volume of oxygen, $P_{ET}CO_2$ = end-tidal volume of carbon dioxide, $\dot{V}O_2/\dot{V}CO_2$ = relationship of oxygen uptake and carbon dioxide output, $V_E/\dot{V}O_2$ = ventilatory equivalent of oxygen uptake, $V_E/\dot{V}CO_2$ = ventilatory equivalent of carbon dioxide output; *Metabolic Gas-Exchange*: $\dot{V}CO_2$ = carbon dioxide output, $\dot{V}O_2$ = oxygen uptake, EE = energy expenditure, RER = respiratory exchange ratio, $\dot{V}O_2$/HR = relationship of oxygen uptake and heart rate.

Data Sources and Search Strategy

The online search was conducted using PubMed, which accessed the MEDLINE database within the specified range of times between the years 1960 to present and was conducted over April. This search contained descriptors adapted from Larsen et al. (2016), which are presented in Table 1.

Table 1. Search strategy

Search items 1	Search items 2	Search items 3
Arm [MeSH]	Bicycle ergometer	Blood pressure
Arm crank ergometer	Bicycling [MeSH]	Blood pressure
Arm crank ergometry	CPET leg	Breathing pattern
Arm cycle ergometry	Cycle ergometer	Breathing rate
Arm cycling	Cycle ergometry	Caloric cost
Arm ergometer	Cycle exercise	Calories
Arm ergometry	Cycling	Carbohydrate oxidation
Arm work	Electromagnetically braked ergometer	Carbon dioxide output
CPET arm		Cardiopulmonary
Cranking	Ergometry [MeSH]	Cardiovascular
Hand crank	Leg [MeSH]	Constant work rate
Hand cycling	Leg Cardiopulmonary exercise testing	End expiratory lung volume
Hand ergometer		End-tidal volume
Upper body ergometer	Leg cycle ergometry	Energy expenditure
Upper body exercise	Leg cycling	Heart rate
Upper-body cycling	Leg ergometry	Isocaloric
	Leg exercise	Metabolic gas exchange
	Lower body exercise	Oxidative metabolism
		Oxygen uptake
		Pulmonary gas exchange
		Respiratory exchange ratio
		Respiratory quotient
		Respiratory rate
		Submaximal CPET
		Tidal volume
		V-slope
		Ventilation
		Ventilatory
		Ventilatory capacity
		Ventilatory equivalents
		Ventilatory reserve
		Ventilatory timing

Citation Management

A free and open-source reference management software was used to manage bibliographic data and related research materials (Zotero, Center for History and New Media, George Mason University, USA). Titles and abstracts were exported as a word processing document for subsequent screening and data characterization of full articles.

Eligibility Criteria

The inclusion criteria of the present scoping review included peer-reviewed articles in the English language comparing acute cardiopulmonary responses between arm and leg aerobic cycling exercise in human adults without chronic medical conditions and loss of function (i.e., spinal cord injury). Studies including any other form of arm ergometry other than cycling were excluded. Studies that did not report submaximal measures of both modalities were excluded. The cross-sectional investigations included consisted of crossover and parallel study designs published after the year 1960. Sources pertaining to grey literature indexed by non-scientific databases, case studies, and abstracts proceedings from scientific events were excluded from consideration. Studies not presenting a clear statistical treatment were also excluded

Data Characterization

The second part of the screening procedure continued with a full-text examination for the references deemed relevant. Studies were excluded at this phase if they were found not to meet the eligibility criteria. The specific study characteristics form was developed retroactively by the researchers and completed during screening. Each publication's year, authors, sample descriptive, exercise protocols, and primary outcomes were recorded in this form.

Data Summary and Synthesis

Data were compiled in chronological order in Table 2, which lists the studies' first author and year, articles' quoted sample description, protocol and outcomes of interest, and results. The main independent variables of interest were arm cycling (AC) and leg cycling (LC) exercises. Dependent variables include breathing/respiratory rate/frequency (f_R), carbon dioxide output ($V\text{CO}_2$), work rate (WR), end-expiratory lung volume (EELV), end-inspiratory lung volume (EILV), energy expenditure (EE), heart rate (HR), blood pressure (BP), oxygen uptake ($\dot{V}\text{O}_2$,), respiratory exchange ratio/respiratory quotient (RER), tidal volume (V_T), ventilation (V_E), ventilatory equivalent of oxygen uptake (V_E/ $\dot{V}\text{O}_2$), ventilatory equivalent of carbon dioxide output ($V_E/V\text{CO}_2$), ventilatory threshold (VT) oxygen uptake economy ($\dot{V}\text{O}_2\text{E}$), gross economy (GE), delta economy (DE), work economy (WE), net economy (NE).

Table 2. Article summary and synthesis

Author (year)	Sample	Protocol	Outcomes of interest	Results
Bevergard (1966)	“*Physically active but did not take part in athletics regularly.*” *N*: 6 Age: 24±1.3 y Sex: males Body mass:75±2.8 kg Height: 184±2.2 cm BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: not reported LC $\dot{V}O_2$ peak: not reported	AC: submaximal GXT, 6-7 min at each intensity (≈30 and ≈65 W) separated by 45 min LC: submaximal GXT, 6-7 min at each intensity (≈80 and ≈160 W) separated by 45 min	HR, $\dot{V}O_2$, Lactate	• HR: AC (65 W) > LC (80 W) • CO: AC = LC • $\dot{V}O_2$: AC (65 W) = LC (80 W) AC (60 W) = LC (150 W) AC (90 W) = LC (200-250 W) • V_E: AC > LC • Lactate (arterial): AC > LC
Vokac et al. (1975)	“*Healthy non-competitive cross-country skiers*” *N*: 7 Age: 22–25 y Sex: males Body mass: 77.5±2.3 kg Height: 185±2.3 cm BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: not reported LC $\dot{V}O_2$ peak: not reported	AC: submaximal and discontinuous GXT with ≈6 min intervals at each intensity (≈50,100,150 W) with 5 min of rest between work-rates LC: submaximal and discontinuous GXT with ≈6 min intervals at each intensity (≈50,100,150 W) with 5 min of rest between work-rates	HR, V_E, $\dot{V}O_2$, $\dot{V}O_2$/WR, HR/$\dot{V}O_2$	• HR: AC = LC at 50 W AC > LC at 100,150 W • V_E: AC > LC at $\dot{V}O_2$ of 2 l/min • $\dot{V}O_2$ AC = LC at 50 W AC > LC at 100,150 W • $\dot{V}O_2$/WR: AC < LC at 50,100,150 W • HR/ $\dot{V}O_2$: AC > LC at $\dot{V}O_2$ of 2 l/min
Freyschuss (1975)	“*Healthy participants.*” *N*: 30 Age: 31±1.4 y (males) 30±2 y (females) Sex: males, females Body mass: 73.8±2.4 kg (males) 58.4±2.2 kg (females)	AC: maximal GXT ≈16 W increases for females and ≈33 W increases for males every min until exhaustion LC: maximal GXT ≈ 49 W increases for males and ≈	HR/$\dot{V}O_2$ slope, V_E slope, $\dot{V}O_2$/WR slope	• HR/$\dot{V}O_2$ slope: AC > LC • V_E slope: AC > LC • $\dot{V}O_2$/WR slope: AC > LC

Author (year)	Sample	Protocol	Outcomes of interest	Results
	Height: 177±1.2 cm (males) 165±1.3 (females) BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: not reported LC $\dot{V}O_2$ peak: not reported	33 W increases for females until HR of 170 bpm		
Vrijens et al. (1975)	"*..paddlers…* [and] *reasonably well trained* [individuals]" *N*: 9 Age: 24.7 y Sex: males Body mass: 74.4 kg Height: 176.6 cm BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: 3.793 l/min LC $\dot{V}O_2$ peak: 4.468 l/min	AC: maximal GXT with 40 W every 3 min until exhaustion LC: maximal GXT with 40 W every 3 min until exhaustion	HR, V_E, $\dot{V}O_2$	• *HR:* AC> LC at 100 W • *V_E:* AC > LC at 100 W • $\dot{V}O_2$: AC > LC at 100 W
Davis et al. (1976)	"*None of the subjects had undergone systematic endurance training for at least four months prior to the experiment.*" *N*: 30 Age: 22.5±2.6 y Sex: males Body mass: 75.5±9.0 kg Height: 179.8±6.9 cm BMI: not reported BF%: 13.2±6.4% AC $\dot{V}O_2$ peak: 3.793 l/min LC $\dot{V}O_2$ peak: 4.468 l/min	AC: maximal GXT with unloaded cycling for 4 min + ≈16 W every minute min until exhaustion LC: maximal GXT with unloaded cycling for 4 min + ≈33 W every minute min until exhaustion	$\dot{V}O_2$	• $\dot{V}O_2$ at VT (absolute and relative): AC < LC
Cerretelli et al. (1977)	"*Moderately active.*" *N*: 4 Age: 38.1±10.1 y	AC: 5 min at a $\dot{V}O_2$ of ≈ 1 (l/min)	$\dot{V}O_2$	• $\dot{V}O_2$ on-kinetics time constant at 60-70% of mode-specific $\dot{V}O_2$ peak:

Author (year)	Sample	Protocol	Outcomes of interest	Results
	Sex: males Body mass: 84.5±4.8 kg Height: 180.0±5.7 cm BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: 1.8±0.2 l/min LC $\dot{V}O_2$ peak: 3.1±0.3 l/min	LC: 5 min at a $\dot{V}O_2$ of ≈ 0.8, 1.3, 1.9, 2.5 (l/min)		AC = LC • $\dot{V}O_2$ on-kinetics time constant at the same $\dot{V}O_2$: AC > LC
Sawka et al. (1982)	No report of physical activity level and/or sport/exercise experience *N*: 4 Age: 28±4 y Sex: males Body mass: 84.5±4.8 kg Height: not reported BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: 2.27±0.3 l/min LC $\dot{V}O_2$ peak: 3.31±0.53 l/min	AC: maximal and discontinuous GXT 7 min at each intensity (25,74,98 W + maximal effort) with 20 min of rest between work-rates. LC: AC: maximal and discontinuous GXT 7 min at each intensity (49,98,147 W + maximal effort) with 20 min of rest between work-rates.	HR, V_E, V_t, f_R, V_E/ $\dot{V}O_2$, $\dot{V}O_2$, lactate	• HR (98 W): AC > LC • V_E (98 W): AC > LC • V_t (98 W): AC > LC • f_R (98 W): AC > LC • V_E/ $\dot{V}O_2$ (98 W): AC > LC • $\dot{V}O_2$ (98 W): AC > LC • Lactate (98 W): AC > LC
Miles et al. (1983)	No report of physical activity level and/or sport/exercise experience *N*: 9 Age: 28±6 y Sex: males Body mass: 78±12 kg Height: not reported BMI: not reported BF%: AC $\dot{V}O_2$ peak: 2.3 l/min LC $\dot{V}O_2$ peak: 3.3 l/min	AC: maximal and discontinuous GXT with 7 min at each intensity (25, 74, 98 W) LC: maximal and discontinuous GXT with 7 min at each intensity (49, 98, 147 W)	HR, blood pressure	• HR: AC > LC • Blood pressure: AC > LC

Author (year)	Sample	Protocol	Outcomes of interest	Results
Pimental et al. (1984)	No report of physical activity level and/or sport/exercise experience *N*: 9 Age: 22±3 y Sex: males Body mass: 71.4±6.9 kg Height: 172±8 cm BMI: not reported BF%: 13% AC $\dot{V}O_2$ peak: 48.7±6.8 ml/min/kg LC $\dot{V}O_2$ peak: 34.9±5.8 ml/min/kg	AC: 60 minutes at a $\dot{V}O_2$ of 1.6 l/min (absolute) and 60 min at 60% of $\dot{V}O_2$ peak (relative) performed in separate days LC: 60 minutes at a $\dot{V}O_2$ of 1.6 l/min (absolute) and 60 min at 60% of $\dot{V}O_2$ peak (relative) performed in separate days	HR, V_E/ $\dot{V}O_2$, lactate	• HR absolute: AC > LC at 30–60 min • HR relative: AC < LC at 10–60 min • V_E/ $\dot{V}O_2$ absolute and relative: AC > LC at 20,40,60 min • Lactate absolute: AC > LC • Lactate relative: AC = LC
Vander et al. (1984)	No report of physical activity level and/or sport/exercise experience *N*: 10 Age: 29.8±4.3 y Sex: females Body mass: 57.9±5.9 kg Height: 166.6±7.5 cm BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: 1.6±0.26 l/min LC $\dot{V}O_2$ peak: 2.02±0.43 l/min	AC: maximal GXT with ≈24 W every 3 min until exhaustion LC: maximal GXT with ≈24 W every 3 min until exhaustion	HR, V_E, $\dot{V}O_2$, RER	• *HR:* AC > LC at 48,72 W • V_E: AC > LC at 24,48,72 W • $\dot{V}O_2$: AC > LC at 24,48,72 W • RER: AC > LC at 48,72 W
Nikolic, Todorovic (1984)	"*Physical education students*" *N*: 60 Age: 19.6±1.2 y (males), 19.19±0.4 y (females) Sex: males (41), females (19) Body mass: 70.9±6.5 kg (males), 55.9±6.3 kg (females) Height: 177.6±7.0 cm (males), 164.6±6.5 cm (females) BMI: not reported	AC: maximal GXT 25 W + 15 W every min until exhaustion for males and 25 W + 10 W every min until exhaustion LC: maximal GXT 60 W + 30 W every min until exhaustion for males and 60 W + 30 W after a min	V_E	• V_E at VT: AC < LC

Author (year)	Sample	Protocol	Outcomes of interest	Results
	BF%: not reported AC $\dot{V}O_2$ peak: not reported LC $\dot{V}O_2$ peak: not reported	and then 15 W increases every min until exhaustion		
Washburn & Montoye, (1985)	“*None of the participants had previously been involved with any type of exercise laboratory investigation.*” *N*: 20 Age: 32.2±12.9 y Sex: males Body mass: 79.4±11.4 kg Height: not reported BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: not reported LC $\dot{V}O_2$ peak: not reported	AC: submaximal GXT with 5 min at each intensity (5, 10, 30, 50 W) LC: submaximal GXT with 5 min at each intensity (25, 50, 100 W)	$\dot{V}O_2$	• $\dot{V}O_2$: AC = LC
Ahlborg, Wahren, Felig (1986)	“*Healthy non-obese, physically active and well trained but did not participate in competitive athletic.s*” *N*: AC (6), LC (6) Age: AC (27±1 y), LC (27±2 y) Sex: males Body mass: AC (80±.6 kg), LC (74±4 kg) Height: AC (186±4 cm), LC (181±3 cm) BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: 4.3±0.3 l/min LC $\dot{V}O_2$ peak: 3.9±0.2 l/min	AC: 2 hours at 30% $\dot{V}O_2$ peak (measures at 40,90,120 min) LC: 2 hours at 30% $\dot{V}O_2$ peak (measures at 40,90,120 min)	HR, $\dot{V}O_2$, RER, lactate	• HR: AC > LC • $\dot{V}O_2$: AC = LC • RER: AC > LC • Lactate: AC > LC
Pivarnik et al. (1988)	“*…healthy…had consistently exercised outdoors (cycling, running, or walking 30 to 45 min·day^{-1}) for several weeks prior to the experiments…and were considered to be reasonably well trained…*”	AC: 60 min at 75 W LC: 60 min at 75 W	HR, $\dot{V}O_2$	• HR: AC > LC • $\dot{V}O_2$: AC = LC

Author (year)	**Sample**	**Protocol**	**Outcomes of interest**	**Results**
	N: 8 Age: 28.4 ± 3.6 y Sex: males Body mass: 72.3± 5.5 kg Height: 181.6 ± 3.3 cm BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: 2.6±0.44 l/min LC $\dot{V}O_2$ peak: 4.07±0.52 l/min			
Shephard et al. (1989)	"*Participants were from the university community and most moderately active, but none were highly trained.*" *N*: 16 Age: 28.6±3.8 (males), 31.9±0.4 (females) Sex: males (8), females (8) Body mass: 70.2±8.7 kg (males), 54.1±4.3 kg (females) Height: 181±7 cm (males), 163±4 cm (females) BMI: not reported BF%: 13.1±3.2 %BF (males), 24.3±3.1 %BF (females) AC $\dot{V}O_2$ peak: 1.23±0.19 (l/min) and 702±86 (ml/kg$^{\text{active muscle}}$/min) LC $\dot{V}O_2$ peak: 3.43±0.6 (l/min) and 226±8 (ml/kg$^{\text{active muscle}}$/min)	AC: maximal GXT (work-rates not reported) every minute until exhaustion LC: maximal GXT (work-rates not reported) every minute until exhaustion	$\dot{V}O_2$, $\dot{V}O_2$/WR	• $\dot{V}O_2$ at VT AC < LC (l/min) AC = LC (%$\dot{V}O_2$ peak) • $\dot{V}O_2$/WR AC < LC
Ahlborg and Jensen-Urstad (1991)	"*Physically active.*" *N*: AC (8), LC (8) Age: AC (24.8±0.6 y), LC (27.1±1.4 y) Sex: males	AC: submaximal GXT with 10 min at each intensity (30, 60, 90 W)	HR, $\dot{V}O_2$, V_E, Lactate	• HR: AC (30,60,90 W) = LC (100,150,200-250 W) • $\dot{V}O_2$: AC (30 W) = LC (100 W) AC (60 W) = LC (150 W)

Author (year)	**Sample**	**Protocol**	**Outcomes of interest**	**Results**
	Body mass:AC (72.3±.8 kg), LC (76.0±2.7 kg) Height: AC (182±2 cm), LC (178±3 cm) BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: 2.13±0.8 l/min LC $\dot{V}O_2$ peak: 4.13±0.16 l/min	LC: submaximal GXT with 10 min at each (100,150, 200-250 W)		AC (90 W) = LC (200-250 W) • V_E: AC (30 W) < LC (100 W) AC (60 W) < LC (150 W) AC (90 W) < LC (200-250 W) • Lactate: AC (30 W) > LC (100 W) AC (60 W) > LC (150 W) • AC (90 W) = LC (200-250 W)
Jensen-Urstad and Ahlborg (1992)	"*…highly arm-trained, four were flatwater kayakers, and three were oarsmen.*" *N*: 7 Age: 24.1±0.9 y Sex: males and females Body mass: 79.0±3.8 kg Height: 182±3 cm BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: 2.92±0.28 l/min LC $\dot{V}O_2$ peak: 4.13±0.36 l/min	AC: submaximal GXT with 10 min at each intensity (30%, 50%, 80% of $\dot{V}O_2$ peak) LC: submaximal GXT with 10 min at each intensity (30%, 50%, 80% of $\dot{V}O_2$ peak)	HR, $\dot{V}O_2$, RER, lactate	• HR: AC = LC • $\dot{V}O_2$: AC < LC • RER: AC (50%) > LC (50%) • Lactate: AC (30,50%) > LC (30,50%)
Kang et al. (1997)	"*Healthy participants. None engaged in any type of competitive sports*" *N*: 8 Age: 21±3 y Sex: males Body mass: 71.5±7.1 kg Height: 176±2 cm BMI: not reported BF%: 9±3 %BF AC $\dot{V}O_2$ peak: 2.24±0.54 (l/min) LC $\dot{V}O_2$ peak: 2.98±0.58 (l/min)	AC: submaximal GXT with 7 min at unloaded, 50, 60, 90% of $\dot{V}O_2$ peak separated by 10 min LC: submaximal GXT with 7 min at unloaded, 50, 60, 90% of $\dot{V}O_2$ peak separated by 10 min	HR, V_E, $\dot{V}O_2$ (GE,NE,DE,WE) RER	• HR (50,60,90% of $\dot{V}O_2$): AC < LC • V_E (50% of $\dot{V}O_2$): AC < LC • $\dot{V}O_2$ (50,60,90% of $\dot{V}O_2$): AC < LC • GE and NE: AC = LC • WE and DE:

Author (year)	**Sample**	**Protocol**	**Outcomes of interest**	**Results**
				AC < LC • RER (60% of $\dot{V}O_2$): AC > LC
Schneider, Wing, Morris (2002)	“*Participants were not currently involved in a training program for sports that predominantly used either the lower body or upper body musculature.*” *N*: 10 Age: 21.6±1.3 y Sex: males Body mass: 80.7±3.1 kg Height: 180.2±1.2 cm BMI: not reported BF%: not reported AC VO_2 peak: 3.10±0.14 l/min LC VO_2 peak: 2.08±0.11 l/min	AC: 7:15 min square-wave test at Δ50% (between VT and $\dot{V}O_2$ peak) LC: 7:15 min square-wave test at Δ50% (between VT and $\dot{V}O_2$ peak)	$\dot{V}O_2$	• $\dot{V}O_2$ at VT: AC < LC (l/min) AC = LC (relative to $\dot{V}O_2$%) • $\dot{V}O_2$ at 3 min: AC < LC • $\Delta\dot{V}O_2$ (7-3 min): AC = LC • $\Delta\ \dot{V}O_2$ (7-3 min; relative to unloaded cycling) AC > LC
Marais et al. (2002)	“*Physical education students*” *N*: 12 Age: 22±1 y Sex: males Body mass: 74.6+4.6 kg Height: 179.2±6.7 cm BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: 33.5±4.1 ml/min/kg LC $\dot{V}O_2$ peak: 46.4±8.4 ml/min/kg	AC: submaximal and discontinuous GXT with 4 min intervals at each intensity (20,40,60,80% of PP) LC: submaximal and discontinuous GXT with 4 min intervals at each intensity (20,40,60,80% of PP)	HR, V_E, $\dot{V}O_2$, $\dot{V}O_2E$ (GE, DE, WE)	• HR (20,40,60,80% of PP): AC = LC • V_E (20,40,60,80% of PP): AC < LC • $\dot{V}O_2$ (20,40,60,80% of PP): AC < LC • GE: AC < LC • DE: AC = LC • WE (20% of PP): AC = LC • WE (40,60,80% of PP): AC < LC

Author (year)	Sample	Protocol	Outcomes of interest	Results
Dekerle et al. (2002)	"*Students in physical education who practiced different sports activities such as cycling, running, or swimming and whose skills emphasize specifically the upper or lower body.*" *N*: 20 Age: 22 +2.2 y Sex: males Body mass: 73.5±5.3 kg Height: 180±60 cm BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: 2.7±0.4 l/min LC $\dot{V}O_2$ peak: 3.8±0.6 l/min	AC: maximal GXT with 30 W + 15 W every min until exhaustion LC: maximal GXT with 60 W + 30 W every min until exhaustion	$\dot{V}O_2$, $\dot{V}CO_2$, V_E, $V_E/\dot{V}O_2$, $V_E/\dot{V}CO_2$	• $\dot{V}O_2$ (mL/kg/min) at VT and RCP: AC < LC (absolute) AC < LC (relative; % $\dot{V}O_2$ peak) • $\dot{V}CO_2$ at VT and RCP: AC < LC • V_E at VT and RCP: AC < LC • HR at VT and RCP: AC = LC
Cerny, Ucer (2004)	"*Healthy with no history of cardiovascular or pulmonary disease.*" *N*: 6 Age: 26.5±4 y Sex: males Body mass: 75±18.9 kg Height: 175±10.7cm BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: not reported LC $\dot{V}O_2$ peak: not reported	AC: submaximal GXT with 4 minutes at each stage 30,60,90% of $\dot{V}O_2$ peak LC: work rates to match the same V_E obtained at 30,60,90% of AC $\dot{V}O_2$ peak for 4 minutes at each stage	V_E, V_t, f_R, EELV, EILV, $\dot{V}O_2$,	• V_E: AC (30,60,90%) = (matching V_E of AC at 30,60,90% of $\dot{V}O_2$ peak) • f_R: AC (60,90%) > LC (matching V_E of AC at 30,60% of $\dot{V}O_2$ peak) AC (30%) = LC (matching V_E of AC at 30% of $\dot{V}O_2$ peak) • V_t: AC (60,90%) < LC (60,90%) AC (30%) = LC (30%) • EELV: AC (30,60,90%) = LC (matching V_E of AC at 30,60,90% of $\dot{V}O_2$ peak) • EILV: AC (30,60,90%) = LC (matching V_E of AC at 30,60,90% of $\dot{V}O_2$ peak)

Author (year)	Sample	Protocol	Outcomes of interest	Results
				• $\dot{V}O_2$: AC (30,60%) = LC (matching V_E of AC at 30,60% of $\dot{V}O_2$ peak) AC (90%) < LC (matching V_E of AC at 90% of $\dot{V}O_2$ peak)
Leitch et al. (2008)	"*Healthy, active university students.*" *N*: 17 Age: 21.6±5.8 y Sex: male Body mass: 78.6±9.4 kg Height: 183±7 cm BMI: not reported BF%: 16.7±5.1% AC $\dot{V}O_2$ peak: not reported LC $\dot{V}O_2$ peak: not reported	AC: submaximal GXT with 15 minutes at each intensity (50% and 65% of HR max) LC: submaximal GXT with 15 minutes at each stage 50% and 65% of (HR max)	HR, HRV, V_E, V_t, f_R, $\dot{V}O_2$, RER	• HR AC = LC • HRV AC > LC • V_E: AC = LC • f_R: AC = LC • $\dot{V}O_2$: AC < LC • RER: AC > LC
Souza et al. (2017)	"*Well-trained male triathletes 7±2 y experience) and underwent intensive training during 14 ± 4 h/week for at least 3 years.*" *N*: 10 Age: 23.2 ± 4.5 y Sex: males Body mass: 72.3 ± 6.6 kg Height: 180.8 ± 8.3 cm BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: 3.4±0.4 (l/min) LC $\dot{V}O_2$ peak: 4.7±0.6 (l/min)	AC: 6 min at 25%Δ above VT (VTΔ25% = [VT + 0.25 x ($\dot{V}O_2$ peak − VT)]. LC: 6 min at 25%Δ above VT (VTΔ25% = [VT + 0.25 x ($\dot{V}O_2$ peak − VT)].	$\dot{V}O_2$	• $\dot{V}O_2$: AC < LC • $\dot{V}O_2$ on-kinetics amplitude primary AC < LC • $\dot{V}O_2$ slow component AC = LC
Tiller et al. (2019)	"*recreationally active*" *N*: 8	AC: 4 min at work rates equivalent to those attained	V_E, V_T, f_R, $V_E/\dot{V}CO_2$, $\dot{V}O_2$	• V_E AC = LC

Author (year)	Sample	Protocol	Outcomes of interest	Results
	Age: 24 ± 5 y Sex: males Body mass: 74 ± 11 kg Height: 179 ± 0.07 cm BMI: not reported BF%: not reported AC $\dot{V}O_2$ peak: 2.36 ± 0.54 (l/min) LC $\dot{V}O_2$ peak: 3.12 ± 0.72 (l/min)	at 20, 40, 60, 80, and 100% of the peak V_E LC: 4 min at work rates equivalent to those attained at 20, 40, 60, 80, and 100% of the peak V_E during AC		• $\dot{V}O_2$ at 40,60,80% of $\dot{V}O_2$ peak AC < LC • V_T at 60,80% of $\dot{V}O_2$ peak AC < LC • f_R AC = LC • $V_E/\dot{V}CO_2$ AC > LC

Notes: $N = 25$; AC = arm cycling; LC = leg cycling; BMI = body mass index; BF = body fat; BP = blood pressure, HR = heart rate, HRV = heart rate variability; f_R = respiratory frequency, V_T = tidal volume, EELV = end-expiratory lung volume, EILV = end-inspiratory lung volume; $\dot{V}O_2/\dot{V}CO_2$ = relationship of oxygen uptake and carbon dioxide output, $V_E/\dot{V}O_2$ = ventilatory equivalent of oxygen uptake, $V_E/\dot{V}CO_2$ = ventilatory equivalent of carbon dioxide output; $\dot{V}CO_2$ = carbon dioxide output, $\dot{V}O_2$ = oxygen uptake, EE = energy expenditure, RER = respiratory exchange ratio, $\dot{V}O_2$/HR = relationship of oxygen uptake and heart rate; GE = gross efficiency; NE = net efficiency; WE = work efficiency; DE = delta efficiency; VT = ventilatory threshold

Results

Search and Selection of Articles

The last search was conducted in April 2021 and resulted in 2,508 potentially relevant citations. Twenty-five articles were included in the analysis.

General Characteristics of Included Articles

The general characteristics of the included studies are listed in Table 3. These characteristics relate to the geographic region, the primary outcomes studied, participants’ characteristics, and their physical activity/exercise status. None of the studies included have been conducted from research groups based in South America or Asia. The most studied cardiopulmonary outcome in the included studies was oxygen uptake, which pertains to the metabolic gas exchange category in Table 3. Blood pressure responses during exercise were reported in one study, whereas heart rate was the second most studied outcome; both pertain to the cardiovascular category. Pulmonary gas exchange outcomes were the least studied CPET category of included studies. The average number of participants studied was 14 (range: 4–60 participants). Only 20% of the studies included female participants, with one including female participants only.

Furthermore, no studies have reported the race or ethnicity of the participants included. The majority of the studies included young adults between 20–30 years of age, with the average age being 26 years old. The participants' body composition was reported in five out of the 25 studies (20%). The average body fat reported among studies was

14%, which indicates that the majority of the studies generally examined lean to normal individuals. Only two of the studies included participants' physical activity status reported as experience level at a sports activity and the average amount of training per week. Forty-four percent of the studies did not include any physical activity level description. Moreover, three studies described participants as "physical education students" which cannot be categorized as under any physical activity level.

Table 3. General characteristics of included articles

Characteristic	Number	Percentage
Geographic Region*		
North America	11	44%
South/Central America	0	0%
Europe	12	48%
Asia	0	0%
Oceania	2	8%
CPET Outcomes		
Cardiovascular	15	60%
Ventilatory	13	52%
Metabolic gas exchange	22	88%
Pulmonary gas exchange	4	16%
Participants' Characteristics		
Male	20	80%
Female	1	4%
Mixed	4	16%
Physical Activity Level		
"Untrained"	1	4%
"Moderately active"	2	8%
"Physically active"	11	44%
Not reported	11	44%

Notes: *N* = 25; CPET = cardiopulmonary exercise test; BF = body fat; Articles may have included one or more CPET outcome; * based on the lead researcher. #Value obtained from five studies.

Methodological Characteristics of Included Articles

The methodological characteristics of the included studies are listed in Table 4. The majority of the studies chose submaximal graded exercise protocols to compare cardiopulmonary differences between AC and LC at submaximal intensities. In these studies, a range of two to five different work-rates were used. In general, maximal graded exercise protocols used stages with shorter duration when compared to submaximal and constant work-rate protocols. One study did not report the work-rates used during testing. All of the maximal incremental exercise test protocols used absolute increases in work-rate, while all constant-work trial studies based their intensity on cardiopulmonary parameters. The majority of the studies using constant-duration tests lasted between 11–30 minutes. Two studies included a protocol lasting one hour, and one study included a two-hour protocol. The shortest protocol among the studies included a 5-minute test.

Table 4. Methodological characteristics of included articles

Characteristic	Number	Percentage*
Exercise protocol		
Constant-work	6	24%
Submaximal GXT	10	40%
Maximal GXT	9	36%
Exercise intensity determination		
Used absolute WR	13	52%
Used WR relative to HR	1	4%
Used WR relative to $\dot{V}O_2$	6	24%
Used WR relative to V_E	1	4%
Used WR relative to VT	2	8%
Used WR relative to PPO	1	4%
Exercise length (min)		
1–5	1	4%
6–10	2	8%
11-20	5	20%
21–30	4	16%
> 31	4	16%
Until exhaustion	9	36%

Notes: $N = 25$; GXT = graded exercise test; WR = work-rates; HR = heart rate; $\dot{V}O_2$ = oxygen uptake; V_E = ventilation; VT = ventilatory threshold; PPO = peak power output; *averaged numbers

Reported Challenges and Limitations

Several studies did not include a limitation section or study limitations in general; only three of the studies clearly stated their limitations (Cerretelli et al., 1977; Leicht et al., 2008; Sousa et al., 2017). The most frequent concern reported was related to the correct estimation of exercise efficiency during AC (Ahlborg et al., 1986; Bevegård et al., 1966; Cerny & Ucer, 2004; Leicht et al., 2008; Marais et al., 2002; Shephard et al., 1989), and this was frequently attributed to issues relating to accounting for unmeasured work. Discrepancies in crank and pedal rates was a challenge reported in some studies attempting to compare their results to the available literature (Dekerle et al., 2002; Marais et al., 2002). Souza et al. (2017) reported that not including a retest in their protocol could have limited the confidence in the model to estimate the oxygen uptake kinetics. Not including muscle biopsies was another limitation reported. Lastly, differences in muscle fiber type composition or phenotype of the arm and legs were pointed as a potential reason for inconsistent results by many of the studies included (Ahlborg et al., 1986; Dekerle et al., 2002; Kang, 2004; Leicht et al., 2008; Nikolic & Todorovic, 1984; Shephard et al., 1989).

Discussion

In this scoping review of the literature, an overview of the published literature comparing the cardiopulmonary responses between AC and LC at submaximal exercise intensities was presented, and recommendations for future research in this area can now be considered. This review does not include longitudinal training responses to these exercise modalities or any of the results reported in the clinical population literature. The overview of the cardiovascular, ventilatory, pulmonary, and metabolic gas exchange variables have been included herein under different subsections to provide a discernible frame of reference. Table 5 summarizes cardiopulmonary responses between AC and LC.

Table 5. Overall cardiopulmonary responses to arm and leg cycling at relative intensities

Variables	Moderate work-rates		Heavy work-rates	
	Arm cycling	Leg cycling	Arm cycling	Leg cycling
HR	+ +	+ +	+ + ·	+ + ·
V_T	+ +	+ + ·	+ + ·	+ + + ·
f_R	+ +	+ +	+ + +	+ + +
V_E	+ + +	+ + +	+ + + + ·	+ + + + + ·
$\dot{V}O_2$	+ + + ·	+ + + + ·	+ + + + + ·	+ + + + + + +
$\dot{V}CO_2$	+ + + ·	+ + + + ·	+ + + + + ·	+ + + + + + + ·

Notes: + one-fold increase from resting values; · half-fold increase from resting values.HR = heart rate; V_T = tidal volume; f_R = respiratory rate/frequency; V_E = ventilation; $\dot{V}O_2$ = oxygen uptake; $\dot{V}CO_2$ = carbon dioxide output.

Overview of the cardiovascular responses

At the same absolute work-rates, AC generally results in increased HR responses compared to LC. For work rates of 98 W (Sawka et al., 1982) and 100 W (Vokac et al., 1975), HR responses were higher for AC but similar at a lower work rate (50 W) in a group of non-competitive cross-country skiers (Vokac et al., 1975). For AC exercises performed at a lower work rate than LC, HR and blood pressure were also higher (Miles et al., 1983). However, when using work rates three times lower for AC than LC, Ahlborg and Jensen-Urstad (1987) reported similar HR during submaximal graded exercise tests lasting 30 minutes. In another study, while also testing physically active individuals, outputs of 65 W produced significantly higher HR for AC when compared to 80 W during LC during seven minutes of exercise (Bevegård et al., 1966).

For exercises performed at the same absolute oxygen uptake, HR responses are also greater during AC than LC (Pimental et al., 1984). These widely reported augmented HR responses during AC reflect the greater intensity of contraction exerted by a smaller skeletal muscle mass in achieving the same work rate performed by a larger muscle group (Ahlborg et al., 1986; Borg et al., 1987). Since there is a strong association between HR and systemic metabolic demand, these differences seem to be attenuated in upper-body trained individuals (Vokac et al., 1975).

When exercising at the same HR (50 and 65% of HR max obtained from a maximal treadmill test), the parasympathetic autonomic function of the heart, as measured by heart rate variability, was significantly greater during AC in comparison to LC (Leicht et al., 2008). The authors considered this increased HRV response to reflect a greater vagal response, or less likely, simultaneous autonomic activation of the sympathetic and parasympathetic branches of the heart compared to LC. However, the mechanism to achieve the same cardiac output differs between AC and LC, and a lower stroke volume likely resulted in a decreased exercise intensity even though HR was matched (Miles et al., 1989). This reduced stroke volume is widely reported in AC literature and is typically evidenced by an increased HR/$\dot{V}O_2$ slope obtained from GXT (Bevegård et al., 1966; Freyschuss, 1975).

Given that a comparison between AC and LC using absolute work-rates does not take into consideration the specific aerobic power of different muscle groups, Ahlborg et al. (1986) reported a higher HR response at 40, 90, and 120 minutes during a prolonged exercise lasting two hours performed at 30% of $\dot{V}O_2$ peak. Results showed that HR during arm cycling was 25–40% higher than LC, and this difference was attributed to a fivefold increase in lactate levels in AC reported within the first 20 minutes of exercise. The hyperlactemia state described, and the accompanying increase in systemic metabolism and HR, were attributed to a deficit in lactate clearance by the liver, as the authors indicated an increased lactate delivery to the splanchnic bed (Ahlborg et al., 1986). Conversely, Pimental et al. (1984) reported lower HR responses during 60 minutes of AC exercise performed at 60% of mode-specific $\dot{V}O_2$ peak while also reporting a peak in lactate responses at 20 minutes of exercise for both modalities. The disagreement in these findings is most likely related to the different exercise intensities between the two studies (30 vs. 60% of mode-specific $\dot{V}O_2$ peak).

In a different study, Kang et al. (1997) compared several mode-specific work-rates between 50 and 90% $\dot{V}O_2$ peak. At these relative intensities, HR responses were lower during AC exercise in a sample of healthy males. For several exercise intensities based on PPO (20–80% of PPO max), Marais et al. (2002), using a discontinuous GXT, showed similar responses during AC. Similarly, Dekerle et al. (2002) showed marginally lower but not significantly different HR responses obtained at the VT and respiratory compensation point (RCP).

Overview of the ventilatory responses

The study of the altered breathing patterns resulting from upper body exercise has been critical to explain some of the main differences between exercises performed with the arms and legs (Astrand et al., 1968; Cerny & Ucer, 2004; Martin et al., 1991; Paek & Mccool, 1992; Sawka, 1986). Among these, the marked intensification in rates of perceived exertion has been hypothesized to result from an increased work of breathing (Borg et al., 1987; Cerny & Ucer, 2004; Leicht et al., 2008). In fact, during AC, entrainment of breathing with pedaling frequency has been reported to dictate breathing responses (Paek & Mccool, 1992; Tiller, Price, et al., 2017a; Vokac et al., 1975). The higher demand for breathing muscles to perform respiration and actively contribute to task performance has been deemed to increase energy cost and decrease efficiency during AC at heavier intensities (Cerny & Ucer, 2004; Tiller et al., 2019; Vokac et al., 1975).

In concordance to cardiovascular responses, the same absolute work-rates produce excessive ventilation during AC than LC (Bevegård et al., 1966; Sawka et al., 1982; Vokac et al., 1975). Interestingly, this hyperventilation experienced during AC has been suggested to enhance ventricular filling in the absence of an antigravitational leg pump as excessive ventilation increases venous tone (Bevegård et al., 1966). However, at mode-specific VT, differences are inverted, and ventilatory responses are less pronounced during AC (Nikolic & Todorovic, 1984; Shephard et al., 1989). This response is supported by the much lower work rate required by the arms at VT. Likewise, women typically have lower ventilatory responses when compared to men. Nevertheless, these differences tend to disappear after dividing ventilation by work rate or relative to body mass (Nikolic & Todorovic, 1984; Shephard et al., 1989).

At a similar ventilatory demand, inspiratory and expiratory duration is shorter during AC (Alison et al., 1998; Cerny & Ucer, 2004). Limited by upper body stabilization, a compensatory increase in breathing frequency has been shown by the restricted rib cage expansion (Cerny & Ucer, 2004; Tiller et al., 2019). This breathing pattern is counterproductive for optimal pulmonary gas exchange as less oxygen reaches the lungs (Martin et al., 1991). Therefore, it is plausible that more significant “anaerobic” responses reported during AC may be caused by alterations in pulmonary ventilation patterns that result in insufficient oxygen diffusion (Martin et al., 1991).

Overview of the metabolic and pulmonary gas exchange responses

Oxygen uptake is the most reported parameter in studies comparing submaximal cardiopulmonary responses between arm and leg cycling. Gas exchange is thought to equate cellular metabolism and chemical to mechanical energy conversion, making it a practicable gauge of metabolism resulting from physical activity. Many factors can influence oxygen extraction at the tissue level, and these interactions pose the most significant challenge in the interpretation of pulmonary gas exchange responses during AC and LC (Sawka, 1986).

In a recent meta-analysis, Larsen et al. (2016) showed that AC responses to maximal cardiopulmonary tests are predictably 70% of those achieved during LC. Still, the differences between the two modalities were reported to decrease in less active populations since the upper body is generally less fit than the lower body. This may also be true in individuals with improved upper limb fitness. In this case, a reduced mode-specific fitness difference (i.e., LC – AC $\dot{V}O_2$ peak), due to training the upper body, reduces the difference between AC and LC maximal oxygen uptake (Vrijens et al., 1975). Moreover, Vrijens et al. (1975) showed an increased upper body fitness status impacted exercise performance at submaximal intensities. During AC and LC exercises performed at 100 W, a greater efficiency was shown during AC for upper body-trained individuals compared to a control group that did not perform AC training. Curiously, the control group had better performance for LC than the “trained” group, further supporting the need to weigh the mode-specific fitness concept when comparing exercises of different modes, even among so-called trained individuals.

In trained and untrained populations, and for exercises performed at the same mode-specific intensity relative to peak values, AC $\dot{V}O_2$ responses are typically lower than LC (Cerny & Ucer, 2004; Jensen-Urstad & Ahlborg, 1992; Kang et al., 1997; Leicht et al., 2008; Marais et al., 2002). From the studies included in this scoping review, only Ahlborg and Jensen-Urstad (1986) reported similar V̇O2 responses between AC and LC performed at the same relative intensity (30% of $\dot{V}O_2$ peak).

In a follow-up study, Jensen-Urstad and Ahlborg (1992) tested a group of upper-body trained individuals during AC and LC. In this group, the $\dot{V}O_2$ responses were almost two-fold higher for LC than AC at 30, 50, and 80% of mode-specific $\dot{V}O_2$ peak. It is worth noting that these individuals also had excellent cardiorespiratory fitness for LC (LC $\dot{V}O_2$ peak = 51.7 ± 2.7 mL·min^{-1}·kg^{-1}; ACSM, 2020). Consequently, their mode-specific fitness status difference (i.e., LC – AC $\dot{V}O_2$ peak) was more prominent at 29% than those observed by Vrijens et al. (1975), which reported a smaller gap between modes (11%). Jensen-Urstad and Ahlborg (1992) also reported a higher rate of lactate formation during AC and suggested that aerobic metabolism differences between modes may be due to circulatory adjustments potentially unrelated to training status.

Cerretelli et al. (1977) showed a slower adjustment of $\dot{V}O_2$ kinetics (i.e., plateau) at the onset of AC exercise compared to LC, which was evidenced even at lower work-rates. The authors considered this delayed stabilization as a possible indication of a greater reliance on anaerobic sources during AC. In contrast to Jensen-Urstad and Ahlborg (1992), the authors attributed this difference to the arm muscles' characteristically untrained condition. These findings were later confirmed by Schneider et al. (2002), with a significant increase in the slow component of $\dot{V}O_2$ during AC. The authors further suggested that these responses could be due to the early recruitment of type II fibers during AC compared to LC. It is important to note that in this cohort of participants, the difference between LC to AC $\dot{V}O_2$ peak was 33%. As adaptive responses are specific to movement patterns typically executed, AC exercise results in a lower oxidative potential than the lower body (Dekerle et al., 2002). Similarly, Sousa et al. (2017) confirmed slower $\dot{V}O_2$ on-kinetics for AC than LC in a group of highly trained triathletes. Although participants in this study were considered highly trained in their upper body, LC to AC $\dot{V}O_2$ peak difference was 30%, indicating a greater lower body fitness in relation to the upper body. Nonetheless, this raises an important and unexplored question relating to the maximum aerobic capacity that may be achieved in AC in healthy individuals and how this could affect mode-specific differences.

A few studies have compared the mechanical efficiency between arm and leg cycling (Davies & Sargeant, 1974; Kang et al., 1997; Marais et al., 2002; Vokac et al., 1975), while no studies have considered upper and lower body fitness status or physical activity level. Much of the research pertaining to metabolic efficiency between the two modes is equivocal. Early studies established that absolute submaximal work rates (i.e., 100 and 150W) resulted in lower net efficiency for AC, with this difference being lessened at lower work rates (i.e., < 75 W; Pivarnik et al., 1988; Vokac et al., 1975).

Meanwhile, Kang et al. (1997) normalized work rates in relation to $\dot{V}O_2$ peak intensities and showed a similar gross and net efficiency for AC compared to LC at ranges from 50–90% of $\dot{V}O_2$ peak. Conversely, Marais et al. (2002) showed a lower gross and work efficiency for exercises based on the PPO (40–80%), in which work efficiency was similar between modes at low work rates of 20% of PPO. The latter study also showed a similar delta efficiency in accordance with previous findings from Kang et al. (1997).

Despite the usefulness of mechanical efficiency calculations in determining metabolic enhancement, the precise amount of measured and unmeasured oxygen uptake between upper and lower body skeletal muscles is still unknown. Systemic-to-local factors such as blood flow regulation and capillary density, muscle size and the number of muscles involved, fiber type composition and motor unit recruitment patterns, substrate metabolism and mitochondrial function, could all influence, at least to some degree, the relationship between work ratio and oxygen consumption (Ahlborg & Jensen-Urstad, 1991; Sawka, 1986). Additionally, the different body positions when performing AC and LC could well affect blood perfusion pressure as gravitational forces are not the same (Astrand et al., 1968; Cerretelli et al., 1977).

As circulatory, metabolic, and mechanical factors can widely impact individuals and modes even at relative intensities based on maximal responses during AC and LC, additional physiological markers have also been studied (Davis et al., 1976; Dekerle et al., 2002; Nikolic & Todorovic, 1984; Shephard et al., 1989). For this purpose, the relationship between changes in pulmonary gas exchange (i.e., ventilatory threshold) and metabolism (i.e., lactate threshold) have been widely considered as a sensitive marker to differentiate between intensity domains (Davis et al., 1976; Poole et al., 2021). The first study to examine the VT placement between AC and LC reported lower relative placement during AC. Daily activity patterns and familiarity with LC and the fatigability of smaller muscles of the forearm with the accompanying additional stabilization of the trunk muscles were hypothesized to affect the lower relative placement of VT during AC (Davis et al., 1976). However, when comparing the responses of eight males and eight females during AC and LC trials performed in normoxic and hypoxic environments, Shephard et al. (1989) showed no significant differences in the VT placement. Furthermore, in a more recent study, no differences were found between modes for the VT and the respiratory compensation point, presented as the second ventilatory threshold by Dekerle et al. (2002). Furthermore, the lack of relationship between the thresholds obtained from AC and LC showed in this study corroborates the notion that neither VT nor RCP should be interchangeably extrapolated from exercises or different modes (Dekerle et al., 2002).

Only a few research groups have compared submaximal constant workload AC and LC based on VT placement (Schneider et al., 2002a; Sousa et al., 2017). Schneider et al. (2002) tested a group of untrained males at Δ50% between the VT and the mode-specific $\dot{V}O_2$ peak, while Sousa et al. (2017) tested a group of male athletes and used workloads equivalent to Δ25% above VT. Interestingly, both studies examined the kinetics of oxygen uptake between AC and LC exercises. The main justification for selecting workloads based on the VT placement was to account for potential mode-specific metabolic differences when estimating exercise intensities.

Conclusions

This scoping review described and summarized the published literature on the cardiopulmonary responses to AC and LC performed at submaximal exercise intensities. There seems to be a general consensus that muscle groups involved in AC are smaller and less trained than those involved in LC. Consequently, AC responses have been reported as lower than LC at intensities expressed relative to body mass. However, the magnitude of these differences has not been fully explored as only a few studies have included body composition assessments as part of their design. Studies including criterion methods to estimate differences relating to active skeletal muscle mass are still needed in order to quantify these differences.

Furthermore, the difference in fitness status between AC and LC seems to play an essential role in the cardiopulmonary responses during submaximal exercise. Fitness status has been shown to play a role in this interaction during maximal exercise responses. Therefore, future studies should consider this factor when comparing AC and LC. Moreover, alterations in breathing patterns are widely reported between AC and LC; however, little is known about the impact of AC breathing patterns on the acquisition and validity of fatigue thresholds. Lastly, as AC and LC's exercise intensity domain boundaries may be highly variable among individuals, future studies should prioritize work-rates based on the mode-specific ventilatory thresholds over mode-specific $\dot{V}O_2$ peak.

CHAPTER THREE: METHODS

Participants

Fifty-five low to highly active participants enrolled in this study, which recruited adults 18–44 years old with clearance to exercise as determined by screening questionnaires. All participants signed the provided written informed consent before completing the medical health history and the International physical activity Questionnaire (IPAQ) to determine eligibility and physical activity level. For the later, participants were interviewed in person (i.e., telephone administered version) using the long version (i.e., usual) of the questionnaire (Craig et al., 2003; Wanner et al., 2016).

Exclusion criteria included individuals with a pacemaker, limb amputation, or any contraindication for maximal and submaximal exercise testing (see Fletcher et al., 2013 for a comprehensive list of relative and absolute contraindications). Obese individuals, as determined by a BMI greater than 30 $kg \cdot m^{-2}$, were referred to a physician to receive medical clearance prior to participating. A flow diagram of the progress through recruitment, allocation, and analysis phases of this study are shown in Figure 2 (Moher et al., 2001). A participation rate of 78% is reported for this study. Participants used during the pilot study were excluded from this calculation. The characteristics of the participants that concluded all visits in this investigation are listed in Table 6.

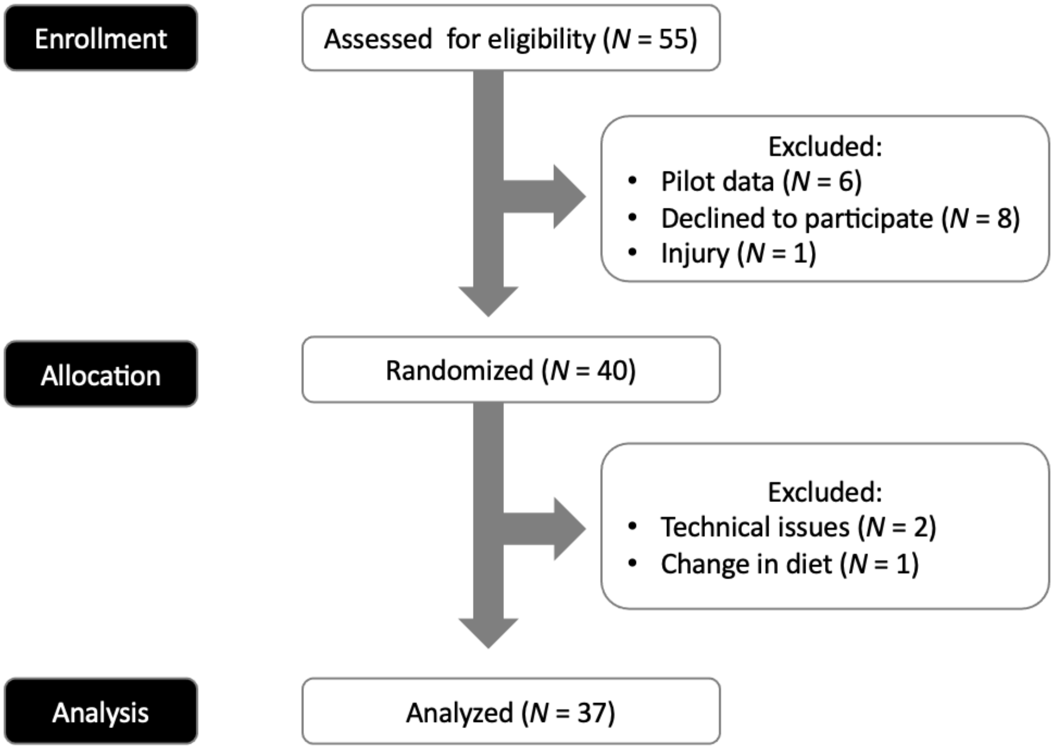


Figure 2. Flow diagram of study participants

Experimental Design

Participants completed a total of eight visits to the Physiology of Work and Exercise Response Laboratory in this randomized, repeated measures study (Figure 3). The study was divided into two blocks with four visits each. The first block consisted of (visit 1) to obtain consent, medical history, and physical activity information as measured by the IPAQ, (visit 2) to measure body composition and familiarize participants with procedures and instrumentation, and (visit 3 & 4) randomized and counterbalanced cardiopulmonary exercise tests for arm cycling (AC and leg cycling (LC) using maximal ramp protocols to estimate the work rate at ventilatory thresholds, peak power output (PPO), and mode-specific peak oxygen uptake ($\dot{V}O_2$ peak). In the second block, randomized and counterbalanced submaximal cardiopulmonary exercise tests using constant work rate and isocaloric protocols were completed (visits 5–8). Before each testing visit, participants received automated text messages with pretesting procedures, also described during the informed consent visit, which were delivered at 24 and 2 hours from testing start time. In these messages, they were reminded to (a) attempt a similar eating and sleeping routine before each test, (b) refrain from exercise for 24 hours, and (c) avoid large meals 3–2-hours before testing. The purpose of these reminders was to increase study protocol compliance. Visits were scheduled for about the same time of the day with the exception of body composition, which was primarily scheduled in the morning.

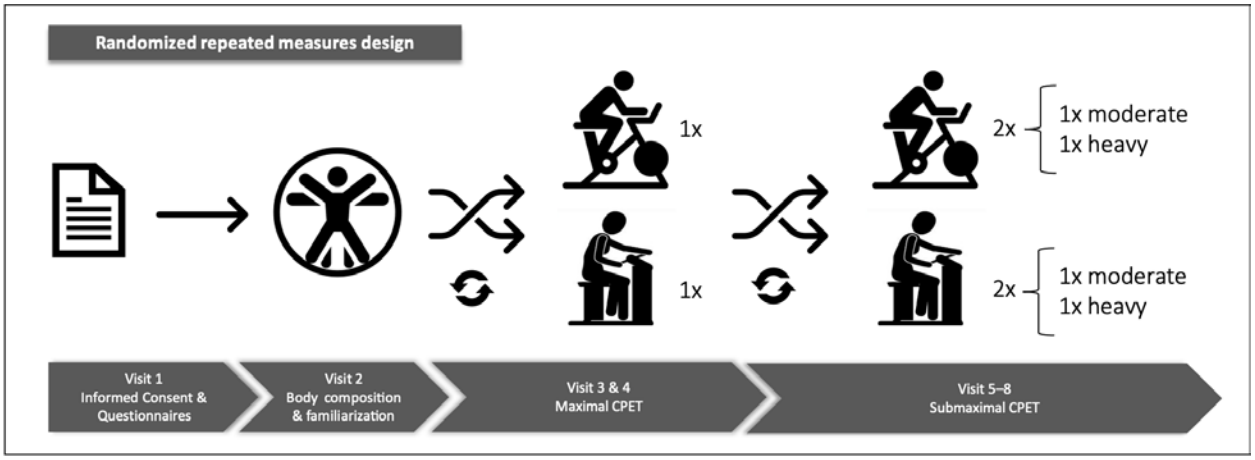


Figure 3. Experimental design

Body Composition Measurements

Participants arrived at the lab for visit two ensuing a minimum of 4-hour fasting period, except for water. Hydration status was tested using the urine-specific gravity method (Human Urine Refractometer, MISCO Refractometer, Cleveland, OH, USA) with a sample provided by the participant. To be considered adequately hydrated, the specific gravity of the urine had to be less than or equal to 1.02. When dehydrated, participants were asked to drink 500 ml of water prior to continuing testing. They were not retested for hydration status. Height was then measured using a stadiometer (500KL Health O Meter, Alsip, IL, USA) following standardized procedures (Haff & Dumke, 2019). Body mass was assessed with the air displacement plethysmography device's built-in scale (Bod Pod, Life Measurement Instruments, Concord, CA), which was subsequently used to assess fat mass (FM), body fat mass percentage (% BF), and fat-free mass (FFM). Participants were categorized into two groups: lean and average (LA) and overfat and obese (OFO). The sample was split by the Fat Mass Index (FMI) equivalent to 5.1 kg $FM \cdot m^{-2}$ for males and 8.2 kg $FM \cdot m^{-2}$ for females (Schutz et al., 2002).

Ergometers

Arm cycling (AC) tests were performed on an arm ergometer (Brachumera Sport, Lode, The Netherlands), and leg cycling (LC) tests were performed on a leg ergometer (Corival CPET, Lode, The Netherlands). The arm ergometer was mounted on a stand and positioned so that the participant's scapula-humeral joint was leveled with the highest end of the crank pedal position. Participants were instructed to sit upright on a chair and to minimize torso rotation while placing primary attention to performing the exercise using the arms. For LC, the participants' seat height was adjusted to ensure a slight bend of the knee at the lowest position of the pedal, while toeclips were adjusted according to the participant's preference. Participants with a BMI greater than 35 kg·m^2 performed leg cycling tests using an oversized bike seat in an attempt to reduce discomfort, while all of the other participants completed the tests on the standard ergometer bike seat. Adjustable settings were matched for both ergometers and for each trial. Cadences for arm and leg cycling tests were limited to 70–80 rpm, with participants having visual access to the cadence displayed on a screen while receiving verbal feedback from the evaluator when out of the designated range (Tiller et al., 2019). These electromagnetically braked ergometers allowed pedaling at a constant power output (PO) and were controlled by external software to ensure well-timed work rate increments during testing (OMNIA Metabolic software, Cosmed, Rome, Italy).

Measurement of Cardiopulmonary Parameters

Heart rate (HR) was measured throughout cardiopulmonary exercise testing using a chest strap monitor (H10, Polar, USA). Participants breathed through a facemask (Hans Rudolph, Inc., Shawnee, KS, USA) attached over their nose and mouth, which was securely tightened using the manufacturer-provided headgear and checked for leakage by feeling for air around the mask (Wagner & Clark, 2016). The metabolic system (K-5, Cosmed, Rome, Italy) was warmed up before each test to ensure accurate spiroergometric measurements. Calibrations were performed per manufacturer recommendation in the following order: (1) flowmeter calibration using a 3- liter syringe, (2) scrubber calibration using the external CO2 cartridge, (3) gas calibration and delay calibration using a known mixture of gases (16% O_2, 5% CO_2, and Bal N_2). Metabolic gas exchange measurements for $\dot{V}O_2$, carbon dioxide output ($\dot{V}CO_2$), and respiratory exchange ratio (RER) as well as ventilatory measurements for minute ventilation ($\dot{V}E$), respiratory frequency (f_R), tidal volume (V_T), were continuously measured using the breath-by-breath mode.

Maximal Incremental Protocols

The maximal incremental protocols were performed in visits three and four and consisted of an unloaded start with continuous increases in the work-rate in a ramp-like fashion. The arm cycling test increased one W every four seconds (15 W per minute) for males and one W every six seconds (10 W every minute) for females. Similarly, the lower body protocol had 35 W increases every minute for males and 30 W increases every minute for females. Participants were instructed and encouraged to exercise until volitional fatigue, which was identified as cadence dropping below 65 rpm for more than 5 seconds despite verbal encouragement. Maximal effort and mode-specific $\dot{V}O_2$ peak were confirmed if two of the following four criteria were met: (a) a $\dot{V}O_2$ plateau, (b) heart rate within 10 bpm of maximal predicted heart rate, (c) respiratory exchange ratio (RER) above 1.1, (d) and/or rate of perceived exertion (RPE) of 8.5 or above on a 10 point RPE scale (Beltz et al., 2016; Haff & Dumke, 2019). Maximal effort was confirmed in all of the tests. The peak power output (PPO) achieved was recorded, and the $\dot{V}O_2$ peak values were reported as the highest 30-s average (Beltz et al., 2016). The time to ventilatory threshold (VT), and RCP, and associated work-rates, were identified by the use of the software's built-in algorithm and confirmed by visual inspection of the following plots: (a) V-slope method, (b) ventilatory equivalents method (VEQ) of $\dot{V}O_2$ and $\dot{V}CO_2$, and (c) end-tidal pressure of O_2 and CO_2 method (P_{ET}). From a simultaneous analysis of the plots, the first departures from linearity for VEQ of $\dot{V}O_2$ without changes in VEQ of CO_2 along with the nadir of $P_{ET}O_2$ without changes in $P_{ET}CO_2$ were determined as the VT, which was further confirmed by the gas exchange threshold method V-slope, where there is a break in the linearity between $\dot{V}CO_2$ and $\dot{V}O_2$ (Beaver et al., 1986; Wasserman et al., 1973). The RCP was determined as the point at which a second break in linearity for VEQ of $\dot{V}O_2$ and a first break in VEQ of CO_2 were presented simultaneously to a drop in $P_{ET}CO_2$. This combined analysis method has been most recently refined and validated by Gaskill et al. (2001). Five AC tests did not manifest an isocapnic buffering region (i.e., a drop in $P_{ET}CO_2$) between VT and RCP, and one LC test did not present a clear break in linearity for VEQ of CO_2 (Davis et al., 1976; Poole et al., 2021; Wasserman & Whipp, 1975). Due to limited knowledge on the validation of VT during arm cycling not presenting an isocapnic buffering region, these data were included in the final analyses and used to determine isocaloric session intensities.

Constant Work Rate Isocaloric Protocols

Participants were scheduled to visit the laboratory to complete four constant work rate isocaloric protocols (visits 5–8) performed at two different exercise intensities for AC and LC as determined from VT assessment obtained from maximal incremental protocols. MODERATE and HEAVY intensities were determined as 80% percent of the work-rate associated with the VT (Fornasiero et al., 2018), and the work-rate equivalent to 30% of the difference between VT and the PPO achieved during the maximal incremental protocol (Tiller, Campbell, et al., 2017), respectively. Before the beginning of each trial, resting data were collected for cardiopulmonary variables while participants were seated for about 10-15 minutes. Resting values were averaged for the last five minutes with the final 30 seconds removed. Participants completed a three-minute warm-up at 30% of the work-rate intended for the session. All tests were performed at the determined intensity until participants reached a total energy expenditure of 100 kcal resulting from the exercise. Energy expenditure was calculated in breath-by-breath mode by the metabolic software using the manufacturer's equation considering ureic nitrogen equal to zero (EE (kcal· min^{-1}) = 3.781 x $\dot{V}O_2$ + 1.237 x $\dot{V}CO_2$) (Campbell et al., 2002). Thirty-second averages were recorded, and tests were ended when participants reached 100 kcal. The duration of each test was recorded as the time to complete 100 kcals (Tkcal_{100}). At the end of the exercise, participants were asked to rate the exercise session using the 10-point rating of perceived exertion scale (RPE) at the end of the test, which they had been previously familiarized with (Borg, 1970, 1982; Noble et al., 1983).

Sample Size Estimates

A priori sample size power calculations using G*Power software (Version 3.1, Düsseldorf, Germany; Faul et al., 2007) for repeated measures ANOVA, within-between interaction including Tkcal_{100} values based upon pilot data obtained from isocaloric trials were calculated to achieve a statistical power (1-β) of 0.80 (Beck, 2013). As a result, a minimum of 15 participants was calculated based on an effect size f(V) of 0.899 for a main effect for exercise mode. Therefore, a total sample size of 30 participants was estimated for both groups (i.e., lean and average and over fat and obese).

Statistical Analyses

All analyses were conducted with an open-source statistical analysis software program (JASP; version 0.14.1). Estimation graphics using Cumming plots and the difference axis to display the effect size were also used (Ho et al., 2019). Results were analyzed according to participant's FMI. Descriptive statistics were obtained on study parameters and reported as mean and standard deviation and mean and standard error for marginal means resulting from the main effects. Alpha level was set a priori at $p \leq 0.05$, whereas a trend was noted if $p \leq 0.06$. Data were assessed for homogeneity of variance across groups with Levene's test.

A two-way mixed factorial ANCOVA [group (LA vs. OFO) x mode (AC vs. LC)] with IPAQ as a covariate determined participants' physiological responses to maximal ramp protocol, including $\dot{V}O_2$, PPO, VT, and RCP. A three-way mixed factorial ANCOVA [group (LA vs. OFO) x mode (AC vs. LC) x intensity (MODERATE vs. HEAVY)] with the mode-specific fitness difference and IPAQ as covariates were run for the cardiopulmonary outcomes for baseline and each trial. Main outcomes of interest included Tkcal_{100}, RPE, $\dot{V}O2$, RER, V_E , V_t, f_R, HR. Holm *post-hoc* analysis were used to evaluate the dependent variables. Cohen's d was calculated for all comparisons and interpreted with magnitude thresholds of 0–0.2, 0.2–0.6, 0.6–1.2,1.2–2.0, and >2.0 as trivial, small, moderate, large, and very large, respectively (Hopkins et al., 2009).

CHAPTER FOUR: RESULTS

Participants physical and behavioral characteristics

Participants included 37 adults: 20 female and 17 males. Of these, 43% identified their ethnicity as Caucasian, 24% as African descendant, 24% as Hispanic, and 9% as Southeast Asian. The physical and behavioral characteristics of participants are listed in Table 6. There were very large differences for fat mass index (FMI; p < 0.01, *d* = -2.15) between lean and average (LA; 4.6 ± 1.7 FM $kg \cdot m^{-2}$) and overfat and obese (OFO; 9.9 ± 3.5 FM $kg \cdot m^{-2}$) groups. Moreover, large differences in percent body fat (%BF; $p < 0.01$, $d = 1.96$), body mass index (BMI; $p < 0.01$, $d = 1.63$), and body mass (BM; $p < 0.01$, $d = 1.29$) were also noted. There were no significant differences in age, height, fat-free mass (FFM), and physical activity levels between groups ($p > 0.05$).

Table 6. Participant's characteristics

	Lean & Average ($N = 24$)	Overfat & Obese ($N = 13$)
Age (y)	23.5 ± 4.8	23.5 ± 2.9
Height (cm)	168.9 ± 7.1	169.3 ± 10.2
Body mass (kg)	67.0 ± 9.4	85.2 ± 20.4 [a]
Fat-Free Mass (kg)	54.1 ± 10.1	57.1 ± 13.7
BMI ($kg \cdot m^{-2}$)	23.5 ± 2.4	29.6 ± 5.5[a]
BF (%)	19.5 ± 6.8	32.8 ± 6.9 [a]
IPAQ ($METs \cdot min^{-1} \cdot week^{-1}$)	4372 ± 2249	3797 ± 2012

Notes: FMI = fat mass index; BMI = body mass index; BF = body fat; IPAQ = International Physical Activity Questionnaire; METs = metabolic equivalents; Values are represented in $M \pm SD$; [a]significantly different than the Lean & Average group ($p \leq 0.05$).

Cardiopulmonary Responses to Maximal Incremental Protocols

The cardiopulmonary responses to the maximal incremental protocols for arm cycling and leg cycling are presented in Table 7. Arm cycling averaged 76% of LC absolute maximal oxygen uptake ($\dot{V}O_2$ peak) for the LA group and 88% for the OFO group.

A significant interaction was observed for absolute $\dot{V}O_2$ peak between mode and group ($p < 0.01$). *Post-hoc* analysis showed no significant differences between LA group and OFO group for AC tests ($p = 0.87$, $d = 0.06$), or LC tests ($p = 0.12$, $d = 0.73$). Furthermore, for $\dot{V}O_2$ peak expressed in terms relative to body mass, significant interactions between mode and group ($p < 0.01$) were found and *post-hoc* analysis revealed significantly lower values for the OFO group within the same mode compared to the LA group (AC: $p = 0.02$, $d = 1.09$; LC: $p < 0.01$, $d = 1.79$) and no difference between

AC performed by the LA group and LC performed by the OFO group O ($p = 0.24$). However, when expressed in terms of fat free mass (FFM), mode differences for $\dot{V}O_2$ peak were only present for LC ($p < 0.01$, $d = 1.11$; AC: $p = 0.46$, $d = 0.36$).

For peak power output (PPO), asignificant interaction between mode and group was revealed ($p = 0.03$). *Post-hoc* analysis indicated significant differences between the LA group and the OFO group for LC tests ($p = 0.04$, $d = 0.76$), whereas non-significant and trivial effect sizes were shown between groups during AC tests ($p > 0.05$, $d = 0.29$).

There were no interactions between mode and group for the placement of the ventilatory threshold (VT) expressed as a percentage of PPO. However, significantly different main effects between exercise modes ($p < 0.01$) and between groups ($p = 0.04$) were observed. *Post-hoc* analysis showed that differences between AC and LC were moderate ($p < 0.01$; $d = -0.59$; AC: 37.2 ± 1.7%, LC: 43.7 ± 1.7%), while the differences between LA group and OFO group were small ($p = 0.04$; $d = 0.37$; LA: 43.4 ± 1.9%, OFO: 37.6 ± 1.9%). Also, a main effect for the respiratory compensation point (RCP) showed significantly different values between AC and LC ($p < 0.01$; $d = -0.53$; AC: 69.3 ± 1.8%, LC: 76.6 ± 1.8%), but no other interactions or main effects were presented ($p > 0.05$). Five AC tests were removed from the analysis for VT and one LC for RCP.

Table 7. Participant's responses to maximal ramp protocol

Variables	Lean & Average ($N = 24$)	Over fat & Obese ($N = 13$)

Arm cycling		
$\dot{V}O_2$ ($L \cdot min^{-1}$)	1.983 ± 0.521	1.952 ± 0.518
$\dot{V}O_2$ ($mL \cdot min^{-1} \cdot kg^{-1}$)	29.5 ± 5.9	23.3 ± 5.3[a]
$\dot{V}O_2$ ($mL \cdot min^{-1} \cdot kg^{-1}FFM$)	36.5 ± 6.0	34.4 ± 5.6
PPO (W)	136.6 ± 34.5	110.3 ± 29.6
Leg cycling		
$\dot{V}O_2$ ($L \cdot min^{-1}$)	2.611 ± 0.591	2.223 ± 0.408
$\dot{V}O_2$ ($mL \cdot min^{-1} \cdot kg^{-1}$)	39.0 ± 7.2	26.9 ± 5.6[a]
$\dot{V}O_2$ ($mL \cdot min^{-1} \cdot kg^{-1}FFM$)	48.4 ± 7.5	40.1 ± 7.5[a]
PPO (W)	257.1 ± 41.6	216.5 ± 41.3[a]

Notes: $\dot{V}O_2$ = oxygen uptake rate; PPO = peak power output; Values are represented in *M* ± *SD*; [a] significantly lower than Lean & Average group at corresponding exercise mode ($p \leq 0.05$).

Cardiopulmonary Responses to Constant Work Rate Isocaloric Protocols

Table 8 displays the cardiopulmonary responses to the constant work rate isocaloric protocols performed at HEAVY and MODERATE exercise intensities for AC and LC. Baseline values for $\dot{V}O_2$ and RER measured at rest were not significantly different within conditions and between groups ($p > 0.05$). All isocaloric trials were completed until ≈ 100 Kcal ($p > 0.05$; AC, HEAVY: 100.0 ± 0.3 Kcal; AC, MODERATE: 100.5 ± 0.3 kcal; LC, HEAVY: 100.5 ± 0.3 Kcal; LC, MODERATE: 100.9 ± 0.3 Kcal). A significant interaction between exercise mode and intensity was shown for work rates used during the isocaloric trials ($p < 0.01$). With the exception of AC at HEAVY not being statistically different compared to LC at MODERATE ($p > 0.05$; $d = -0.231$), LC work-rates were greater than AC overall (MODERATE: $p < 0.01$, $d = 1.62$; HEAVY: $p < 0.01$, $d = 2.71$). The percentage of PPO for AC and LC performed at MODERATE and HEAVY are shown in Figure 4. A significant main effect was also shown between groups ($p = 0.01$). *Post-hoc* analysis revealed that work rates used for the OFO group were lower than those used for the LA group ($p = 0.01$, $d = -0.45$).

No significant interaction were observed for exercise mode, intensity, or group for the time to complete 100 kcal ($Tkcal_{100}$) between tests ($p > 0.05$). A trend was shown for an interaction between mode and group ($p = 0.053$; Figure 5). Exploratory *post-hoc* analysis showed a decreased $Tkcal_{100}$ for the LA group compared to the OFO group during AC ($p = 0.03$, $d = -0.35$) but potentially similar values during LC ($p = 0.42$ $d = -0.29$). A significant main effects for group ($p = 0.04$), intensity ($p < 0.01$), and mode ($p = 0.04$) was shown. *Post-hoc* analysis confirmed that $Tkcal_{100}$ was increased for OFO group ($p = 0.04$, $d = 0.36$), faster trials were evident during HEAVY compared to MODERATE exercise intensities ($p < 0.01$; $d = 2.90$), and longer for AC compared to LC ($p < 0.01$; $d = 1.44$). No significant differences were present for RPE responses to isocaloric exercises ($p > 0.05$), aside from a main effect for exercise intensity ($p < 0.01$. *Post-hoc* analysis showed very large effect sizes for HEAVY compared to MODERATE ($p < 0.01$; $d = 1.83$).

Absolute $\dot{V}O_2$ responses indicated a significant interaction between mode and intensity ($p = 0.02$). *Post-hoc* analysis showed moderate and large effect sizes for LC at comparable intensities to AC (MODERATE: $p < 0.01$, $d = 1.19$; HEAVY: $p < 0.01$, $d = 1.53$, respectively); however, it should be noted that AC responses at HEAVY were higher than LC responses at MODERATE ($p < 0.01$, $d = 0.95$). Between groups, there was a trend with a small effect size for lower $\dot{V}O_2$ responses in the OFO group in comparison to the LA group, as shown by *post-hoc* analysis ($p = 0.058$, $d = 0.32$).

The $\dot{V}O_2$ responses relative to body mass and relative to fat free mass (FFM) indicated a significant interaction between mode and intensity ($p = 0.05$, $p = 0.03$, respectively). *Post-hoc* analysis showed moderate to large effect sizes between LC and AC at comparable intensities to AC for values relative to body mass (MODERATE: $p < 0.01$, $d = 1.13$; HEAVY: $p < 0.01$, $d = 1.45$, respectively), and for values relative to FFM (MODERATE: $p < 0.01$, $d = 1.19$; HEAVY: $p < 0.01$, $d = 1.53$, respectively). The $\dot{V}O_2$ responses relative to body mass and relative to FFM were higher for AC at HEAVY compared to LC at MODERATE ($p < 0.01$, $d = 0.93$ and $p < 0.01$, $d = 0.95$, respectively). A significant main effect between groups was shown for $\dot{V}O_2$ values relative to body mass (p < 0.01); with additional *post-hoc* analysis indicating a significantly lower response in the OFO group in comparison to the LA group ($p < 0.01$, $d = 0.65$); however, no significant differences were reported for values relative to FFM ($p = 0.07$). Moreover, the average oxygen uptake relative to peak oxygen consumption was similar between groups and within exercises of the same intensity ($p > 0.05$; HEAVY: 73 ±1%, MODERATE: 48 ± 1%). Similarly, the average oxygen uptake relative to VT ($p > 0.05$; HEAVY: 144 ± 3%, MODERATE: 95 ± 2.6%) and RCP ($p > 0.05$; HEAVY: 96 ± 2%, MODERATE: 64 ± 2%) were not significant.

There was a significant interaction between mode and intensity for respiratory exchange ratio (RER; $p = 0.04$). *Post-hoc* analysis did not show significant difference between modes at comparable intensities (AC, HEAVY vs. LC, HEAVY: $p > 0.05$, $d = 0.31$; AC, MODERATE vs. LC, MODERATE $p > 0.05$, $d = 0.23$). A significant main effect for intensity was shown ($p < 0.01$). *Post-hoc* analysis showed the RER responses were higher for exercises performed at HEAVY compared to MODERATE intensities ($p < 0.01$, $d = 1.95$).

A significant interaction was noted for ventilatory responses (V_E) between mode and intensity ($p < 0.01$). *Post-hoc* analysis showed responses were higher during LC at HEAVY compared to AC at HEAVY ($p < 0.01$, $d = 0.79$) and AC at MODERATE ($p < 0.01$, $d = 2.59$), and LC at MODERATE compared to AC at MODERATE ($p < 0.01$, $d = 0.73$). The AC responses at HEAVY were higher than LC at MODERATE ($p < 0.01$, $d = 1.78$).

A significant interaction between mode and intensity was also shown for tidal volume (V_t; $p < 0.01$). *Post-hoc* analysis revealed these responses were greater during LC at HEAVY compared to AC HEAVY ($p < 0.01$, $d = 1.42$), LC at MODERATE compared to AC at MODERATE ($p < 0.01$, $d = 1.09$); however, no significant differences were noted between AC at HEAVY and LC at MODERATE ($p < 0.01$, $d = 0.19$). There were no significant interactions for respiratory frequency (f_R; $p > 0.05$). A significant main effect for intensity was shown ($p < 0.01$), and additional *post-hoc* analysis revealed greater values for HEAVY ($p < 0.01$; $d = 1.87$). A significant main effect for mode was also shown ($p < 0.01$), with additional analysis showing greater values during AC ($p < 0.01$; $d = 0.58$).

There was a significant interaction between exercise mode and intensity for the average heart rate (HR) during isocaloric protocols ($p < 0.01$; Figure 6). *Post-hoc* analysis showed arm cycling at HEAVY was significantly lower than LC at HEAVY ($p < 0.01$; $d = 0.87$). Average HR was higher for AC at HEAVY compared to LC at

MODERATE ($p < 0.01$; $d = 1.94$), but no significant differences were observed between AC at MODERATE and LC at MODERATE ($p > 0.05$; $d = 0.34$). The HR average data of eleven participants were excluded from analysis due to technical issues related to excessive artifact detection.

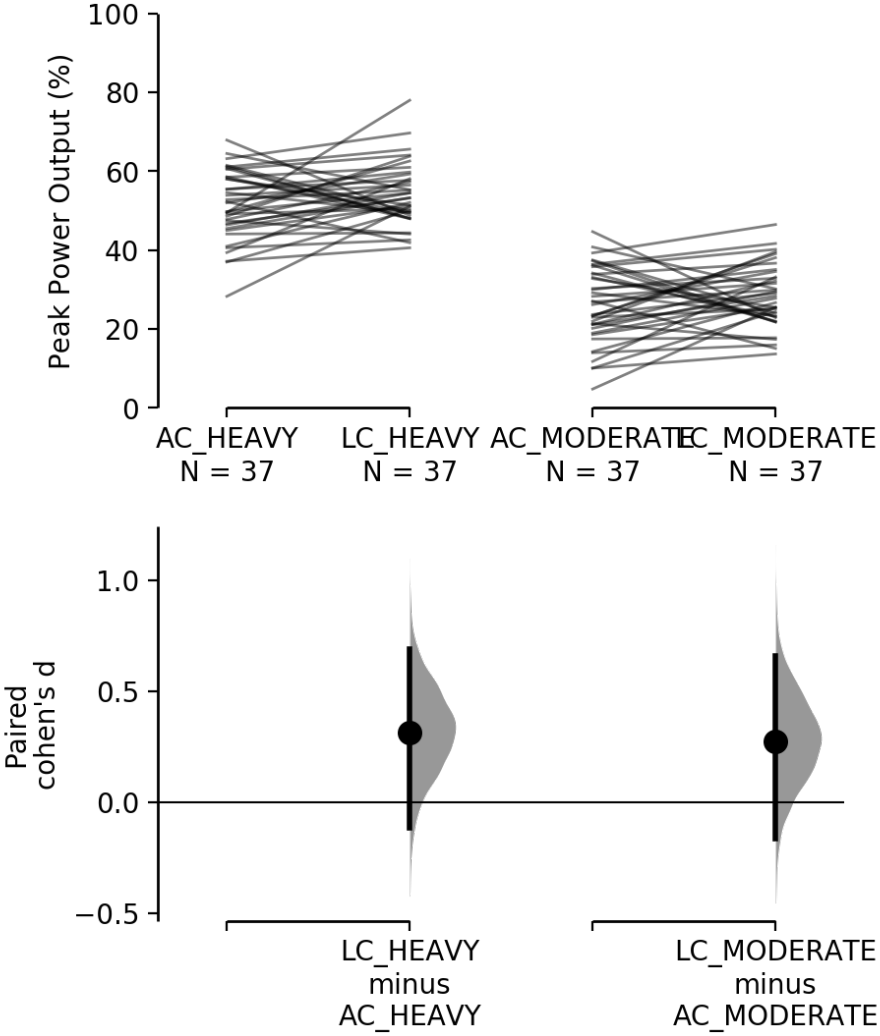


Figure 4. Peak power output percentage

Notes: Participants' peak power output represented in percentage for MODERATE and HEAVY exercise intensities during constant work rate isocaloric protocols using arm cycling (AC) and leg cycling (LC).The paired Cohen's *d* for 2 comparisons are shown in the above Cumming estimation plot. The raw data is plotted on the upper axes; each paired set of observations is connected by a line. On the lower axes, each paired mean difference is plotted as a bootstrap sampling distribution. Mean differences are depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bars (Ho et al., 2019).

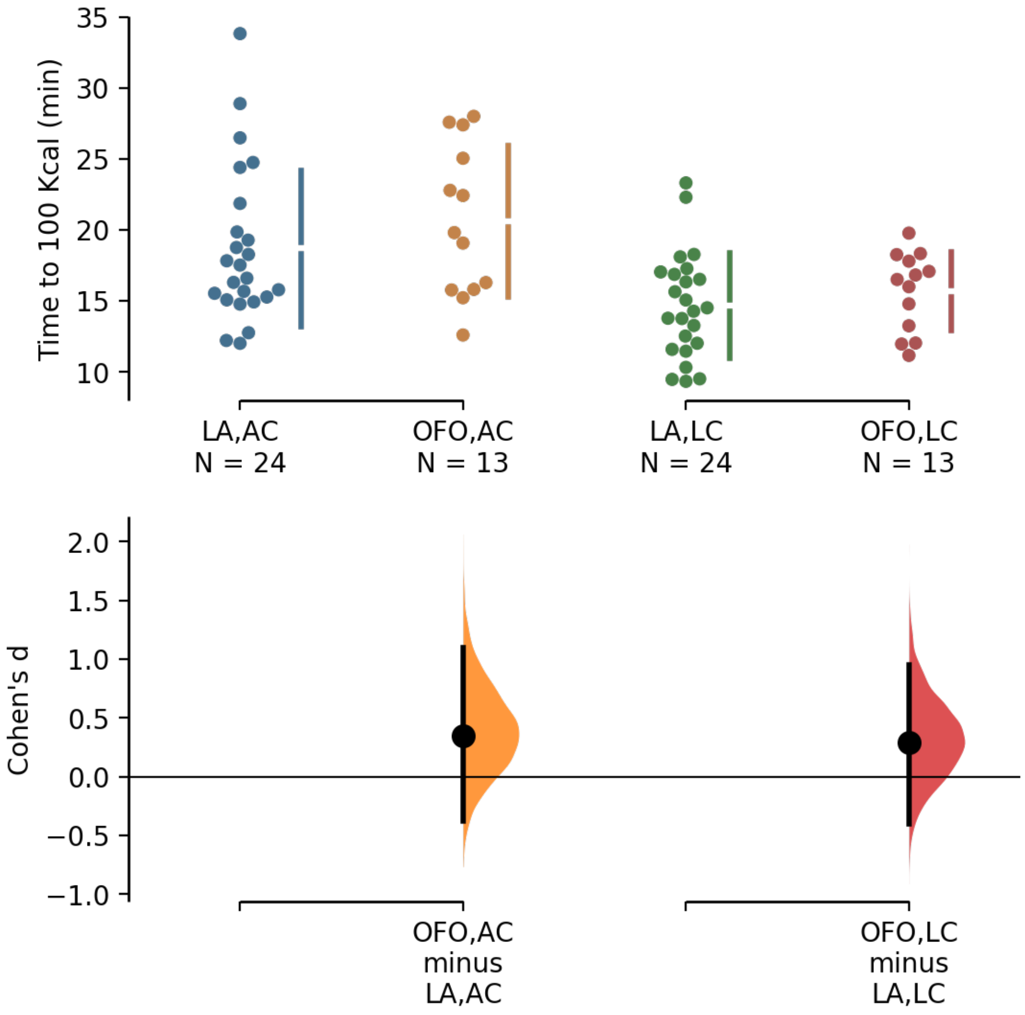


Figure 5. Time to expend 100 kcal
Notes: Lean and average (LA) and overfat and obese (OFO) groups time to expend 100 kcal ($Tkcal_{100}$) in minutes collapsed across MODERATE and HEAVY exercise intensities during constant work rate isocaloric protocols using arm cycling (AC) and leg cycling (LC). The Cohen's d for two comparisons are shown in the above Cumming estimation plot. The raw data is plotted on the upper axes; each mean difference is plotted on the lower axes as a bootstrap sampling distribution. Mean differences are depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bars (Ho et al., 2019).

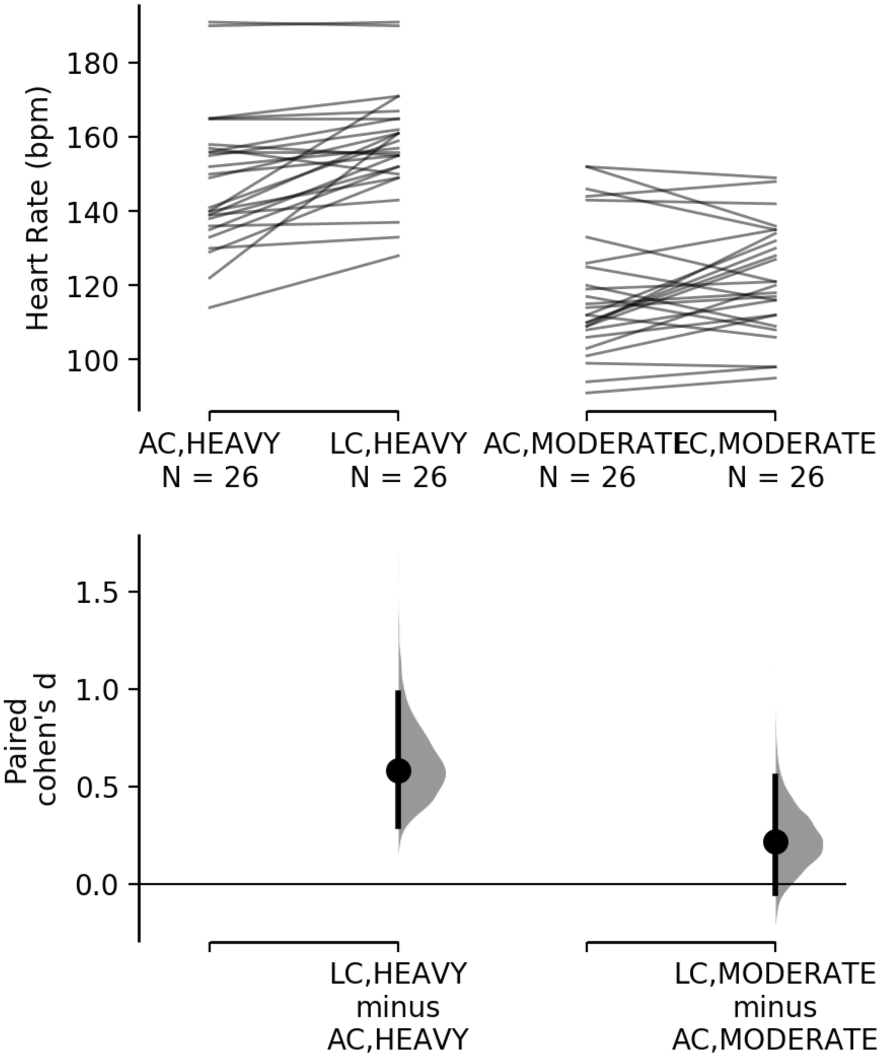


Figure 6. Heart rate responses
Notes: Participants' average heart rate (HR) responses in beats per minute (bpm) for MODERATE and HEAVY exercise intensities during constant work rate isocaloric protocols using arm cycling (AC) and leg cycling (LC). The paired Cohen's d for two comparisons are shown in the above Cumming estimation plot. The raw data is plotted on the upper axes; a line connects each paired set of observations. On the lower axes, each paired mean difference is plotted as a bootstrap sampling distribution. Mean differences are depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bars (Ho et al., 2019).

Table 8. Participant's responses to isocaloric protocol

Variables	Lean & Average (n = 24)		Over fat & Obese (n = 13)	
	Arm Cycling	Leg Cycling	Arm Cycling	Leg Cycling
MODERATE				
Tkcal$_{100}$	22.56 ± 6.43[b]	18.36 ± 5.31[b]	24.46 ± 6.14[a,b]	19.03 ± 4.02[a,b]
RPE	2.9 ± 0.8[b]	2.7 ± 1.2[b]	2.7 ± 0.8[b]	2.6 ± 0.8[b]
$\dot{V}O_2$ ($L \cdot min^{-1}$)	0.965 ± 0.232[c]	1.212 ± 0.342[c]	0.898 ± 0.257[b,c]	1.137 ± 0.272[b,c]
$\dot{V}O_2$ peak ($mL \cdot min^{-1} \cdot kg^{-1}$)	14.39 ± 2.81[b,c]	18.05 ± 4.49[b,c]	10.68 ± 2.58[a,b,c]	13.59 ± 2.70[a,b,c]
$\dot{V}O_2$ ($mL \cdot min^{-1} \cdot kg^{-1}FFM$)	17.8 ± 3.0[b,c]	22.3 ± 4.6[b,c]	15.8 ± 2.9[b,c]	20.2 ± 3.3[b,c]
RER	0.94 ± 0.07[b,c]	0.93 ± 0.07[b,c]	0.93 ± 0.06[b,c]	0.93 ± 0.05[b,c]
V_E ($L \cdot min^{-1}$)	29.04 ± 6.46[b,c]	32.47 ± 7.43[b,c]	26.01 ± 5.50[b,c]	30.41 ± 4.94[b,c]
V_t (L)	1.177 ± 0.356[b,c]	1.444 ± 0.479[b,c]	1.112 ± 0.325[b,c]	1.394 ± 0.408[b,c]
f_R ($1 \cdot min$)	26.2 ± 6.3[b]	23.9 ± 5.4[b]	24.7 ± 4.7[b]	23.2 ± 4.8[b]
HEAVY				
T$_{100kcal}$	14.83 ± 4.72	11.02 ± 2.80	16.74 ± 4.60[a]	12.32 ± 1.97[a]
RPE	5.6 ± 1.6	5.2 ± 1.5	4.8 ± 1.1	5.3 ± 2.0
$\dot{V}O_2$ ($L \cdot min^{-1}$)	1.430 ± 0.328[c]	1.870 ± 0.450[c]	1.299 ± 0.347[a,c]	1.719 ± 0.303[a,c]
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	21.29 ± 3.08[c]	28.00 ± 6.33[c]	15.45 ± 3.49[c]	20.94 ± 4.78[c]
$\dot{V}O_2$ ($mL \cdot min^{-1} \cdot kg^{-1}FFM$)	26.4 ± 4.1[c]	34.7 ± 6.7[c]	22.9 ± 4.0[c]	31.1 ± 6.4[c]
RER	1.01 ± 0.09[c]	1.03 ± 0.08[c]	1.00 ± 0.06[c]	1.02 ± 0.05[c]
V_E ($L \cdot min^{-1}$)	46.65 ± 10.11[c]	53.78 ± 11.75[c]	41.94 ± 8.26[c]	51.93 ± 9.73[c]
V_t (L)	1.487 ± 0.416[c]	1.968 ± 0.586[c]	1.436 ± 0.431[c]	1.783 ± 0.452[c]
f_R ($1 \cdot min$)	32.8 ± 7.3	28.5 ± 6.0	30.9 ± 7.2	30.2 ± 7.4

Notes: Values are represented in *M* ± *SD*; [a] Significantly different than Lean & Average ($p \leq 0.05$); [b] Significantly different than HEAVY ($p \leq 0.05$); [c] Significant interaction between mode and intensity ($p \leq 0.05$). Tkcal$_{100}$ = time to complete 100 kcal; RPE = rate of perceived exertion; $\dot{V}O_2$ = oxygen uptake; RER = respiratory exchange ratio; V_E = ventilation; V_t tidal volume; f_R = respiratory frequency.

CHAPTER FIVE: DISCUSSION

This study compared the acute cardiopulmonary responses of 100 kcal exercise sessions for arm and leg cycling performed at different intensities (HEAVY and MODERATE) among young relatively healthy individuals with and without excess body fat. Among lean and average weight participants (LA), the time taken to expend 100 kcal ($Tkcal_{100}$) during steady-state exercise sessions, regardless of intensity or mode, was about three and a half minutes shorter than in the overfat and obese participants (OFO). In accordance with our primary hypothesis, $Tkcal_{100}$ was more negatively affected in the excess body fat than in participants with lean and average weight. Additionally, this study showed significant cardiopulmonary changes between exercises of different modes and intensities; however, cardiorespiratory responses did not differ between body composition groupings. Contrary to our secondary hypothesis, participants in the OFO group did not show reduced cardiopulmonary responses than the LA group. These findings have a relevant public health impact on the appraisal of an acute arm cycling session based on individualized fatigue thresholds for individuals with excess body fat and obesity.

The reason for the lengthier sessions among OFO participants is unclear. From the analysis of the maximal incremental protocol data, the initial conclusion may be that the OFO group's reduced fitness level affected exercise responses. The increased cardiopulmonary fitness status in the LA group as measured by a higher maximal oxygen consumption ($\dot{V}O_2$ peak) and greater relative ventilatory threshold placement, could explain the improved performance during the isocaloric trials. The enhanced oxygen transport and oxidative phosphorylation would allow LA participants to maintain a similar rating of perceived exertion than the OFO group while exercising at higher work rates during isocaloric exercise sessions (Jones & Molitoris, 1984; Romijn et al., 1993). Therefore, maintaining consistently lower Tkcal_{100}. However, there were no significant differences in $\dot{V}O_2$ peak during maximal arm cycling incremental protocol between LA and OFO participants. An interaction trend between mode and group and subsequent evaluation of effect sizes suggested the time taken to expend 100 kcal during exercise sessions for LA participants was about three and a half minutes longer in arm cycling than during leg cycling trials, regardless of exercise intensity. For OFO participants, this average difference was increased to almost six minutes. As the work rates during isocaloric trials were based on the performance obtained from maximal incremental tests, the difference in work rate for tests performed with the arms between groups was minimal.

Although well-reasoned, the relationship between maximal incremental test results and isocaloric exercise session outcomes is limited and does not completely explain the responses from a constant work-rate exercise. The results obtained from the isocaloric trials may have been further influenced by the distribution of fat mass and skeletal muscle mass between limbs (Li et al., 2001), and mode/intensity-specific metabolic efficiency. First, it is important to note that apart from the greater fat mass volume in the OFO group compared to the LA group, the total amount of fat-free mass was similar between the two groups (57.1 ± 13.7 and 54.1 ± 10.1 kg, respectively).

Nevertheless, to explain the discrepancy between groups solely on fat-free mass content, a valid estimate of muscle mass distribution in the upper and in the lower limbs would need to be made. Sawka et al. (1983) suggested little influence from arm volume and upper body strength on $\dot{V}O_2$ peak obtained from maximal incremental arm cycling tests; however, body composition was not assessed. Additionally, body fat distribution may impact pulmonary function and oxygen uptake during exercise (Li et al., 2001). Excess adipose tissue surrounding the upper body reduces chest wall compliance and generates ventilatory stress and reduced metabolic responses in obese individuals (Li et al., 2001; Whipp & Davis, 1984). This could have been limited to a greater degree during arm cycling isocaloric exercise as it naturally limits chest wall compliance even further than leg cycling (Cerny & Ucer, 2004; Tiller, Campbell, et al., 2017).

Decreased oxygen uptake ($\dot{V}O_2$) during submaximal arm cycling exercise performed at the same relative mode-specific work-rates has been reported in the literature (Cerny & Ucer, 2004; Jensen-Urstad & Ahlborg, 1992; Kang et al., 1997; Schneider et al., 2002b; Sousa et al., 2017). However, the extent of these responses among individuals of different body composition and between sessions of different intensities performed in separate days has not previously been explored. Obesity is linked with mitochondrial dysfunction and reduced ATP production, even in non-diabetic obese individuals (Abdul-Ghani et al., 2009; Kras et al., 2018).

Our results show a lower $\dot{V}O_2$ for the OFO group compared to the LA group for values relative to body mass during isocaloric trials. However, differences between the OFO group and the LA group were eliminated when correcting for fat-free mass.

Conversely, Lafortuna et al. (2011) showed an increased oxygen consumption for obese individuals during submaximal and rhythmic exercises performed with the upper and lower body. They attributed this difference to a lower mechanical efficiency due to the larger mass of body segments. However, the authors also reported significantly larger differences in fat-free mass for obese than normal-weight groups, which could have primarily enhanced energy expenditure outcomes in obese individuals. Coincidentally, in the present study, the OFO and LA groups did not differ in fat-free mass content, only in fat mass. Additionally, the potential impact of limb size between and within groups was accounted for as exercise intensities were relative to cardiopulmonary outcomes, further confirmed by non-significantly different rating of perceived exertion between groups. Interestingly, as the power outputs used by OFO were lower than LA, regardless of the exercise mode, it is possible that segmental differences (i.e., greater limb mass in OFO) could have resulted in relatively similar effort between groups, despite the lower power output evidenced. Hence, a similar $\dot{V}O_2$ during isocaloric exercise was shown. This highlights the relevance of assessing segmental differences in future studies.

As anticipated, our results indicate a higher oxygen consumption during exercises performed at HEAVY compared to MODERATE intensities. This was consistent even for trials involving smaller muscle mass (i.e., arm cycling) in comparison to large muscle mass (i.e., leg cycling) performed at a MODERATE exercise intensity, further supporting the notion that cardiovascular responses are more influenced by the level of metabolic activity of the muscle mass involved in exercise (Lafortuna et al., 2011). It is noteworthy that despite the risk of an inflated RPE due to the slow component of oxygen uptake during constant work rate sessions, MODERATE intensity trials were conducted below the heavy exercise intensity domain (i.e., below VT), and HEAVY sessions were performed below the severe exercise intensity domain (i.e., below RCP) (Sousa et al., 2017). Non-significant differences in RPEs between modes and groups further confirmed that sessions were performed within the moderate and heavy exercise intensity domains as described in the 10-point RPE scale (Borg, 1970; Noble et al., 1983). It is possible that exercise length—approximately 20 minutes—may have reduced the risk of a slowly developing increases in $\dot{V}O_2$ on-kinetics and consequently the ratings of perceived exertion. The relative selection of the work rates at 80% of VT for MODERATE and 30% of the difference between VT and PPO during HEAVY is another important factor.

Correspondingly, RER values were, on average, at 1.0 for HEAVY intensity exercise and close to 0.9 during MODERATE intensity exercise, suggesting a predominantly aerobic energy system contribution. However, a certain level of anaerobic contribution is likely to have occurred, and not accounting for the extent of this energy system's contribution constitutes a limitation of the current study (Hargreaves & Spriet, 2020). Nevertheless, the lack of difference in RER between arm cycling and leg cycling at HEAVY may be suggestive of an equivalent anaerobic contribution across modalities. Previous studies have shown that RER responses are typically higher for arm cycling when performed at the same absolute (Vander et al., 1984) or relative intensities of leg cycling (Ahlborg et al., 1986; Jensen-Urstad & Ahlborg, 1992; Kang et al., 1997; Leicht et al., 2008). To our knowledge, our study is the first to report similar RER responses for steady-state exercises performed at the same relative intensity based on thresholds and maximal performance.

Ventilatory responses were also greater during leg cycling than arm cycling at comparable intensities and higher during HEAVY trials independently of the exercise mode. In the literature, arm cycling is reported to elicit higher ventilatory responses when compared to leg cycling during exercises at similar absolute oxygen consumption, especially at work rates above 50% of $\dot{V}O_2$ peak (Cerny & Ucer, 2004; Sawka et al., 1982). At these work rates, the lower intensity of contraction of larger muscle groups such as those involved during leg cycling is more likely to induce a steady-state condition than arm cycling (Shephard et al., 1988). As the onset of ventilatory thresholds may be lower for arm cycling as reported in this and other studies (Davis et al., 1976; Dekerle et al., 2002), exercise-induced metabolic acidosis and the consequent hyperventilation during exercise (Meyer, 2004) could potentially occur during arm cycling, but not leg cycling exercise, even if performed at the same relative intensities based on the $\dot{V}O_2$ peak.

Arm cycling has been widely reported to alter breathing patterns and reduce tidal volume while increasing breathing rate (Cerny & Ucer, 2004; Sawka et al., 1982; Tiller, Campbell, et al., 2017; Tiller et al., 2019). In this study, we confirmed a reduced tidal volume for arm cycling compared to leg cycling at equivalent intensities. The lack of differences between leg cycling performed at MODERATE and arm cycling performed at HEAVY is also suggestive of a restrictive breathing response during a more metabolically demanding task. As no significant differences were shown between groups, tidal volume may not be affected in overfat and obese young adults. Furthermore, breathing frequency was significantly greater for arm cycling exercise compared to leg cycling, which has been reported to occur as a compensatory breathing alteration during exercise performed with the arms as tidal volume is reduced (Cerny & Ucer, 2004). Tiller et al. (2017) recently showed a greater coupling of breathing and arm cycling at higher cadences, such as those used in this study (70–80 rpm). Lastly, we did not observe any significant differences between LA and OFO groups with respect to ventilation or breathing patterns in general. Li et al. (2001) showed that women with class III obesity and increased fat accumulation in the upper body, as measured by waist to hip ratio below 0.8, had greater ventilatory demand and altered breathing patterns compared to women with class III obesity and predominantly lower body fat accumulation. However, in the present study, we tested participants with and without excess body fat, and participants in the OFO were overweight and obese (class 1).

For the average heart rate response during trials, leg cycling at HEAVY presented a higher response than arm cycling, about 10 beats per minute. Interestingly, no significant differences in HR were observed at MODERATE between modes. In contrast to previous investigations that showed consistently lower (Kang et al., 1997) or higher (Pimental et al., 1984) responses across exercise intensities similar to those used in this study, we showed a divergent HR response between intensities. Consistent with our other results, differences in HR between exercise modes seem to be attenuated at MODERATE in comparison to HEAVY. Leicht et al. (2008) suggested that during exercises performed at the same HR, autonomic regulation of the heart might differ between leg and arm muscles. The authors showed that increased vagal tone measured by heart rate variability analysis was shown for arm cycling than leg cycling during steady-state trials at moderate intensity. Moreover, changes in sympathoadrenal activation have been reported during studies comparing arm cycling and leg cycling, which could account for differences in HR during more demanding exercise intensities (Ahlborg et al., 1986; Ahlborg & Jensen-Urstad, 1991; Davies et al., 1974).

This study has several limitations. The unequal group size increases the chances of error relating to homoscedasticity between groups. However, Levene's test showed that equality of variation was met for our main study variables. The average HR was the only parameter that did not meet this assumption. Furthermore, the proportion of male to female participants was similar between groups, with 46% of males within each group. Another potential limitation in this study relates to oxygen uptake comparisons between arm cycling and leg cycling without accounting for active muscle mass. To minimize this issue, particularly in the OFO group in which the ratio of fat mass to fat-free mass increases, we have included analysis of oxygen uptake relative to fat-free mass measurements.

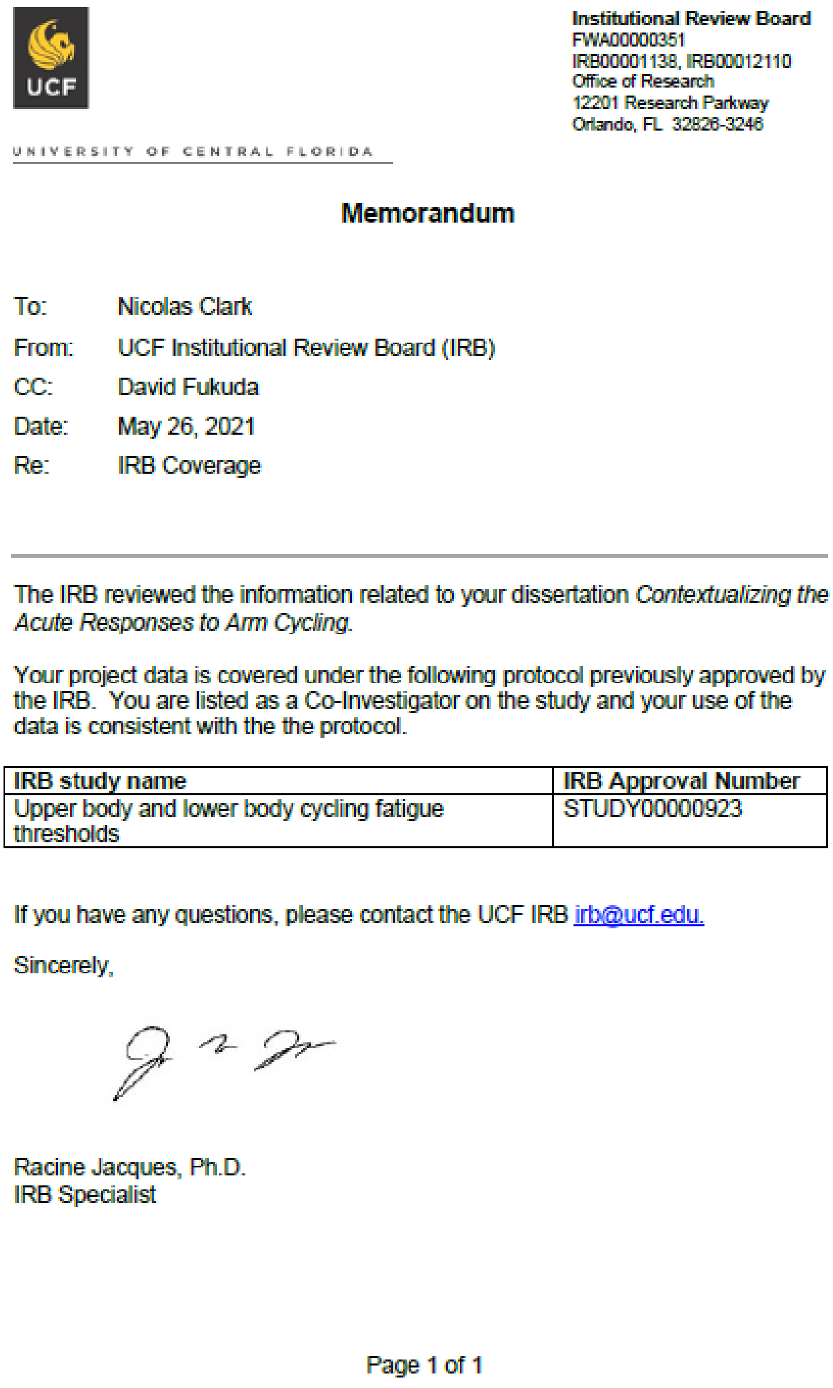
Additionally, the noninvasive assessment of fatigue thresholds using gas exchange analysis includes potential problems in the validation of maximal incremental arm cycling tests, as a locomotor-respiratory coupling exists during upper body work (Tiller, Price, et al., 2017b). As most of the literature has focused on leg cycling, the criteria for validating arm cycling tests remains to be further investigated. In this study, we dichotomized our sample into having or not having excess body fat and obesity (Schutz et al., 2002). This could be problematic as nuances in the physiological responses may exist between lean and average and overfat and obese individuals while not necessarily affecting groups equally. Furthermore, categorizing participants based on the fat-mass index may present a limitation since this is a novel method compared to more established methods such as the body mass index and fat mass percentage. Nevertheless, the fat-mass index is thought to provide a more accurate depiction of fat mass in relation to height, which may affect body fat percentage values among individuals of different sizes (Schutz et al., 2002). Additionally, the fat-free mass index is a construct parallel to the extensively studied body mass index, with the advantage of considering body composition to reduce inaccuracies relating to falsely classifying individuals with large amounts of fat-free mass as overweight or obese. Lastly, participants' weight history was not considered as the onset of obesity/excess body fat could potentially affect the efficiency of fat and carbohydrate metabolism.

Based on the second edition of physical activity guidelines for Americans, it can be estimated that, on average, to achieve the minimum recommended level of 500–1000 $\text{MET}\cdot\text{min}^{-1}\cdot\text{week}$ amount, overfat and obese individuals in this study would have to perform approximately 167–333 minutes per week of arm cycling at moderate intensity (3.0 METs) or 113–243 minutes per week of arm cycling at heavy intensity (4.1 METs). To achieve the same amount of work with leg cycling, weekly minutes would decrease by 30% for a moderate (3.9 METs) and 15% for heavy intensities (5.9 METs). Among LA participants these numbers would decrease even further; approximately 35% during moderate-intensity exercises (arm cycling = 4.1 METs, leg cycling = 5.1 METs) and 30% during heavy intensity exercises (arm cycling = 6.1 METs, leg cycling = 8 METs).

Conclusion

Young adults with excess body fat and obesity appear to respond less favorably to acute arm cycling exercise when compared to lean and average body composition individuals, as evidenced by a longer time taken time to expend 100 kcals is longer. The lower fitness level measured by the relative placement of the ventilatory threshold and the maximal oxygen consumption may explain the differences between the groups during isocaloric trials. Among the cardiopulmonary parameters measured in this study, only oxygen uptake relative to body mass was significantly different between groups; however, differences were no longer evident when oxygen uptake values were considered relative to fat-free mass. Furthermore, cardiopulmonary variables are more affected by exercise intensity than exercise mode, while responses to different intensities are not necessarily proportional. More research is needed to confirm our findings and examine individuals with higher levels of obesity, different upper and lower body fitness levels, age, and physical activity status while also considering the potential role of ethnicity and nutritional behaviors. Physical inactivity and obesity are major contributors to all-cause mortality and are among the most critical public health problems of the 21st century (Gibson et al., 2019). Arm cycling performed at moderate intensity could be an alternative for obese individuals since this exercise modality elicited a metabolic equivalent of 3.0 METs, which is within the moderate intensity suggested by the latest edition if the Physical Activity Guidelines for Americans. Moreover, this study showed that to achieve the same work accomplished with leg cycling, arm cycling requires more time. Generally 10% more time to achieve 100 kcals. Results from this and future studies quantifying the health effects of specific doses of arm cycling could assist exercise prescription among individuals with excess body fat and obesity.

APPENDIX: UCF IRB LETTER



UCF
UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138, IRB00012110
Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

Memorandum

To:	Nicolas Clark
From:	UCF Institutional Review Board (IRB)
CC:	David Fukuda
Date:	May 26, 2021
Re:	IRB Coverage

The IRB reviewed the information related to your dissertation *Contextualizing the Acute Responses to Arm Cycling.*

Your project data is covered under the following protocol previously approved by the IRB. You are listed as a Co-Investigator on the study and your use of the data is consistent with the the protocol.

IRB study name	IRB Approval Number
Upper body and lower body cycling fatigue thresholds	STUDY00000923

If you have any questions, please contact the UCF IRB irb@ucf.edu.

Sincerely,

Racine Jacques, Ph.D.
IRB Specialist

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