# Acute Cardiopulmonary Responses to Different Intensities of Exercise in Healthy Older Adults.

By

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## THESIS EXAMINATION INFORMATION

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An oral defense of this thesis took place on December 9th, 2019 in front of the following examining committee:

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The above committee determined that the thesis is acceptable in form and content and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate during an oral examination. A signed copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

## ABSTRACT

The overall purpose of this thesis was to study the acute cardiopulmonary responses to different intensities of exercise in healthy older adults. Thirty healthy older males and females (69.6 ± 6.2 yrs.; males n = 15) underwent maximal exercise testing to determine maximal oxygen consumption ($VO_{2MAX}$) and peak power output (PPO), and completed each of the following exercise protocols in a randomized crossover design: high intensity interval exercise (HI; 1 minute 90% PPO followed by 1 minute 10% PPO, x10), continuous moderate intensity exercise (MOD; 20 minutes at 50% PPO), and sprint intensity interval exercise (SPRT; 20 second "all-out" sprints followed by 2 minutes of 50W, x3). Oxygen consumption ($VO_2$), ventilation ($V_E$), tidal volume (Vt), respiratory rate (RR), heart rate (HR), tissue saturation index (TSI) of the vastus lateralis and rated perceived exertion (RPE) were monitored during exercise sessions. Heart rate recovery ($HR_{REC}$) was assessed after each exercise session and heart rate variability (HRV) was compared using resting and post-exercise values. Overall, it was found that high fit individuals attained the greatest $VO_2$ peak during MAX while low fit females attained a larger $VO_2$ peak during SPRT compared to MAX. The rate of $HR_{REC}$ was greatest in high fit males. These findings have important implications for the individualization of exercise prescription, Future research will need to compare the three different types of exercise training to determine which protocol leads to larger adaptations in older adults.



**Keywords:** older adults, cardiopulmonary responses, sprint exercise, high intensity exercise, interval exercise, fitness

## CO-AUTHORSHIP STATEMENT

The manuscript included in Chapter 3 will be submitted for publication. Co-authors of such work include Dr. Shilpa Dogra (research supervisor), Dr. Kirsten Burgomaster (committee member), Dr. Melanie Stuckey (committee member), and Nikola Goncin (MHSc student also supervised by Dr. Dogra).

Dr. Dogra was responsible for the idea and contributed to writing of the manuscript. Dr. Burgomaster and Dr. Stuckey both contributed to the design of the study, provided insights and interpretations of physiological data, and reviewed the final manuscript. Nikola Goncin assisted with data collection and reviewed the final manuscript. As the primary contributor, I worked on study design, recruitment, data collection, data analysis and manuscript preparation.

## AUTHOR'S DECLARATION

I hereby declare that this thesis consists of original work of which I have authored. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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The research work in this thesis that was performed in compliance with the regulations of Ontario Tech's Research Ethics Board under REB 14896 on July 19, 2018.

Andrea Linares

## STATEMENT OF CONTRIBUTIONS

The work described in Chapter 3 was performed in the Human Performance Laboratory at Ontario Tech University and will be submitted for publication to the European Journal of Applied Physiology. Co-authors for this paper included Dr. Shilpa Dogra, Dr. Kirsten Burgomaster, Dr. Melanie Stuckey and Nikola Goncin. Data collection was primarily conducted by myself and Nikola Goncin with the occasional help of lab trainees. Dr. Dogra provided guidance as I, the first author, performed all data synthesis, statistical analyses, primary interpretations and writing of results.

I hereby certify that I am the primary author of this thesis and stand behind the ethical guidelines used to collect data and write a manuscript using proper referencing practices to acknowledge ideas or other materials that belong to others.

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This has been an interesting journey to say the least. As I think back to the past two years, I am proud of how far this project has come. However, this would have not been possible without a number of amazing individuals.

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### CHAPTER 3

**LIST OF ABBREVIATIONS**

| NOTATION | DESCRIPTION |
|---|---|
| ADP | Adenosine Diphosphate |
| ATP | Adenosine Triphosphate |
| $(a\text{-}v)O_{2diff}$ | Arteriovenous Difference |
| Q | Cardiac Output |
| $VCO_2$ | Carbon Dioxide Production |
| VT1 | First Ventilatory Threshold |
| HR | Heart Rate |
| $HR_{REC}$ | Heart Rate Recovery |
| HRV | Heart Rate Variability |
| HI | High Intensity Interval Exercise |
| HF | High Frequency |
| Pi | Inorganic Phosphate |
| LF | Low Frequency |
| MAX | Maximal Exercise |
| $VO_{2MAX}$ | Maximal Oxygen Consumption |
| $V_E$ | Minute Ventilation |
| MOD | Moderate Intensity Continuous Exercise |
| $VO_2$ | Oxygen consumption |
| PPO | Peak Power Output |
| $VO_{2PEAK}$ | Peak $VO_2$ calculated |
| RPE | Rated Perceived Exertion |
| RR | Respiratory Rate |
| VT2 | Second Ventilatory Threshold |
| SPRT | Sprint Intensity Interval Exercise |
| SV | Stroke Volume |
| Vt | Tidal Volume |
| TSI | Tissue Saturation Index |
| VT | Ventilatory Threshold |

## Chapter 1. Introduction

## 1.1 Thesis Overview

To date, endurance training at a continuous moderate intensity (MOD), has been the traditional means to improve cardiopulmonary fitness (Hautala et al., 2006; Jones & Carter, 2000; Scharhag-Rosenberger, Walitzek, Kindermann, & Meyer, 2012; Vollaard et al., 2009), and has been extensively studied, even among older adults (Bouchard & Rankinen, 2001; Huang, Gibson, Tran, & Osness, 2005; Karavirta et al., 2011; Kasch & Wallace, 1976; Lanza et al., 2008; Sisson et al., 2009). More recently, interval exercise, such as high intensity interval (HI) and repeated sprint exercise (SPRT) have been introduced, in lieu of MOD, for its reduced time requirement (Gibala et al., 2006; Gillen & Gibala, 2014; Gist, Fedewa, Dishman, & Cureton, 2014). Although, interval exercise is different from continuous exercise in nature, similar improvements in cardiopulmonary fitness have been observed after HI and SPRT training (Daussin et al., 2007; Daussin et al., 2008; Esfandiari, Sasson, & Goodman, 2014; Gibala et al., 2006; Gillen et al., 2016; Gillen et al., 2014; MacInnis & Gibala, 2017). However, the differences in the acute responses to MOD and interval exercise (i.e. HI and SPRT) are not well described. That is, the current literature is primarily based on physiological improvements after long-term exercise training.

Moreover, current research on the cardiopulmonary responses to exercise heavily focus on either young or athletic populations. For example, research on the acute cardiopulmonary responses, in young adult males , indicates that the acute oxygen consumption ($VO_2$) response to MOD is lower when compared to HI (Falz et al., 2019). Additional responses of minute ventilation ($V_E$), heart rate (HR), and cardiac output (Q) were also found to be lower during MOD when compared to HI. Consequently, there is a lack of research on the study of the acute responses to exercise in older adults, particularly in response to HI and SPRT. This is important as aging is associated with a variety of complex physiological changes such as increased stiffness of the myocardium, decreased ventricular compliance, and increased stiffness of arterial walls (Ferrari, Radaelli, & Centola, 2003; Pugh & Wei, 2011). Together, these physiological changes affect the response to exercise. Although healthy aging implies an individual is free of pathological abnormalities, physiological changes as those mentioned above still occur in healthy aging and play a role in the cardiopulmonary responses to exercise.

This is important as studies have found that the individual responses to exercise are highly variable (Bonafiglia et al., 2016; de Lannoy, Clarke, Stotz, & Ross, 2017; Montero & Lundby, 2017). In fact, studies have shown that some individuals may not respond to a given dose of exercise that is associated with significant benefits in others (Bonafiglia et al., 2016; Bouchard & Rankinen, 2001; Chmelo et al., 2015; Hautala et al., 2006; Karavirta et al., 2011; Mann, Lamberts, & Lambert, 2014; Montero & Lundby, 2017; Ross, de Lannoy, & Stotz, 2015; Scharhag-Rosenberger et al., 2012; Weatherwax, Harris, Kilding, & Dalleck, 2016). As such, there is a need for studies to explore the acute cardiopulmonary responses to different types of exercise protocols in older adults. Thus, the primary aim of this thesis was to describe acute cardiopulmonary responses to MOD, HI, and SPRT in older males and females. This is a crucial first step in understanding how to best prescribe exercise to optimize adaptations.

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## Chapter 2. Literature Review

The proceeding literature review will detail the central and peripheral cardiopulmonary variables of the Fick equation, specifically with regard to the acute responses to different doses of exercise. To begin with, this review will cover key variables associated with exercise prescription such as intensity and mode of exercise. Next, central cardiopulmonary responses to exercise such as: oxygen consumption, stroke volume, cardiac output, ventilatory parameters, heart rate, heart rate recovery, and heart rate variability will be reviewed. Finally, an overview of peripheral cardiopulmonary responses to exercise such as the arteriovenous difference and its association with tissue saturation index will be addressed. Additionally, the influence of sex and age on cardiopulmonary responses will be integrated throughout the review as most of the current literature focuses on younger and athletic populations. With this in mind, the need for studies on older adults and acute responses to exercise should become apparent.

### *2.1 Aerobic Capacity*

During exercise, the cardiovascular and respiratory systems work to deliver oxygenated blood to the working muscles. This is crucial as oxygen ($O_2$) is necessary for aerobic work. However, skeletal muscle has adapted to meet metabolic needs by utilizing energy pathways, either in the presence (i.e. aerobic) or in the absence (i.e. anaerobic) of $O_2$ (Spriet, Soderlund, Bergstrom, & Hultman, 1987). Such pathways are referred to as oxidative phosphorylation and substrate phosphorylation, respectively (Spriet et al., 1987). Additionally, both pathways synthesize adenosine triphosphate (ATP) from adenosine diphosphate (ADP) and inorganic phosphate (Pi) (Spriet et al., 1987).

The aerobic system requires $O_2$ to support working muscles with ATP (Gastin, 2001). The metabolic production of ATP aims to provide the energy required for maintaining skeletal muscle contractions (i.e. generation of force and ultimately work) at a sustainable rate (Gastin, 2001). Additionally, the aerobic system aims to adequately respond to changes in metabolic demands such as at the onset of exercise when demand significantly increases from rest (Gastin, 2001). However, at high demands, the maximal rate of aerobic ATP production is insufficient (Spriet et al., 1987). That is, as exercise intensity increases and reaches above maximal efforts, there is a greater mismatch between aerobic ATP production and demand (Spriet et al., 1987). As a result, when the aerobic system is unable to sustain the rate of ATP synthesis the anaerobic systems supply energy until fatigue (Spriet et al., 1987).

Anaerobic systems provide muscle cells with immediate energy by breaking down high-energy phosphate compounds and stored ATP, as well as muscle glycogen via glycolysis (Gastin, 2001). The latter leading to lactate production (Gastin, 2001). Specifically, anaerobic metabolism is defined as the production of ATP without the immediate use of $O_2$ (Spriet et al., 1987). Thus, anaerobic systems are essential when exercise intensity is above maximal efforts and the maximal rate of ATP production is less than what is required by the working muscles (Spriet et al., 1987). However, a rapid reduction in phosphate compounds and accumulation of lactate leads to fatigue and eventually the cessation of exercise (i.e. short bursts of high energy) (Spriet et al., 1987).

To summarize, aerobic ATP production is the dominant system involved in sustaining work at lower demands of exercise (i.e. submaximal) however, as the metabolic demand reaches above maximal efforts the anaerobic systems work to support metabolism (i.e. supramaximal). Additionally, it is evident that each system has its limitations; anaerobic systems produce ATP at higher workloads however, the amount of available ATP is limited (Spriet et al., 1987). Whereas, the aerobic system can produce and sustain ATP for longer periods of time yet it is limited by the ability to deliver $O_2$ to working muscles (i.e. cardiovascular and respiratory limitations) (Spriet et al., 1987).

### *2.2. The Fick Equation*

Aerobic capacity (i.e. $VO_2$) is the amount of $O_2$ the body is able to deliver and utilize for metabolic purposes. This requires an integrative response of the cardiovascular, pulmonary, and neuromuscular systems. Specifically, $VO_2$ is the product of cardiac output (Q) and the arteriovenous difference ($(a\text{-}v)O_{2diff}$) and is summarized by the Fick equation (Albouaini, Egred, Alahmar, & Wright, 2007; Beck et al., 2006; Lundby, Montero, & Joyner, 2017). The Fick equation, as shown below, thereby establishes the relationship between a number of cardiopulmonary variables and oxidative metabolism at rest and during exercise, as each of the components are further influenced by other systems in the body (Albouaini et al., 2007; Beck et al., 2006; Lundby et al., 2017).

$$\mathbf{VO_2 = Q \times (a\text{-}v)O_{2diff}}$$

$$\mathbf{VO_2 = (SV \times HR) \times (a\text{-}v)O_{2diff}}$$

Where

Q = cardiac output (L/min)

SV = stroke volume (ml)

HR = heart rate (bpm)

$VO_2$ = oxygen consumption (ml/kg/min)

$(a\text{-}v)O_{2diff}$ = oxygen content of arterial blood – oxygen content of mixed venous blood (ml/100ml)

The greatest amount of $O_2$ that can be consumed and/or utilized by an individual is known as $VO_{2MAX}$ (Albouaini et al., 2007; Figueira, Caputo, Machado, & Denadai, 2008). Current literature suggests there are two rate-limiting steps of $VO_{2MAX}$: $O_2$ delivery (i.e. Q) and $O_2$ uptake (i.e. $(a\text{-}v)O_{2diff}$) (Figueira et al., 2008; Hughson, Tschakovsky, & Houston, 2001; McNarry, Kingsley, & Lewis, 2012). That is, $VO_{2MAX}$ is defined by limitations of the cardiopulmonary variables of the Fick equation (Albouaini et al., 2007; Beck et al., 2006). Previous research has found however, that $VO_{2MAX}$ is generally attained as a result of reduced Q and $O_2$ extraction limitations (Beck et al., 2006). Moreover, in healthy individuals, the aerobic response to exercise is linear where $VO_2$ increases until $VO_{2MAX}$ is attained and thereafter $VO_2$ plateaus (Albouaini et al., 2007). The cardiovascular responses to exercise are relatively similar: Q and HR increase linearly, SV increases linearly with a plateau at around 40 to 50% $VO_{2MAX}$, and the $(a\text{-}v)O_{2diff}$ increases as a result of increased metabolism (i.e. $O_2$ uptake) (Albouaini et al., 2007; Astrand, Cuddy, Saltin, & and Stenberg, 1964; Beck et al., 2006; Gulati et al., 2010; Robbins, 1999; Robinson, Epstein, Beiser, & Braunwald, 1966; Vella & Robergs, 2005).

Cardiopulmonary responses of Q, SV, HR, $VO_2$ and $(a\text{-}v)O_{2diff}$ to submaximal and maximal exercise have been compared between males and females (Astrand, Cuddy, Saltin, & and Stenberg, 1964; Astrand & Saltin, 1961; Beck et al., 2006; Ogawa et al., 1992; Proctor et al., 1998; Sullivan, Cobb, & Higginbotham, 1991; Wheatley, Snyder, Johnson, & Olson, 2014). Wheatley et al., noted that females required greater cardiovascular efforts to meet the same demands during exercise in comparison to males (2014). At maximal exercise, similar observations have been noted; Q and SV are lower in females (Ogawa et al., 1992). In contrast, no differences in Q and SV during submaximal exercise have also been noted between males and females (Sullivan et al., 1991). Additionally, reductions in SV and HR during submaximal and maximal exercise have been attributed to increased age in both sexes (Ogawa et al., 1992). Interestingly, reductions are greatest in older untrained females (Ogawa et al., 1992; Proctor et al., 1998). This may suggest that the effects of aging on cardiopulmonary fitness and/or aerobic capacity may be greater in females due to menopause. Previous research has found that arterial compliance, as measured with systolic blood pressure, during submaximal exercise is greater in females who are not using hormone replacement therapy (Green et al., 2002; Pines et al., 1996). Although no differences in $VO_2$ have been observed during submaximal and maximal exercise between females on hormone replacement and those not on therapy (Green et al., 2002; Pines et al., 1996; Stathokostas, Kowalchuk, Petrella, & Paterson, 2008), it is evident that menopause plays a role on the cardiovascular system and is associated with pathologies like coronary heart disease (Carr, 2003; Grodstein, Manson, & Stampfer, 2006).

The integrative cardiopulmonary responses during exercise can be assessed using a non-invasive approach by measuring: the aerobic response (i.e. $VO_2$) and acute ventilatory responses such as minute ventilation ($V_E$) using direct gas analysis (Crouter, Antczak, Hudak, DellaValle, & Haas, 2006), HR and its cardioautonomic derived health indices of heart rate recovery ($HR_{REC}$) and heart rate variability (HRV) using wireless HR monitoring (Weippert et al., 2010), Q and SV using impedance cardiography, and oxygenation of working muscles using near infrared spectroscopy to calculate the tissue saturation index (TSI) (Boushel et al., 2001; Jones, Hesford, & Cooper, 2013). These non-invasive techniques are better suited to laboratory research targeting older adults, as invasive techniques are costly and less appealing to participants. For example, true $(a\text{-}v)O_{2diff}$ can be collected through catherization (Cuschieri et al., 2005) and the standard methods for collection of Q are the direct Fick method (i.e. catherization) and rebreathing techniques (Hoeper et al., 1999). However, these methodologies are quite impractical during exercise which is why current research aims to study the cardiovascular responses to exercise using non-invasive methodologies.

### *2.3 Exercise Protocols*

*2.31 Exercise Type*

The three types of protocols that will be discussed are moderate intensity continuous exercise (MOD), high intensity interval exercise (HI), and sprint intensity interval exercise (SPRT). For the purpose of this thesis peak power output (PPO), also known as the maximal workload attained during a maximal exercise test, was used to determine the intensities for the MOD and HI protocols (Bentley & McNaughton, 2003; McNaughton, Roberts, & Bentley, 2006) whereas body weight was used to determine intensity for the SPRT protocol (i.e. 0.05kg/kg body weight) (Gillen et al., 2016; Gillen et al., 2014). PPO provides information on aerobic performance (Bentley & McNaughton, 2003; McNaughton et al., 2006). Additionally, a significant relationship between PPO and $VO_{2MAX}$ has been observed which allows for the prediction of $VO_{2MAX}$ from PPO (Hawley & Noakes, 1992). Thus, PPO can be used to prescribe the workload or intensity of a cycling exercise in lieu of common prescription variables such as maximal HR or $VO_{2MAX}$.

*2.32 Continuous Exercise: Moderate Intensity*

MOD is a form of continuous exercise performed at moderate intensity for the entirety of the session. Certain variables which have been previously implemented to prescribe intensity include maximal HR,$VO_{2MAX}$, and PPO (MacInnis & Gibala, 2017; Ramos, Dalleck, Tjonna, Beetham, & Coombes, 2015). For example, a moderate intensity level is one which increases HR from 60 to 70% of $HR_{MAX}$, increases $VO_2$ from 60 to 75% of $VO_{2MAX}$, and work output from 50 to 65% of PPO (Currie, Dubberley, McKelvie, & MacDonald, 2013; Klonizakis et al., 2014; MacInnis & Gibala, 2017; Ramos et al., 2015). Additionally, exercise sessions generally last 30 to 60 minutes (MacInnis & Gibala, 2017; Ramos et al., 2015). MOD has been observed to improve vascular function (i.e. dilation of arterial walls), cardiopulmonary fitness (e.g. $VO_{2MAX}$), and cardiovascular disease risk factors (e.g. blood pressure and weight) (Ramos et al., 2015). However, when compared to interval exercise such as HI, MOD has shown to be less effective at improving the above measures (Ramos et al., 2015).

*2.33 Interval Exercise: High and Sprint Intensity*

Interval exercise is based on repeated bouts of high intensity exercise which has individuals at or above their lactate threshold separated by lower intensity recovery periods (Billat, 2001; Currie et al., 2013; Faria, Parker, & Faria, 2015; Gillen et al., 2016; Gillen et al., 2014; Klonizakis et al., 2014; Ramos et al., 2015). Moreover, two common types of interval exercise are HI and SPRT. However, HI exercise is based on exercise intensities below $VO_{2MAX}$ (i.e. submaximal) whereas SPRT is supramaximal (MacInnis & Gibala, 2017). Supramaximal refers to an exercise intensity greater than or equal to 100% $VO_{2MAX}$ (Gist, Fedewa, Dishman, & Cureton, 2014). As mentioned earlier, anaerobic systems are essential when exercise intensity is above maximal efforts (i.e. supramaximal and above the lactate threshold) (Spriet et al., 1987). Thus, SPRT protocols are a form of anaerobic exercise. Additionally, HI sessions require a constant load (i.e. consistently 90% PPO during each high intensity interval) whereas SPRT sessions use an "all-out" approach throughout each high intensity interval, and is therefore effort dependent (Buchheit & Laursen, 2013). Nonetheless, this form of exercise has been found to improve $VO_{2MAX}$ and the oxidative potential of skeletal muscle (Burgomaster et al., 2008; Burgomaster, Hughes, Heigenhauser, Bradwell, & Gibala, 2005; Cocks et al., 2016; Gillen et al., 2016).

The variables which have been previously used to prescribe intensity in HI protocols are: $HR_{MAX}$, $VO_{2MAX}$, and PPO (MacInnis & Gibala, 2017; Ramos et al., 2015). HI protocols include a series of high intensity intervals followed by lower intensity recovery periods (Buchheit & Laursen, 2013; Gillen & Gibala, 2014; Karlsen, Aamot, Haykowsky, & Rognmo, 2017). For example, a high intensity level is one which increases HR from 85 to 95% of $HR_{MAX}$ and one which increases $VO_2$ from 80% to 90% of $VO_{2MAX}$ (Buchheit & Laursen, 2013; Karlsen et al., 2017). A popular HI protocol is a form of low-volume HI which consists of 10 minutes of high intensity exercise at 90% PPO and the total exercise session is less than 30 minutes, including warm-up and cool-down (Gillen & Gibala, 2014). This has been used safely and effectively in a variety of populations including individuals with chronic obstructive pulmonary disease, type 2 diabetes, and metabolic disease (e.g. elevated blood pressure and obesity) (Kortianou, Nasis, Spetsioti, Daskalakis, & Vogiatzis, 2010; Little et al., 2011; Metcalfe, Babraj, Fawkner, & Vollaard, 2012; Tjonna et al., 2008; Weston, Wisloff, & Coombes, 2014). During SPRT sessions, the workload or intensity is dependent on body weight (kg) and varies due to increasing levels of fatigue (Bar-Or, 1987; Beneke, Pollmann, Bleif, Leithauser, & Hutler, 2002; Cocks et al., 2016). The most common SPRT protocol is made up of a series of Wingate tests (e.g. 4-6x30s all-out at 7.5% bodyweight) with 4-minute recovery periods in between each Wingate (Gist et al., 2014). More recently, SPRT protocols that use a 3x20s "all-out" intensity at 5% body weight have shown to be effective as well (Beneke et al., 2002; Gillen et al., 2016; Gillen et al., 2014; Metcalfe et al., 2012).

### *2.4 Central Cardiopulmonary Responses to Exercise*

The Fick equation (section 2.2.) establishes the relationship between a number of cardiopulmonary responses and $VO_2$. When the Fick equation is further reduced, the Q response is the product of SV and HR. That is, increases in Q and thus $VO_2$ are dictated by changes in SV or HR and represent the central component of $O_2$ delivery (Daussin et al., 2008; Lavie et al., 2015). Moreover, SV is affected by vascular function (i.e. cardiac afterload), blood volume (i.e. venous return), and myocardial contractility (Allsager & Swanevelder, 2003; Lundby et al., 2017). Such parameters are further affected by catecholamines, peptides (e.g. growth hormone) and steroid hormones (Lundby et al., 2017). On the other hand, HR is affected by neurohormonal modulations of the autonomic nervous system that may either be involuntary or responsive (Robinson et al., 1966; Valentini & Parati, 2009).

*2.41 Oxygen Consumption*

As mentioned above, $VO_2$ is the result of a number of central and peripheral cardiopulmonary responses. As such responses shift based on the cellular demand of $O_2$, $VO_2$ fluctuates until the point in which $VO_2$ is limited by the maximal rate of $O_2$ delivery and/or utilization (i.e. $VO_{2MAX}$) (Albouaini et al., 2007). Additional factors which may affect $VO_{2MAX}$ include: genetic factors, the mass of exercising/working muscle, age, sex, body mass, and even motivation (Albouaini et al., 2007). In healthy individuals, it is expected for $VO_2$ to plateau at near maximal efforts (Albouaini et al., 2007). That is, a linear relationship exists between $VO_2$ and workload until intake plateaus and/or declines (Mitchell, Sproule, & Chapman, 1958). Additionally, the exercise mode (i.e. cycle ergometer vs. treadmill) used in studies may affect the results as ergometry primarily uses leg muscles and thus, places more stress on peripheral responses than central cardiac factors (Cunningham, McCrimmon, & Vlach, 1979). Nonetheless, there is large a variability in the $VO_2$ response to maximal exercise (Williamson, Atkinson, & Batterham, 2017).

***Sex and Age Differences***

$VO_{2MAX}$ has been found to decrease with age (Esfandiari, Sasson, & Goodman, 2014; Ogawa et al., 1992). For example, in a study by Esfandiari et al., males aged 20 to 29 years had a $VO_{2MAX}$ of 44.7 ± 3.9 ml/kg/min and males aged 40 to 49 years had a $VO_{2MAX}$ of 35.4 ± 3.3

ml/kg/min (2014). It is suggested that this observation is the result of decreased maximal Q with age (Ogawa et al., 1992). Additionally, between sedentary and trained males aged 25 to 65 years, the estimated rate of decline in $VO_{2MAX}$ was found to 40% slower in trained males (Ogawa et al., 1992). In females, $VO_{2MAX}$ is generally lower when compared to males at maximal and submaximal exercise (Ogawa et al., 1992; Wheatley et al., 2014), partly due to limitations in cardiac performance as suggested by Wheatley et al. (2014). That is, females need to work harder at the same absolute intensity. Further, normalization for body weight between age groups, showed that body composition did not entirely account for the differences in $VO_{2MAX}$ (Ogawa et al., 1992).

*Summary:*

- Females and older individuals have a lower $VO_{2MAX}$ when compared to males and younger individuals, respectively.
- $VO_2$ is the product of a number of cardiopulmonary parameters. Thus, the change in one particular variable will affect the overall $VO_2$ response to exercise.

*Research Gap:*

- There is a lack of research studying the acute $VO_2$ responses during a single bout of HI and SPRT within older healthy males and females.

*2.42 Cardiac Output and Stroke Volume*

Early work by Astrand et al., found SV to increase rapidly during the first few minutes of exercise until it plateaued at 40% $VO_{2MAX}$ (1964), suggesting that after a certain % of $VO_{2MAX}$, SV is unable to increase, despite an increase in intensity. Four main types of SV responses to exercise have been described in the literature since then: plateau, a plateau with a drop, plateau with a secondary increase, and a progressive increase (Vella & Robergs, 2005). Further, conflicting observations in SV exist between trained and untrained individuals (Vella & Robergs, 2005).

As mentioned earlier, Q is the product of SV and HR. Moreover, Q is the total volume of blood ejected from the left ventricle per minute (Allsager & Swanevelder, 2003). Additional parameters which influence SV and thus Q include myocardial contractility, preload (i.e. venous return), and afterload (Allsager & Swanevelder, 2003; Lundby et al., 2017). In young trained males, similar maximal Q responses were observed across endurance exercise (i.e. 45 minutes at 70% $HR_{MAX}$), short interval HI, and long interval HI exercise protocols (i.e. 15s intervals at 90% $HR_{MAX}$ vs. 4 minute intervals at the same intensity), prior to exercise training (Helgerud et al., 2007). It was suggested that the improvement in $VO_{2MAX}$ was a result of increased SV that led to improvements in Q (Helgerud et al., 2007).

In sedentary males, similar maximal Q responses have been observed between HI (i.e. 95-100% $VO_{2MAX}$ intervals) and MOD (i.e. 65% $VO_{2MAX}$) exercise protocols (Esfandiari et al., 2014). However, unlike the study with trained males, both interval and continuous exercise protocols led to improvements in $VO_{2MAX}$ (Esfandiari et al., 2014). In a study of young and older endurance trained males and females, the slope analysis of the $Q/VO_2$ relationship indicated that Q increased with $VO_2$ at similar rates between all groups (Proctor et al., 1998). Moreover, there was no difference in the absolute Q values observed between groups when compared at specific $VO_2$ values (Proctor et al., 1998).

***Sex and Age Differences***

During maximal exercise, Q values have been shown to vary between young and older sedentary individuals (Ogawa et al., 1992). This observation was attributed to lower $HR_{MAX}$ values during maximal exercise in older individuals (Ogawa et al., 1992). That is, approximately 40% of the difference in maximal Q was due to lower HR values in older adults when compared to younger adults. This suggests that with age, Q decreases even in healthy adults (Stratton, Levy, & Cerqueira, 1994). At submaximal intensity, similar Q responses have been observed between young trained males and females (Astrand, Cuddy, Saltin, & and Stenberg, 1964). However, males have shown to attain higher Q values at near maximal intensity (i.e. approximately 100% $VO_{2MAX}$) (Astrand, Cuddy, Saltin, & and Stenberg, 1964). In sedentary middle-aged males, similar Q responses have been observed during interval (i.e. 80-85% $VO_{2MAX}$) and continuous exercise (i.e. 60-65% $VO_{2MAX}$) (Matsuo et al., 2014). At supramaximal intensity (i.e. resistance at 150% of PPO until exhaustion), mean Q values were almost three times higher in young trained males than sedentary older males (Crisafulli, Orru, Melis, Tocco, & Concu, 2003),. Additionally, this study found that Q was lower during passive recovery, in comparison to active recovery, due to decreased muscular engagement causing a faster return to resting HR values (Crisafulli et al., 2003).

In regard to SV, early work observed lower mean values during submaximal and maximal exercise in females when compared to males (Astrand, Cuddy, Saltin, & Stenberg, 1964; Astrand, Cuddy, Saltin, & and Stenberg, 1964). However the increase in SV from rest to maximal intensity increased by the same magnitude, of 50%, in both males and females (Astrand, Cuddy, Saltin, & and Stenberg, 1964). Additional studies have found no differences in resting and submaximal exercise SV between young and older males and females (Proctor et al., 1998); however between sexes the values were lower in females as workload increased. In young males, SV has been observed to continue its increase even at intensities of 90% $VO_{2MAX}$ whereas, older males and younger females plateau at 40% $VO_{2MAX}$ (Proctor et al., 1998). Further, at 70% $VO_{2MAX}$ and above, older females and males are unable to maintain SV (Proctor et al., 1998). Interestingly, the largest decrease in SV was observed in older females when compared to males and younger adults, at near maximal intensity (90% $VO_{2MAX}$) (Proctor et al., 1998). Ogawa et al., also observed the largest decrease in SV from 50% to 100% $VO_{2MAX}$, to occur within older females (1992). Further, Procter et al., found that in trained older females, there was an apparent inability to maintain SV at near maximal intensities when compared to trained males and younger adults (1992). This suggests cardiac limitations in females regardless of fitness levels.

In a study of healthy young and older sedentary and endurance trained males and females, it was found that in all groups, the highest SV was attained at 50% $VO_{2MAX}$ (Ogawa et al., 1992). Moreover, SV was observed to drop between 50% and 100% $VO_{2MAX}$. It must be noted that although the SV response was similar across groups in this particular study, the SV in females was lower at all workloads when compared to males even after normalization for weight (Ogawa et al., 1992). Additional studies have noted similar results, that is, SV reaches its maximum at 50% $VO_{2MAX}$ and then levels off through maximal exercise, in both males and females (Sullivan et al., 1991). The study by Sullivan et al., also found a similar increase in the SV index from rest to exercise in both males and females (1991). It was suggested that sex does not influence the SV response to exercise if healthy individuals are matched for body size and fitness level (Sullivan et al., 1991).

A more in depth study of young and older males found similar SV responses between the groups however, it was found that young males increased SV through increases in pressure work of ejection whereas older males increased SV through increased cardiac dilation (Stratton et al., 1994). However, these significant acute observations did not lead to different adaptations between the groups of young and older males (Stratton et al., 1994). Additional studies found that older adults increase cardiac pressure work during exercise whereas young adults increase cardiac volume work (Ogawa et al., 1992).

*Summary:*

- Males and younger individuals tend to have higher Q and SV values at rest and during submaximal to maximal exercise when compared to females and older adults.

*Research Gap:*

- There is a lack of research comparing the acute Q and SV response to a single bout of HI and SPRT between older males and females.

*2.43 Ventilatory Parameters*

Increased minute ventilation ($V_E$) is an acute response to exercise which serves to increase $VO_2$ and regulate the arterial partial pressure of $O_2$ (i.e. arterial oxygenation) (Bruce, 2017). During submaximal exercise the increase in $V_E$ is proportional to the increases in $VO_2$ and production of carbon dioxide ($VCO_2$); also known as the ventilatory response (Bruce, 2017). However, there is a point in which the ventilatory equivalent of $VO_2$ ($V_E/VO_2$) increases with no change in the equivalent of $VCO_2$ ($V_E/VCO_2$) (i.e. rate of ventilation increases faster than aerobic capacity) (Balady et al., 2010; Gaskill et al., 2001; Myers & Ashley, 1997). This is known as the first ventilatory threshold (VT1) (also a nonlinear increase in ventilation) (Myers & Ashley, 1997). A second ventilatory threshold (VT2), or a second inflection, occurs as a result of further increases in ventilation (Takano, 2000). As a result of a mismatch between ventilation and $VO_2$ (i.e. imbalance between $O_2$ supply and demand), a greater emphasis is placed on anaerobic energy systems (Balady et al., 2010).

***Breathing Volume and Frequency***

As a result of the increased metabolic demands of exercise, breathing volume (i.e. tidal volume; Vt) and frequency increase (RR). That is, Vt increases as a result of an increase in the maximal amount of inhaled air (i.e. inspiratory reserve volume) and through a decrease in the maximal amount of exhaled air (i.e. expiratory reserve volume) (Pellegrino, Brusasco, Rodarte, & Babb, 1993). At moderate intensities, the main respiratory response required to meet $O_2$ demands is for Vt to increase with minimal increases in RR (Sheel & Guenette, 2008). At higher intensities, Vt may plateau once it reaches 50 to 60% of the maximal inspiratory capacity (i.e. vital capacity); thereafter, further increases in $V_E$ are due to increased RR (Sheel & Guenette, 2008). However, smaller lung volumes and thus maximal lung capacities, have been observed in females in comparison to men (Sheel & Guenette, 2008; Sheel, Richards, Foster, & Guenette, 2004). Thus, as $V_E$ increases with intensity, the work of moving air in and out of the lungs is much higher in females (Sheel & Guenette, 2008). For example, at $V_E$ of >90 L/min, females must work twice as hard as men to sustain $VO_2$ (Sheel & Guenette, 2008).

*Summary:*

- $V_E$ increases with exercise intensity in order to increase $VO_2$ however, females must work harder to sustain $VO_2$ when compared to males.

*Research Gap:*

- The comparison of acute ventilatory parameters to a single bout of HI and SPRT within older adults lacks in the literature.

*2.44 Heart Rate*

HR is controlled by the central nervous system through neurohormonal modulations in sympathetic and parasympathetic control of nerve fibers at the sinoatrial node that may either be involuntary or responsive (Robinson et al., 1966; Valentini & Parati, 2009; Yamamoto, Hughson, & Peterson, 1991). In healthy individuals, HR increases in response to exercise as a result of decreased vagal tone, increased sympathetic tone, and circulating catecholamines (Chaitman, 2003). That is, as exercise intensity increases, sympathetic activity increases, which leads to the acceleration of HR (Robinson et al., 1966). Thus, HR increases linearly with intensity.

In previous work with young adults, no significant differences were observed in the average HR response between interval and continuous exercise (Tschakert et al., 2015). However, it was attributed to the matched workloads between the protocols as the exercise sessions were performed for the same duration and load (Tschakert et al., 2015). This is important to note as the HI and MOD exercise protocols included in this thesis are matched for overall workload.

***Sex and Age Differences***

At submaximal and maximal intensities, higher HR responses have been observed in females when compared to males (Sullivan et al., 1991; Wheatley et al., 2014). Although females tend to show higher HR trends during exercise, such increases are not enough to compensate for the lower SV response and thus females demonstrate lower Q responses to exercise, when compared to males (Wheatley et al., 2014). The effect of age has been studied at submaximal intensity; in work by Proctor et al., older males and females had significantly lower peak HR values in comparison to their younger counterparts (1998). Additionally, no differences were observed between sexes and peak HR during submaximal exercise (Proctor et al., 1998). It must be noted that the participants of this study were endurance trained. Ogawa et al., also found similar results in trained and untrained older and younger adults (1992) such that during submaximal and maximal treadmill exercise, similar peak HR values were observed in males and females, regardless of training status or age (Ogawa et al., 1992). Additional studies have also noted no significant differences between sex and average HR during high intensity recreational sports (Boyd et al., 2011).

*Summary:*

- Research shows that females tend to have a higher HR response to submaximal and maximal exercise. However, the HR response to exercise in the current literature is highly variable due to differences in exercise protocols and sample populations.

*Research Gap:*

- There is a lack of research comparing the acute HR response to a single bout of HI and SPRT within older males and females.

*2.45 Heart Rate Recovery*

Heart rate recovery ($HR_{REC}$) indicates the responsiveness of the autonomic nervous system. The intensity of exercise is said to influence the recovery response (Mann, Webster, Lamberts, & Lambert, 2014). In trained runners, $HR_{REC}$, within 1 minute after cessation of exercise, was found to be faster after higher intensities of exercise (i.e. 70 and 80% $VO_{2MAX}$) in comparison to lower intensities (i.e. 60% $VO_{2MAX}$) (Mann, Webster, et al., 2014). Moreover, no significant difference in $HR_{REC}$ was observed between the higher intensities of exercise suggesting that there may be an exercise intensity threshold at which $HR_{REC}$ reaches "saturation" (Mann, Webster, et al., 2014). That is, at maximal intensities, it seems that $HR_{REC}$ within the first minute is delayed (Mann, Webster, et al., 2014). Further, it was suggested that $HR_{REC}$ is independent of intensity when below $VO_{2MAX}$ (Mann, Webster, et al., 2014). However, in a study of young sedentary males, the magnitude of $HR_{REC}$ was similar after interval (i.e. 85% $VO_{2MAX}$ high intervals) and continuous exercise (i.e. 65% $VO_{2MAX}$) (Matsuo et al., 2014).

At supramaximal intensity, HR declines rapidly within 5 minutes of passive seated recovery, plateaus, and then remain significantly elevated above resting values for up to 30 minutes post-exercise (Kilgour, Mansi, & Williams, 1995). However, during sprints (i.e. supramaximal intensity), it is common for individuals to perform the Valsalva maneuver which may possibly affect $HR_{REC}$ (i.e. further increasing HR) (Kilgour et al., 1995). This is important to consider as one of the aims of this thesis is to analyze $HR_{REC}$ after sprints. The type of recovery is also important for $HR_{REC}$. That is, decreased muscular engagement during passive recovery allows for a faster return to resting HR values in comparison to passive recovery (Crisafulli et al., 2003), which in turn will affect $HR_{REC}$.

*Summary:*

- As exercise intensity increases the rate of $HR_{REC}$ decreases (i.e. takes longer to return to baseline values).

*Research Gap:*

- There is a lack of research studying the $HR_{REC}$ response to a single bout of MOD, HI, and SPRT within older adults.

*2.46 Heart Rate Variability*

Heart rate variability (HRV) is the overview of beat to beat fluctuations in HR over time (Perkins, Jelinek, Al-Aubaidy, & de Jong, 2017). The balance and regulation between the sympathetic and parasympathetic divisions of the autonomic nervous system is reflected and analyzed through HRV; also known as sympathovagal balance (Perkins et al., 2017). Sympathetic modulation of autonomic cardiac control is denoted by changes in the low frequency (LF) spectrum and parasympathetic tone is detonated by changes in the high frequency (HF) spectrum (Brennan, Palaniswami, & Kamen, 2002). Most studies use the following power bands to define these: 0.04-0.15 Hz (LF) and 0.15-0.4 Hz (HF) (Brennan et al., 2002; Goshvarpour & Goshvarpour, 2015).

After high intensity exercise, $V_E$ increases significantly, which may have mechanical effects on the sinoatrial node, thus, increasing the HF spectrum (Cottin et al., 2004). In a study comparing HRV after submaximal and supramaximal exercise, LF spectrum was found to be significantly higher than the HF spectrum after submaximal exercise (Cottin et al., 2004). The opposite was seen after supramaximal exercise such that the LF spectrum was significantly lower than the HF spectrum (Cottin et al., 2004). Further spectral density analysis found that after submaximal exercise, the LF spectrum was dominant in comparison to the HF spectrum (Cottin et al., 2004). Additionally, after supramaximal exercise, the HF spectrum was dominant with little to no spectral LF density present (Cottin et al., 2004). Thus, during supramaximal exercise, it seems that autonomic control of HR is less responsive compared to submaximal exercise (Cottin et al., 2004). A limitation to this study however is that it was conducted on well trained adolescents. In a study of older healthy adults, after low intensity exercise (i.e. 30% of PPO), LF and HF spectrums significantly increased during the first minutes of recovery (Martinmaki & Rusko, 2008). After high intensity exercise (i.e. 60% of PPO), the LF spectrum increased for the first three minutes and the HF spectrum increased for the first two minutes (Martinmaki & Rusko, 2008). This is relatively similar to the results of the prior study after submaximal exercise, where the LF spectrum was higher than HF spectrum (Cottin et al., 2004). The main finding from this study was that the HF spectrum increased, along with decreased HR, after both low and high intensity exercise, suggesting heightened activity of the vagal system during the first minute of recovery from exercise (Martinmaki & Rusko, 2008).

***Sex and Age Differences***

Autonomic nervous system activity has been found to fluctuate during the menstrual cycle (Sato, Miyake, Akatsu, & Kumashiro, 1995), such that significant physiological differences may be noted between the follicular and luteal phases (Sato et al., 1995). During the luteal phase, increases in the LF spectrum component and decreases in the HF spectrum component have been observed, resulting in a higher LF/HF ratio (Sato et al., 1995). This suggests that sympathetic nervous system activity is predominant in the luteal phase of the menstrual cycle (Sato et al., 1995). In older individuals, HF and LF spectrum values ($ms^2$/Hz) have been found to be significantly lower in comparison to younger individuals (Liao et al., 1995). For the purposes of this thesis there are no conflicts with hormone fluctuations associated with menstruation.

*Summary:*

- As exercise intensity increases (i.e. from submaximal to supramaximal), the autonomic control of HR is less responsive; partly due to increases in ventilation.

*Research Gap:*

- HRV after a single bout of MOD, HI, and SPRT within older adults has not been previously analyzed.

### *2.5 Peripheral Cardiopulmonary Responses to Exercise*

*2.51 Arteriovenous Oxygen Difference*

Although Q is thought to be the primary determinant of $VO_{2MAX}$, the $(a\text{-}v)O_{2diff}$ also plays a significant role in limiting $VO_{2MAX}$ (Mitchell et al., 1958). The $(a\text{-}v)O_{2diff}$ is the relative difference in $O_2$ content of arterial to mixed venous blood and is a measure of $O_2$ extraction (Albouaini et al., 2007; Lundby et al., 2017). During exercise the $(a\text{-}v)O_{2diff}$ increases due to a decrease in the mixed venous $O_2$ content (i.e. increased $O_2$ extraction) (Albouaini et al., 2007). For example, in healthy males, at rest an $(a\text{-}v)O_{2diff}$ of $6.5 \pm 0.7$ ml/100ml has been observed compared to $14.3 \pm 2.7$ ml/100ml at $VO_{2MAX}$ (Mitchell et al., 1958). It has been suggested that an impaired $(a\text{-}v)O_{2diff}$ would require Q to increase by a factor of 10 to properly support metabolically active tissues (Mitchell et al., 1958). Moreover, the $(a\text{-}v)O_{2diff}$ response to exercise may be affected by skeletal muscle adaptations such as an increased mitochondrial density, or increased capillarization and thus oxidative capacity (Lundby et al., 2017). As such, this would allow for greater $O_2$ extraction (i.e. larger $(a\text{-}v)O_{2diff}$ difference) (Lundby et al., 2017). At exhaustion (i.e. maximal intensity), larger $(a\text{-}v)O_{2diff}$ values have been observed in skeletal muscle of trained individuals versus untrained (Rud, Foss, Krustrup, Secher, & Hallen, 2012).

***Sex and Age Differences***

In females, the lack of estrogen related to menopause has been mentioned as a potential factor for the sex differences in hemodynamic responses to exercise (McCole et al., 1999). McCole and colleagues found the $(a\text{-}v)O_{2diff}$ to increase significantly with exercise intensity (i.e. 40% to 100% $VO_{2MAX}$), in older sedentary, physically active, and athletic females (1999). However, no significant difference in $(a\text{-}v)O_{2diff}$ response to exercise was observed between sedentary, physically active, and athletic females (McCole et al., 1999). In a study of younger and older females, similar peak $(a\text{-}v)O_{2diff}$ values were observed during maximal cycling (Proctor et al., 2004); 12.1 ± 0.8 ml/100ml and 12.3 ± 0.4 ml/100ml, respectively.

A study which looked at the effect of sex, age, and fitness on cardiovascular responses to exercise found a significant difference in $(a\text{-}v)O_{2diff}$ between young and old sedentary males; 15.1 ± 1.4 and 13.6 ± 1.1 ml/100ml, respectively (Ogawa et al., 1992). A significant difference was also observed between older trained and older untrained males; 14.7 ± 1.4 and 13.6 ± ml/100ml, respectively (Ogawa et al., 1992), suggesting that age and fitness had an impact on the $(a\text{-}v)O_{2diff}$ response to maximal exercise (Ogawa et al., 1992). That is, in this particular group of males it was noted that age decreased the $(a\text{-}v)O_{2diff}$ and fitness increased the $(a\text{-}v)O_{2diff}$. In regard to females, Ogawa and colleagues found similar training and age effects on $(a\text{-}v)O_{2diff}$; trained females had higher $(a\text{-}v)O_{2diff}$ and older females had lower $(a\text{-}v)O_{2diff}$ values (1992). A comparison between sexes found a significant difference in young sedentary males and females (i.e. 15.1 ± 1.4 and 13.5 ± 1.0 ml/100ml respectively), and a significant difference between older sedentary males and females (i.e. 13.6 ± 1.1 and 11.9 ± 1.6 ml/100ml respectively) (Ogawa et al., 1992). Similar results were noted in a recent study where females showed a lower $(a\text{-}v)O_{2diff}$ response to submaximal exercise when compared to males (Wheatley et al., 2014).

*Summary:*

- Age decreases and fitness increases the $(a\text{-}v)O_{2diff}$.
- Males show a larger $(a\text{-}v)O_{2diff}$ response during exercise which suggests greater $O_2$ extraction and thus utilization.

*Research Gap:*

- The comparison of an acute $(a\text{-}v)O_{2diff}$ response to a single bout of HI and SPRT within older adults lacks in the literature.

*2.52 Tissue Saturation Index*

The tissue saturation index (TSI), measures the dynamics of tissue oxygenation by quantifying the balance between oxygenated and deoxygenated hemoglobin (Boushel et al., 2001; Ferrari, Radaelli, & Centola, 2003). In turn allowing for insight on $O_2$ delivery to working muscles and $O_2$ consumption of capillary beds in the sampled muscle area (Bendahan, Chatel, & Jue, 2017; Boushel et al., 2001; Ferrari et al., 2003). Previous studies have found larger TSI values to indicate increased $O_2$ delivery (Patterson, Bezodis, Glaister, & Pattison, 2015).

Researchers have observed decreases in blood flow to highly oxidative muscles, during moderate intensity exercise, as a result of ageing (DeLorey, Kowalchuk, & Paterson, 2004; Donato et al., 2006; Lawrenson, Hoff, & Richardson, 2004; Poole, Behnke, & Musch, 2006). In younger females, the leg vasodilatory response to dynamic leg exercise has been found to be greater than males (Parker, Smithmyer, Pelberg, Mishkin, & Proctor, 2008). However, in older females during peak exercise, decreases in leg blood flow and estimated leg vascular conductance have been observed (Proctor et al., 2004). It was suggested that this reduction is a result of both reduced central (i.e. Q) and peripheral limitations (i.e. reduced vascular delivery) (Proctor et al., 2004).

***Sex and Age Differences***

A study of untrained and trained post-menopausal females, performing submaximal exercise, found that trained women have faster $VO_2$ kinetics in comparison to untrained women; suggesting that there may be a training effect which improves $O_2$ delivery to tissues (Dogra, Spencer, Murias, & Paterson, 2013). Additional studies at maximal exercise, have found reduced blood flow in older females by 30% when compared to young females (Proctor et al., 2004).

*Summary:*

- TSI measures the dynamics of tissue oxygenation.
- Aging decreases blood flow to highly oxidative muscles.

*Research Gap:*

- The acute TSI response to a single bout of MOD, HI and SPRT within older adults has not been previously described in the literature.

### *2.6 Rationale and Purpose*

Research has focused on improvements in cardiopulmonary outcomes to continuous and interval exercise (Daussin et al., 2007; Daussin et al., 2008; Eddy, Sparks, & Adelizi, 1977; Esfandiari et al., 2014; Gillen et al., 2016; Gist et al., 2014; Matsuo et al., 2014; Montero & Lundby, 2017; Ross, de Lannoy, & Stotz, 2015; Whipp & Ward, 2009; Wisloff, Ellingsen, & Kemi, 2009). Additionally, sex and age differences in cardiopulmonary responses, autonomic cardiac modulation, and respiratory function have been previously investigated (Astrand, Cuddy, Saltin, & and Stenberg, 1964; Boyd et al., 2011; Liao et al., 1995; Mann, Lamberts, & Lambert, 2014; Ogawa et al., 1992; Sheel & Guenette, 2008; Sheel et al., 2004; Sullivan et al., 1991; Wheatley et al., 2014). This is important as exercise has been shown to be important for the prevention and management of several chronic conditions (Kortianou et al., 2010; Little et al., 2011; Metcalfe et al., 2012; Tjonna et al., 2008; Weston et al., 2014). However, studies assessing acute cardiopulmonary responses to different intensities of exercise are limited, particularly in older adults.

Moreover, studies have shown that cardiopulmonary responses to exercise are highly variable (Bonafiglia et al., 2016; Bouchard & Rankinen, 2001; de Lannoy, Clarke, Stotz, & Ross, 2017; Mann, Lamberts, et al., 2014; Montero & Lundby, 2017; Ross et al., 2015). That is, some individuals may not respond to a given dose of exercise which is associated with significant benefits among others (Bonafiglia et al., 2016; Bouchard & Rankinen, 2001; Chmelo et al., 2015; Hautala et al., 2006; Karavirta et al., 2011; Mann, Lamberts, et al., 2014; Montero & Lundby, 2017; Ross et al., 2015; Scharhag-Rosenberger, Walitzek, Kindermann, & Meyer, 2012; Weatherwax, Harris, Kilding, & Dalleck, 2016). As such, there is a need for studies which assess acute responses to exercise in order to help identify what exercise doses and protocols maximize physiological adaptations; further ensuring that individuals benefit from the activities they engage in. Thus, the purpose of the following research was **1)** to describe acute cardiopulmonary responses to MOD, HI, and SPRT and **2)** to compare such responses between the different exercise protocols, in healthy older adults.

### *2.7 Research Question*

i. What are the acute cardiopulmonary responses of $VO_2$, $V_E$, Vt, RR, HR, $HR_{REC}$, HRV, and TSI to MOD, HI, and SPRT in healthy older males and females?

*2.8 Hypotheses*

For each cardiopulmonary parameter being assessed, a hypothesis is available below. These hypotheses are based on the literature reviewed above.

I. **$VO_2$:** We hypothesize that SPRT will lead to the *highest $VO_2$ response* when compared to MOD and HI because an "all-out" intensity against 0.05kg/kg body weight will lead to a supramaximal workload, and thus a higher $VO_2$ than that attained at submaximal intensities of MOD and HI.

II. **Ventilation:** We hypothesize that SPRT will also lead to the *highest $V_E$, Vt, and RR* responses because ventilatory parameters will increase in order to meet the demands of the higher $VO_2$.

III. **HR:** We hypothesize MAX, HI, and SPRT will lead to *similar responses in HR* because HR increases linearly with intensity but is typically achieved before $VO_{2MAX}$.

IV. **Cardioautonomic:** We hypothesize that *$HR_{REC}$ will be slowest* after SPRT because the autonomic nervous system will be stimulated the most by SPRT and thus will require more sympathetic withdrawal to return to resting values (i.e. longer time).

V. **Cardioautonomic:** We hypothesize that *post exercise* HRV parameters of LF and HF will be *greater than resting values* because of heightened activity of the vagal system during the first minute of recovery from exercise.

VI. **TSI:** We hypothesize that SPRT will lead to the *highest TSI response* because TSI quantifies the dynamics of tissue oxygenation. Thus, during the high metabolic demands of SPRT, oxygen consumption and delivery should increase.

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## Chapter 3. Manuscript

# High Intensity Exercise and Healthy Older Adults:

# Does Fitness Affect the Acute Cardiopulmonary Responses?

### *3.1 Abstract*

PURPOSE: To describe the acute cardiopulmonary responses to different intensities of exercise in healthy older adults. METHODS: Participants completed five laboratory sessions: 1) maximal exercise test familiarization 2) maximal exercise test (MAX) to determine maximal oxygen consumption ($VO_{2MAX}$) and peak power output (PPO) for prescription of intensity of subsequent sessions and, 3-5) the following in random order, high intensity interval exercise (HI; 1 minute 90% PPO followed by 1 minute 10% PPO, x10), continuous moderate intensity exercise (MOD; 20 minutes at 50% PPO), and sprint intensity interval exercise (SPRT; 20 second "all-out" sprints followed by 2 minutes of 50W, x3). Oxygen consumption ($VO_2$), ventilation ($V_E$), tidal volume (Vt), respiratory rate (RR), heart rate (HR), tissue saturation index (TSI) of the vastus lateralis and rated perceived exertion (RPE) were monitored during all exercise sessions. Heart rate recovery ($HR_{REC}$) was assessed after each exercise session and heart rate variability (HRV) was compared using pre-exercise and active-recovery values. Participants were split into high and low fit groups based on the median $VO_{2MAX.}$ RESULTS: Thirty healthy older adults (69.6 ± 6.2 yrs.) completed all protocols. Data indicated that high fit individuals attained the highest $VO_2$ peak during MAX while low fit females attained a higher $VO_2$ peak during SPRT compared to MAX. The slope of $HR_{REC}$ ($R^2$) was fastest in high fit males. CONCLUSION: The comparison of acute cardiopulmonary responses to different intensities of exercise indicates that responses are variable in an older population.

**Keywords:** older adults, aging, cardiopulmonary responses, sprint exercise, high intensity exercise, interval exercise

### *3.2 Introduction*

Interval exercise has been introduced as an alternative to traditional endurance training due to its time efficiency and effectiveness (Gibala et al., 2006; Gillen & Gibala, 2014; Gist, Fedewa, Dishman, & Cureton, 2014). The most commonly studied interval protocols include high intensity interval (HI), which is performed at near maximal intensities, and repeated sprint intensity interval exercise (SPRT) which is performed at supramaximal intensity (MacInnis & Gibala, 2017). Research comparing the improvements in a variety of parameters such as cardiopulmonary fitness (Bacon, Carter, Ogle, & Joyner, 2013; Gillen et al., 2016; Jimenez-Pavon & Lavie, 2017), skeletal muscle oxidation (Burgomaster et al., 2008), glucose metabolism (de Lannoy, Clarke, Stotz, & Ross, 2017), lactate threshold (Bonafiglia et al., 2016), and even enjoyment (Stork, Gibala, & Martin Ginis, 2018) after interval exercise protocols indicate that such interval exercise is either superior or equivalent to moderate intensity continuous exercise (i.e. endurance training) (Daussin et al., 2007; Daussin et al., 2008; Esfandiari, Sasson, & Goodman, 2014; Gibala et al., 2006; Gillen et al., 2016; Gillen et al., 2014; MacInnis & Gibala, 2017). However, the study of acute cardiopulmonary responses between MOD and interval exercise (i.e. HI and SPRT) is not well described, particularly in older adults (Falz et al., 2019).

This is crucial as healthy aging is related to a number of complex physiological changes (Ferrari, Radaelli, & Centola, 2003; Gerstenblith, 2000; Pugh & Wei, 2011). Functional alternations of the cardiovascular system occur as a result of either central (i.e. at the level of the heart) or peripheral (i.e. vascular based) modifications (Ferrari et al., 2003; Pugh & Wei, 2011). As such, the acute exercise response of the cardiovascular system is blunted when comparing older adults to younger adults. In particular, cardiac output (Q) has been found to be lower in older adults during maximal exercise when compared to younger adults (Fleg et al., 1995; Ogawa et al., 1992);

maximal Q is reached through further increases in stroke volume (SV) which compensate for a blunted heart rate (HR) response in older adults (Fleg et al., 1995; Ogawa et al., 1992; Rodeheffer et al., 1984).

Additional parameters which have been observed to change with increasing age include lung function (McClaran, Babcock, Pegelow, Reddan, & Dempsey, 1995). McClaran et al., found the minute ventilation ($V_E$) response at maximal exercise to be primarily driven by increases in respiratory rate (RR), rather than tidal volume (Vt) in older adults, indicating worse ventilatory efficiency (1995). Further, at any given $V_E$, RR was found to be larger in older adults when compared to middle-aged adults during baseline testing (McClaran et al., 1995). This suggests that the ventilatory stress, and thus work associated with exercise may increase with age (McClaran et al., 1995).

Given the physiological changes observed in cardiovascular and respiratory physiology with aging, it is not surprising then that maximal oxygen consumption ($VO_{2MAX}$) decreases with increasing age (Dehn & Bruce, 1972; Gitlin et al., 1992; Kohrt et al., 1991; Ogawa et al., 1992; Panton et al., 1996). A further contributor to lower $VO_{2MAX}$ in older adults may be related to age-associated changes in the cardioautonomic system as the responses of heart rate recovery ($HR_{REC}$) and heart rate variability (HRV), at rest and after exercise training are blunted in older adults (Buchheit et al., 2004; Danieli et al., 2014; Liao et al., 1995; Pichot et al., 2005; Soares-Miranda, 2014; Stein, Ehsani, Domitrovich, Kleiger, & Rottman, 1999; Stein, Kleiger, & Rottman, 1997; Tulppo, Makikallio, Seppanen, Laukkanen, & Huikuri, 1998). At rest, HRV has been observed to be lower in older adults (Liao et al., 1995; Tulppo et al., 1998); however, little research is available on the acute response to exercise.

Finally, the age-associated loss of muscle mass (Goodpaster et al., 2006). may also contribute to the lower $VO_{2MAX}$ in older adults. The loss of mass may have implications on the metabolic demands and delivery of $O_2$ to working muscles. Previously, tissue oxygen saturation (TSI), has been studied during exercise as it provides information on the dynamics of tissue oxygenation by quantifying the balance between oxygenated and deoxygenated hemoglobin (Boushel et al., 2001; Ferrari et al., 2003). Studies have found larger TSI values to indicate increased $O_2$ delivery (Patterson, Bezodis, Glaister, & Pattison, 2015). However, the acute response of TSI to exercise in older adults lacks in the literature.

Thus, the main purpose of the present study was to describe the acute cardiopulmonary responses to a single bout of exercise. Particularly, we were interested in documenting the acute responses of $VO_2$, VE, RR, Vt, HR, $HR_{REC}$, HRV and TSI to MOD, HI, and SPRT exercise. We hypothesized that in older adults, sprint exercise would 1) lead to the highest $VO_2$ response and thus, 2) the highest $V_E$, Vt, and RR responses, 3) the slowest rate of $HR_{REC}$, 5) the lowest increase in HRV from rest, and 6) the largest TSI response due to the intensity being supramaximal.

### *3.3 Methods*

#### *3.31 Study Design*

A randomized crossover design was used. Participants attended five laboratory sessions, each separated by one week. All exercise sessions were performed at the same time of day and on the same day of the week. Participants were instructed to abstain from consuming caffeine and alcohol for 12 hours and from vigorous exercise for 24 hours prior to their session. During session one, participants were familiarized with a maximal incremental exercise test and with equipment to be used for the remainder of the study. In session two, participants completed a maximal exercise test (MAX).

*3.32 Exercise Protocols*

The remaining sessions (three to five) consisted of the following protocols conducted in random order: 1) MOD: 50% PPO for 20 minutes, 2) HI: 1 minute 90% PPO followed by 1 minute 10% PPO, repeated 10 times, and 3) SPRT: 20 second "all-out" intensity sprints against 0.05kg/kg body weight followed by 2 minutes at 50W, repeated 3 times. During each protocol, participants were instructed to remain ±10 rpm of their preferred cadence. All protocols included a 2-minute warmup at 10% PPO and 5-minute active recovery at 10% PPO (Figure 1).

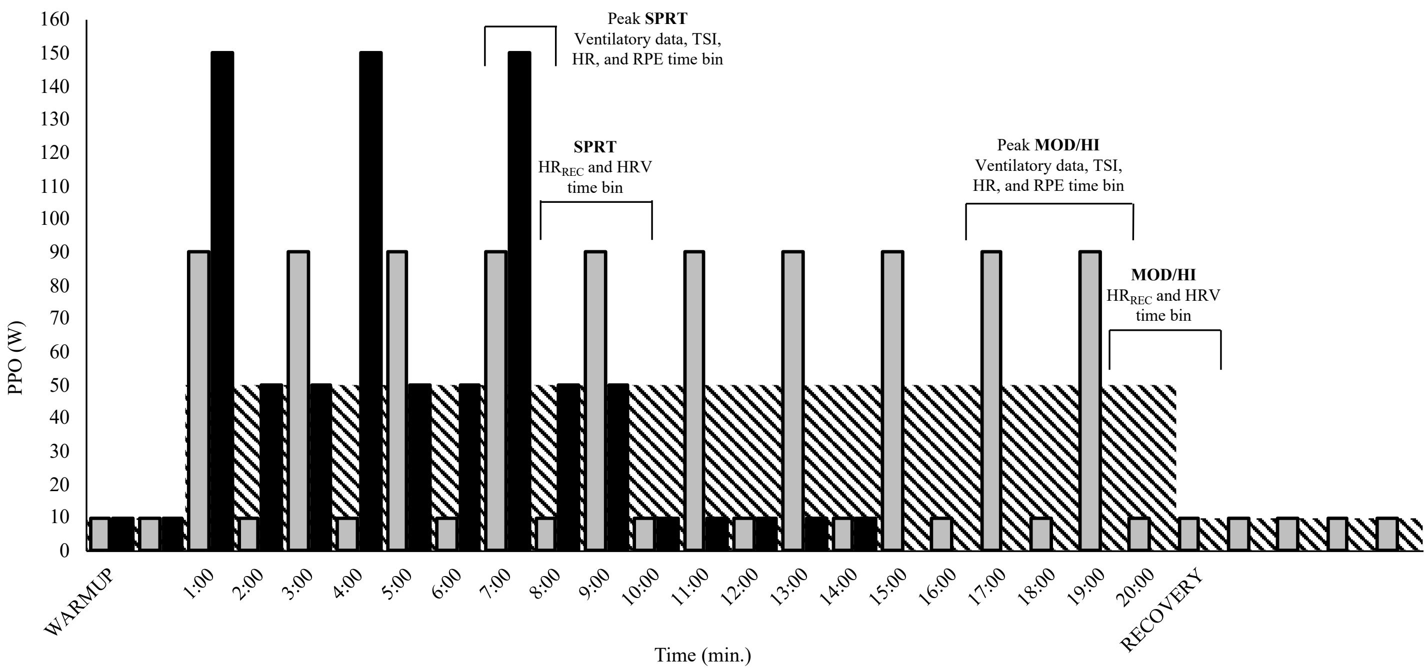


**Figure 1:** Schematic protocol of exercise sessions. MOD (broken lines), HI (grey bars), and SPRT (black bars). Black bars for the 20 second sprints of SPRT indicate an expected average PPO.

PPO was determined from MAX as the highest attained value, in Watts (W). For this, participants cycled on an ergometer (Lode Excalibur Sport; Lode Medical Technology, Gronigen, Netherlands) starting at 25W at a preferred cadence within a range of 50-90 rpms. The work rate was then increased by 1W every 3 seconds; participants were verbally encouraged to continue cycling until they reached volitional exhaustion, that is, until they were unable to maintain cadence. The flow diagram of the study can be found in Figure 2.

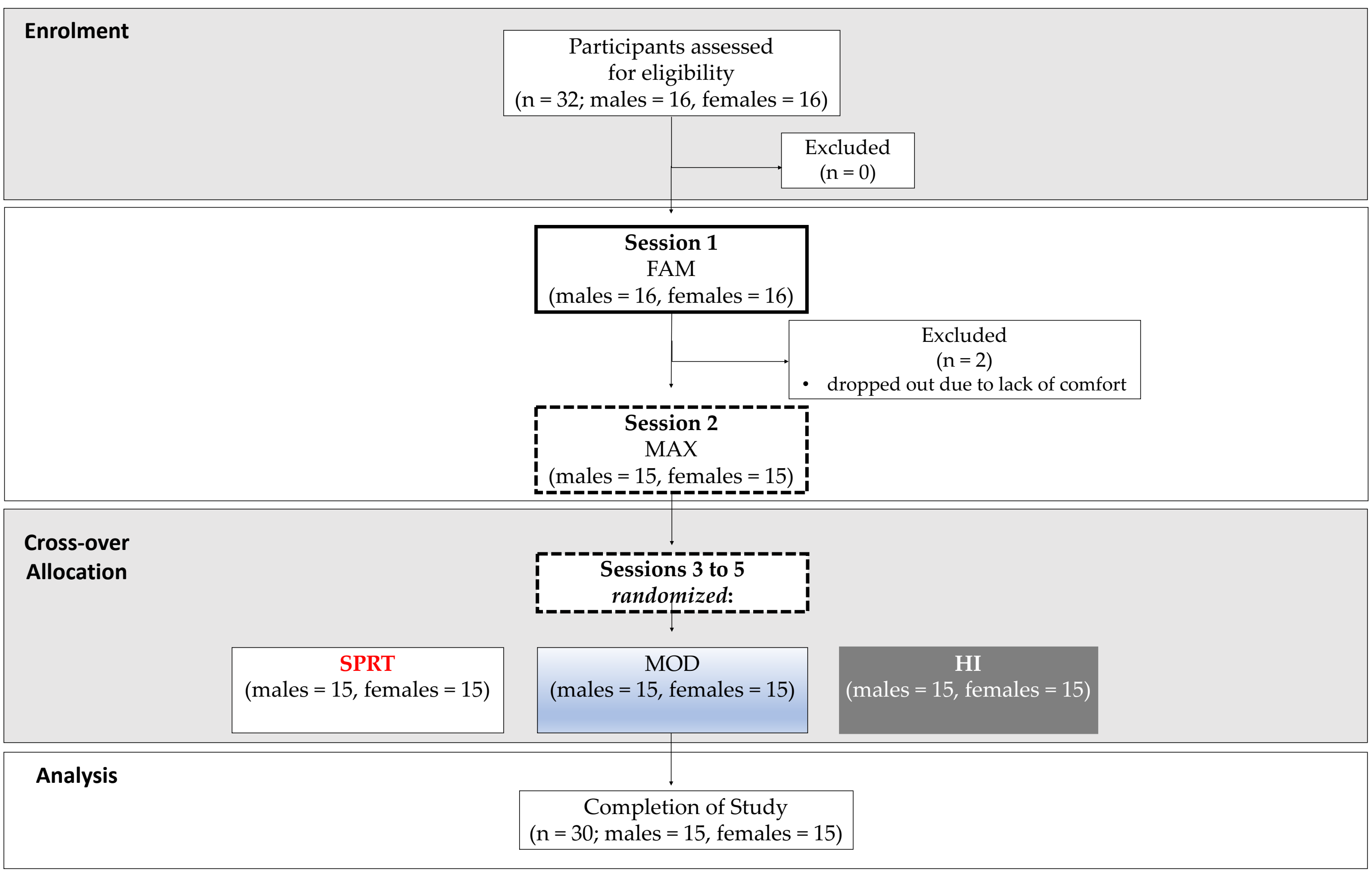


**Figure 2:** Study flow diagram.

*3.33 Participants*

Eligible participants were adults aged 60 years and older with no smoking history, respiratory, cardiovascular, or metabolic disease. Inclusion was also limited to those who were not taking any of the following medications: beta blockers, calcium channel blockers (i.e. hypertensive medication), insulin, corticosteroids (i.e. asthma medication), and antibiotics. Participants were recruited from cycling clubs and recreational centers. All participants provided written and informed consent prior to voluntary participation in the study. This study was approved by the Ontario Tech University Research Ethics Board (REB 14896).

*3.34 Measures*

$VO_2$, $VCO_2$, and $V_E$, RR, Vt, and RER were continuously measured and recorded during exercise (TrueOne 2400; Parvo Medics, Murray, Utah USA). Expired airflow and gases were collected using a two-way valve (Hans Rudolph Inc, Shawnee KS, USA) connected to the Parvo Medics 4L mixing chamber using a corrugated plastic flexible hose. The Parvo Medics system was calibrated for expired gas using room air (20.99% $O_2$, 0.04% $CO_2$) and ventilation using a 3L syringe (Hans Rudolph Inc, Shawnee, KS, USA) every morning before exercise sessions.

Ventilatory data were summarized in 10 second intervals and digitally exported to Microsoft Excel (Version 16.25) for analysis. Values that were ± 10 units from neighbouring values were deemed as outliers and manually removed (without removing more than 5% of raw data). Peak ventilatory values were calculated as a mean of 20 seconds using the highest values from minutes 17:00 to 20:00 of MOD and HI and from minutes 6:40 to 8:00 of SPRT (Figure 1).

$VO_{2MAX}$ was calculated as the highest mean recorded over 20 seconds (i.e. equivalent to 5 breaths). Our criteria for the maximal exercise test were volitional fatigue, an RER >1.15, and a plateau in $VO_2$ with an increase in workload. Participants were categorized as low fit (females: <

20 ml/kg/min; males: < 27 ml/kg/min) and high fit (females: > 20 ml/kg/min; males: >27 ml/kg/min) based on a sex-specific median split of $VO_{2MAX}$. RER during MAX was calculated as the highest mean recorded over 20 seconds near volitional exhaustion. Ventilatory threshold ($T_{vent}$) was quantified using the disproportional increase in $V_E$ vs $VO_2$ (ml/kg/min) (Davis, Vodak, Wilmore, Vodak, & Kurtz, 1976).

TSI was continuously measured and recorded during exercise (OxyMon Mk III Near Infrared Spectrophotometer; Artinis Medical Systems, Einsteinweg, The Netherlands). The OxyMon was manually calibrated every morning prior to exercise sessions. Single probe placement was specific to each individual by measuring 12 centimeters superiorly from the left lateral epicondyle of the femur (i.e. vastus lateralis). The surface probe was then covered with a small black vinyl sheet and secured with a tensor bandage. Sampling rate was set at 50 Hz and the distance between the transmitters and the detector in the optode holder was set to 40 cm. Digital data was down sampled to 1 Hz before being exported to Microsoft Excel (Version 16.25). Raw exercise TSI data were then normalized to each participant by calculating and using the average TSI during warm-up (i.e. baseline). Peak TSI values were then calculated as a mean of 20 seconds of data which coincided with the time stamp of peak $VO_2$ values.

A wireless monitor (Polar V800; Polar Electro, Kempele, Finland) was used to collect RR intervals (RRi) at 1000 Hz during 10 minutes of rest prior to exercise and during 5 minutes of seated active recovery. Upon arrival, participants were fitted with a dampened Polar H7 chest strap just below the chest muscles. All RRi data were digitally uploaded to the PolarFlow website and exported to Microsoft Excel for cleaning purposes (Version 16.12). Equipment setup can be seen in Figure 3.

The following RRi time bins were selected and cleaned: 3 stable minutes from baseline, minutes 20:00-23:00 from MOD, 19:00-22:00 from HI, and 7:00-10:00 from SPRT. Technical artifacts were identified by calculating the mean and standard deviation of the selected bin and using such values to calculate the individual z-scores for each raw data point as follows: (mean – raw data point) / standard deviation. Calculated z-scores which were greater than ± 2 standard deviations from the mean were manually removed. Data files which required manual removal of more than 20% were not included in analysis.

Clean RRi data were then analyzed using Kubios Standard HRV 3.1.1 to 1) remove any artifacts not detected in excel by using the medium threshold artifact correction (i.e. physiological artifacts) and 2) to calculate the frequency domain parameters of HRV. The frequency bands used in Kubios were very low frequency (VLF: 0 - 0.04 Hz), low frequency (LF: 0.04 - 0.15 Hz) and high frequency (HF: 0.15 - 0.4 Hz). The frequency values reported are low frequency (LF) and high frequency (HF). The percent change in recovery HRV of LF (Hz) and HF (Hz) from rest was calculated as follows: percent change = ((recovery value – rest value)/rest value)*100.

Continuous HR was calculated in excel using raw RRi data as follow: HR = (60 / raw RRi data point). Peak HR was calculated as the highest value from minutes 17:00 to 20:00 of MOD and HI and from minutes 6:40 to 8:00 from SPRT (Figure 1). Additionally, the highest HR during each minute of each exercise session was manually recorded.

$HR_{REC}$ was assessed by recording HR at the end of each exercise session ($HR_{END}$) and then 30 seconds ($HR_{30}$) and 60 seconds ($HR_{60}$) from the end. The following times were used to indicate the end of exercise (i.e. $HR_{END}$): minute 20 for MOD, minute 19 for HI (after the last 90% interval), and minute 7 for SPRT (after the last sprint) (Figure 1). A slope of $HR_{REC}$ from each session was calculated ($R^2$).

Lastly, throughout all sessions, participants were asked to provide a rating of perceived exertion using a standard scale (RPE; 6-20) during each minute of exercise (Borg, 1982). Peak RPE was calculated as the highest value from minutes 17:00 to 20:00 of MOD and HI and from minutes 6:40 to 8:00 from SPRT (Figure 1). Weight (kg) and height (cm) were recorded during the first visit to the laboratory using a standard medical scale (Model 439; DETECTO, Webb City, Missouri, USA). Participants removed their shoes and wore minimal clothing for these measures. The timeline schematic for all laboratory sessions is presented in Figure 4.

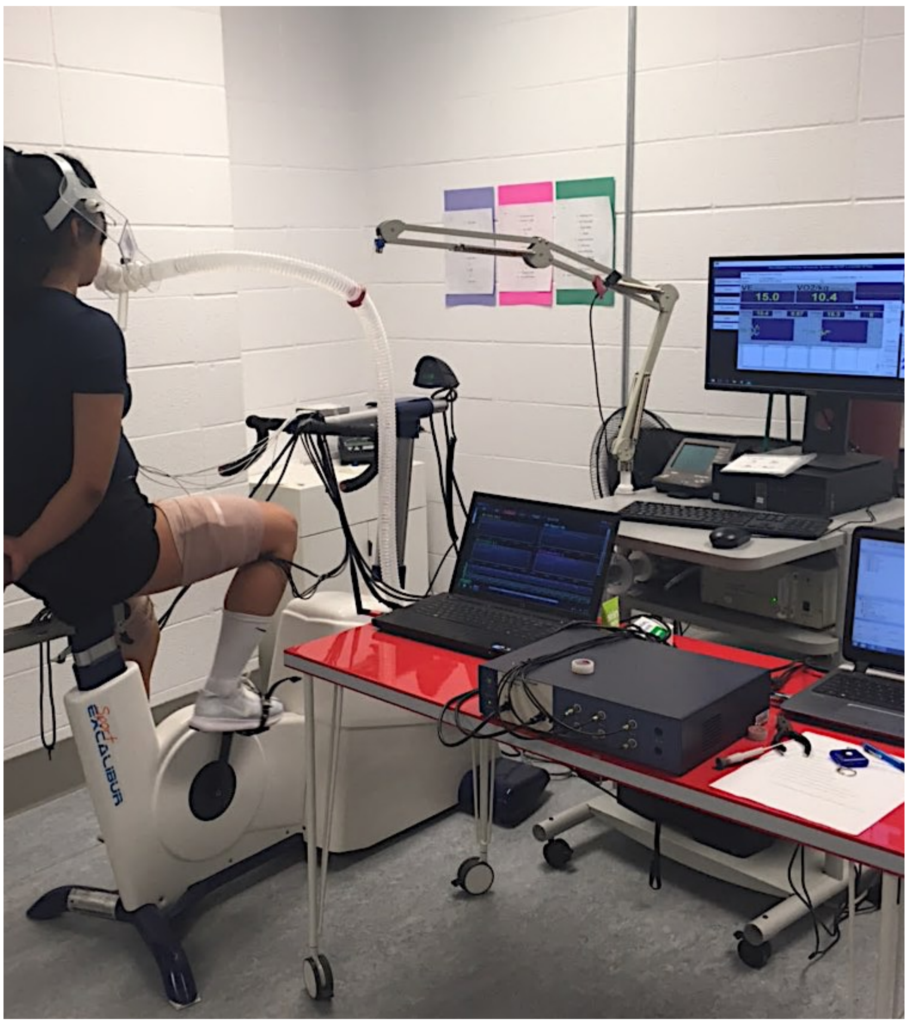


**Figure 3:** Image of equipment setup and instrumentation during all exercise sessions.

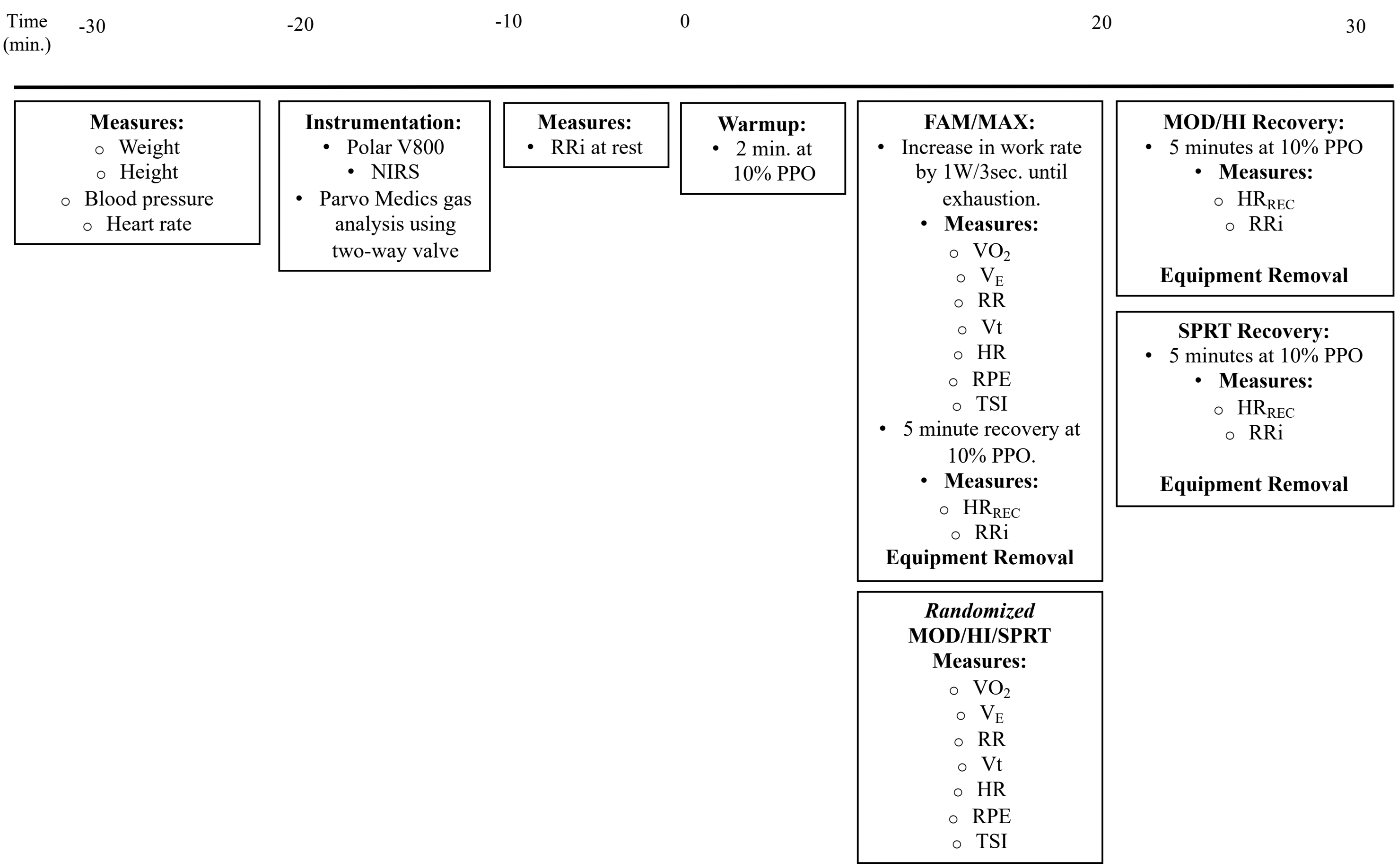


**Figure 4:** Timeline schematic for all laboratory sessions.

*3.35 Statistical Analysis*

Independent sample t-tests were used to compare participant characteristics of males and females as well as low fit and high fit groups. One-way repeated measures ANOVAs were performed to test for differences in 1) peak cardiopulmonary measures between exercise sessions, 2) peak $VO_2$ and PPO between sprints, 3) $HR_{REC}$ at each of the three time points, and 4) the absolute difference in HRV. Analyses were conducted in the sample of males and females separately, as well as the sample split by fitness levels (IBM SPSS Statistics, Version 25); Mauchly's Test of Sphericity was used to report appropriate F statistics and pairwise comparisons were made using a test of within-subjects contrast.

***3.4 Results***

Thirty older adults (male: n=15; female: n=15), met the eligibility criteria and completed the study. Participant characteristics and results from the maximal incremental test are shown in Table 1. Males attained a higher $VO_{2max}$, $T_{vent}$, PPO, and RPE compared to women ($p<0.05$). The average $T_{vent}$ was 74.6% of $VO_{2MAX}$ and 71.6% of $VO_{2MAX}$ in males and females, respectively. Using the $VO_{2MAX}$ median thresholds, we had the following groups: high fit males (n=6), low fit males (n=9), high fit females (n=6), and low fit females (n=9). $VO_{2MAX}$ was higher in *high fit* groups ($p<0.01$); high fit males: 33.92 ± 2.5, low fit males: 24.37 ± 0.77, high fit females: 28.04 ± 2.0, and low fit females: 17.84 ± 0.56. No other characteristics were significantly different.

**Table 1:** Participant Characteristics by Sex.

| | Males | Females |
|---|---|---|
| Age (years) | 70.1 ± 1.6 | 67.7 ± 1.4 |
| Height (cm) | 174.8 ± 2.6 | 162.1 ± 2.0* |
| Mass (kg) | 78.3 ± 2.6 | 63.3 ± 2.6* |
| Resting HR (bpm) | 65 ± 2.9 | 69 ± 1.9 |
| $HR_{max}$ (bpm) | 148 ± 4.4 | 148 ± 3.4 |
| $VO_{2max}$ (ml/kg/min) | 28.1 ± 1.7 | 22.1 ± 1.6* |
| RER | 1.42 ± 0.03 | 1.48 ± 0.07 |
| $T_{vent}$ (ml/kg/min) | 21. 2 ± 1.7 | 15. 8 ± 1.1* |
| Power Output (W) | 216.6 ± 14.1 | 147.1 ± 7.8* |
| RPE | 19 ± 0.42 | 17 ± 0.73* |

Values are presented as the means ± SEM. *Mean difference is significant at the .05 level.

*3.41 $VO_2$*

Peak $VO_2$ during exercise sessions are presented by sex in Table 2 and by fitness levels in Table 3. A main effect of exercise session was observed for peak $VO_2$ in males ($F(3, 42) = 39.936$, $p<0.001$, $\eta p^2 =0.740$) and in females ($F(2.130, 42) =18.188$, $p<0.001$, $\eta p^2 =0.539$) such that, in males, the highest $VO_2$ peak was observed during MAX, and in females the highest $VO_2$ peaks were observed during MAX and SPRT. A main effect of exercise session was also observed for $VO_2$ peak in high fit males ($F(3, 15) = 24.471$, $p<0.001$, $\eta p^2 =0.830$), low fit males ($F(3, 24) =37.146$, $p<0.001$, $\eta p^2 =0.823$), high fit females ($F(1.815, 15) = 9.539$, $p<0.01$, $\eta p^2 =0.656$), and low fit females ($F(3, 24) =29.203$, $p<0.001$, $\eta p^2 =0.785$) such that in *high fit* males and females the largest $VO_2$ peak was observed during MAX. In *low fit* males similar $VO_2$ peaks were observed between MAX and SPRT and in *low fit* females, the highest $VO_2$ peak was observed during SPRT. Continuous male and female $VO_2$ responses to MOD, HI and SPRT are presented by fitness in Figures 5 and 6, respectively.

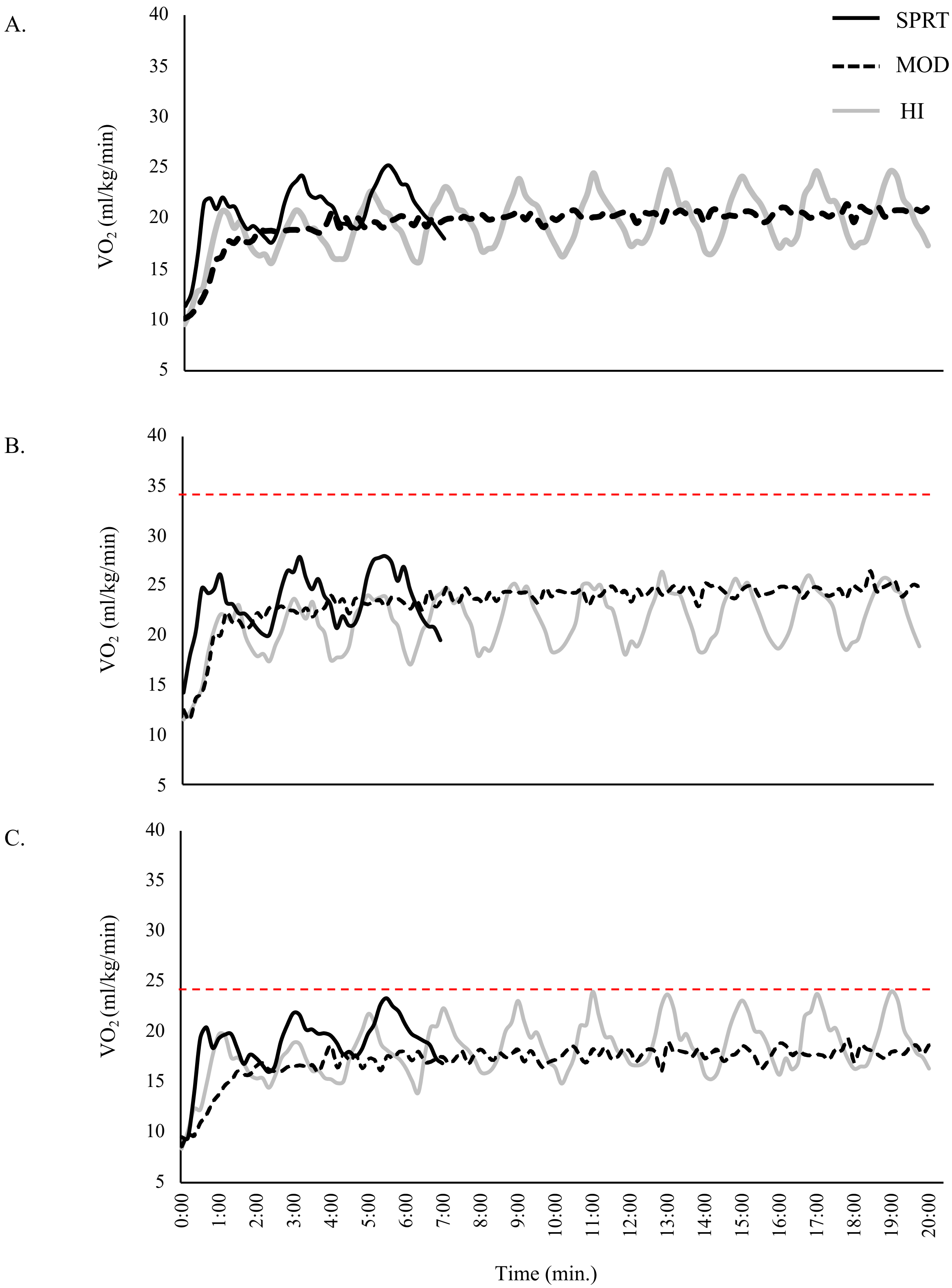


**Figure 5:** $VO_2$ response in. **A)** all males (n= 15), **B)** high fit males (n= 6), and **C)** low fit males (n= 9) to HI, SPRT, and MOD. Red broken lines indicate the average $VO_{2MAX}$ for the respective group.

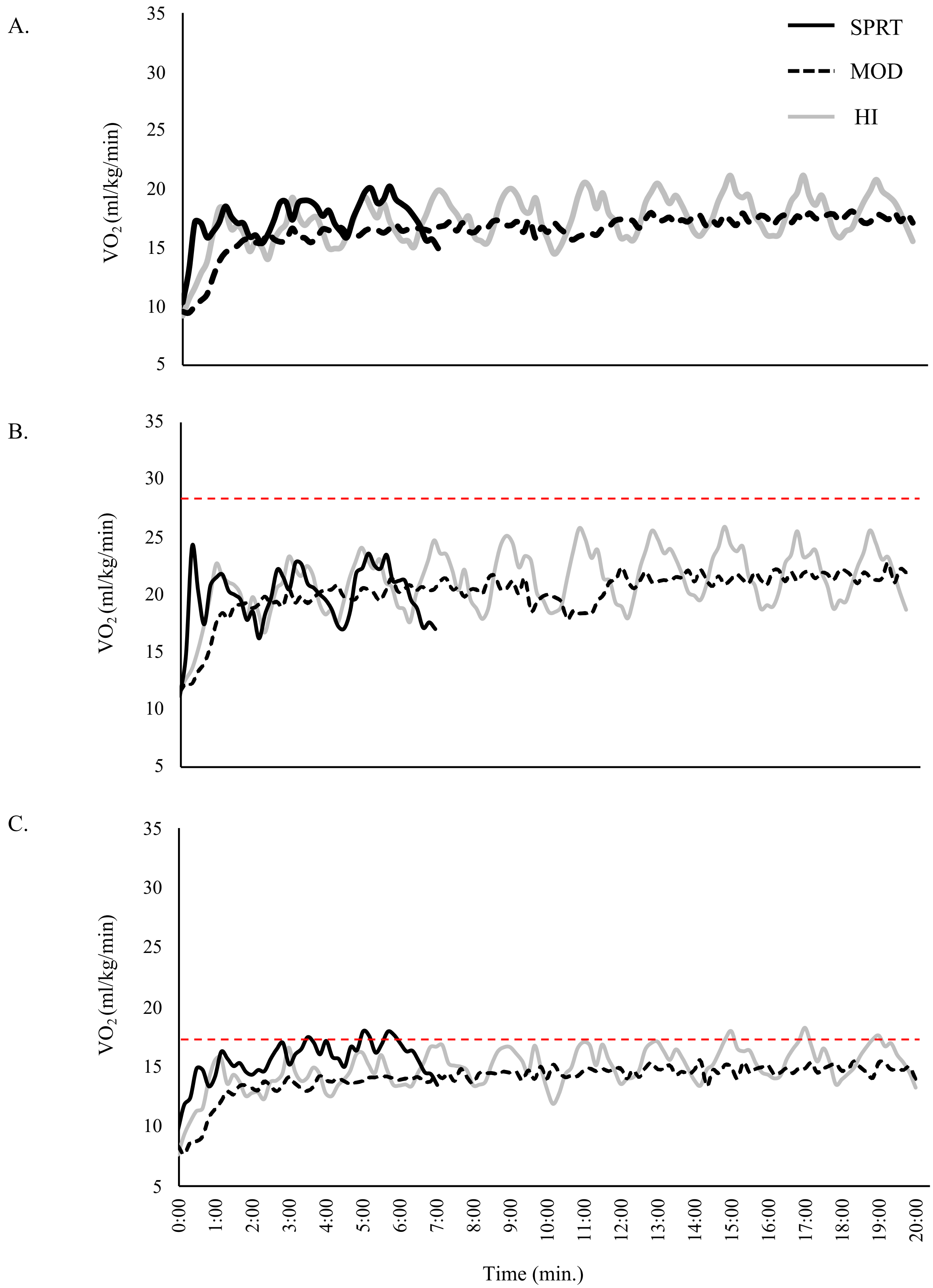


**Figure 6:** $VO_2$ response in. **A)** all females (n= 15), **B)** high fit females (n= 6), and **C)** low fit females (n= 9) to HI, SPRT, and MOD. Red broken lines indicate the average $VO_{2MAX}$ for the respective group.

**Table 2**: Peak Cardiopulmonary Values by Sex.

| | MAX | MOD | HI | SPRT |
|---|---|---|---|---|
| **Males** | | | | |
| $VO_2$ (ml/kg/min) | 28.5 ± 1.7 | 21.7 ± 1.2$^{*}$ | 24.9 ± 1.4$^{*, †}$ | 26.4± 1.1$^{*, †, §}$ |
| $V_E$ (L/min) | 100.1 ± 6.4 | 56.3 ± 3.1$^{*}$ | 79.7 ± 6.0$^{*, †}$ | 98.7 ± 5.3$^{†, §}$ |
| RR (bpm) | 41.6 ± 2.1 | 28.2 ± 1.6$^{*}$ | 35.1 ± 1.9$^{*, †}$ | 41.1 ± 2.4$^{†, §}$ |
| Vt (L) | 2.6 ± 0.1 | 2.2 ± 0.1$^{*}$ | 2.5 ± 0.1$^{†}$ | 2.7 ± 0.1$^{†, §}$ |
| Normalized TSI (%) | 94.5 ± 5.1 | 86.3 ± 2.6 | 86.3 ± 4.6 | 104.2± 2.1$^{*, †, §}$ |
| HR (bpm) | 148.1 ± 4.3 | 132.2 ± 5.4$^{*}$ | 144.3 ± 4.2$^{†}$ | 148.6 ± 3.7$^{†}$ |
| RPE | 18.7 ± 0.4 | 13.3 ± 0.8$^{*}$ | 15.3 ± 0.9$^{*, †}$ | 17.4 ± 0.5$^{*, †, §}$ |
| **Females** | | | | |
| $VO_2$ (ml/kg/min) | 22.3 ± 1.6 | 18.2 ± 1.1$^{*}$ | 19.9 ± 1.3$^{*, †}$ | 21.8 ± 1.0$^{†, §}$ |
| $V_E$ (L/min) | 63.3 ± 2.7 | 43.3 ± 2.2$^{*}$ | 55.1 ± 2.7$^{*, †}$ | 67.9 ± 2.7$^{†, §}$ |
| RR (bpm) | 36.7 ± 1.6 | 31.8 ± 1.7$^{*}$ | 37.2 ± 2.7$^{†}$ | 42.8 ± 1.9$^{*, †, §}$ |
| Vt (L) | 1.9 ± 0.1 | 1.5 ± 0.1$^{*}$ | 1.7 ± 0.1$^{*, †}$ | 1.8 ± 0.1$^{†}$ |
| Normalized TSI (%) | 93.5 ± 3.0 | 101.5 ± 2.5$^{*}$ | 94.2 ± 2.8 | 93.4 ± 3.2 |
| HR (bpm) | 148.1 ± 3.4 | 136.3 ± 4.7$^{*}$ | 147.0 ± 4.2$^{†}$ | 148.5 ± 4.7$^{†}$ |
| RPE | 17.3 ± 0.4 | 13.9 ± 0.9$^{*}$ | 16.3 ± 0.6$^{*, †}$ | 18.0 ± 0.5$^{†, §}$ |

Values are presented as the means ± SEM.The mean difference is significant at the .05 level.
$^{*}$difference from MAX;
$^{†}$difference from MOD;
$^{§}$difference from HI;

**Table 3:** Peak Ventilatory Values by Fitness.

| | MAX | MOD | HI | SPRT |
|---|---|---|---|---|
| **High Fit Males** | | | | |
| $VO_2$ (ml/kg/min) | 33.9 ± 2.5 | 25.3 ± 1.9$^{*}$ | 28.4 ± 2.7$^{*}$ | 29.3 ± 1.8$^{*, †}$ |
| $V_E$ (L/min) | 113. 0 ± 11.2 | 64.2 ± 4.3$^{*}$ | 91.0 ± 9.4$^{*, †}$ | 111.8 ± 6.3$^{†, §}$ |
| RR (bpm) | 43.8 ± 3.6 | 30.7 ± 2.8$^{*}$ | 38.1 ± 2.9$^{†}$ | 43.6 ± 2.9$^{†, §}$ |
| Vt (L) | 2.77 ± 0.2 | 2.33 ± 0.2$^{*}$ | 2.62 ± 0.2 | 2.86 ± 0.1$^{†}$ |
| **Low Fit Males** | | | | |
| $VO_2$ (ml/kg/min) | 24.4 ± 0.8 | 18.8 ± 0.6$^{*}$ | 22.0 ± 0.9$^{*, †}$ | 23.8 ± 0.9$^{†, §}$ |
| $V_E$ (L/min) | 91.6 ± 6.5 | 51.1 ± 3.3$^{*}$ | 72.1 ± 7.2$^{*, †}$ | 90.0 ± 6.5$^{†, §}$ |
| RR (bpm) | 40.2 ± 2.6 | 26.6 ± 1.9$^{*}$ | 33.2 ± 2.5$^{*}$ | 39.3 ± 3.5$^{†, §}$ |
| Vt (L) | 2.53 ± 0.2 | 2.18 ± 0.1$^{*}$ | 2.37 ± 0.1$^{*, †}$ | 2.61 ± 0.1$^{†, §}$ |
| **High Fit Females** | | | | |
| $VO_2$ (ml/kg/min) | 28.0 ± 2.0 | 22.0 ± 1.7$^{*}$ | 24.4 ± 1.6$^{*, †}$ | 25.0 ± 1.4$^{*}$ |
| $V_E$ (L/min) | 72.0 ±1.8 | 45.2 ± 2.9$^{*}$ | 58.3 ± 3.5$^{*, †}$ | 70.3 ± 2.9$^{†, §}$ |
| RR (bpm) | 37.8 ± 1.9 | 28.8 ± 1.7$^{*}$ | 32.0 ± 2.4$^{*, †}$ | 40.0 ± 1.9$^{†, §}$ |
| Vt (L) | 2.15 ± 0.1 | 1.66 ± 0.1$^{*}$ | 1.93 ±0.1$^{†}$ | 2.03 ± 0.1$^{*, †}$ |
| **Low Fit Females** | | | | |
| $VO_2$ (ml/kg/min) | 17.8 ± 0.6 | 15.4 ± 0.6$^{*}$ | 16.8 ± 0.9$^{*, †}$ | 19.5 ± 0.8$^{*, †, §}$ |
| $V_E$ (L/min) | 57.5 ± 3.2 | 41.9 ± 3.2$^{*}$ | 52.8 ± 3.9$^{†}$ | 66.3 ± 4.1$^{*, †, §}$ |
| RR (bpm) | 36.0 ± 2.5 | 33.9 ± 2.3 | 40.7 ± 3.7$^{†}$ | 44.9 ± 2.6$^{*, †}$ |
| Vt (L) | 1.74 ± 0.1 | 1.33 ± 0.1$^{*}$ | 1.49 ± 3.9$^{*, †}$ | 1.69 ± 0.1$^{†, §}$ |

Values are presented as the means ± SEM.The mean difference is significant at the .05 level.
$^{*}$difference from MAX;
$^{†}$difference from MOD;
$^{§}$difference from HI;

*3.42 Ventilatory Parameters*

Peak ventilatory responses of $V_E$, RR, and Vt during exercise sessions are presented by sex in Table 2 and by fitness levels in Table 3. A main effect of exercise session was observed for peak $V_E$ in males ($F(2, 42) = 27.651$, $p<0.001$, $\eta p^2 = 0.664$) and in females ($F(3, 42) = 36.336$, $p<0.001$, $\eta p^2 = 0.722$) such that $V_E$ peak was highest during MAX and SPRT. A main effect of exercise session was also observed for peak $V_E$ in high fit males ($F(1.240, 15) = 24.918$, $p<0.01$, $\eta p^2 = 0.833$), low fit males ($F(3, 24) = 38.871$, $p<0.001$, $\eta p^2 = 0.829$), high fit females ($F(3, 15) = 23.511$, $p<0.001$, $\eta p^2 = 0.825$), and low fit females ($F(3, 24) = 19.331$, $p<0.001$, $\eta p^2 = 0.707$) such that in *high fit* individuals and *low fit* males had the highest $V_E$ peaks during MAX and SPRT. In *low fit females*, the largest $V_E$ peak was observed during SPRT.

A main effect of exercise session was observed for peak RR in males ($F(3, 42) = 65.291$, $p<0.001$, $\eta p^2 = 0.823$) and in females ($F(1.4, 42) = 9.692$, $p<0.05$, $\eta p^2 = 0.409$) such that in males the highest peak RR was observed during SPRT and MAX, and in females the highest RR peak was observed during SPRT. A main effect of exercise session was also observed for peak RR in high fit males ($F(3, 15) = 11.491$, $p<0.001$, $\eta p^2 = 0.697$), low fit males ($F(3, 24) = 14.631$, $p<0.001$, $\eta p^2 = 0.647$), high fit females ($F(3, 15) = 26.464$, $p<0.001$, $\eta p^2 = 0.841$), and low fit females ($F(1.401, 24) = 5.195$, $p<0.001$, $\eta p^2 = 0.394$) such that, in *high fit* individuals and *low fit* males, highest RR peaks were observed during MAX and SPRT. In *low fit females*, the largest RR peak was observed during SPRT.

A main effect of exercise session was observed for peak Vt in males ($F(3, 42) = 16.438$, $p<0.001$, $\eta p^2 = 0.540$) and in females ($F(3, 42) = 11.198$, $p<0.001$, $\eta p^2 = 0.444$) such that in males the highest Vt peaks were observed during SPRT, MAX, and HI. In females, Vt peak was highest during MAX, SPRT, and HI. A main effect of exercise session was also observed for peak Vt in high fit males ($F(1.240, 15) = 24.918$, $p<0.01$, $\eta p^2 = 0.833$), low fit males ($F(3, 24) = 38.871$, $p<0.001$, $\eta p^2 = 0.829$), high fit females ($F(3, 15) = 23.511$, $p<0.001$, $\eta p^2 = 0.825$), and low fit females ($F(3, 24) = 19.331$, $p<0.001$, $\eta p^2 = 0.707$) such that in *high fit* individuals and *low fit* males, the highest Vt peak was observed during MAX and SPRT. In *low fit females,* the highest Vt peak was observed during SPRT. Continuous male and female $V_E$, RR, and Vt responses to MOD, HI and SPRT are presented in Figures 7 and 8, respectively.

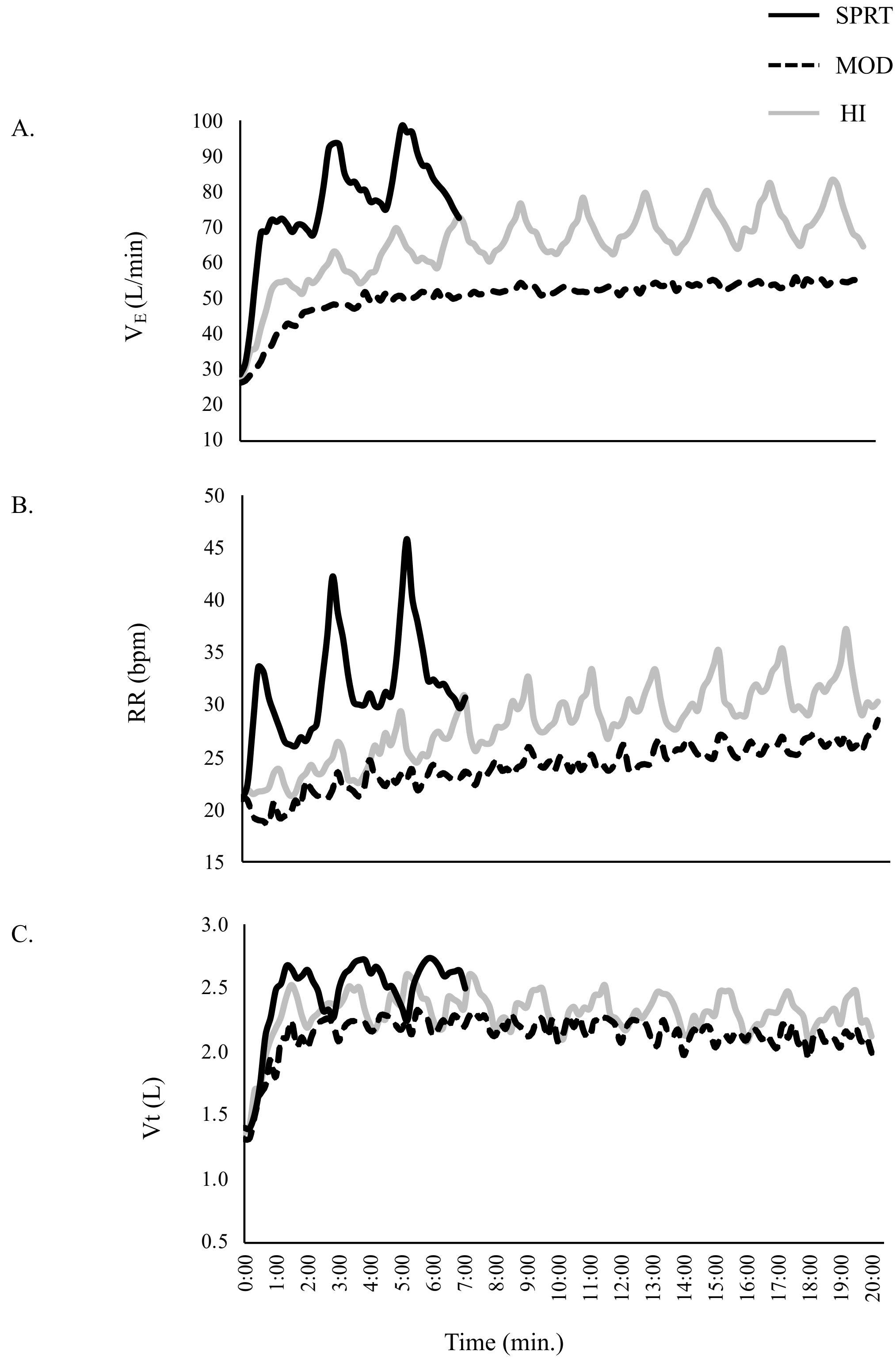


**Figure 7:** Male ventilatory responses of **A)** $V_E$, **B)** RR, and **C)** Vt to HI, SPRT, and MOD (n=15).

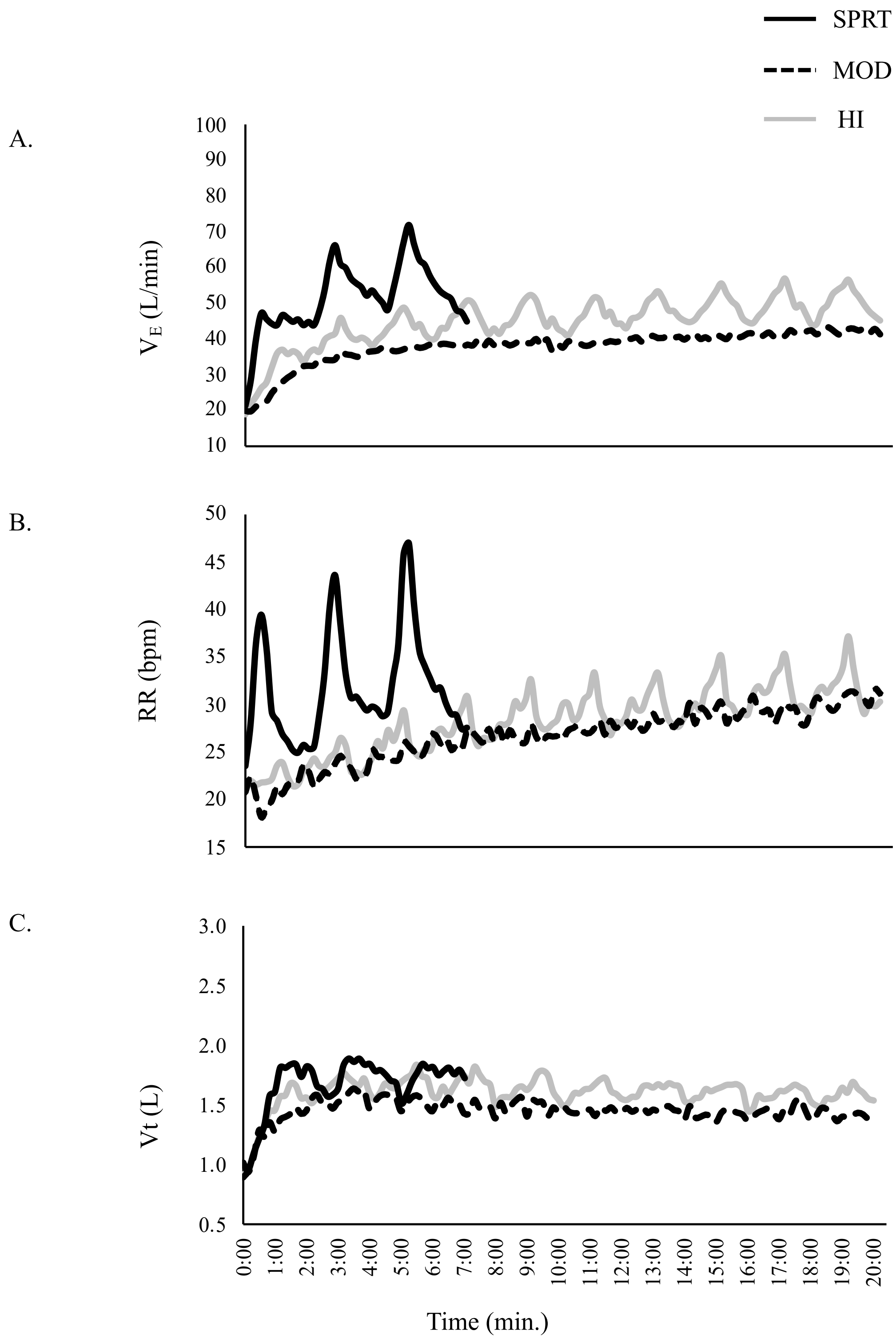


**Figure 8:** Female ventilatory responses of **A)** $V_E$, **B)** RR, and **C)** Vt to HI, SPRT, and MOD (n=15).

*3.43 TSI*

Peak TSI during exercise sessions are presented by sex in Table 2. A main effect of exercise session was observed for peak TSI in males (F(3, 27;) = 6.717, p<0.002, $\eta p^2$ =0.427) such that the largest TSI peak was observed during SPRT; similar TSI peaks were observed between MAX, MOD and HI. In females, no effect of exercise session was observed for peak TSI. The general TSI responses of the vastus lateralis to all exercise sessions are presented by sex in Figure 9.

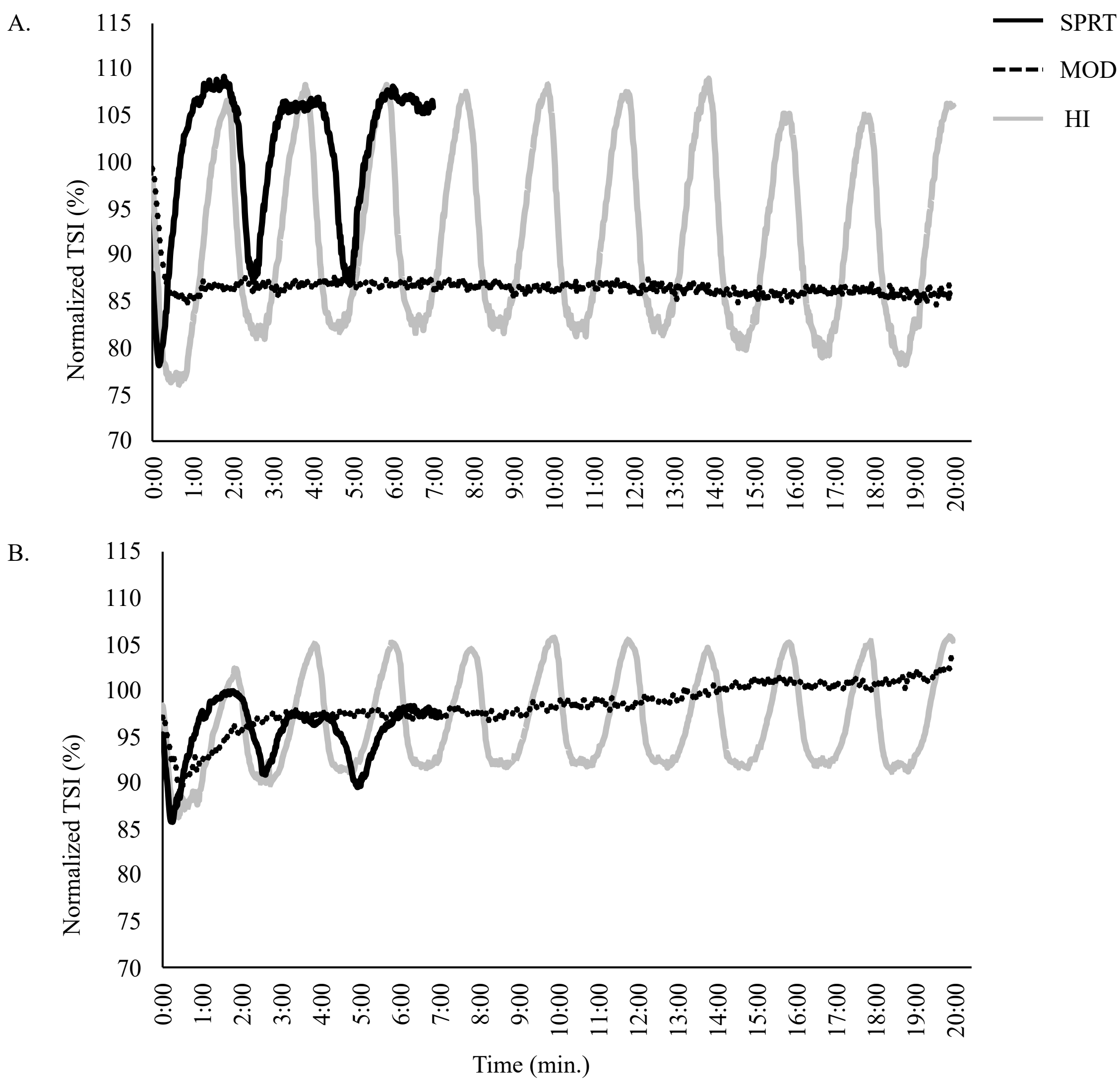


**Figure 9:** TSI responses in **A)** males and **B)** females to HI (males: n=14, females: n=14) SPRT (males: n=14, females: n=14), and MOD (males: n=14, females: n=12).

*3.44 HR*

Peak HR during exercise sessions are presented by sex in Table 2. A main effect of exercise session was observed for peak HR in males ($F(1.855, 39) = 9.059$, $p<0.001$, $\eta p^2 = 0.411$) and in females ($F(2.027, 42) = 5.275$, $p<0.01$, $\eta p^2 = 0.274$) such that peak HR was lowest was during MOD, and similar between the remaining exercise sessions. The HR responses during each minute of exercise sessions are presented by sex in Figures 10.

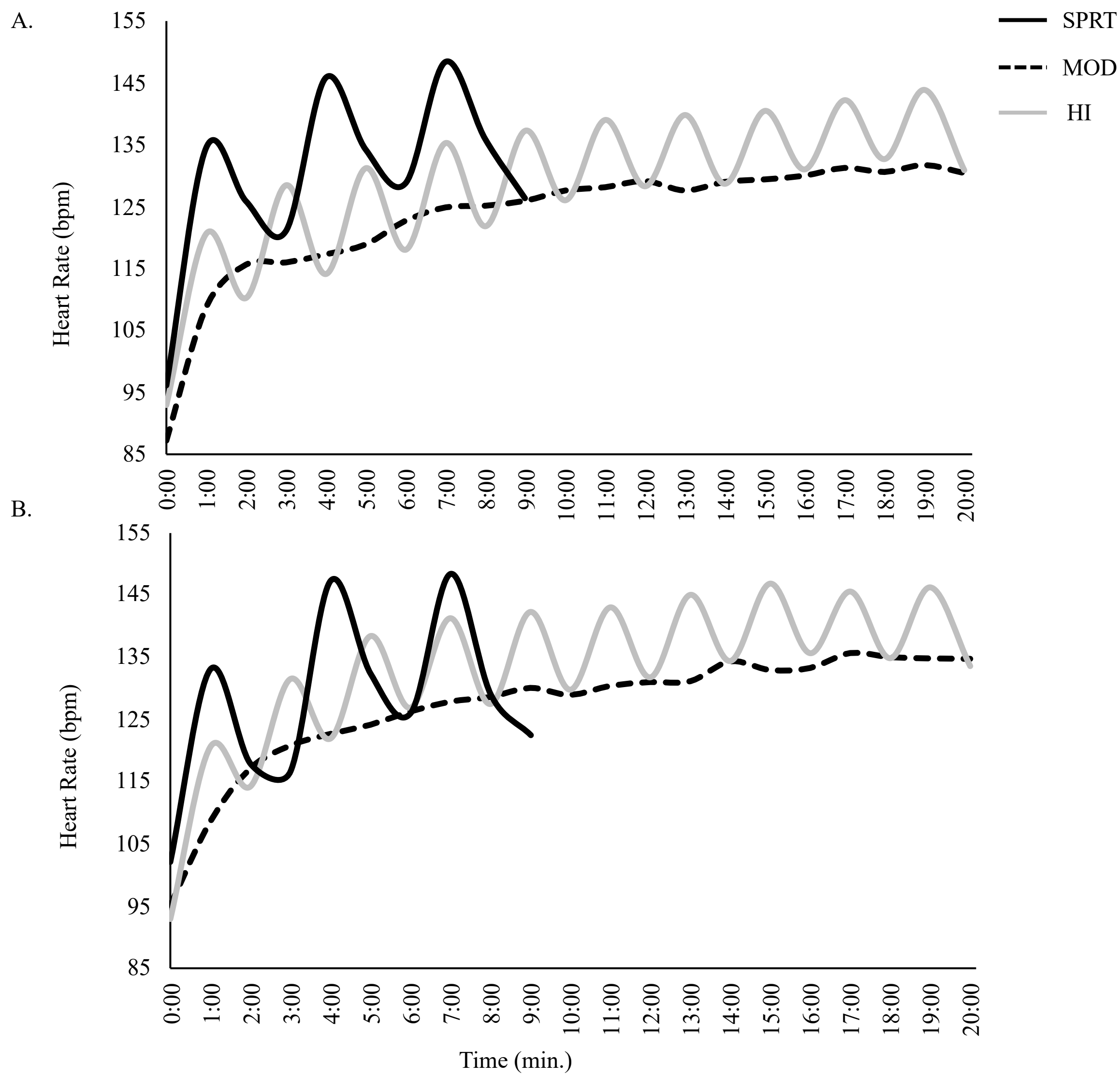


**Figure 10:** HR response during each minute of exercise in **A)** males (n= 15) and **B)** females (n=15) to HI, SPRT, and MOD.

*3.45 $HR_{REC}$*

The $HR_{REC}$ responses to all exercise sessions are presented by fitness in Figure 11. We compared the slope of the line of $HR_{REC}$ ($R^2$) between sessions and between fitness levels (Table 4). A significant difference was observed in the slope of $HR_{REC}$ between high and low fit males ($p<0.01$) such that the rate of recovery was *faster in high fit males* across all exercise sessions. There were no differences in the slope of $HR_{REC}$ when comparing high and low fit females.

| Session | Males | | Females | |
|---|---|---|---|---|
| | **Low Fit** | **High Fit** | **Low Fit** | **High Fit** |
| **MOD** | 0.9844 | 0.9998* | 0.9514 | 0.9971 |
| **HI** | 0.9844 | 0.9995* | 0.9946 | 0.9973 |
| **SPRT** | 0.9737 | 0.9969* | 0.9974 | 0.9706 |

**Table 4:** Slope of $HR_{REC}$ values by fitness and sex. *$p<0.01$.

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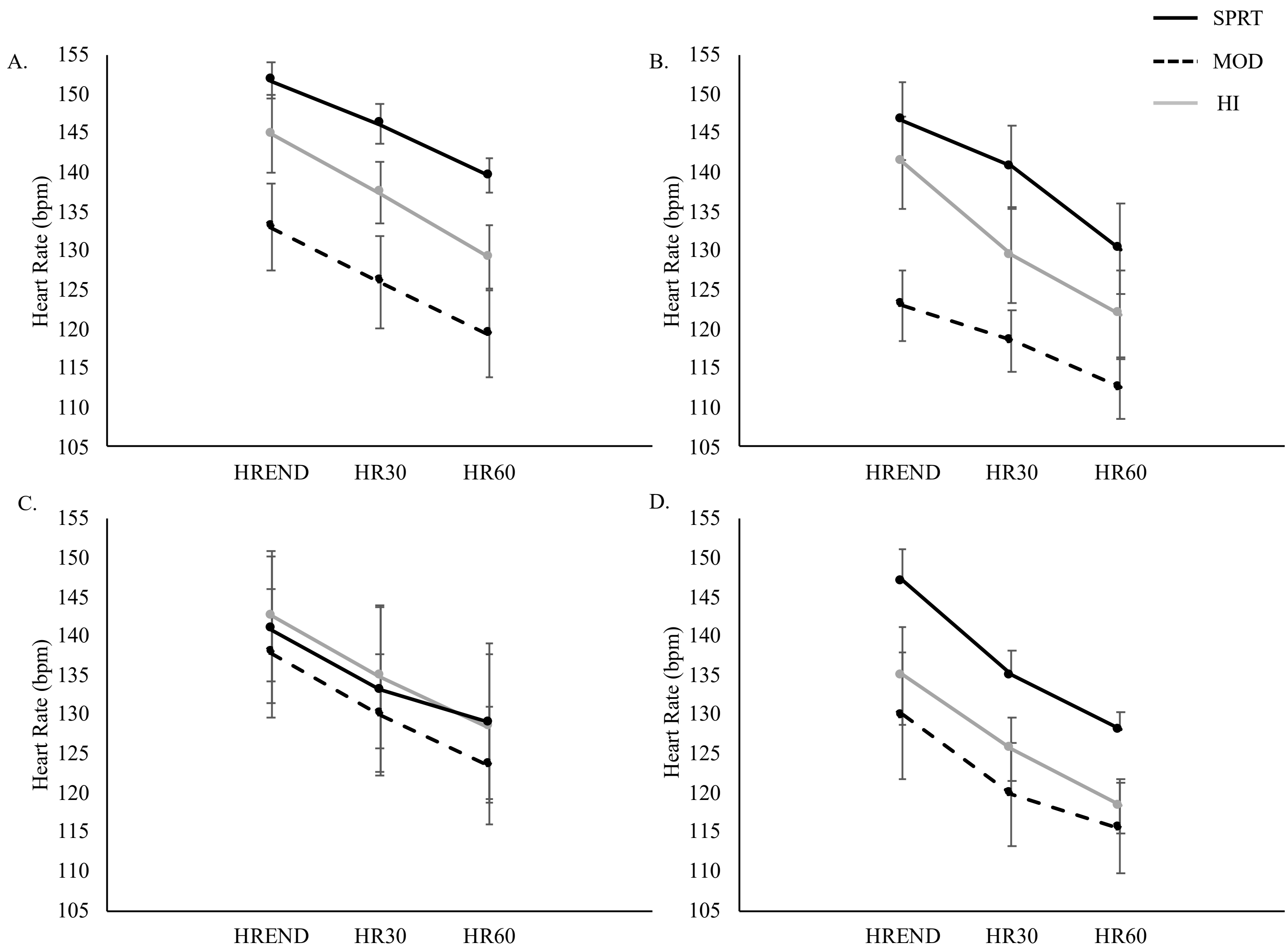


**Figure 11:** Slope of $HR_{REC}$ in **A)** high fit males (n=6), **B)** low fit males (n=9), **C)** high fit females (n=6), and **D)** low fit females (n=9) to HI, SPRT, and MOD. HR was recorded at the end (HREND), 30 seconds from end (HR30), and 60 seconds from end (HR60).

*3.46 HRV*

The percent change in LF and HF from rest to active recovery periods of all exercise sessions are presented by sex in Figure 12. No significant differences were observed in the percent change between rest and recovery during all exercise sessions, in both groups.

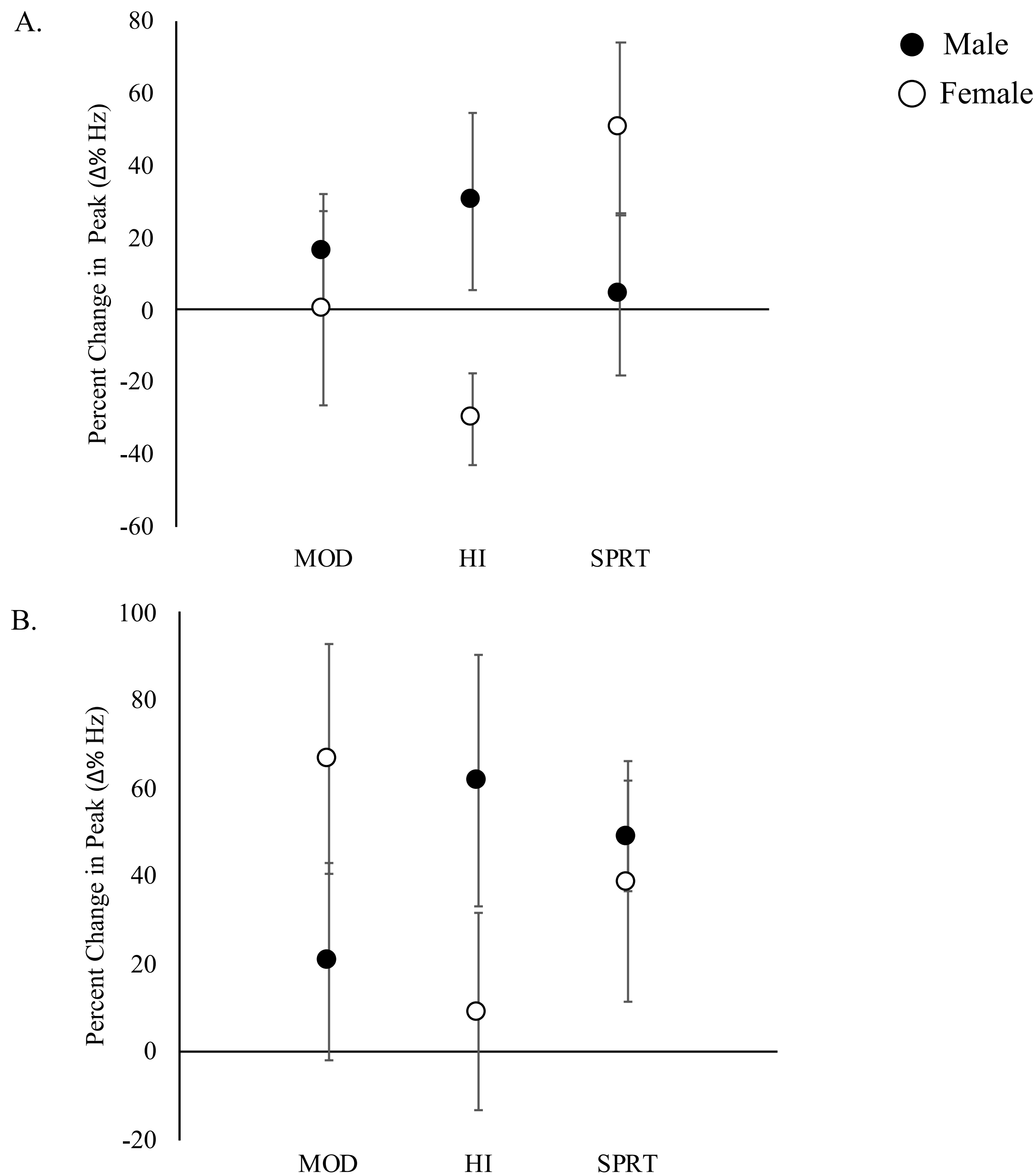


**Figure 12: A)** LF and **B)** HF percent change in males (n= 6) and females (n= 5) from rest to MOD, HI, and SPRT active recovery periods.

*3.47 RPE*

Peak RPE during exercise sessions are presented by sex in Table 2. A main effect of exercise session was also observed for peak RPE in males ($F(3, 39) = 20.205$, $p<0.001$, $\eta p^2 = 0.608$) and in females ($F(3, 42) = 11.010$, $p<0.001$, $\eta p^2 = 0.440$) such that in males the largest RPE peak was observed during MAX. In females, similar RPE peaks were observed between MAX and SPRT, and MAX and HI. The RPE responses during each minute of exercise sessions are presented by sex in Figure 13.

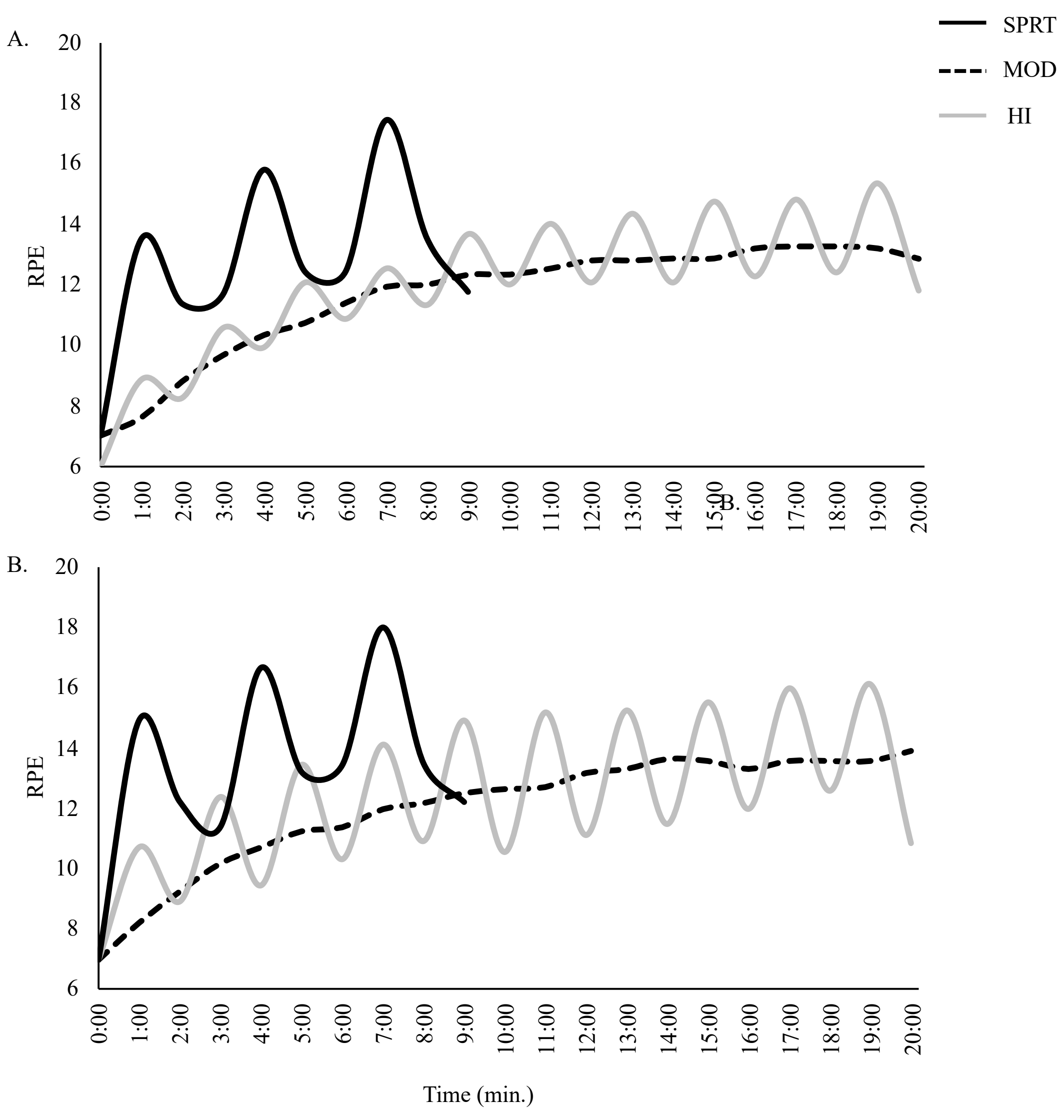


**Figure 13:** RPE response during each minute of exercise in **A)** males (n= 15) and **B)** females (n=15) to HI, SPRT, and MOD.

*3.48 Work Performed during Sprints*

Peak $VO_2$ across sprints are presented by sex and fitness levels in Figure 14. A main effect of order was observed for peak $VO_2$ in males ($F(1.19, 28) = 6.430$, $p<0.02$, $\eta p^2 = 0.315$) and in females ($F(1.33, 28) = 7.273$, $p<0.01$, $\eta p^2 = 0.342$) such that the largest $VO_2$ peak was observed during the third sprint, in both groups. A main effect of order was also observed for peak $VO_2$ in *high fit males* ($F(2, 10) = 6.376$, $p<0.05$, $\eta p^2 = 0.560$) such that similar $VO_2$ peaks were observed between the second and third sprint. A main effect of order was also observed for peak $VO_2$ in *low fit females* ($F(2, 16) = 45.694$, $p<0.001$, $\eta p^2 = 0.851$) such that the largest $VO_2$ peak was observed during the third sprint. There were no significant effects for peak $VO_2$ in *low fit* males and *high fit* females.

PPO across sprints are presented by sex and fitness levels in Figure 15. A main effect of order was observed for peak PPO in females ($F(1.35, 26) = 12.657$, $p<0.001$, $\eta p^2 = 0.493$) such that the largest power generated was observed during the first sprint. No significant effects were observed in PPO in the sample of males. A main effect of order was also observed for PPO in high fit males ($F(2, 8) = 11.367$, $p<0.01$, $\eta p^2 = 0.740$), low fit males ($F(2, 16) = 13.548$, $p<0.001$, $\eta p^2 = 0.629$), and low fit females ($F(2, 14) = 22.071$, $p<0.001$, $\eta p^2 = 0.759$) such that the largest power generated was observed during the first sprint. There were no significant effects in high fit females.

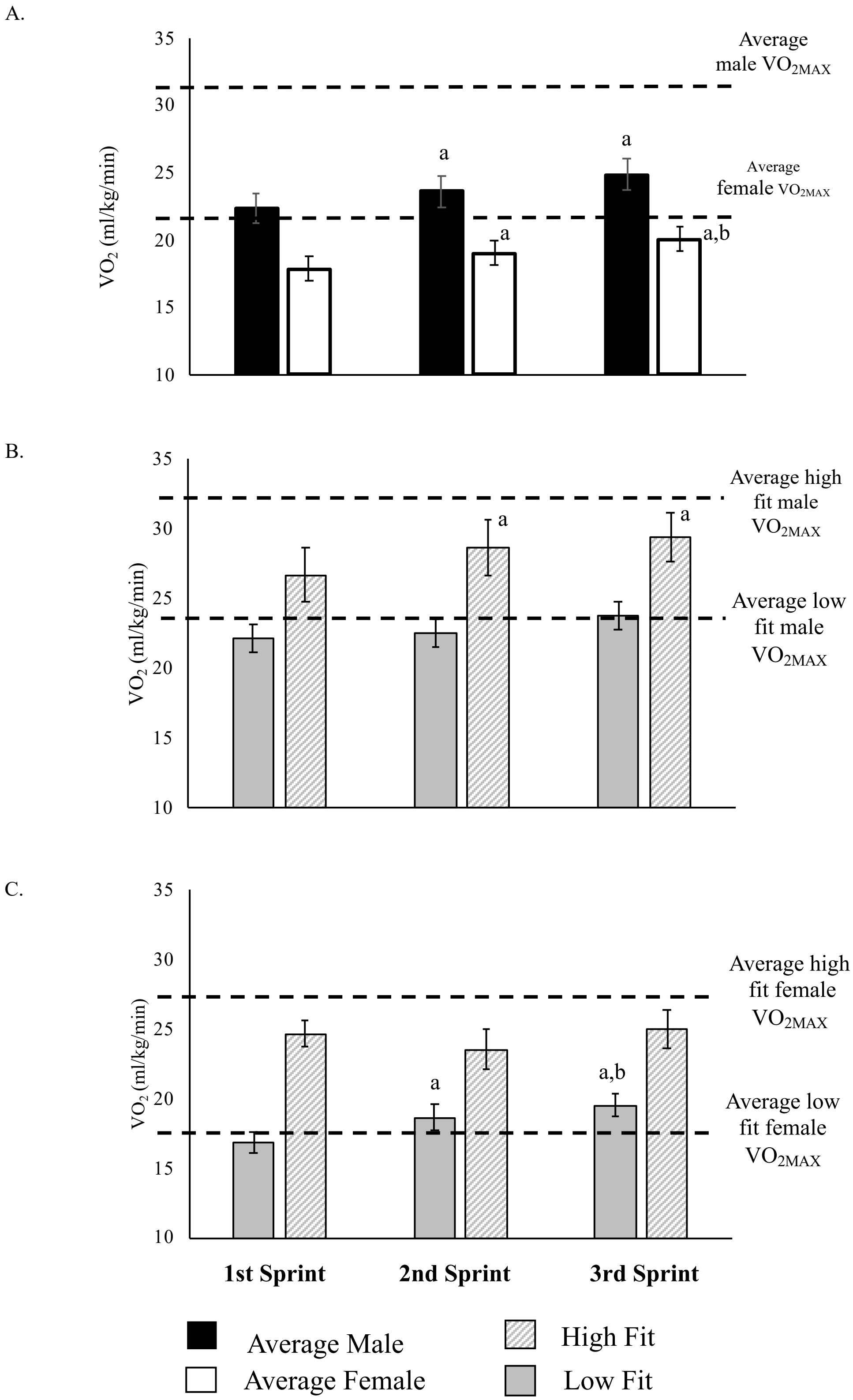


**Figure 14:** Peak $VO_2$ response across sprints in **A)** all participants (males; n= 15, females; n=15), **B)** males separated by $VO_2$ (high fit n=6; low fit n=9), and **C)** females separated by $VO_2$ (high fit n=6; low fit n=9). Significance at the .05 level; [a]difference from sprint 1, [b]difference from sprint 2.

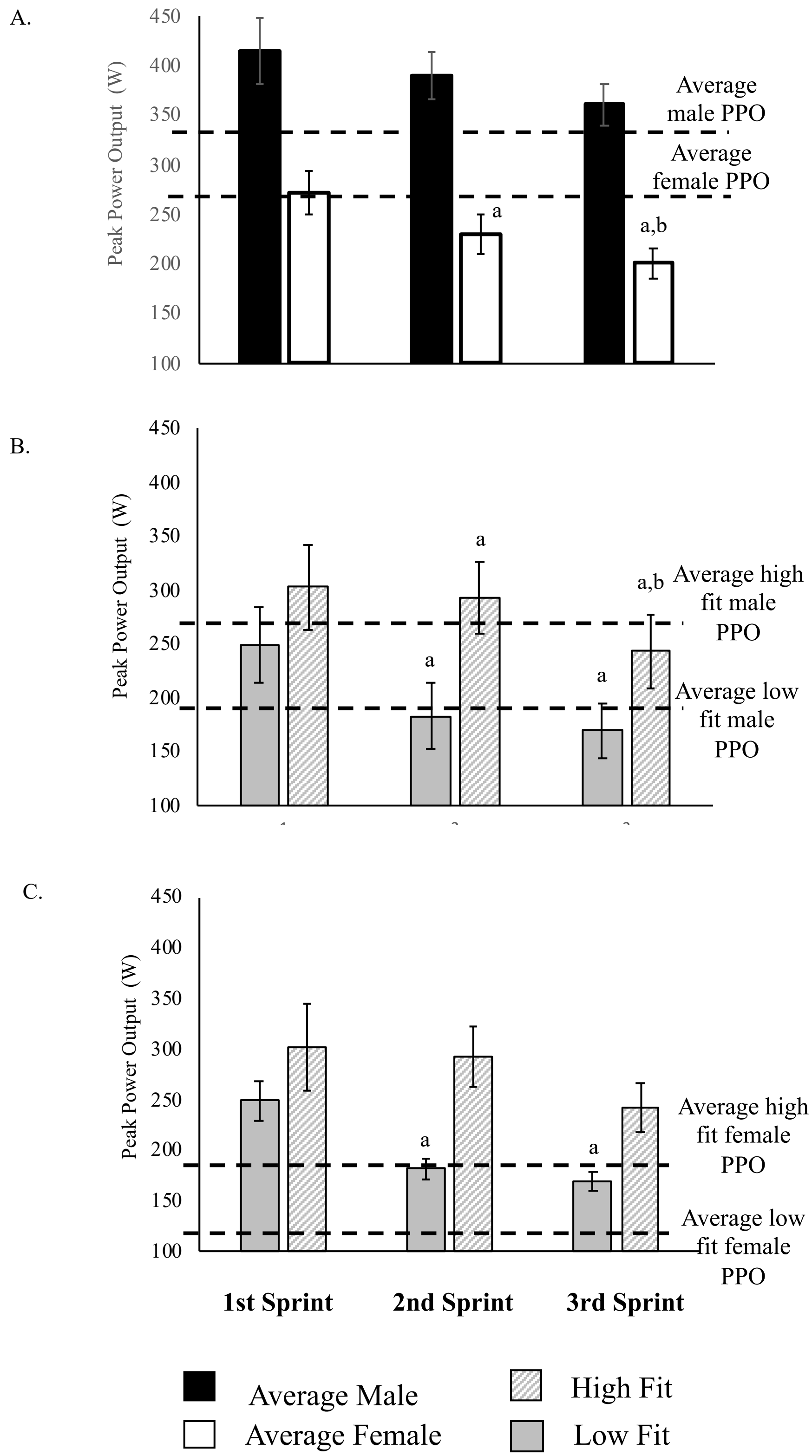


**Figure 15:** PPO response across sprints in **A)** all participants (males; n= 15, females; n=15), **B)** males separated by $VO_2$ (high fit n=6; low fit n=9), and **C)** females separated by $VO_2$ (high fit n=6; low fit n=9). Significance at the .05 level.

### *3.5 Discussion*

We sought to describe the acute cardiopulmonary responses of healthy older adults to moderate and high intensities of exercise. The primary finding of this randomized crossover study was that sprint interval exercise led to the highest cardiopulmonary peaks when compared to high intensity interval or moderate continuous exercise, in both older males and females. A secondary finding was that cardiorespiratory fitness appears to influence these acute responses. Older females with low cardiorespiratory fitness levels attained a larger $VO_2$ peak during sprint exercise when compared to their maximal exercise test, indicating that exercise testing protocols in this group may require a supramaximal workload. To our knowledge, these findings are the first to describe and report on the acute cardiopulmonary responses to different intensities of exercise among healthy older males and females. Our data support previous studies that have shown that individual cardiopulmonary responses to exercise are highly variable; this may have implications for exercise testing and prescription in older adults.

#### *3.51 $VO_2$*

Participants in the high fit groups attained the highest $VO_2$ peak during MAX. However, males in the low fit group attained similar $VO_2$ peaks between MAX and SPRT, and females in the low fit group attained the highest $VO_2$ peak during SPRT despite our verification criteria during the MAX session. Our criteria were volitional fatigue, that is, the test ended when the participant was no longer able to maintain the cadence on the cycle ergometer, despite verbal encouragement, as well as an RER >1.15, and a plateau in $VO_2$ with an increase in workload. Our participants achieved an average RPE of 19 ± 0.42 (males) and 17 ± 0.44 (females) and RER of 1.42 ± 0.03 (males) and 1.48 ± 0.07 (females) at the cessation of the maximal exercise test.

A possible explanation for the observed trend in low fit females may be explained by fatigue. Previous research has also noted that in lean non-athletic females, the primary reason for terminating maximal exercise is due to leg fatigue (Hulens, Vansant, Lysens, Claessens, & Muls, 2001). This suggests that less fit females may be terminating exercise during MAX due to fatigue. With this in mind, it is possible that perceived exertion, and thus fatigue, was influenced by lack of experience with cycling in our female sample; our male participants were recruited from cycling clubs while females engaged in a variety of physical activities. Research has shown that $VO_{2MAX}$ is significantly higher during incremental tests on the treadmill when compared to cycle ergometry (Basset & Boulay, 2000; Buchfuhrer et al., 1983; Hanson et al., 2016) suggesting that the mode of exercise chosen may have affected the results of the current study. That is, in less fit older adults, ergometry may not be favourable for $VO_{2MAX}$ testing due to early onset of muscle fatigue which is more likely to occur during cycling. Additionally, there is no opportunity to recover during a continuous maximal exercise test.

Taken together with our results, it seems as though lower fit individuals, females in particular, may benefit from a supramaximal workload to study and test for cardiopulmonary fitness. Previous research has found supramaximal workloads to be beneficial for verifying $VO_{2MAX}$ in sedentary populations (Astorino, White, & Dalleck, 2009). Additional studies have looked at the use of verification procedures to confirm $VO_{2MAX}$ (Dalleck et al., 2012; Possamai et al., 2019). Thus, future research should assess different modes of exercise testing, like the treadmill, or by implementing a supramaximal protocol.

*3.52 Sprints*

Data from our SPRT session indicated that males and females in the low fit group experienced a significant decrease in PPO after the first sprint whereas, males and females in the high fit group only experienced a decline in PPO during the final sprint. Previous research indicates that PPO decreases linearly during repeated-sprint exercise even in recreationally active young males (Mendez-Villanueva, 2008). In older adults, loss of muscle mass has been shown to be associated with a decline in strength (Goodpaster et al., 2006). Additionally, power output, and thus strength, has been found to be related to muscle mass and physiology (i.e. fiber type and cross-sectional area) (Ellefsen et al., 2014; van der Zwaard et al., 2018). With this in mind, our observations could be the result of 1) age-related muscle mass loss, 2) a lesser muscle mass in low fit individuals or, 3) low cardiopulmonary fitness levels. Although research has found that the recruitment of different metabolic pathways to support force production may also explain the decrease in power during repeated sprints (Mendez-Villanueva, Hamer, & Bishop, 2008).

*3.53 HR, $HR_{REC}$, and HRV*

As hypothesized, we observed similar peaks in HR during MAX, HI, and SPRT. Previous research has found a desensitisation of norepinephrine stimulation in older individuals (Pugh & Wei, 2011). That is, the maximal HR possibly achieved by an older individual, declines as a result of elevated levels of catecholamines in the blood which lead to such desensitisation of norepinephrine (Pugh & Wei, 2011). Furthermore, significant functional changes in ß-adrenergic receptors result in decreased responsiveness to increases in HR as induced by stressors like exercise (Ferrari et al., 2003). However, we observed no irregular response in HR to high intensity exercise in our sample of healthy older adults.

The slope of $HR_{REC}$ was expected to be smallest after SPRT as previous work indicates that the rate of recovery is attenuated after higher intensities of exercise due to prolonged sympathetic stimulation which sustains HR (Pierpont, Stolpman, & Gornick, 2000). Thus, a faster recovery is dependent on parasympathetic reactivation which is more dominant after lower intensities of exercise (Cunha, Midgley, Goncalves, Soares, & Farinatti, 2015). However, contrasting observations have been noted where $HR_{REC}$ was faster after 70% and 80% $VO_{2MAX}$ than 60% $VO_{2MAX}$ (Mann, Webster, Lamberts, & Lambert, 2014). Moreover, no differences in $HR_{REC}$ were observed between 70% and 80% $VO_{2MAX}$. The authors of this study suggest that $HR_{REC}$ is delayed within the first minute after high intensity exercise due to a possible "saturation" of parasympathetic reactivation (Mann, Webster, et al., 2014). The reactivation of the parasympathetic system has been found to be associated with faster rates of $HR_{REC}$ (Cunha et al., 2015; Pierpont et al., 2000). This may explain why we observed no significant differences in $HR_{REC}$ between HI and SPRT.

It has also been suggested that during sprint exercise, it is common for individuals to perform the Valsalva maneuver which may possibly affect $HR_{REC}$ (i.e. further increase HR and thus slow the rate) (Kilgour, Mansi, & Williams, 1995). Moreover, during supramaximal exercise, it seems that autonomic control of HR is less responsive compared to submaximal exercise (Cottin et al., 2004). As such, $HR_{REC}$ after SPRT should have been slower; suggesting that different trends may exist within older adults. Interestingly, we observed the rate of recovery to be fastest in high fit males across all exercise sessions. However, this may be due to the larger body mass index of males (Ramaekers, Ector, Aubert, Rubens, & Van de Werf, 1998).

Lastly, we saw no significant differences in the absolute change of LF or HF between rest and recovery during all exercise sessions, in both groups. Previous studies have found after submaximal exercise, the LF spectrum to increase more than the HF (Cottin et al., 2004). However, this work was done in young trained adolescents. Further studies have observed the HF spectrum to increase after both low and high intensity exercise, suggesting heightened activity of the vagal system during the first minute of recovery from exercise (Martinmaki & Rusko, 2008). With this in mind, we acknowledge that our HRV analysis compared resting values to active recovery suggesting that the fluctuations occurring during this point may be too varied for analysis.

*3.57 Experimental Limitations and Strengths*

We acknowledge that there are several limitations to our study. Our primary aim was to describe the central and peripheral cardiopulmonary variables of the Fick equation to different intensities of exercise. However, due to technical difficulties with impedance cardiography (PhysioFlow Enduro, Folschviller, France), SV and Q were not measured during exercise in this study. This would have added to whether different doses of exercise elicited greater central and/or peripheral responses of the Fick equation in older adults.

Secondly, the SPRT protocol used was effort dependent which may have affected our observations. That is, a number of external factors, such as objective factors like muscle mass and subjective factors like motivation, could have limited or affected the effort response to SPRT. We also did not base study inclusion on aerobic fitness levels. This may have affected the results seen during MAX. That is, it could be argued that individuals who regularly exercise are more likely to be comfortable with the unpleasant sensations associated with high and near maximal exercise intensities. Moreover, our designation to high fit or low fit groups was based on the median split of $VO_{2MAX}$ data which does not necessarily fit textbook parameters. However, to our knowledge, this is a study first of its kind to describe and compare acute cardiopulmonary responses between different intensities of exercise, in the same group of healthy older adults.

## ***3.6 Conclusion***

In conclusion, we found that older adults with a higher cardiorespiratory fitness attained the highest $VO_2$ peak during their maximal exercise test, while females with a lower cardiorespiratory fitness attained a higher $VO_2$ peak during sprint exercise than their $VO_{2MAX}$.

Future research needs to implement the aforementioned exercise protocols more than once (i.e. exercise training programs), in order to assess and quantify the long-term improvements of cardiopulmonary responses to the different intensities of exercise. This will aid in better understanding the doses and types of exercise required to see benefits in older adults.

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## Chapter 4. General Discussion

### *4.1 Thesis Summary*

The primary objective of this thesis was to describe the acute cardiopulmonary responses of $VO_2$, $V_E$, RR, Vt, HR, $HR_{REC}$, HRV, and TSI to moderate intensity continuous, high intensity interval, and sprint intensity interval exercise, in healthy older adults. For each cardiopulmonary parameter assessed, we observed:

I. **$VO_2$:**
   a. High fit individuals attained the largest peak in $VO_2$ during MAX.
   b. Low fit males attained similar $VO_2$ peaks between MAX and SPRT.
   c. Low fit females attained a larger $VO_2$ peak during SPRT than their $VO_{2MAX}$.

II. **Ventilation:**
   a. High fit individuals attained similar peaks in $V_E$, RR, and Vt during MAX and SPRT.
   b. Low fit males also attained similar peaks in $V_E$, RR, and Vt during MAX and SPRT.
   c. Low fit females attained the largest peak in $V_E$, RR, and Vt during SPRT.

III. **HR:**
   a. Similar peak in HR during MAX, HI, and SPRT in the sample of all males and females.

IV. **$HR_{REC}$:**
   a. The slope of $HR_{REC}$ ($R^2$) was significantly larger during MOD, HI, and SPRT in high fit males when compared to low fit males. There was no difference in the slope of $HR_{REC}$ between high and low fit females.

V. **HRV:**
   a. No significant differences were found in the absolute difference between post-exercise and resting HRV parameters of LF and HF, in males or females.

VI. **TSI:**
   a. In males the largest TSI peak was observed during SPRT. In females, no effect of exercise was observed on TSI.

### *4.2 Implications*

The purpose of this study was to describe the acute cardiopulmonary responses to different intensities of exercise. In doing so, we observed the acute responses to differ between our allocated groups of high fit and low fit individuals such that individuals with a higher cardiorespiratory fitness were able to attain their highest $VO_2$ peak during maximal exercise whereas lower fit individuals attained higher $VO_2$ peaks during the higher intensity sessions of HI and SPRT when compared to maximal exercise testing. This has implications for cardiopulmonary testing in older adults. That is, maximal exercise testing in lower fit populations, or even older populations, may require a supramaximal workload to confirm $VO_{2MAX}$. Many exercise testing protocols utilized are continuous; however, less fit and older adults may require a discontinuous protocol. Flawed exercise testing protocols are likely leading to flawed exercise prescription. In fact, studies have found that not all individuals respond to exercise similarly (Bonafiglia et al., 2016; Bouchard & Rankinen, 2001; Chmelo et al., 2015; Hautala et al., 2006; Karavirta et al., 2011; Mann, Lamberts, & Lambert, 2014; Montero & Lundby, 2017; Ross, de Lannoy, & Stotz, 2015; Scharhag-Rosenberger, Walitzek, Kindermann, & Meyer, 2012; Weatherwax, Harris, Kilding, & Dalleck, 2016). This could be a result of improper exercise prescription such that individuals who did not achieve a true $VO_{2MAX}$ may not have been working at the right exercise intensity. If so, the implications of studying acute responses may be crucial for understanding the proper doses and/or intensities necessary at the individual level in order to observe long term improvements from exercise training.

To conclude, the results from this study, have important implications for understanding how older adults respond to different intensities of exercise. That is, knowing how individuals respond to a certain intensity of exercise may aid in identify the types and doses of exercise required for long-term improvements in the described cardiopulmonary parameters. However, a number of gaps remain:

- **Research Gap:** The acute responses of Q and SV to high intensities of exercise in older adults remain undescribed. Moreover, comparisons of acute responses between HI and SPRT exercise are needed.
- **Research Gap:** We observed an increase in the TSI response during MOD in older females. However, ANOVA results indicated that there was no significance in the effect of exercise on peak TSI, within the female group. Further, we had to drop 3 MOD data files due to technical difficulties and this may have affected the significance observed.
- **Research Gap:** We observed no significance in the percent change of post-exercise LF and HF values (Hz) from resting values. However, we speculate that this may be due to the selected time bin of data. That is, the "post-exercise" HRV time bin was during *active recovery exercise.* There are two problems with this 1) during active recovery, HR is still elevated due to sympathetic modulation thus, parasympathetic reactivation is minimal in comparison to what would be expected at the cessation of exercise and 2) during active recovery, $V_E$ is above resting values. Breathing frequency has been shown to affect the ability to properly analyze parasympathetic modulation. To minimize this some studies have instructed their participants to follow a predetermined breathing frequency. Our concluding suggestions would be to analyze RRi after active recovery when participants are seated and resting after exercise.

### *4.3 Future Considerations*

To our knowledge, this is the first study to **1)** report and compare the acute cardiopulmonary responses to moderate, high, and supramaximal intensities of exercise and **2)** to study the responses to higher intensities of exercise within a group of healthy older adults. Such work provides preliminary information on the potential benefits of certain exercise protocols among a group of older adults. Future research is required to establish if in fact the analysis of acute responses can aid in identifying the proper exercise dose for prescription of long-term training. If so, it is expected to see improvements in cardiopulmonary fitness in the analysis of individual data. To do so, the exercise protocols included in this study must be implemented more than once and if possible, within the same individuals (with considerate washout periods) to quantify and compare the magnitude of improvements to each protocol.

# APPENDICIES

## APPENDIX A – Consent/Waivers

A1. Informed Consent

A1. Informed Consent

## STUDY INFORMATION AND CONSENT FORM
## UOIT Research Ethics Board

**Project Title:** Acute Behavioural and Physiological Responses to Variable Intensity Exercise

**Principal Investigator (PI):**
Dr. Shilpa Dogra, PhD, CSEP-CEP (UOIT)

**Primary Researchers:**
Andrea Linares, BSc (UOIT)
Nikola Goncin, BSc (UOIT)
**Contact number:** 905-721-8668 ext: 3618

**Introduction:**
You are invited to participate in a research study that is being conducted at the University of Ontario Institute of Technology (UOIT). Throughout this document you will find the study purpose, procedure, benefits and risks, as well as your right to refuse to participate or withdraw from the study. Please thoroughly read and understand all sections of this document before you agree to participate in this study. This is known as the informed consent process. Should you have any questions concerning any of the information, words, or your rights, please contact the researchers above to gain full understanding before signing this consent form.

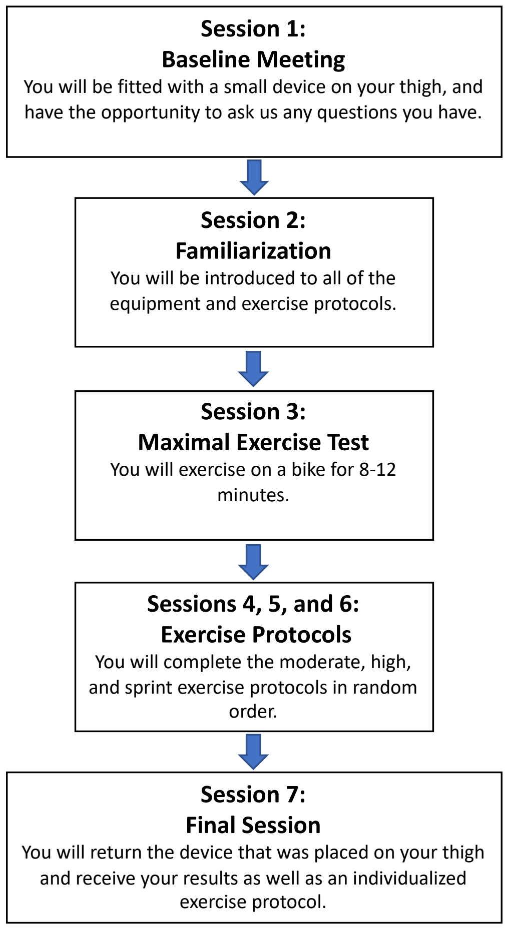
**Purpose and Explanation of the Study:**
Our goal is to understand how age and sex affect the physiological (e.g. oxygen consumption and heart rate) and behavioral (e.g. increase in sedentary time) responses to three different exercise protocols: moderate intensity continuous, high intensity interval, and sprint intensity interval. For the purpose of this study, moderate intensity exercise will involve cycling at 50% of your maximal exercise capacity for 20 minutes. This feels like a fast walk or riding up a small hill. For the high intensity interval exercise session, you will cycle at 90% of your maximal exercise capacity for 1 minute and then recover for 1 minute, repeated 10 times. For the sprint intensity exercise session, you will cycle at an “all-out” intensity for 20 seconds and recover for 2 minutes, repeated 3 times.

In order to be eligible for this research, you must be **60+ years**, have a normal body weight for your height, be a non-smoker, and **not** be taking any off the following: beta blockers, calcium channel blockers (i.e. hypertensive medication), insulin, corticosteroids (i.e. asthma medication), antibiotics, and thyroid medication.

**Screening:**
You will be asked to complete the Get Active Questionnaire (GAQ). This questionnaire allows us to understand if you are at risk of any adverse events with exercise participation. We will then assess your resting heart rate and blood pressure. Based on this information, we will determine if it is safe for you to proceed with our exercise protocols. If we are uncertain of your risk, you may be required to obtain a physician’s note clearing you to proceed.

**Assessment Procedures:**
As a participant of this study, during each session we will be taking a variety of measurements. Some of these will be objective (e.g. heart rate, weight, tissue oxygenation etc.), while others will be self-reported (e.g. how you're feeling, enjoyment). However, none of the measures we are collecting are invasive (e.g. blood tests). You will be introduced to said measures during your second session (see study overview). Additionally, you will be asked to wear a small device on your thigh during the entirety of the study (6 to 7-weeks). This device will be changed each week.

**Study Overview:**




The approximate time commitments for each session are as follows:

- Session 1 – 15min.
- Session 2 – 1hr.
- Session 3 – 45min.
- Session 4 – 45min.
- Session 5 – 45min.
- Session 6 – 45min.
- Session 7 – 15min.

Additionally, we aim to have you visit the laboratory once a week until the completion of the study.

**Participant Compensation:**
You will not be paid for your participation in this study; however, you have much to gain! You will be sent your personal results from each of the exercise sessions in the form of an email at the end of the study. These data will provide you with an in-depth understanding of your current physical fitness. Additionally, you will be provided with a personalized 12-week exercise-training program upon completion of the study.

**Risks and Participant Safety:**
Participation in any research study is associated with some risks. The potential risks of this study include: an elevated heart rate and blood pressure during exercise, light-headedness after exercise, dehydration and feelings of faintness due to the body's reaction to exercise, discomfort in the thigh from the probe or the tape used to secure the device in place and feeling coerced in to participating in the study. To minimize these risks, and to ensure your safety throughout this study, the researchers involved with the study are certified in First Aid and CPR. Additionally, an emergency action plan is posted in the laboratory where sessions are taking place. We will also encourage you to follow all instructions closely and immediately report any unusual exercise related symptoms. In the case of any discomfort and/or health concerns, the UOIT Campus Health Centre is open Monday to Friday from 9:00 am to 4:30 pm. You may also contact the Health Centre at healthcentre@uoit.ca or by calling 905.721.3037. Lastly, please know that if you are a student of the researchers, there will be no benefit or penalty for participation or withdrawal related to this study.

**Benefits:**
There are numerous benefits to you as a participant in this study. Regular exercise is necessary for healthy aging. That is, research has shown that by engaging in exercise, older individuals can reduce the risk of the following: chronic disease, premature mortality, functional limitations, and disability. However, research has also found that the individual responses to exercise are highly variable. Thus, engaging in the study will provide you with a better understanding of the specific type of exercise that will lead to health benefits at the individual level. In addition, you will be given a personalized 12-week exercise program following completion of this study. Adherence to this exercise program will provide additional health and fitness benefits.

**Cost of Participating:**
There are no costs associated with participation in this study. There will be no reimbursement for any costs incurred for participating in this study (e.g. transportation fees etc.).

**Withdrawal:**
You have the right to withdraw from the study without any consequence and will be allowed to do so at any point during the study. If you would like the data that we have collected from you to be withdrawn, please let us know by **April 2019.** Please contact us using the information provided below.

**Participant Confidentiality:**
At each session, the student researcher and an assistant will be present to collect data. Following the session, only the student researchers (Andrea or Nikola) and PI (Shilpa) will have access to your data. Your data will be kept confidential and will be coded (therefore stored anonymously). All hard copies of your data will be stored in a locked cabinet in a laboratory at UOIT. Furthermore, identifier codes will be stored in a separate office. Your data will be stored on a password protected laptop of the student researcher. Once the study has been completed, all hard copies of the data will be destroyed, and electronic data will be stored on a password protected external hard drive that will be stored in a locked cabinet, in a locked office on campus. Your data may be used for secondary use if it is requested for use in a systematic review. In this case, identifier codes would not be provided to ensure your confidentiality.

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## CONSENT

I understand the procedures, potential risk and benefits of this study. Any questions regarding this study have been answered to my satisfaction.

I understand my consent to participate, or to not participate in this study is voluntary. I also understand my right to withdraw from any part or all of this study for any reason. I waive no legal rights by participating in this study.

If I have any questions regarding my rights as a research participant, or about any issues relating to this study, I will contact Dr. Shilpa Dogra at (905)721-8668 ext. 6240.

Please indicate below if you consent to the information collected in the eligibility questionnaire being used in the study.

☐ - Yes
☐ - No

Please indicate below if you consent to the use of your data for secondary analysis/purposes. All data will continue to remain confidential for secondary purposes.

☐ - Yes
☐ - No

I hereby consent to participate in this study.

☐ - Yes
☐ - No

______________________________ _______________________ _______/______/_________
Participant (Print Name) Signature Date

**For a member of the research study:** I have ensured the named participant above has thoroughly understood all aspects of this research study and have answered all questions to their satisfaction.

______________________________ _______________________ _______/______/_________
Research Member (Print Name) Signature Date

**Participant Concerns and Reporting:**

If you have any questions concerning the research study or experience any discomfort related to the study, please contact the researchers Nikola Goncin or Andrea Linares at exercise.uoit@gmail.com.

This study has been approved by the UOIT Research Ethics Board REB #14896 on July 19, 2018.

Any questions regarding your rights as a participant, complaints or adverse events may be addressed to the Research Ethics Board through the Research Ethics Officer - researchethics@uoit.ca or 905.721.8668 x.3693.

## APPENDIX B – Questionnaires and Scales

B1. Eligibility Questionnaire

**PARTICIPANT ELIGIBILITY QUESTIONNAIRE**

Responses to the following questions are confidential and being used to determine your eligibility in our study.

1. Please enter your date of birth in the space provided (MM/DD/YYYY):

   Date: ___________________________

2. What is your biological sex?
   - ☐ Female
   - ☐ Male
   - ☐ Other

3. Has a physician ever told you that you have a respiratory, cardiovascular, or metabolic disease such as: asthma, chronic bronchitis, cystic fibrosis, cardiac arrhythmias, hypertension, heart attacks, Type I or II diabetes, or obesity?
   - ☐ Yes
   - ☐ No

4. Are you currently taking prescription or over-the-counter medication that may alter your breathing, blood pressure, or heart rate (e.g., bronchodilators, opiates, diuretics, vasodilators, beta blockers)?
   - ☐ Yes
   - ☐ No

   If yes, which medications?__________________________________________

5. Do you smoke or use vaporizers?
   - ☐ Yes
   - ☐ No

   If yes, how many times per week?____________________________________

6. Has a doctor ever advised you not to exercise?
   - ☐ Yes
   - ☐ No

   If yes, why?______________________________________________________

7. Do you have any conditions or injuries that may limit you from cycling on a stationary bicycle?

   ☐ Yes

   ☐ No

   If yes, what are the injuries/conditions?______________________________

8. How many days per week do you engage in exercise that causes you to breath heavy or sweat?

   ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

9. Please indicate the date in which you prefer to begin data collection on the table below. A reminder that you will need to be available to attend 7 sessions in consecutive weeks.

| Please indicate which date you prefer to start by circling one of the following: | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| -- | -- | August 6 | August 7 | August 13 | August 14 | August 20 | August 21 | August 27 | August 28 |
| September 3 | September 4 | September 10 | September 11 | September 17 | September 18 | September 24 | September 25 | --- | --- |
| October 1 | October 2 | October 8 | October 9 | October 15 | October 16 | October 22 | October 23 | October 29 | October 20 |
| November 5 | November 6 | --- | --- | --- | --- | --- | --- | --- | --- |
| January 14 | January 15 | January 21 | January 22 | January 28 | January 29 | --- | --- | --- | --- |
| February 4 | February 5 | February 11 | February 12 | February 18 | February 19 | February 25 | February 26 | --- | --- |

| Corresponding End Dates | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| -- | -- | September 17 | September 18 | September 24 | September 25 | October 1 | October 2 | October 8 | October 9 |
| October 15 | October 16 | October 22 | October 23 | October 29 | October 30 | November 5 | November 6 | --- | --- |
| November 12 | November 13 | November 19 | November 20 | November 26 | November 27 | December 3 | December 4 | December 10 | December 11 |
| December 17 | December 18 | --- | --- | --- | --- | --- | --- | --- | --- |
| February 25 | February 26 | March 4 | March 5 | March 11 | March 12 | --- | --- | --- | --- |
| March 18 | March 19 | March 25 | March 26 | April 1 | April 2 | April 8 | April 9 | --- | --- |

B2. Borg Scale of Perceived Exertion

6 – No Exertion at all

7 – Extremely Light

8

9 – Very Light

10

11 – Light

12

13 – Somewhat Hard

14

15 – Hard (heavy)

16

17 – Very Hard

18

19 – Extremely Hard

20 – Maximal Exertion

## APPENDIX C – Recruitment and Instruction Materials

C1. Recruitment Poster
C2. Verbal Recruitment Script for Older Adult Group
C3. Email Response to Recruitment Poster for Interested Participants
C4. Follow Up Eligible Participant Email
C5. Follow Up Ineligible Participant Email
C6. Initial Meeting/Session 1 Instruction Email
C7. Initial Laboratory/Session 2 Instruction Email
C8. Laboratory Instruction Email
C9. Emergency Action Plan
C10. Script for Reminder of Confidentiality (After Session 3)

C1. Recruitment Poster

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# Participate in our Exercise Study and Learn About your Health! FREE!

- ✓ Want to know your aerobic fitness levels?
- ✓ Interested in learning how to properly perform high intensity interval exercise?
- ✓ If you are **60+** you may be eligible for our study!

**Our goal**: We want to know how men and women, and younger and older adults respond to different intensities of exercise.

**What does this mean for you?**

- ✓ Participation in the study will involve 7 sessions
- ✓ 5 sessions will involve exercise on a stationary bike

**You may be eligible to participate if:**

- ✗ You do **not** smoke
- ✗ You do **not** have any respiratory, cardiovascular, and/or metabolic abnormalities (e.g. asthma, hypertension, or obesity)

## FREE individualized exercise program upon completion!

To learn more about the study or sign up please contact the researchers Andrea Linares or Nik Goncin using the information below:

Email: **exercise.uoit@gmail.com**
Phone: (905) 721-8668 ext: 3618

This study has been approved by the UOIT Research Ethics Board REB #14896 on July 19, 2018. Any questions regarding your rights as a participant, complaints or adverse events may be addressed to the Research Ethics Board through the Research Ethics Officer - researchethics@uoit.ca or 905.721.8668 x. 3693

C2. Verbal Recruitment Script for Older Adult Group

Hello,

Our names are Andrea Linares and Nikola Goncin. We are doing research as part of our master's research project in the Faculty of Health Sciences here at UOIT. We are here to briefly talk to you about participating in our research study "Acute Behavioural and Physiological Responses to Variable Intensity Exercise." We are currently recruiting adults 60 or older. Participation in this study requires completion of 7 sessions, 5 of which will be in the lab involving different types of exercise. If you're interested in participating in this study, you can email us at nikola.goncin@uoit.net or andrea.linares@uoit.net.

Thank you for your time today.

C3. Email Response to Recruitment Poster for Interested Participants

Dear (*Participant Name*)

Thank you for inquiring about our study!

Please find attached an eligibility questionnaire. All information collected within this questionnaire will be used for determining eligibility and all information will be kept confidential. Please complete this questionnaire and return it to this email address at your earliest convenience.

Please note, that participation in this study is voluntary. If you wish to withdraw from the study, please contact one of the researchers via email or in person.

If you have any questions concerning the research study or experience any discomfort related to the study, please contact any one of the researchers Andrea Linares (andrea.linares@uoit.net), Nikola Goncin (nikola.goncin@uoit.net) or Dr. Shilpa Dogra at (905)721-8668 ext. 6240 or shilpa.dogra@uoit.ca.

This study has been approved by the UOIT Research Ethics Board REB #14896 on July 19, 2018.

Any questions regarding your rights as a participant, complaints or adverse events may be addressed to Research Ethics Board through the Ethics and Compliance Officer - researchethics@uoit.ca or 905.721.8668 x. 3693.

Please do not hesitate to contact us if you have any questions/concerns.

Sincerely,

Andrea Linares and Nikola Goncin

C4. Follow Up Eligible Participant Email

Dear (*Participant Name*)

Thank you for completing the eligibility questionnaire for our study "Acute Behavioural and Physiological Responses to Variable Intensity Exercise." Based on your responses to the eligibility questionnaire you are eligible to participate in the initial screening process for this study, which will determine your eligibility for the subsequent laboratory visits. Please find attached an informed consent document outlining the details of the study. Please read through the document carefully. A copy of this document will be available at the laboratory for you to sign during your first visit. Below is a list of times we have available for your first laboratory visit, please choose a time that is of convenience to you and reply to this email.

Please note, that participation in this study is voluntary. If you wish to withdraw from the study, please contact one of the researchers via email or in person.

If you have any questions concerning the research study or experience any discomfort related to the study, please contact any one of the researchers, Andrea Linares (andrea.linares@uoit.net) or Nikola Goncin (nikola.goncin@uoit.net)

This study has been approved by the UOIT Research Ethics Board REB #14896 on July 19, 2018.

Any questions regarding your rights as a participant, complaints or adverse events may be addressed to Research Ethics Board through the Ethics and Compliance Officer - researchethics@uoit.ca or 905.721.8668 x. 3693.

(*List of Dates and Times)*

Sincerely,

Andrea Linares and Nikola Goncin

C5. Follow Up Ineligible Participant Email

Dear (*Participant Name*)

Thank you for completing the eligibility questionnaire for our research project entitled "Acute Behavioural and Physiological Responses to Variable Intensity Exercise." Based on your responses on the eligibility questionnaire you are not eligible to participate in this study; however, we thank you for your time and your interest. In addition, all of the information collected will remain confidential and will be destroyed.

If you have any questions concerning the research study or experience any discomfort related to the study, please contact any one of the researchers, Andrea Linares (andrea.linares@uoit.net) or Nikola Goncin (nikola.goncin@uoit.net)

This study has been approved by the UOIT Research Ethics Board REB #14896 on July 19, 2018.

Any questions regarding your rights as a participant, complaints or adverse events may be addressed to Research Ethics Board through the Ethics and Compliance Officer - researchethics@uoit.ca or 905.721.8668 x. 3693.

Sincerely,

Andrea Linares and Nikola Goncin

C6. Initial Meeting/Session 1 Instruction Email

Dear (*Participant Name),*

You have been scheduled in for your first meeting on (Day/Time) at (place). Prior to attending this session, we ask that you follow a few simple instructions. We ask that you bring shorts to your initial meeting. An activity monitor will be applied and secured to your thigh during this initial meeting. If you could please ensure that the center of your right thigh is accessible for application of the activity monitor. Please shave any excess hair as it may interfere with how the activity monitor adheres to the area. Please see the photo below for reference of the location where the activity monitor will be placed.

Please note, that participation in this study is voluntary. If you wish to withdraw from the study, please contact one of the researchers via email or in person.

If you have any questions concerning the research study or experience any discomfort related to the study, please contact any one of the researchers, Andrea Linares (andrea.linares@uoit.net) or Nikola Goncin (nikola.goncin@uoit.net)

This study has been approved by the UOIT Research Ethics Board REB #14896 on July 19, 2018.

Any questions regarding your rights as a participant, complaints or adverse events may be addressed to Research Ethics Board through the Ethics and Compliance Officer - researchethics@uoit.ca or 905.721.8668 x. 3693.

Thank you for your adherence to these instructions,

Sincerely,

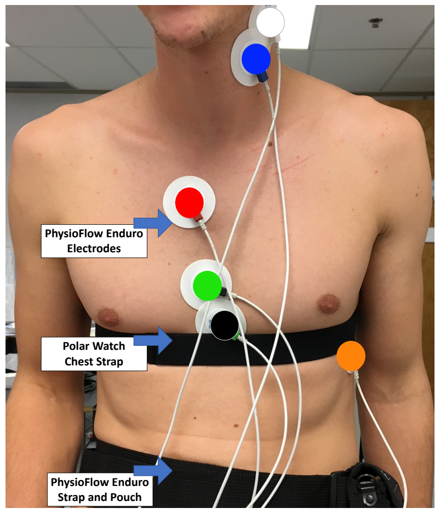
Andrea Linares and Nikola Goncin

C7. Initial Laboratory/Session 2 Instruction Email

Dear (*Participant Name),*

You have been scheduled in for your second meeting on (Day/Time) at (place). Prior to attending this session, we ask that you bring shorts and a fitted shirt to your initial exercise session.

You will be fitted with a wireless heart rate monitor around the chest along with a series of electrocardiogram electrodes. Please shave any excess hair as it may interfere with application of electrodes (please refer to image below) and signal detection.




Additionally, the activity monitor you received in session 1 will be reprogrammed and reapplied to your right quadriceps at the end of the session.

Please note, that participation in this study is voluntary. If you wish to withdraw from the study, please contact one of the researchers via email or in person.

If you have any questions concerning the research study or experience any discomfort related to the study, please contact any one of the researchers, Andrea Linares (andrea.linares@uoit.net) or Nikola Goncin (nikola.goncin@uoit.net)

This study has been approved by the UOIT Research Ethics Board REB #14896 on July 19, 2018. Any questions regarding your rights as a participant, complaints or adverse events may be addressed to Research Ethics Board through the Ethics and Compliance Officer - researchethics@uoit.ca or 905.721.8668 x. 3693.

Thank you for your adherence to these instructions,

Sincerely,

Andrea Linares and Nikola Goncin

C8. Laboratory Instruction Email

Dear (*Participant Name),*

You have been scheduled in for your laboratory testing session on (Day/Time). Prior to attending this session, we ask that you follow a few simple instructions. Prior to attending this session, we ask that you:

- Bring exercise clothing (i.e. shorts and a short sleeve)
- Be prepared to exercise!
- Please do not consume alcohol or caffeine 12 hrs prior to the session
- Please do not perform any vigorous exercise at least 24 hrs prior to the session

If for any reason the activity monitor is no longer applied to your thigh, please bring it to the laboratory session.

Please note, that participation in this study is voluntary. If you wish to withdraw from the study, please contact one of the researchers via email or in person.

If you have any questions concerning the research study or experience any discomfort related to the study, please contact any one of the researchers, Andrea Linares (andrea.linares@uoit.net) or Nikola Goncin (nikola.goncin@uoit.net)

This study has been approved by the UOIT Research Ethics Board REB #14896 on July 19, 2018

Any questions regarding your rights as a participant, complaints or adverse events may be addressed to Research Ethics Board through the Ethics and Compliance Officer - researchethics@uoit.ca or 905.721.8668 x. 3693.

Thank you for your adherence to these instructions,

Sincerely,

Andrea Linares and Nikola Goncin

C9. Emergency Action Plan

In the event a participant experiences a serious event, defined as light headedness or difficulty breathing that is not responsive to suspending exercise, the following steps will be taken.

**Step 1: Help the participant to the floor to lay down and elevate feet.**

- Exercise mats will be present in the laboratory for participants to lay down on.
- Feet will be elevated on to a chair and if the feeling of light headedness or increased breathing rate does not begin to subside or worsens within 2 minutes proceed to step 2

**Step 2: One researcher or assistant will contact the Campus Emergency Response Team (extension 2400) or 911.**

- The participants' emergency contact will also be contacted at this time.

Participant Emergency Contact

- Name: ________________________________
- Relationship:___________________________
- Phone Number: ________________________

C10. Script for Reminder of Confidentiality (After Session 3)

At this point, we would like to remind you that your participation in this study is completely voluntary. If you would like to withdraw your participation or if you would like to withdraw your data, please inform one of the researchers via email or in person. In addition, we would like to remind you that all the data collected throughout this study will remain confidential. Please do not hesitate to contact us if you have any questions or concerns.

## APPENDIX D – Participant Acknowledgment Materials

D1. Thank you Email
D2. Participant Results

D1. Thank you Email

Dear *(Participant Name),*

We would like to thank-you for your participation in the research study entitled "Acute Behavioural and Physiological Responses to Variable Intensity Exercise." Your participation in this study will help to further understand cardiopulmonary responses and behavior change after different intensities of exercise in younger and older adults. Your time is greatly appreciated. As a token of our appreciation, we have created a 12-week individualized exercise program for you (please see attached).

If you have any questions concerning the research study or experience any discomfort related to the study, please contact any one of the researchers, Andrea Linares (andrea.linares@uoit.net) or Nikola Goncin (nikola.goncin@uoit.net)

This study has been approved by the UOIT Research Ethics Board REB #14896 on July 19, 2018.

Any questions regarding your rights as a participant, complaints or adverse events may be addressed to Research Ethics Board through the Ethics and Compliance Officer - researchethics@uoit.ca or 905.721.8668 x. 3693.

Sincerely,

Andrea Linares and Nikola Goncin

D2. Participant Results

Please see below for your assessment results along with a brief explanation of your results in context to overall fitness. (Below is an example for REB purposes).

| **Assessment.** | **Your Score** | **Interpretation** | **Explanation** |
|---|---|---|---|
| Body Mass Index | 24 $kg/m^2$ | 18.5-24.9 is considered normal | According to your results, your BMI falls in the normal category. BMI is based on your height and weight. |
| Aerobic Capacity | 45ml/kg/min | >40 is very good | According to norms for your age, you fall in the very good category. This means that your heart, lungs and muscles are working efficiently and that your aerobic fitness is high. |

| **Heart Rate Zones** | **Zones** | | **Heart Rate (bpm)** | **Explanation** |
|---|---|---|---|---|
| | Zone 5 (90-100%HR) | Maximal Exercise | 180-200 | These are the necessary heart rate ranges for different intensities of exercises. These ranges are predicted using data from you exercise sessions performed in the study. |
| | Zone 4 (80-90% HR) | High Intensity Exercise | 160-180 | |
| | Zone 3 (70-80% HR) | Moderate Intensity Exercise | 140-160 | |
| | Zone 2 (60-70% HR) | Light Intensity Exercise | 120-140 | |
| | Zone 1 (50-60% HR) | Warm-up | 100-120 | |

| **High Intensity Exercise** | **Peak Power Output** | **90% Peak Power Output** | **10% Peak Power Output** | **Explanation** |
|---|---|---|---|---|
| | 200 watts | 180 watts | 20 watts | These are the workloads necessary for your High Intensity Interval exercise. You will spend 1 minute at 90% of your PPO followed by 1 minute at 10% of your PPO. Repeat 10 times. |

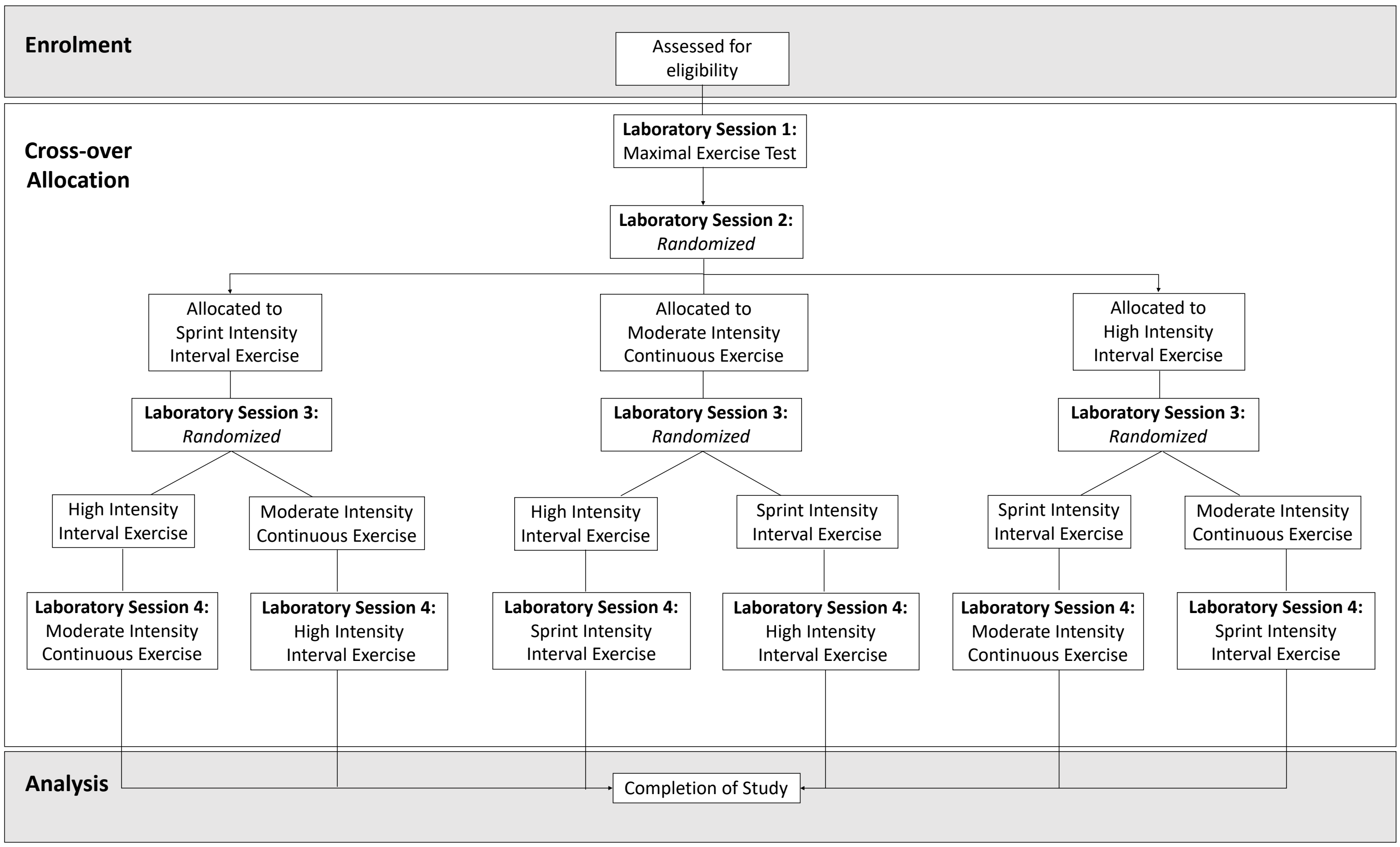
In addition, your average step count over the course of the study was 10,080. Your most inactive days were those that were directly following an exercise session. Breaking up and/or decreasing your sitting time is very important. We encourage you to try and not sit without getting up for any longer than 30 minutes at a time!

The exercises sessions you participated in were well tolerated i.e. no adverse reactions to exercise. As such, it is safe for you to exercise at high intensities (as you did in the lab). There are many benefits to such high intensity exercise, but if you do not enjoy it, moderate intensity exercise is equally beneficial for maintaining health.

We thank you for your participation in this study and are happy to answer any questions you may have regarding your results or the attached exercise program.

## APPENDIX E – Flow Charts of Laboratory Sessions

## E1. Possible Randomization of Sessions



E2. Timeline Schematic of Laboratory Sessions

| Time (min.) | -30 | -20 | -10 | 0 | | 20 | 30 |
|---|---|---|---|---|---|---|---|

**Measures:**
- Weight
- Height
- Blood pressure
- Heart rate

**Instrumentation:**
- Polar V800
- NIRS
- Parvo Medics gas analysis using two-way valve

**Measures:**
- RRi at rest

**Warmup:**
- 2 min. at 10% PPO

**FAM/MAX:**
- Increase in work rate by 1W/3sec. until exhaustion.
- **Measures:**
  - $VO_2$
  - $V_E$
  - RR
  - Vt
  - HR
  - RPE
  - TSI
- 5 minute recovery at 10% PPO.
- **Measures:**
  - $HR_{REC}$
  - RRi

**Equipment Removal**

***Randomized* MOD/HI/SPRT**
**Measures:**
- $VO_2$
- $V_E$
- RR
- Vt
- HR
- RPE
- TSI

**MOD/HI Recovery:**
- 5 minutes at 10% PPO
- **Measures:**
  - $HR_{REC}$
  - RRi

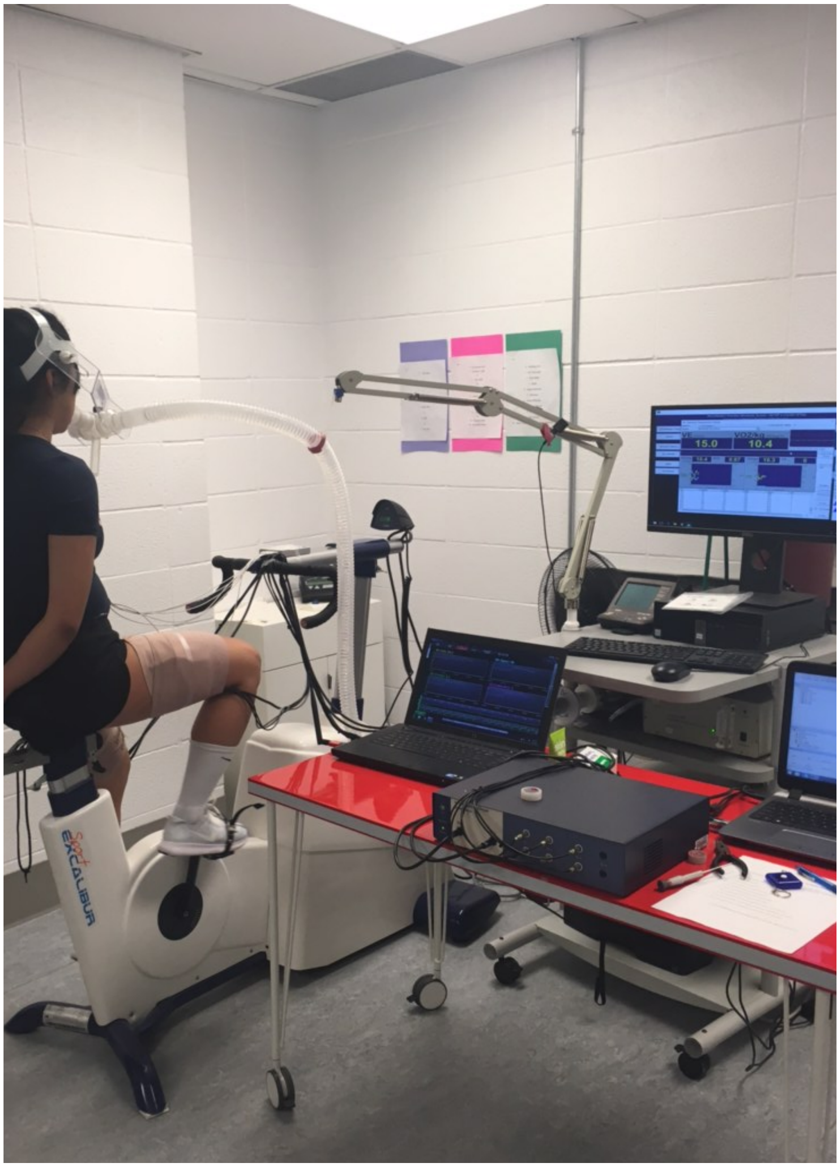
**Equipment Removal**

**SPRT Recovery:**
- 5 minutes at 10% PPO
- **Measures:**
  - $HR_{REC}$
  - RRi

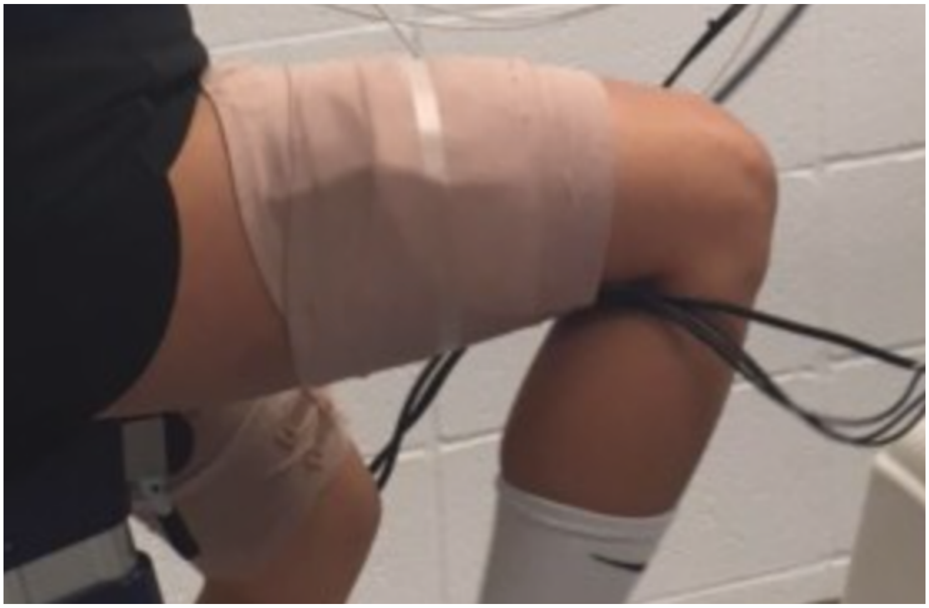
**Equipment Removal**

## APPENDIX F – Figures

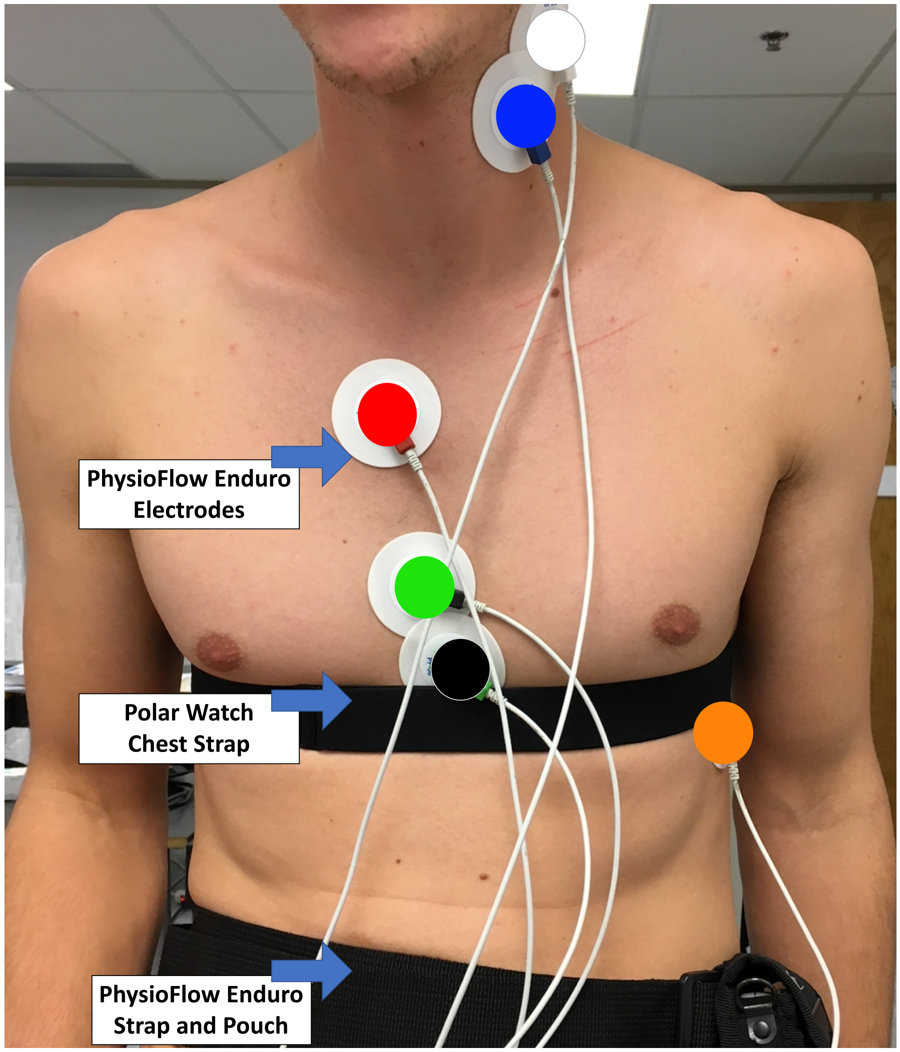
F1. Direct Maximal Exercise Test on the Cycle Ergometer



F2. Probe Placement for Near Infrared Spectroscopy



F3. Wireless Polar Placement



## APPENDIX G – Data Collection Sheet

G1. Session 3 Sheet
G2. Sessions 4 to 6 Sheets

G1. Session 3 Sheet

**MAXIMAL EXERCISE SESSION DATA COLLECTION SHEET**

**Date:** ______________________________

**Time:** ______________________________

**Data Collectors:** ______________________

| Participant Data | | |
|---|---|---|
| **Date of Birth:** ______ **(MM/DD/YYYY)** | **Height:** ______ **(cm)** | **Weight:** ______ **(kg)** |
| **Resting HR:** ______ **(bpm)** | Resting HR (trial 2 if needed): ______ (bpm) | |
| **Resting BP:** ______ **(mmHg)** | Resting BP (trial 2 if needed): ______ (mmHg) | |
| **Temperature:** ______ | **Humidity:** ______ | |
| **PPO (W) from max:** ______ | **NIRS:** **R1: LEFT / R2: RIGHT** ☐ - Yes ☐ - No ______ | **ActivPAL:** **RIGHT** ☐ - Yes ☐ - No |

| MAX SESSION | | | | |
|---|---|---|---|---|
| **Time** | **Heart Rate** | **RPM** | **Watts** | **RPE** |
| END 2MIN WARM UP | | | | |
| **WATCH TIME (START):<br>+ COMMENT <u>START MAX</u>** | | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 10 | | | | |
| 11 | | | | |
| 12 | | | | |
| 13 | | | | |
| 14 | | | | |
| **WATCH TIME (END):<br>+ COMMENT <u>END MAX</u>** | | | | |
| **START COOL-DOWN** | | | | |
| END 5MIN COOLDOWN | | | | |

G2. Sessions 4 to 6 Sheets

**MODERATE INTENSITY CONTINOUS DATA COLLECTION SHEET**

**Date: ___________________________________**

**Time: ___________________________________**

**Data Collectors: __________________________**

| Participant Data | | |
|---|---|---|
| **Date of Birth:** ______________ **(MM/DD/YYYY)** | **Height:** ______________ **(cm)** | **Weight:** ______________ **(kg)** |
| **Resting HR:** ______________ **(bpm)** | Resting HR (trial 2 if needed): ______________ (bpm) | |
| **Resting BP:** ______________ **(mmHg)** | Resting BP (trial 2 if needed): ______________ (mmHg) | |
| **Temperature:** ______________ | **Humidity:** ______________ | |
| **PPO (W) from max:** ______________ | **NIRS:** **R1: LEFT / R2: RIGHT** ☐ - Yes ☐ - No ______________ | **ActivPAL:** **RIGHT** ☐ - Yes ☐ - No |

| MOD SESSION | | | | |
|---|---|---|---|---|
| **Time** | **Heart Rate** | **RPM** | **Watts** | **RPE** |
| END 2MIN WARM UP | | | | |
| **WATCH TIME (START): + COMMENT START MOD** | | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
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| 13 | | | | |
| 14 | | | | |
| 15 | | | | |
| 16 | | | | |
| 17 | | | | |
| 18 | | | | |
| 19 | | | | |
| 20 | | | | |
| **WATCH TIME (END): + COMMENT END MOD** | | | | |
| END 5MIN COOLDOWN | | | | |

## HIGH INTENSITY INTERVAL DATA COLLECTION SHEET

**Date:** ______________________________

**Time:** ______________________________

**Data Collectors:** ______________________

| Participant Data | | |
|---|---|---|
| **Date of Birth:** ________ **(MM/DD/YYYY)** | **Height:** ________ **(cm)** | **Weight:** ________ **(kg)** |
| **Resting HR:** ________ **(bpm)** | Resting HR (trial 2 if needed): ________ (bpm) | |
| **Resting BP:** ________ **(mmHg)** | Resting BP (trial 2 if needed): ________ (mmHg) | |
| **Temperature:** ________ | **Humidity:** ________ | |
| **PPO (W) from max:** ________ | **NIRS:** **R1: LEFT / R2: RIGHT** ☐ - Yes ☐ - No ________ | **ActivPAL:** **RIGHT** ☐ - Yes ☐ - No |

| HIT SESSION | | | | |
|---|---|---|---|---|
| **Time** | **Heart Rate** | **RPM** | **Watts** | **RPE** |
| END 2MIN WARM UP | | | | |
| **WATCH TIME (START):**<br>**+ COMMENT <u>START HIT</u>** | | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
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| 14 | | | | |
| 15 | | | | |
| 16 | | | | |
| 17 | | | | |
| 18 | | | | |
| 19 | | | | |
| 20 | | | | |
| **WATCH TIME (END):**<br>**+ COMMENT <u>END HIT</u>** | | | | |
| END 5MIN COOLDOWN | | | | |

## SPRINT INTENSITY INTERVAL DATA COLLECTION SHEET

**Date:** ___________________________

**Time:** ___________________________

**Data Collectors:** ____________________

| Participant Data | | |
|---|---|---|
| **Date of Birth:** ______ **(MM/DD/YYYY)** | **Height:** ______ **(cm)** | **Weight:** ______ **(kg)** |
| **Resting HR:** ______ **(bpm)** | Resting HR (trial 2 if needed): ______ (bpm) | |
| **Resting BP:** ______ **(mmHg)** | Resting BP (trial 2 if needed): ______ (mmHg) | |
| **Temperature:** ______ | **Humidity:** ______ | |
| **PPO (W) from max:** ______ | **NIRS:** **R1: LEFT / R2: RIGHT** ☐ - Yes ☐ - No ______ | **ActivPAL:** **RIGHT** ☐ - Yes ☐ - No |

| SIT SESSION | | | | |
|---|---|---|---|---|
| **Time** | **Heart Rate** | **RPM** | **Watts** | **RPE** |
| END 2MIN WARM UP | | | | |
| **WATCH TIME (START):<br>+ COMMENT START SIT** | | | | |
| SPRINT | | | | |
| 1 | | | | |
| 2 | | | | |
| SPRINT | | | | |
| 1 | | | | |
| 2 | | | | |
| SPRINT | | | | |
| 1 | | | | |
| 2 | | | | |
| **WATCH TIME (END):<br>+ COMMENT END SIT** | | | | |
| **START COOL-DOWN** | | | | |
| END 5MIN COOLDOWN | | | | |

## APPENDIX H – References

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