EFFECTS OF BLOCKED AND PERIODIC INTERVAL TRAINING ON CARDIORESPIRATORY FITNESS AND AFFECTIVE RESPONSES AMONG COLLEGE STUDENTS

By

WILLIAM RYOTA YAKU

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of WILLIAM RYOTA YAKU find it satisfactory and recommend that it be accepted.

Christopher P. Connolly, Ph.D., Chair

Sarah Ullrich-French, Ph.D.

Amanda McMahon, Ph.D.

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EFFECTS OF BLOCKED AND PERIODIC INTERVAL TRAINING ON

CARDIORESPIRATORY FITNESS AND AFFECTIVE

RESPONSES AMONG COLLEGE STUDENTS

Abstract

by William Ryota Yaku, M.S.
Washington State University
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Chair: Christopher P. Connolly

Physical activity (PA), defined as any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above a basal level, is negatively associated with adverse health outcomes and positively associated with health and fitness. However, 46% of all American adults are not meeting aerobic PA guidelines (i.e., 150 minutes of moderate-intensity activity, 75 minutes of vigorous-intensity activity, or equivalent combination), and of those not meeting guidelines, more than half do not engage in any purposeful aerobic PA whatsoever. Perceived lack of time is the most cited barrier to PA in young adults and may partially explain the above findings. Interval training (IT) has emerged as an effective, time-efficient mode of exercise to potentially attenuate the time barrier, thus enabling young adults to meet PA guidelines. The purpose of this study was to compare different weekly frequencies of interval training on cardiorespiratory fitness adaptations and affective responses among university students. Fourteen students were recruited and randomly assigned into a six-week exercise intervention group. The “blocked” group (HIIT1) performed the weekly recommended exercise volume in one session every week. The “periodic” group (HIIT3) performed the same volume spread out across three weekly sessions. The intensity of the intervention sessions was set at 80% of $\dot{V}O_{2max}$ for each participant. Baseline and post-intervention graded exercise testing were conducted to compare differences in cardiorespiratory fitness ($\dot{V}O_{2max}$) improvements. Affective responses were assessed by rating of perceived exertion (RPE) and the Feeling Scale (FS) and were measured within the intervention. Both groups experienced significant ($p < 0.05$) increases in $\dot{V}O_{2max}$, with the greatest effect observed in the HIIT3 group (HIIT1, +8.2% ± 6.8%; HIIT3, +11.3% ± 9.2%; $p = 0.04$). RPE average across the intervention was significantly higher in the HIIT1 group (HIIT1: 6.3 ± 2.1, HIIT3: 3.2 ± 2.3, $p < 0.001$). FS score session averages, on the other hand, were lower for HIIT1 than HIIT3 (HIIT1: -0.2 ± 1.4, HIIT3: 3.5 ± 0.6, $p < 0.001$). Interestingly, neither RPE nor FS scores changed across the intervention in the HIIT3 group ($p > 0.05$ for both), whereas the HIIT1 group experienced decreases in RPE (-2.4 ± 0.4, $p = 0.02$) and increases in FS score (+3.6 ± 0.8, $p = 0.008$). The present study demonstrated that the $\dot{V}O_{2max}$ improvement was greater in the HIIT3 group compared to the HIIT1 group even with matched relative intensity and weekly exercise volume. Additionally, the HIIT3 group had more adaptive affective responses throughout the intervention. These findings suggest that spreading a weekly volume of exercise across multiple days may be superior to completing it in one session in terms of both cardiorespiratory fitness improvement and affective responses.

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Dedication

This thesis is dedicated to

My family, whom I need more than they know,

My companions, who kept me pressing on and pursuing,

My advisor, who showed extreme patience and support in assisting me throughout,

And,

To the Lord, who day by day loads me with good (Psalm 68:19).

CHAPTER ONE: INTRODUCTION

Physical activity (PA) has been defined by the U.S. Department of Health and Human Services as any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above a basal level (U.S. Department of Health and Human Services, 2018, pg. 29). An array of studies has demonstrated negative associations between PA and adverse health outcomes, including all-cause mortality (ACM; Eijsvogels et al., 2016; Fletcher et al., 1996; Kelly et al., 2014; Stewart et al., 2017), cardiovascular (CV) disease (CVD; Eijsvogels et al., 2016; Fletcher et al., 1996; Morris et al., 1953; Sattelmair et al., 2011; Thompson et al., 2003), overweight and obesity (Fan et al., 2013; Thompson et al., 2003), type 2 diabetes mellitus (T2DM; Aune et al., 2015), and various cancers (Lee, 2003). Furthermore, PA is positively associated with overall health and fitness (Eijsvogels et al., 2016; Thompson et al., 2003), functional capacity (Fletcher et al., 1996), improved mental health (Fletcher et al., 1996), and immune system function (Chastin et al., 2020). Physical fitness, which is generally improved by PA, also possesses an inverse relationship with negative health outcomes. For instance, cardiorespiratory fitness (CRF), or the body's ability to perform continuous exercise with large muscle groups (U.S. Department of Health and Human Services, 2018), is itself negatively associated with ACM and CVD mortality (Lee et al., 2011; Ross et al., 2016) as well as CVD (Ross et al., 2016). Hence, PA plays a key role in the realm of health and disease.

PA is comprised of multiple domains that are characterized by mode or setting, including leisure-time (LTPA), occupational, transportation, and household. Exercise typically falls within the LTPA domain and is defined as a form of physical activity that is planned, structured, repetitive, and performed with the goal of improving health or fitness (U.S. Department of Health and Human Services, 2018, pg. 29). The current *Physical Activity Guidelines for Americans* recommends that adults perform 150 minutes per week of moderate-intensity or 75 minutes per week of vigorous-intensity aerobic PA (U.S. Department of Health and Human Services, 2018). According to the data from the National Health Interview Survey (NHIS) published by the Centers for Disease Control and Prevention (2022), in 2018, 46% of all American adults did not meet aerobic exercise guidelines. Furthermore, of those not meeting guidelines, 55% (25% of all American adults) did not engage in any LTPA whatsoever. Given the cumulative health benefits of PA as well as the specific relationships previously shown for PA with disease and mortality, these are alarming parameters. There is an urgent need for a nationwide elevation in PA levels, particularly given that sedentary behavior (SB) levels have increased in the last twenty years.

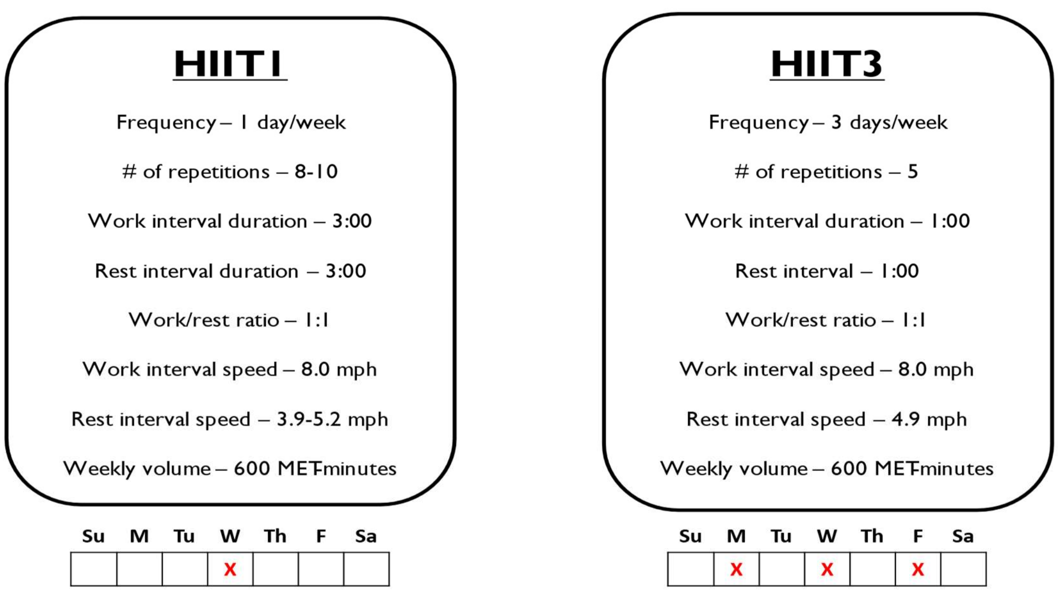
SB is positively associated with risk for ACM and CVD mortality (Biswas et al., 2015; Ekelund et al., 2016; Fletcher et al., 1996; Grøntved & Hu, 2011; Matthews et al., 2015; Patterson et al., 2018), CVD (Biswas et al., 2015; Fletcher et al., 1996; Grøntved & Hu, 2011), T2DM (Biswas et al., 2015; Grøntved & Hu, 2011; Patterson et al., 2018), and cancer incidence and mortality (Biswas et al., 2015). Alarmingly, National Health and Nutrition Survey (NHANES) data for the years 2007-2016 showed an increase in total sitting time across all age groups (Du et al., 2019; Yang et al., 2019). Moreover, there was a concomitant increase in total computer usage outside school or work for all age groups (Yang et al., 2019). While these data are concerning, it appears that replacing SB with PA can attenuate (Ekelund et al., 2016; Matthews et al., 2015) or possibly eliminate (Ekelund et al., 2016) the negative effects of SB.

NHANES data for the 2017-2018 cycle revealed that the young adult subpopulation (age 18-24 years) was the most active, with 55.2% meeting the aerobic LTPA guideline (Whitfield et al., 2021). Unfortunately, inactivity levels have increased within this subgroup by 2.0% from the 2007-2008 cycle. This slight rise in inactivity at least suggests that SB among young adults has not improved within the last decade. This likely results from various barriers that affect this population, primarily in university and college students (UCS). These barriers include perceived lack of time, energy, motivation, and resources (Daskapan et al., 2006). Furthermore, students likely incur high levels of stress from sources such as academic endeavors, moving to a new location, and financial independence. These stressors have been reported to predispose UCS to poorer PA and nutrition behaviors (Plotnikoff et al., 2015). Because lifestyle behavior improvements can lower non-communicable disease risk (Plotnikoff et al., 2015), it is crucial that interventions to improve PA levels target specific barriers and lifestyle factors. As the most commonly reported barrier to PA in UCS, perceived lack of time may be an ideal intervention target (Daskapan et al., 2006).

Interval training (IT) has emerged within the last fifteen years as an effective, time-efficient mode of exercise (Gibala & Jones, 2013). Research on this topic has questioned the popular notion that aerobic exercise should be submaximal and lengthy in nature, while promoting instead that both untrained and recreationally active people can substantially improve fitness with relatively lower exercise durations at higher intensities (Gibala & Jones, 2013). Recent work has even shown that IT is superior to traditional moderate-intensity continuous training (MICT) for both central (O'Driscoll et al., 2018) and peripheral (Granata et al., 2017) exercise-induced adaptations. Moreover, IT is advantageous in that it is "almost infinitely variable" (Gibala & Jones, 2013, pg.

51); it can be organized into many configurations of varying duration and intensity. Traditionally, IT is dichotomized into high-intensity interval training (HIIT) and sprint interval training (SIT). HIIT is characterized by longer, "near maximal" exercise bouts performed at ≥80% maximal heart rate (HR), whereas SIT involves shorter, "all-out" exercise bouts (Gibala et al., 2019; MacInnis & Gibala, 2017). A recent review comparing HIIT and SIT to MICT showed overall superiority for both IT modes, although HIIT appeared more effective at producing adaptations than SIT (Gibala et al., 2019). However, most studies included in this review that compared MICT and HIIT interventions used matched frequencies (e.g., three days per week). What remains unclear is whether IT-induced physiological adaptations differ when energy expenditure is matched but frequency is unmatched (e.g., 150 minutes of moderate-intensity aerobic exercise spread out over one vs. three days per week; Figure 1). Determining the relationship between exercise frequency and CRF improvements was the primary aim of this study.

Figure 1. Overview of experimental protocol.



Psychological responses to IT have also been investigated. According to the Dual-Mode Theory, exercise intensities exceeding the anaerobic threshold are related to negative affective responses (Ekkekakis, 2003; Ekkekakis et al., 2011). Because IT is generally characterized by intensities that exceed the anaerobic threshold, it is reasonable to postulate that IT would produce unfavorable psychological states compared with MICT. However, other work has shown that IT can produce greater exercise enjoyment in both sedentary (Oliveira et al., 2018) and recreationally active (Bartlett et al., 2011; Thum et al., 2017) individuals, likely due to a lower time commitment (Oliveira et al., 2018; Thum et al., 2017). Furthermore, in their study of untrained adults, Jung and colleagues (2014), reported that the majority of participants preferred HIIT to MICT. While studies such as these reported positive outcomes, the psychological responses to IT remain ambiguous (Poon et al., 2018; Thum et al., 2017), which could be the result of varying study methodology (Oliveira et al., 2018). Because of the correlation of core affective responses with exercise adherence (Williams, 2008), examination of this factor with regard to different types of IT is warranted. This was a secondary aim of this study.

Research Questions & Hypotheses

***Research Question 1*: Does blocked or periodic exercise more effectively induce improvements in cardiorespiratory fitness in lightly active college students when energy expenditure is matched but frequency is unmatched?**

Hypothesis 1: Periodic exercise will more effectively improve maximal oxygen uptake compared to blocked exercise.

Hypothesis 2: Periodic exercise will more effectively improve running economy compared to blocked exercise.

***Research Question 2*: Does blocked or periodic exercise produce more adaptive affective responses in lightly active college students?**

Hypothesis: Periodic exercise will produce more adaptive affective responses compared to blocked exercise.

Although the majority of young adults are participating in some activity throughout the week, there is a need for increased activity among UCS to reach PA guidelines. The growing body of literature clearly indicates IT to be an effective and perhaps superior method of exercise. Much work has already been done concerning the relationships of exercise intensity and duration with physiological adaptations. What remains to be elucidated are the relationships among training frequencies and CRF improvements within IT exercise modalities. Furthermore, affective responses to IT need to be clarified to resolve whether this may be realistically adopted as an exercise mode for insufficiently active young adults. This thesis project was presented in full in the forthcoming chapters, including a thorough review of literature, project methodology, and complete manuscript to be submitted for publication.

CHAPTER TWO: REVIEW OF LITERATURE

Introduction

Plenteous research has examined the integrated relationships between PA, SB, exercise intensity, health, disease, and fitness. An all-inclusive exploration into these topics is necessary for a complete understanding of these relationships. For this purpose, a review of existing literature was conducted which will investigate the following major topics: (1) the effects of PA on health and fitness outcomes, (2) the effects of CRF on health outcomes (3) PA guidelines and trends in the United States (US), (4) the effects of SB on health outcomes (5) SB trends in the US, (6) PA and SB trends in young adults, (7) health and physiologic improvements from and configurations of IT, and (8) psychological responses to PA and IT. Much has already been elucidated concerning the effects of PA and exercise on health and fitness; however, IT has only been examined closely within the last 15 years, which is why discussion on this topic was placed later in this review. Previous literature was comprehensively examined following an extensive database search. The databases used for this review were PubMed, EBSCO, and Google Scholar.

Physical Activity, Health, and Fitness

PA is defined as any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above a basal level (U.S. Department of Health and Human Services, 2018, pg. 29). A multitude of studies has demonstrated inverse relationships between PA and negative health outcomes, including ACM (Eijsvogels et al., 2016; Fletcher et al., 1996; Kelly et al., 2014, Stewart et al., 2017), CVD (Eijsvogels et al., 2016; Fletcher et al., 1996; Morris et al., 1953; Sattelmair et al., 2011; Thompson et al., 2003), overweight and obesity (Fan et al., 2013;

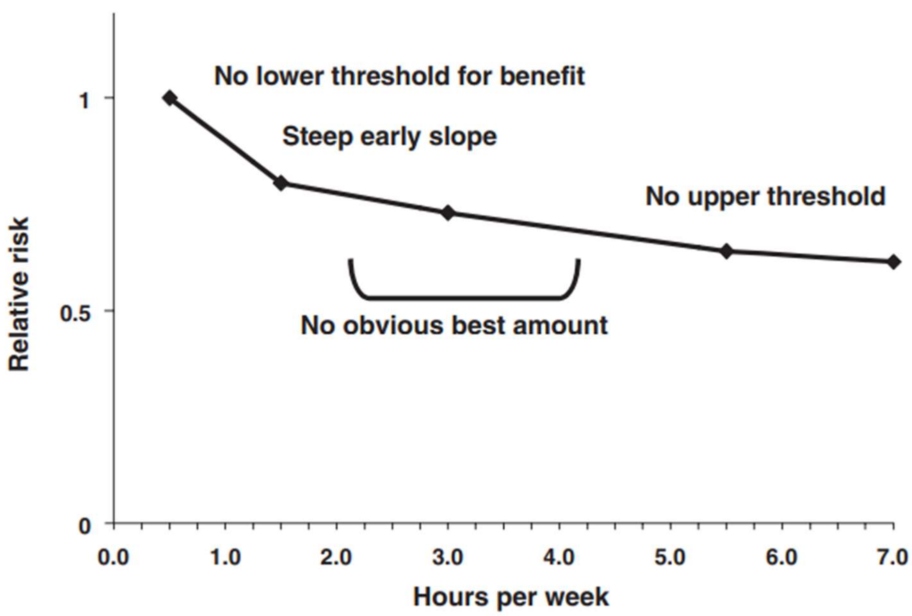
Thompson et al., 2003), T2DM (Aune et al., 2015), and various cancers (Lee, 2003). Additionally, health and fitness can be improved or maintained through regular PA (Eijsvogels et al., 2016; Ross et al., 2016; Thompson et al., 2003). Improved CRF, which is generally attained through aerobic PA, is also inversely associated with ACM and CVD mortality (Lee et al., 2011; Ross et al., 2016) as well as CVD (Ross et al., 2016). Such findings underline the importance of PA in mediating health and disease.

Physical Activity and All-Cause Mortality

The effects of PA on health and disease have been observed since the ancient past, as shown in Plato's quote: "Lack of activity destroys the good condition of every human being, while movement and methodological physical exercise save it and preserve it." Within the last two centuries, discussion on this subject has proliferated (Paffenbarger et al., 1986). One of the earliest observational studies examining PA and health was done by Guy (1843), who noted that people who were occupationally the most active had the healthiest and longest lives. The author concluded that active occupations decreased both the incidence and severity of tuberculosis and other diseases, but lamented the lack of available data (Guy, 1843). Since then, many longitudinal cohort studies have been conducted, totaling millions of participants, to determine a relationship between PA and ACM. Paffenbarger and colleages (1986) studied a large cohort of college alumni (n = 16,936) prospectively to determine if PA levels predicted ACM and longevity. The authors found that increased weekly levels of PA, such as walking and sports ($p < 0.001$ for both activities), were inversely related to ACM. Importantly, they observed that further reductions in mortality risk diminished as PA levels increased. The longevity benefits bestowed by PA even lessened when energy expenditure exceeded 3,500 kilocalories (kcal) per week (relative risk [RR] 0.62 vs. 3,000-

3,499 kcal/week RR 0.46). Furthermore, age-stratified data revealed that increasing PA levels from the lowest level (<500 kcal/week) to the second-lowest level (500-1,999 kcal/week) was more beneficial for the older age groups than the younger ones (28% vs. 3% RR reduction). The authors noted that older adults at are greater risk for terminal diseases (e.g., cancer) which would likely result in less active lifestyles; they postulated that elevating PA levels in the diseased older adult population may be the origin of the steepness in the initial part of the older adults' mortality curve. All of these data indicate that the association between PA and ACM is curvilinear, suggesting that the greatest benefits are accrued when going from no activity to some activity. The first edition of the *Physical Activity Guidelines for Americans* highlighted this curvilinear relationship between PA and ACM (U.S Department of Health and Human Services, 2008; Figure 2).

Figure 2. Curvilinear relationship of physical activity and all-cause mortality risk (retrieved from Powell *et al.*, 2011).



More recent studies have examined the PA-ACM association for various populations and PA domains. Manini and coworkers (2006), using doubly labeled water as an objective measurement of energy expenditure, investigated the effect of PA on mortality in older adults. Those who expended >770 kcal/day had a dramatically reduced mortality risk compared with those who expended <521 kcal/day (hazard ratio [HR] 0.31, 95% confidence interval [CI] 0.14-0.69). Such a strong association may indicate that self-report measures for PA assessment may underestimate mortality reduction benefits in older adults (Manini et al., 2006). Lee et al. (2004) studied a unique population known as "weekend warriors," defined as those who perform one or two prolonged bouts of exercise per week which collectively meet exercise guidelines (i.e., energy expenditure ≥1,000 kcal/week). Overall, mortality risk among weekend warriors was not significantly lower than that of sedentary individuals (<500 kcal/week) and was significantly higher than for those in the regularly active group (≥1,000 kcal/week across >2 sessions). However, when groups were stratified by presence of mortality risk factors, low-risk weekend warriors had a significantly lower mortality rate compared with low-risk sedentary individuals (RR 0.41, 95% CI 0.21-0.81). Similar observations were reported in a later study (O'Donovan et al., 2017): compared to inactive individuals, weekend warriors experienced a 34% reduction in ACM risk (HR 0.66, 95% CI 0.62-0.72) and a 40% reduction in CVD mortality (HR 0.60, 95% CI 0.52-0.69), even when those with CVD or cancer at baseline were included. These results indicate that, for healthy individuals, a high weekly frequency of PA may not be necessary to promote longevity (Lee et al., 2004). Stewart and colleagues (2017) examined PA and ACM risk from the perspective of secondary prevention in CHD patients (n = 15,486). Using quantified PA obtained through self-report measures, they identified a dose-response relationship that shallowed at higher PA levels. In fact, based on the data obtained in this study, the PA-ACM curve for CHD patients appears to be steeper at low PA levels than curves for healthy individuals (as seen in other studies). Hence, it seems that PA plays a major role in secondary prevention of ACM and CV events. The authors concluded that sedentary persons may benefit the most from PA increases. As for PA modes, Kelly et al. (2014) conducted a systematic review and meta-analysis with a total of more than 450,000 participants to analyze the relationship between walking or cycling and ACM. They reported that walking and cycling similarly reduced risk at guidelines-recommended PA levels (walking RR 0.89, 95% CI 0.83-0.96; cycling RR 0.90, 95% CI 0.87-0.94). Beyond the guidelines benchmark, risk reduction was attenuated but not plateaued for both walking and cycling up to 50 metabolic equivalent of task (MET)-hours per week and 65 MET-hours per week, respectively. These findings also support the notion of a curvilinear relationship between PA and ACM.

Physical Activity and Cardiovascular Disease

CVD is the number one cause of morbidity and mortality worldwide; more than 10 million deaths globally are caused by heart disease, stroke, and other CV conditions (Centers for Disease Control and Prevention, 2021). The seminal work of Morris et al. (1953) was the first study to demonstrate an association between PA and CVD (Eijsvogels et al., 2016). Here, Morris and colleagues examined the relationship between occupational PA levels and incidence of coronary heart disease (CHD) in London Transport workers ($n \approx 31{,}000$). They observed that bus conductors had lower incidence and severity of CHD compared with bus drivers. Within the same study, the authors also examined CHD in three grades of occupations in terms of PA (high, postmen; intermediate, postal and telegraph officers; low, executives and clerks). They found a significant trend indicating a decrease in CHD risk as PA levels increased ($p < 0.01$), demonstrating a possible dose-response relationship of PA with CVD risk. Based on these data, the authors proposed that CHD incidence and mortality were lower in those who were more physically active at work.

Similar to the study by Guy (1843), the statistical power of the study may have been diminished due to a low overall number of cases (Morris et al., 1953). Regardless, these findings generated many epidemiological studies which support the existence of the relationship between PA and CVD. Twenty-five years later, Paffenbarger and colleagues (1978) investigated the risk of myocardial infarction (MI) in college alumni (n = 16,936) based on PA levels. Using self-report measures, they found that risk was significantly reduced for more active alumni based on weekly energy expenditure (RR 1.64; $p < 0.001$). In line with the position of Morris et al. (1953), Paffenbarger et al. concluded that PA provides an "evident protective influence against heart attack" (pg. 173), even independent of other health and lifestyle factors. Almost ten years later, the link between PA and CVD risk had become widely established, to the point that researchers began attempting to prove a causal relationship. A systematic review by Powell et al. (1987) synthesized epidemiological studies which concerned the effects of PA on CHD risk. The authors contended that the association between PA and CHD fulfills all the requirements to confirm causation, in that it is consistent, strong, appropriately sequenced, graded, plausible, and coherent. Although the seventh criterion (experimental evidence) was not met due to suggested logistical and cost problems with composing a randomized controlled trial, Powell and colleagues definitively concluded that PA levels exhibit a causal effect on CHD risk (Powell et al., 1987). A statement by the American Heart Association (AHA; Thompson et al., 2003) on the prevention and treatment of atherosclerotic CVD affirmed these findings, saying that a causal relationship can be inferred.

Since the publication of these works, research has aimed towards analyzing dose-response relationships between PA and CVD to identify PA levels which significantly lower disease risk. Sattelmair and colleagues (2011) conducted a meta-analysis of 33 studies which examined PA and

CHD risk. They found that those who participated in double the guidelines-recommended LTPA levels (i.e., 300 min/week of moderate-intensity PA or 150 min/week of vigorous intensity PA, or equivalent combination) had a lower risk of CHD compared to those who performed the guideline PA levels (RR 0.80 vs. 0.86; referent group was the lowest category of PA). Interestingly, generalized least squares regression spline models comparing sex-based interactions revealed that the PA-CHD association was stronger among women than men ($p = 0.03$). These findings support the existence of a causal relationship between PA and CHD. Huai et al. (2013) later examined a possible dose-response relationship between PA and hypertension (HT) risk. Categorizing LTPA into low, moderate, and high levels, they found that both high (RR 0.81, 95% CI 0.76-0.85) and moderate (RR 0.89, 95% CI 0.85-0.94) LTPA levels were significantly more effective than low LTPA levels at reducing HT risk. This association was not found for occupational PA, suggesting that LTPA possesses the strongest relationship with CVD out of all PA domains. While this study suggested an inverse dose-response relationship between LTPA and risk of HT, it had several limitations, one of which was variation in the definitions of PA levels across the meta-analyzed studies. Furthermore, the categorization of PA itself prevented quantification of the PA-HT dose-response relationship. With this in mind, Liu et al. (2017) conducted a meta-analysis of studies which quantified LTPA levels, harmonizing them to the unit of MET-hours/week. For every 10 MET-hour/week increase in LTPA, a 6% reduction in HT risk was found (RR 0.94, 95% CI 0.92, 0.96). In support of this, linear cubic spline model analysis revealed a linear dose-response relationship between LTPA and HT risk ($p_{\text{nonlinearity}} = 0.094$). Hence, there appears to be no point at which HT risk reduction is not further attenuated by increases in LTPA (Liu et al., 2017).

Physical Activity and Other Health Conditions

Obesity, defined as a body mass index (BMI) of ≥30 kg/m^2, is associated with increased risk for ACM, CVD, T2DM, and other risk factors (Swift et al., 2018). More than one-third of the US population is obese (Swift et al., 2018). Furthermore, it is estimated that the annual cost of obesity treatment in the US is almost $150 billion (Kim & Basu, 2016). Thus, the prevention and treatment of excessive weight gain is presumably beneficial in terms of both health and the economy (Swift et al., 2018). Ample research has been done exploring the link between PA and weight outcomes. A study by Fan and colleagues (2013) examined NHANES data for 4,511 adults who were on average overweight (BMI 25.0-29.9), taken from the 2003-2006 cycles. Using BMI measurements and objectively measured (accelerometry) PA, higher intensities of exercise were related to better weight outcomes compared to lower intensities. This may be related to the physiological mechanism by which absolute fat oxidation is enhanced at greater intensities of exercise (Tremblay et al., 1994). Importantly, lower BMI occurred with higher-intensity exercise bouts whether they were ≥10 or <10 minutes in duration. These data show that weight benefits can be accrued through bout durations below the 10-minute minimum recommended by the 2008 PA guidelines (U.S. Department of Health and Human Services, 2008), provided that exercise intensity is high enough. LTPA, however, is not the primary factor with regard to weight outcomes. In a randomized controlled trial involving a sample of 439 postmenopausal women, a combination of diet and exercise was more effective at inducing weight loss than diet ($p = 0.03$) and exercise ($p < 0.0001$) alone (Foster-Schubert et al., 2012). Therefore, lifestyle interventions targeting the obese population should include nutritional improvement as well as PA increases to generate maximal benefit.

Comparable to obesity, the prevalence of T2DM is increasing at a high rate globally (Aune et al., 2015). This is alarming because, at the time of writing, a cure has not been found or developed for T2DM. A plethora of studies have reported an association between PA and prevention and management of T2DM. A meta-analysis by Aune and coworkers (2015) investigated different PA types in relation to T2DM risk. Interestingly, when compared to low PA levels, the relative risk reduction for high PA levels was similar across all PA intensities (vigorous PA RR 0.61, 95% CI 0.51-0.74; moderate PA RR 0.68, 95% CI 0.52-0.90; low-intensity PA RR 0.66, 95% CI 0.47-0.94). These results indicate that, for T2DM prevention, any intensity is beneficial at high compared to low PA levels. This is supported by the additional finding that high levels of walking produced a 15% risk reduction compared with low levels of walking (RR 0.85, 95% CI 0.79-0.91). In terms of disease management, Tanasescu et al. (2003) studied CVD and mortality rates among male T2DM patients. Increased total PA ($p = 0.005$) and walking ($p = 0.002$) were associated with decreased mortality risk. Walking pace was also inversely related to mortality; walking at a brisk pace (≥4 mph) resulted in a 58% decrease in mortality risk compared with walking at an easy pace (<2 mph). Hence, similar to obesity, exercise intensity seems to be a mediating factor in the management of T2DM. The timing of exercise may also be an important consideration. In a randomized controlled trial of insulin-resistant individuals, Francois and colleagues (2014) compared pre-meal MICT and short, high-intensity exercise bouts ("exercise snacks") on postprandial glycemic control. The "exercise snacks" regime was more effective than MICT in decreasing postprandial glucose concentrations following breakfast ($p = 0.02$) and dinner ($p = 0.04$). "Exercise snacks" also decreased mean glucose concentrations the following day compared to MICT ($p = 0.01$). Thus, low-volume, high-intensity exercise performed right before meals appears to benefit glycemic control in insulin-resistant individuals (Francois et al., 2014).

Behind CVD, cancer is the second leading cause of death in the US, with over 600,000 deaths projected to occur this year (Siegel et al., 2023). While cancer-related mortality has decreased by one-third in the last 30 years, certain cancers have become more prevalent, such as those of the breast, prostate, and uterus (Siegel et al., 2023). The concept of an association between PA and cancer risk has been conceived very recently compared with associations between PA and other health outcomes (e.g., ACM, CVD), with the earliest epidemiological studies on the subject conducted only one century ago (Lee, 2003). Since then, research in this area has rapidly progressed; however, different forms of cancer appear to respond to PA differently (Lee, 2003; Matthews et al., 2020), making an umbrella association between PA and cancer risk virtually impossible to develop. However, epidemiological studies have indicated that can significantly decrease the risk for many types of cancer. In an earlier investigation, Lee (2003) reviewed existing studies concerning the PA-cancer relationship. The two cancer types that had the greatest risk reduction through PA were colon (~30%-40% decrease) and breast (~20%-30% decrease). For both cancers, dose-response relationships were concluded, and risk reduction only occurred by meeting or exceeding PA guidelines (i.e., 30-60 min/day of moderate-to-vigorous PA; Lee, 2003). A recent meta-analysis (Matthews et al., 2020) used quantified PA to assess risk for 15 different cancers. The results confirmed the existence of dose-response relationships between PA and colon and breast cancer, as well as endometrial, head and neck cancer, and esophageal carcinoma. When PA associations were examined based on exercise intensity (i.e., moderate vs. vigorous), moderate exercise significantly reduced risk of breast and kidney cancer, while vigorous exercise significantly reduced risk of endometrial cancer ($p \leq 0.01$ for all). For colon cancer and endometrial carcinoma, U-shaped curves were observed for vigorous exercise; benefits were greatest within the range of meeting PA guidelines (i.e., 7.5-15 MET-hours/week; $p_{nonlinearity} < 0.05$ for both), with attenuations in risk reduction at higher PA levels. Hence, performing the recommended PA dosage seems to be sufficient, if not better, at reducing the risk of several cancers (Matthews et al., 2020).

Physical Activity and Fitness

Beyond its protective benefits against ACM and numerous noncommunicable diseases, PA also confers improvements in fitness. Physical fitness is defined as "the ability to carry out daily tasks with vigor and alertness, without undue fatigue, and with ample energy to enjoy leisure-time pursuits and respond to emergencies" (U.S. Department of Health and Human Services, 2018, pg. 33). Generally, physical fitness is compartmentalized into five categories: CRF, musculoskeletal fitness, flexibility, balance, and speed. Cardiorespiratory fitness refers to the ability to perform large-muscle, whole-body, continuous exercise; musculoskeletal fitness, the ability to perform work through the integrated function of muscular strength, endurance, and power; flexibility, the range of motion for the joints of the body; balance, the ability to maintain static or dynamic equilibrium; and speed, the ability to move the body quickly (U.S. Department of Health and Human Services, 2018). Physical fitness is generally enhanced by PA and is intrinsically related to health and disease outcomes. Physiological adaptations are specific to the type of PA that is performed (Coffey & Hawley, 2007; Hawley, 2002; Hawley et al., 2014; Powell et al., 2011). For example, aerobic exercise enhances the capacity of the cardiorespiratory and metabolic systems to produce energy, and resistance exercise augments musculoskeletal strength and function (Powell et al., 2011). This review of literature will focus primarily on CRF due to its relevance to the forthcoming thesis study.

Whole-body, large-muscle aerobic exercise performance is mediated by the integrated, concomitant function of multiple biological systems, including the cardiovascular, skeletal muscle (SM), and nervous systems (Hawley et al., 2014). CRF, also known as aerobic or endurance capacity, is often assessed as maximal oxygen uptake ($\dot{V}O_{2max}$), which was first described by pioneering physiologist A.V. Hill (1925) and is generally considered to be the gold standard measurement (Poole & Jones, 2017). This value represents the body's ability during maximal exercise to (1) take in atmospheric oxygen through mechanical ventilation, (2) diffuse O_2 into the circulatory system via binding to hemoglobin, (3) increase cardiac output ($\dot{Q}$) by the synchronous elevation of HR and stroke volume (SV), (4) swiftly circulate O_2-rich blood to the working SM, (5) deliver the O_2 to the SM via diffusion and transfer from hemoglobin to myoglobin, and (6) utilize oxygen within mitochondria to create energy in the form of adenosine triphosphate (Dominelli et al., 2021; Hawley et al., 2014). The autonomic and somatic components of the nervous system also play an important role in exercise through sympathetic stimulation of the heart and activation of motor units (Hawley et al., 2014). Exercise-induced physiological adaptations are based upon the principle that the PA stimulus produces cellular disturbances, coercing the body out of homeostasis and provoking a response by many of the body's tissues (Hawley et al., 2014). Accumulated cellular disturbances resulting from recurrent exercise bouts produce chronic adaptations in which the affected cells are modified to be more efficient at producing energy and/or performing work (Hawley, 2002). For example, aerobic exercise training has reportedly improved $\dot{V}O_{2max}$ (Hickson et al., 1977; Bassett & Howley, 2000; Matsuo et al., 2014; Milanović et al., 2015;

Montero et al., 2015b), maximal cardiac output ($\dot{Q}_{max}$; Bassett & Howley, 2000; Gibala et al., 2019; Montero et al., 2015a, 2015b), SV (Bassett & Howley, 2000; Hawley et al., 2014; Matsuo et al., 2014; Powell et al., 2011), left ventricular mass (Matsuo et al., 2014), SM slow-twitch contractile protein content (Baar, 2006) and capillary density (Hawley et al., 2014; Montero et al., 2015a), inspiratory muscle strength (Dunham & Harms, 2012), mitochondrial volume (Baar, 2006; Bishop et al., 2014; Burgomaster et al., 2005; Granata et al., 2016a, 2016b, 2017, 2018; Holloszy, 1967; Holloszy & Coyle, 1984; Montero et al., 2015a), respiration (Bishop et al., 2014; De Jong et al., 2022; Granata et al., 2016a, 2016b, 2017, 2018; Holloszy, 1967; Holloszy & Coyle, 1984), and biogenesis (Baar, 2006; Bishop et al., 2014; Granata et al., 2016a, 2017, 2018; Hawley et al., 2014), blood plasma and erythrocyte volume (Montero et al., 2015a), beta oxidation (Baar, 2006; Bassett & Howley, 2000; De Jong et al., 2022; Holloszy & Coyle, 1984), and exercise economy (Barnes & Kilding, 2015b; Hill, 1925). These central and peripheral adaptations, among others, are the consequences of regular participation in aerobic PA.

The type and degree of physiological adaptations to exercise training are governed by the PA volume, which is comprised of the duration, frequency, and intensity of the activity (Hawley, 2002; Hickson et al., 1977; MacInnis & Gibala, 2017; Powell et al., 2011). There is evidence of an interaction effect in which the PA volume (i.e., the combination of the three components) has a greater impact on health and performance outcomes than its individual parts (U.S. Department of Health and Human Services, 2008). Thus, for appropriate exercise prescription, the duration, frequency, and intensity of PA need to be considered in conjunction with one another. However, when controlling for the other two factors, each is a substantial contributor to CRF improvement.

In a meta-analysis of 13 studies, Montero et al. (2015b) found a significant association between exercise program duration and arteriovenous O_2 difference (a-$\dot{V}O_{2diff}$; >8.0 weeks standardized mean difference [SMD] 1.10, 95% CI 0.55-1.65 vs. ≤8.0 weeks SMD -0.10, 95% CI -0.41-0.21; $p_{diff} < 0.001$). For this study, the authors assessed training load (i.e., volume) as the product of intensity (each study was categorized as one of six "statuses," 0-5, with 0 being the lowest and 5 being the highest), number of hours spent per week, and duration of training in weeks. In the same subgroup analyses, a-$\dot{V}O_{2diff}$ increases were significantly associated with training load (higher load SMD 0.84, 95% CI 0.35-1.32 vs. lower load SMD -0.20, 95% CI -0.54-0.14; $p_{diff} < 0.001$), but not intensity (intensity status >4 SMD 0.09, 95% CI -0.57-0.74 vs. intensity status ≤4 SMD 0.25, 95% CI -0.18-0.68; $p_{diff} = 0.69$). These results indicate that the duration of the exercise program may be more important than the intensity in mediating a-$\dot{V}O_{2diff}$ improvements (Montero et al., 2015b). Another meta-analysis examined 28 studies which compared no-exercise controls against MICT or HIIT interventions on $\dot{V}O_{2max}$ improvement (Milanović et al., 2015). The results showed that, compared to shorter durations, longer training intervention durations were associated with greater increases in $\dot{V}O_{2max}$ for both MICT and HIIT (Milanović et al., 2015). From these two studies it appears that, regardless of the training protocol, a longer training program duration were more effective at improving CRF than a shorter one.

The current *Physical Activity Guidelines for Americans* recommend that aerobic PA be done on at least three days per week for health benefits and injury risk reduction, and that the PA be spread out throughout the week (U.S. Department of Health and Human Services, 2018). Thus, exercise interventions in studies investigating CRF outcomes typically spread weekly exercise bouts over three or more days (De Jong et al., 2022; Dunham & Harms, 2012; Hickson et al., 1977;

Granata et al., 2016a; Matsuo et al., 2014; Montero et al., 2015a). Compared with duration and intensity, evidence on the effect of varying frequency on CRF is more limited. Granata and coworkers (2016a) utilized a unique three-phase intervention in which ten healthy subjects completed four weeks of normal-volume training (three days per week), then 20 consecutive days of high-volume training (twice per day), and finally two weeks of low-volume training (five sessions total). The intensity was kept constant throughout the intervention. While mitochondrial respiration and biogenesis were unchanged during the normal-volume training, high-volume training induced increases in all markers except mitochondrial-specific respiration. The subsequent low-volume training led to a return to baseline values for all markers except for citrate synthase activity. This suggests that, even when intensity is maintained, a dramatic reduction in training volume via a decreased weekly frequency can be detrimental to CRF (Granata et al., 2016a). In support of this, a cross-sectional comparison (Kohl et al., 2009) of "weekend warriors" and men who exercised on ≥3 days/week found that "warriors" were much more likely to have low CRF than those doing higher exercise frequencies, even when weekly exercise totaled 150-300 minutes (OR 4.8, 95% CI 2.7-8.5) or ≥300 minutes (OR 1.9, 95% CI 0.85-4.5). It seems from these results that frequency plays a key role in determining CRF even when the physical activity recommendations are exceeded. Of note is that this study only considered moderate-intensity PA; associations with vigorous-intensity PA cannot necessarily be assumed from these results.

Of the three components of PA, the intensity of exercise appears to be the most studied. One reason for this is that intensity is relatively easier to correlate to aerobic capacity or physiological markers. For example, Medbø et al. (1988) found a linear relationship between treadmill intensity (speed with 6° incline) and oxygen demand. Another possibility is that a plethora of recent studies (Barnes & Kilding, 2015b; Bishop et al., 2014; Dunham & Harms, 2012; Gibala et al., 2019; Granata et al., 2016b, 2017, 2018; Hamer et al., 2017; Hawley et al., 2014; MacInnis & Gibala, 2017; Matsuo et al., 2014; Milanović et al., 2015; Montero et al., 2015a) have indicated that the intensity of aerobic PA is a key mediator of physiological adaptation to exercise, which has led to rapid growth in the domain of IT research. One example of a marker of CRF for which intensity possesses a modulating effect is mitochondrial respiration. In a randomized controlled trial (Granata et al., 2016b), 29 healthy men performed either MICT, HIIT, or SIT (MICT and HIIT matched for total work) for four weeks. Only SIT led to significantly higher maximal mitochondrial respiration as well as mitochondrial biogenesis, even with much lower workload (~35% less). The authors suggested that the genetic pathways of mitochondrial biogenesis may be more related to mitochondrial respiration (regulated by exercise intensity) than content (regulated by exercise volume [Granata et al., 2018]; Granata et al., 2016b). Matsuo and colleagues (2014) used similar exercise intervention groups to assess changes in $\dot{V}O_{2max}$ and cardiac mass in 42 healthy adults. While $\dot{V}O_{2max}$ increased in all three groups, left ventricular mass and SV increased, and resting HR decreased only in the HIIT and SIT groups, despite a much lower exercise volume (e.g., 50% less for HIIT vs. MICT). Therefore, while total training volume is a useful measure to predict CRF improvement in the general population (U.S. Department of Health and Human Services, 2008), it seems that, at least in healthy individuals, that intensity may be the most important factor with regard to aerobic capacity enhancement.

Cardiorespiratory Fitness and Health

CRF is a measurement of whole-body aerobic capacity that is improved as a result of acute and chronic adaptations at the cellular and systemic levels (Hawley et al., 2014). There are several key factors modulating CRF, which include duration, frequency, intensity, and the aggregate of those three components, volume (Powell et al., 2011). The intensity of exercise appears to be receiving the most attention out of the three elements of training volume due to its clear relevance to physiological adaptations. This attention has given rise to the popularity of IT both in research and in clinical and recreational practice. While CRF, like other components of fitness, is generally associated with performance measures, research has indicated that it is also highly applicable to health and disease outcomes.

Cardiorespiratory Fitness and All-Cause Mortality

CRF may be more reliable in appraising mortality risk than PA due to its greater objectivity (Blair et al., 1989, 1995). That is, while large-scale epidemiological studies have primarily used self-report data for PA measurement, CRF can be assessed objectively by means of an outcome (e.g., $\dot{V}O_{2max}$, MET_{max}) obtained during a maximal exercise test. Compared to PA, the relationship between CRF and ACM has only begun close examination more recently (Blair et al., 1989), with little research on the subject until the works of Blair and colleagues (1989, 1995). In their earlier study, the authors examined 13,344 people (male n = 10,224, female n = 3,120) as part of the Aerobics Center Longitudinal Study (ACLS; Blair et al., 1989). After grouping the participants into quintiles based on a maximal treadmill exercise test performance, they found that those in the lowest fitness category had a 244% (95% CI 105%-477%) and 365% (95% CI 122%-875%) greater ACM risk than those in the highest fitness category for men and women, respectively. Using MET_{max} values achieved during the exercise test, the authors determined optimal fitness levels relative to marginal reductions in ACM risk, which were 10 METs ($\dot{V}O_{2max}$ 35 mL/kg/min) for men and 9 METs ($\dot{V}O_{2max}$ 32.5 mL/kg/min) for women. The greatest reductions in ACM risk occurred between the lowest and second-lowest quintiles of fitness, showing that increasing aerobic PA levels may be the most beneficial for unfit and/or sedentary individuals. Furthermore, the CRF-ACM trends were similar even when adjusting for parental history of heart disease, indicating that CRF may contribute more to mortality than genetics (Blair et al., 1989).

In the latter study, the authors investigated 9,777 men from the ACLS who completed two maximal exercise tests (interval between exercise tests = 4.9 ± 4.1 years; Blair et al., 1995). The subjects were stratified into unfit and fit categories, with unfit representing the lowest fitness quintile and fit representing the upper four fitness quintiles combined. This was done because, in the earlier study (Blair et al., 1989), the lowest fitness quintile had a considerably greater ACM risk than the second-lowest quintile (Blair et al., 1995). Men who progressed from the unfit category to the fit category were 44% (95% CI 25%-59%) less likely to die than those who were in the unfit category for both exercise tests. Improvements in systolic blood pressure (BP), cholesterol levels, smoking, and CRF in the lowest quintile were associated with decreased ACM risk. However, only the association between CRF improvements in unfit individuals and ACM risk was significant (RR 0.38, 95% CI both bounds <1.00, not reported). This suggests that CRF may be more impactful to ACM risk than cardiovascular, metabolic, and lifestyle factors. Using maximal treadmill time as a continuous variable, each minute improvement decreased ACM risk by 7.9% ($p = 0.001$). Thus, changes in CRF over time, rather than just CRF at a given exposure, may influence ACM risk (Blair et al., 1995). The results of these two studies demonstrate that there is a need for unfit and/or sedentary individuals to increase CRF through participation in PA to improve health outcomes (Blair et al., 1989, 1995).

Fourteen years later, Kodama and colleagues (2009) conducted the first meta-analysis of 33 studies (total $n = 102{,}980$) examining the CRF-ACM relationship using METs to quantify CRF. Every 1 MET_{max} increase in CRF (or, every 1 km/hour increase in running speed) resulted in a 13% (95% CI 10%-16%) decrease in ACM risk. Categorically, those with low CRF (MET_{max} <7.9 METs) had an RR of 1.70 (95% CI 1.51-1.92; $p < 0.001$) compared to those with high CRF (MET_{max} ≥10.9 METs). Furthermore, compared to the intermediate fitness category (MET_{max} 7.9-10.8 METs), those in the low category had a 56% (95% CI 39%-75%; $p < 0.001$) greater ACM risk. Finally, those with intermediate CRF had a 13% (95% CI 4%-22%) greater mortality risk compared to those with high CRF. These continuous and categorical data indicate an inverse dose-response relationship between CRF and ACM. Additionally, sensitivity analyses showed that the association between CRF and ACM maintained strength when adjusting for risk factors such as smoking, indicating that CRF may be independently related to mortality. Adding to the work of Blair et al. (1989), the authors approximated the minimum CRF levels to reduce risk of adverse health events: 9 and 7 METs (age ~40 years), 8 and 6 METs (age ~50 years), and 7 and 5 METs (age ~60 years) for men and women, respectively (Kodama et al., 2009).

Rather than treating BMI as a variable to control for, Lee et al. (2011) investigated the independent and combined associations of CRF and BMI with ACM within the ACLS population. A total of 14,345 men were examined using maximal treadmill tests performed across at least two examinations. Similar to Blair and coworkers (1995), the authors of this study stratified the subjects into groups based on loss or gain in CRF and BMI, and also included a category for maintenance of CRF and BMI. Independent, multivariable analyses showed a 30% (95% CI 17%-41%) and 39% (95% CI 27%-49%) lower mortality risk for those who maintained or gained CRF, respectively. Per 1 MET_{max} increase, there was an associated 15% (95% CI 11%-20%) decrease in ACM risk. Importantly, combined analyses showed that increased ACM risk in those who lost CRF was independent of changes in BMI. This finding added on to the previous literature, supporting CRF's status as perhaps the most crucial contributor to ACM risk (Lee et al., 2011). A later statement by the AHA highlighted the major points of the previous works, that (1) CRF is potentially a greater predictor of mortality than smoking, HT, high cholesterol, and T2DM, (2) ACM risk reduction is greatest for those who are the least fit, and (3) health outcomes can be improved by CF improvements even in those with health risk factors (Ross et al., 2016).

Following the work of Lee and colleagues (2011), a recent retrospective cohort study examined the independent and combined associations of CRF with ACM risk (Gorny et al., 2023). Participant quintiles were developed based on completion time for a 2.4 km run. Compared with the highest fitness quintile, those who were in the lowest fitness quintile experienced a greater ACM risk (HR 1.68, 95% CI 1.09-2.59); significant associations were not found for comparisons with the other three fitness quintiles. In combined analyses, those who were unfit with a BMI <23.0 kg/m^2 (HR 1.74, 95% CI 1.18-2.55) and those who were fit (HR 1.58, 95% CI 1.16-2.16) and unfit (HR 1.49, 95% CI 0.99-2.24) with a BMI ≥23.0 kg/m^2 had a greater mortality risk compared to those who were fit with a BMI <23.0 kg/m^2. Contrary to the previous studies, these results suggest that, for those with a BMI ≥23.0 kg/m^2, CRF levels do not predominantly determine ACM risk. It is worth noting that this study examined young men aged 16-25 years with a relatively short follow-up period. With data collection beginning in 1995, the oldest possible participant would be 53 years old at the time of publication; this might not be sufficient time to analyze ACM associations (Gorny et al., 2023).

Finally, a recent meta-analysis (Han et al., 2022) of 34 cohort studies (total $n = 625{,}400$) confirmed the existence of a dose-response relationship between CRF and ACM. Along with more recent studies, the authors utilized updated cohort follow-up data from studies used in the previous meta-analytical work of Kodama et al. (2009). Like Kodama and colleagues (2009), the authors used low, intermediate, and high categories of fitness, but here they were based on the categories used in the included studies rather than as MET_{max} cutoff points. For every 1 MET_{max} increase in CRF, there was a 12% (95% CI 7%-17%; $p < 0.001$) decrease in ACM risk. Subgroup analyses revealed that risk reductions were significant regardless of sex, region, equipment, sample size, and follow-up period ($p \leq 0.005$ for all); results did not differ within strata. Those in the low fitness category had an RR of 0.67 (95% CI 0.61-0.74) compared with the intermediate category, and an RR of 0.47 (95% CI 0.39-0.56) compared with the high category. These recent findings validate the inverse dose-response nature of the CRF-ACM relationship and highlight the need for increased aerobic PA participation in those with low CRF (Han et al., 2022).

Cardiorespiratory Fitness and Cardiovascular Disease

Prior to the work of Blair and colleagues (1989), Sobolski et al. (1987) conducted the Belgian Physical Fitness Study. In this prospective cohort study, 2,109 healthy, predominantly sedentary men (age 40-55 years) were followed for five years to examine the relationship between CRF and ischemic heart disease (IHD). Using a submaximal bicycle exercise test, CRF was estimated as the workload at an HR of 150 bpm. PA levels were assessed by questionnaires for occupational PA and LTPA. Men without IHD had significantly higher baseline CRF values compared with those with IHD when workload was standardized for body weight ($p < 0.05$). When the subjects were separated into quartiles based on workload, a higher CRF predicted a lower IHD risk ($p_{trend} < 0.05$). For both occupational PA and LTPA, the associations with IHD risk were nonsignificant. The authors concluded that CRF standardized for body weight was a better predictor of IHD than self-reported PA levels.

Adding to the debate concerning the roles of activity and fitness in CVD prediction, Williams (2001) meta-analyzed 23 studies which assessed either PA or CRF with respect to CVD or CHD risk (total $n = 118{,}779$; PA studies $n = 90{,}830$; CRF studies $n = 27{,}949$). Beginning from the 25th and 30th percentiles of PA and CRF, respectively, each percentile increase was linearly associated with decreased CVD or CHD ($p < 0.001$ for both). Between the 30th and 100th percentiles, risk reductions were more substantial from CRF improvements than PA level increases ($p \leq 0.04$). This was mainly due to an abrupt drop for the CRF trend between the 1st and 25th percentiles; the slopes of the regression lines were similar afterward (PA slope -0.0031 ± 0.0006, CRF slope -0.0038 ± 0.0009; $p_{difference} = 0.51$). These results seem to indicate that CRF contributes more to CVD or CHD risk reduction than PA at low percentiles. However, according to subsequent editorial commentary by Blair and Jackson (2001), there were several limitations of this study, including the arbitrary mingling of categorical and continuous data. Nonetheless, the commentors agreed with the author of the study that improving CRF is most crucial in those who are least fit (Blair et al., 2001; Williams et al., 2001).

Besides ACM, the meta-analysis of Kodama and coworkers (2009) examined CRF and CVD as well. Per 1 MET_{max} increase (or, every 1 km/hour increase in running speed), there was a 15% (95% CI 12%-18%) decrease in the risk of CVD/CHD events. Low-CRF individuals had an RR of 1.40 (95% CI 1.32-1.48) compared to high-CRF individuals. Compared to intermediate-CRF individuals, low-CRF individuals experienced a 47% (95% CI 36%-61%) greater risk of

CVD/CHD events. Finally, intermediate-CRF individuals had a 7% (95% CI 1%-13%) greater CVD risk compared to high-CRF individuals. These data indicate an inverse dose-response relationship between CRF and CVD, although the trend might be non-linear, as shown by the relatively small (albeit significant) difference between intermediate and high CRF levels. Furthermore, sensitivity analyses revealed a weaker association between continuously-measured CRF and CVD/CHD events when adjusting for risk factors such as smoking. The authors suggested that the relationship between CRF and CVD may be explained by coronary risk factors (Kodama et al., 2009). This is supported by an AHA statement (Ross et al., 2016), which suggested that CRF is only the fourth-leading risk factor for CVD. However, when CRF is increased in those with CVD risk factors, the risk of adverse health outcomes is decreased (Ross et al., 2016).

CV events were also researched by Khan et al. (2017) as part of the Kuopio Ischemic Heart Disease Risk Factor Study, where 2,089 men (age 42-61 years) were followed for 19.1 ± 8.4 years. In this study, only nonfatal events were examined. Baseline CRF was assessed by a cycle ergometer exercise test and electrocardiography was used to assess left ventricular hypertrophy and resting HR. For every 1 MET_{max} increase, the adjusted HRs for MI, stroke, and heart failure were 0.93 (95% CI 0.88-0.97; $p = 0.003$), 0.94 (95% CI 0.87-1.01; $p = 0.103$), and 0.84 (95% CI 0.78-0.91; $p < 0.001$), respectively. Those in the lowest quartile of CRF had a greater risk of MI and heart failure compared with those in the highest quartile ($p < 0.001$ for both). When the data were further adjusted for left ventricular hypertrophy or resting heart rate, the associations remained similar. These results demonstrate a strong, inverse, and independent correlation between CRF and nonfatal MI and heart failure, and a weak correlation between CRF and nonfatal stroke (Khan et al., 2017).

The recent retrospective cohort study of Gorny and colleagues (2023) also investigated CV events, including both fatal and nonfatal MI, stroke, coronary revascularization, and CV mortality. Compared with the lowest fitness quintile, those in the third- (HR 1.60, 95% CI 1.09-2.35), second- (HR 1.60, 95% CI 1.10-2.33), and highest (HR 1.58, 95% CI 1.09-2.30) fitness quintiles were significantly likely to experience a CV event, although the linear trend of this categorical analysis was nonsignificant ($p_{\text{nonlinearity}} = 0.188$). Combined analyses revealed that both fit (HR 2.06, 95% CI 1.60-2.64) and unfit (HR 3.08, 95% CI 2.35-4.04) individuals with a BMI ≥23.0 kg/m^2 had a greater risk of CV events compared to those with a BMI <23.0 kg/m^2, but not unfit individuals with a BMI <23.0 kg/m^2 (HR 1.05, 95% CI 0.72-1.51). Hence, unlike for ACM, it seems that the association between CRF and CV events is weaker with a lower BMI, and stronger with a greater BMI. These recent composite data indicate a need for public health communication to focus on both CRF and BMI (Gorny et al., 2023).

While CRF is generally improved by aerobic PA, recent work has examined the interaction between aerobic and resistance training with respect to CVD. Schroeder et al. (2019) separated 69 hypertensive, overweight, and sedentary adults (age 58 ± 7 years) into three exercise groups or a non-exercise control group. The three exercise protocols were: (1) 60 minutes of aerobic exercise, (2) 60 minutes of resistance training, and (3) 30 minutes of aerobic exercise plus 30 minutes of resistance exercise (combined training), all of which were done three days/week for eight weeks. The authors created a composite risk factor score comprising baseline-to-follow-up changes for mean arterial pressure, total cholesterol, lower body strength, CRF, and body fat percentage. Compared with the control group, both aerobic and combined training increased CRF (7.7 mL/kg/min [95% CI 3.9 mL/kg/min-11.5 mL/kg/min] and 4.9 mL/kg/min [95% CI 1.1

mL/kg/min-8.7 mL/kg/min], respectively; $p < 0.05$ for both). However, only combined training decreased peripheral (-4 mmHg; $p = 0.04$) and central (-4 mmHg; $p = 0.05$) diastolic BP. Additionally, compared to the control group, only the combined training group experienced a reduction in the composite risk factor score. Hence, with regard to CVD risk factors, combining aerobic and resistance training may be more beneficial than doing one modality alone for the same duration (Schroeder et al., 2019).

Physical Activity Guidelines and Trends in the United States

The various domains of PA include LTPA, occupational, transportation, and household, and are characterized by mode or setting. Exercise, a subcomponent of LTPA, is defined as a form of physical activity that is planned, structured, repetitive, and performed with the goal of improving health or fitness (U.S. Department of Health and Human Services, 2018, pg. 29). Although all PA involves bodily movement produced by SM contraction, research indicates that associations with health and disease outcomes differ by PA domain. Specifically, several studies have indicated that LTPA possesses the strongest relationship with mortality, CVD, cancer, and other health factors compared with other modes of PA (Autenrieth et al., 2009, 2011; Huai et al., 2013; Samitz et al., 2011). For example, Huai and colleagues (2013) showed an inverse dose-response relationship between LTPA and HT incidence, whereas neither high nor moderate levels of occupational PA significantly decreased risk compared to low levels. Although findings such as these suggest superiority of LTPA and exercise above other PA modes in predicting health outcomes, the current *Physical Activity Guidelines for Americans* advocates for increasing total PA within all domains (U.S. Department of Health and Human Services, 2018).

Physical Activity Guidelines

The American PA guidelines recommend that adults do 150 minutes per week of moderate-intensity, 75 minutes per week of vigorous-intensity, or an equivalent combination of aerobic PA (U.S. Department of Health and Human Services, 2018). According to the World Health Organization (n.d.), this is roughly equivalent to 10 MET-hours, or 600 MET-minutes, per week. The guidelines also note that doing more than the minimum recommended PA dose is associated with further benefits. The current guidelines added to the previous edition (U.S. Department of Health and Human Services) by including recently published information concerning brain, cancer, and fall-related injury benefits, SB risks, and the acknowledgement of the benefits incurred by PA bouts <10 minutes in duration. The latter recommendation is crucial because it underlines the fact that virtually any amount of PA is beneficial. In tandem with this idea, the recognition of SB risks indicates a need for sedentary individuals to do at least some activity to improve health and quality of life (U.S. Department of Health and Human Services, 2018).

Physical Activity Trends

NHANES is an ongoing, cross-sectional, nationally representative survey which has been used to appraise the health and nutritional status of the noninstitutionalized US population since 1971 (Curtin et al., 2012). Self-report and physical examination data on demographics, socioeconomic status, health conditions, and health-related behaviors are obtained in two-year cycles. In a comparison of the 2007-2016 cycles (total $n = 27{,}343$), Du and colleagues (2019) found that adherence to aerobic PA guidelines did not significantly increase ($p_{\text{trend}} = 0.15$) when weighted based on sample size and characteristics. Encouragingly, improvements were seen in women ($p = 0.04$), non-Hispanic blacks ($p < 0.001$), and obese individuals ($p = 0.03$). However, for those strata (sex, race/ethnicity, and BMI category), each subgroup had a significantly lower prevalence of meeting aerobic PA guidelines compared to the most active subgroup (men, non-Hispanic white, and normal weight, respectively) during the 2015-2016 cycle ($p < 0.001$ for all). Furthermore, PA guideline adherence was inversely related to age ($p < 0.001$ for all cycles). Thus, solving the problem of the plateau in meeting aerobic PA guidelines may require addressing barriers related to sex, race/ethnicity, body weight, and age (Du et al., 2019).

A later analysis added data from the 2017-2018 cycle (Whitfield et al., 2021). Similar to the previous study, the authors here found linear increases in prevalence of meeting aerobic PA guidelines for women (+5.0%), non-Hispanic blacks (+10.3%), and obese individuals (+6.9%). Unlike the previous study, meeting PA guidelines significantly linearly increased overall, both for older adults (age 65+ years; +8.6%), and for Hispanics (+8.9%). Furthermore, the prevalence of meeting the LTPA guidelines grew linearly by 4.0% between 2007 and 2018. Additionally, a quadratic increase of 4.5% in the prevalence of meeting guidelines with occupational or household PA was observed; contrarily, the rate of meeting guidelines with transportation PA cubically declined (-2.7%). These recent data indicate an overall rise in the prevalence of meeting the aerobic PA guidelines and support what was reported by Du et al. (2019) that subgroups with previously low participation in PA are becoming more active. Besides advocating for subgroup-specific interventions, the authors also suggested that increasing transportation PA levels may be useful in helping US adults reach aerobic PA guidelines (Whitfield et al., 2021).

NHIS, similar to NHANES, is an ongoing national survey studying health within the noninstitutionalized population of the US, operating since 1957 (Massey, 1989). Like NHANES data (Whitfield et al., 2021), NHIS data (Centers for Disease Control and Prevention, 2022) also revealed a significant increase in meeting aerobic PA guidelines (54.2% in 2018; +0.9% per year). Additionally, the prevalence of meeting high aerobic PA guidelines (moderate-intensity PA for >300 minutes/week, vigorous-intensity PA for >150 minutes/week, or an equivalent combination) significantly increased (37.4% in 2018; +0.7% per year). Similar trends were observed for the rate of meeting muscle-strengthening and combined aerobic and muscle-strengthening activity guidelines. However, nearly half of US adults are still not meeting aerobic exercise guidelines. Furthermore, although there was a significant downward trend (-0.9% per year), in 2018 one-quarter of US adults did not engage in any LTPA (Centers for Disease Control and Prevention, 2022). The yearly trends are promising; nonetheless, many American adults are putting themselves at an increased risk of adverse health outcomes due to a lack of or insufficient PA participation.

Sedentary Behavior and Health

SB is defined as any waking behavior characterized by a low energy expenditure (Pate et al., 2008; U.S. Department of Health and Human Services, 2018). Examples of SB include sleeping, sitting, lying down, and watching television. While PA has been shown to have an inverse relationship with many negative health outcomes, SB exhibits a positive relationship with morbidity and mortality. However, physical inactivity may not be entirely identical to SB (van der Ploeg & Hillsdon, 2017). In fact, research has indicated that PA and SB levels may independently mediate health risks (Katzmarzyk et al., 2009; Matthews et al., 2015). The public health impact of SB is such that it has been described as a global pandemic (Ding et al., 2016; Kohl et al., 2012), which cost healthcare systems worldwide an equivalent of almost $54 billion in 2013 (Ding et al., 2016). Such work examining associations between SB and health is relatively modern; in a review by Pate et al. (2008), the authors suggested that SB needs to be defined more clearly for relationships to be properly elucidated. Large-scale epidemiological studies as well as objective PA-measuring devices have contributed to a body of evidence which demonstrates that SB is a crucial factor in public health. Thus, PA levels alone may not give sufficient information to predict population health outcomes.

Sedentary Behavior and All-Cause Mortality

Early work associating ACM with PA (Guy, 1843; Paffenbarger et al., 1986) and CRF (Blair et al., 1989, 1995) hinted at a necessity for inactive individuals to get active. In support of this, an AHA statement (Fletcher et al., 1996) stated that sedentary people have the greatest risk for ACM. While this was certainly a correct assessment, at that time there had not been many advancements in this topic. Katzmarzyk and colleagues (2009) examined the relationship between SB and ACM in 17,013 Canadians (age 18-90 years) as part of the Canada Fitness Survey. Across quintiles of SB, higher sitting time was associated with elevated ACM risk ($p_{trend} < 0.0001$). When bisected by activity level, this trend was seen in both active (≥7.5 MET-hours/week) and inactive (<7.5 MET-hours/week) groups, although associations seemed to be stronger for the inactive group. That is, for the most sedentary quintile, the HR for the active group was 1.40 ($p = 0.008$), and for the inactive group the HR was 1.86 ($p < 0.0001$). The authors highlighted the existence of a dose-response relationship, and suggested that, concomitant with encouragement to participate in aerobic PA, extended periods of SB should be discouraged (Katzmarzyk et al., 2009).

Sitting time was also investigated in a prospective cohort study of 154,614 older adults (age 59-82 years) by Matthews and coworkers (2015). SB levels were separated into quintiles ranging from <5 hours/day to ≥12 hours/day. ACM risk significantly increased between the lowest and highest categories of SB for both men (HR 1.21, 95% CI 1.11-1.31; $p_{trend} < 0.01$) and women

(HR 1.40, 95% CI 1.27-1.54; $p_{trend} < 0.01$). The authors also used isotemporal modeling to examine the magnitude of benefit for replacing sitting time with PA. This involved creating a Cox model where total reported time was placed in as well as its constituents, exercise and non-exercise PA (including sitting time). Models were created separately for less active (<2 hours/day of activity) and more active (≥2 hours/day of activity) participants. For the less active adults, ACM risk dramatically decreased for each hour of SB replaced with both exercise (HR 0.58, 95% CI 0.54-0.63) and non-exercise PA (HR 0.70, 95% CI 0.66-0.74). Although all exercise intensities reduced ACM risk, moderate-to-vigorous-intensity exercise was much more beneficial than light-intensity exercise (HR 0.58, 95% CI 0.54-0.62 vs. HR 0.81, 95% CI 0.75-0.88). For the more active adults, the effect size was greatly attenuated; exercise significantly decreased risk (HR 0.91, 95% CI 0.88-0.94), while non-exercise PA did not (HR 1.00, 95% CI 0.98-1.02). Additionally, while moderate-to-vigorous-intensity exercise reduced risk (HR 0.96, 95% CI 0.94-0.98, light-intensity exercise did not (HR 1.04, 95% CI 1.01-1.08). These results indicate that replacing SB with moderate-to-vigorous-intensity exercise is beneficial for both active and inactive individuals, while those who are sedentary can also reduce their risk of ACM through light-intensity exercise or non-exercise PA. Evidently, decreasing SB levels in less active adults may be crucial for overall public health improvement (Matthews et al., 2015).

Besides sitting time, the ACM association with television viewing (TV) has also received much attention, given that it is the most prevalent leisure-time SB in developed countries (Grøntved & Hu, 2011; Wijndaele et al., 2011). Wijndaele and colleagues (2011) prospectively studied 13,197 people (age 61.5 ± 9.0 years) as part of the European Prospective Investigation into Cancer and Nutrition study. There was a linear positive relationship between 1-hour increments of

TV and ACM, such that each hour-increase resulted in a 4% higher risk (95% CI, 1%-9%; adjusted for BMI and waist circumference). The authors also estimated the population attributable fraction for TV (the proportion of ACM in the population that TV is responsible for), comparing the highest (>3.6 hours/day) and lowest (<2.5 hours/day) level of TV. They found that 5.4% of deaths from all causes could be eliminated by reducing TV time from the highest to the lowest level. These data implicate TV as a crucial target for public health recommendations, especially due to its high prevalence in industrialized countries (Wijndaele et al., 2011).

Grøntved & Hu (2011) conducted a meta-analysis of three cohort studies (total $n = 26{,}509$) which investigated the effect of TV on ACM risk. For every two-hour increase in TV, the associated RR was 1.13 (95% CI, 1.07-1.18; $p < 0.001$). Dose-response modeling through piecewise regression analysis revealed that the TV-ACM relationship appeared to be positively exponential ($p_{\text{nonlinearity}} = 0.007$); the ACM risk slope steepened greatly at approximately 3 hours/day of TV. Hence, similar to what was reported by Wijndaele et al., (2011), it seems that reducing TV time to less than 3 hours/day may significantly decrease ACM risk. While this meta-analysis only included three studies that studied ACM risk, the existence of a dose-response, albeit nonlinear, relationship between TV and risk of ACM is clear (Grøntved & Hu, 2011).

With regard to overall SB (including sitting and TV), several meta-analyses of high-quality studies have been conducted since then to confirm a relationship with ACM. Biswas et al. (2015) meta-analyzed 13 studies (total $n = 829{,}917$) and found that the pooled HR for greater time spent in SB was 1.22 (95% CI 1.08-1.38). Joint-effects analysis of PA, SB, and health outcomes showed that relative ACM risk among sedentary people was greater in those with high PA levels (HR 1.16, 95% CI 0.84-1.59) than those with low PA levels (HR 1.46, 95% CI 1.22-1.75). This indicates that increasing PA levels improves health outcomes even in those who are quite sedentary (Biswas et al., 2015). The more recent meta-analysis by Patterson and coworkers (2018) included 21 studies with a total combined baseline sample of 1,138,042 people. Generalized least-squares regression revealed a nonlinear relationship between SB and ACM ($p_{\text{nonlinearity}} < 0.05$). The summary RR for this association was 1.02 (95% CI, 1.01-1.03; $p < 0.001$). There seemed to be an inflection point at roughly 8 hours of SB per day. Below 8 hours/day, for each hour of SB there was an RR of 1.01 (95% CI 1.00-1.01), and an RR of 1.04 (95% CI 1.03-1.05) was calculated for each hour of SB above 8 hours/day. In line with the findings of Grøntved and Hu (2011), this meta-analysis also found a nonlinear relationship between TV time and ACM. The summary RR was 1.05 (95% CI 1.04-1.05; $p < 0.001$). Below the 3.5 hour/day inflection point, each additional hour increased risk by 3% (95% CI 1%-4%), which became 6% (95% CI 1.05-1.08) above 3.5 hours/day. The authors also estimated the population attributable fraction for TV in England, which was found to be 8% (95% CI 6%-10%). While these data only apply to the population of one country, the contribution of TV to nearly 10% of ACM is highly suggestive (Patterson et al., 2018).

With PA and SB independently affecting the risk of ACM (Katzmarzyk et al., 2009; Matthews et al., 2015), the question becomes whether or not there exists a threshold of PA at which the detrimental effects of SB are eliminated. This is the question that Ekelund and colleagues (2016) sought to answer in their meta-analysis of 16 studies of more than one million individuals. Analysis was differentiated based on whether the SB involved was sitting or TV, and joint analyses were conducted combining SB and quantified PA levels. For the joint analyses, the authors stratified the participants by PA quartile with SB quartiles nested as subcategories. A curvilinear dose-response relationship was observed, ranging from individuals who were the most active

(>35.5 MET-hours/week) and sat the least (<4 hours/day) to those who were the least active (≤2.5 MET-hours/week) and sat the most (>8 hours/day). Comparing these two extremes, the group with the least PA and most sitting time had a 59% (95% CI 1.52-1.66) greater mortality risk than the group with the most PA and least sitting time. For the least active quartile, any amount of sitting time significantly increased ACM risk. In the second most active group (30 MET-hours/week), sitting <4 hours/day was not associated with a higher mortality risk. Additionally, participants in the most active quartile did not incur risk increases for any amount of sitting time, even in those who sat the most (HR 1.04, 95% CI 0.99-1.10; $p < 0.0001$). Comparatively, those who were the least active and sat the least had a significantly increased ACM risk (HR 1.27, 95% CI 1.22-1.30). These data indicate that the benefits of high weekly PA levels outweigh the harms of prolonged daily sitting. Unfortunately, such a strong association was not found for TV time. The dose-response relationship was less well-defined; one intriguing finding was that risk was dramatically higher in all PA quartiles for those who watched the most television. In the most active quartile, TV for ≥5 hours/day was associated with increased mortality hazard (HR 1.16, 95% CI 1.05-1.28); the other three levels of TV did not significantly increase risk in this group. The group that was the least active and watched the least television had a HR of 1.32 (95% CI 1.20-1.46 $p = 0.007$). Overall, TV time may have a stronger relationship with ACM than sitting time, although the deleterious effects of TV were eliminated at <5 hours/day. The results of this meta-analysis are promising, showing that 60-75 minutes per day of moderate-to-vigorous-intensity PA may effectively eliminate the ACM risk of high sitting time, and attenuate the risk of high TV time (Ekelund et al., 2016).

Sedentary Behavior and Cardiovascular Disease

According to an analysis by Ding et al. (2016), the population attributable factors of SB were 4.0% for CHD and 4.5% for stroke. In 2013, global healthcare costs for the two CVDs were $5.0 billion and $6.0 billion, respectively. Thus, SB is highly responsible for morbidity as well as mortality. Healy and colleagues (2008) examined the association between TV time and metabolic risk factors in 4,064 people who were part of the Australian Diabetes, Obesity and Lifestyle study. There were significant trends observed for increased TV time and higher systolic BP for both men ($p = 0.023$) and women ($p = 0.039$). The authors advocated for public health guidelines for SB (Healy et al., 2008). Grøntved & Hu also examined TV-CVD associations using four cohort studies (total $n = 34{,}253$). They found that a two-hour increase in TV time resulted in an associated RR of 1.15 (95% CI 1.06-1.23; $p < 0.001$). Unlike for ACM, the dose-response relationship for CVD was linear ($p_{\text{nonlinearity}} = 0.37$), demonstrating that all increases in TV time resulted in significantly increased risk (Grøntved & Hu, 2011). Finally, Biswas and coworkers (2015) meta-analyzed the relationship between overall SB and CVD incidence from 14 studies (total $n = 551{,}366$). The pooled HR for greater SB time was 1.14 (95% CI 1.00-1.30) independent of PA (Biswas et al., 2015). For the global pandemic of SB to end, there is a need for the worldwide collaboration of all sectors of society (Kohl et al., 2012).

Sedentary Behavior Trends in the United States

While the prevalence of adults engaging in no LTPA decreased from 2008-2018 (Centers for Disease Control and Prevention, 2022), SB levels in the US are still high, and the prevalence of certain behaviors is even rising in some populations. NHANES data on 31,898 adults (age 20+ years) from the 2003-2016 cycles were obtained for the study by Yang and colleagues (2019), who examined the trends in (1) sitting screen behaviors, (2) recreational computer usage, and (3) total sitting time (hours/day). For young and middle-aged adults (age 20-64 years), the prevalence of engaging in sitting screen behaviors for ≥2 hours/day non-significantly decreased by 0.7% (95% CI -5.6-4.1; $p_{\text{trend}} = 0.82$), while in older adults (age 65+ years) there was a significant 3.5% increase (95% CI -1.2-8.1; $p_{\text{trend}} = 0.03$). The trends in watching for ≥2 hours/day were nonsignificant for adults combined; however, trends in watching for ≥3 hours/day and ≥4 hours/day increased ($p_{\text{trend}} < 0.05$ for both). This may suggest that those who are already spending ≥2 hours/day partaking in sitting screen behaviors are doing more. In terms of PA levels, trends were stable for both active and inactive individuals ($p_{\text{trend}} > 0.05$). The prevalence of recreational computer usage for ≥1 hour/day increased by 18.5% (95% CI 14.9-22.2) in the young and middle-aged adults and 38.0% (95% CI 30.7-45.4) in the older adults ($p_{\text{trend}} < 0.001$ for both categories). Finally, total sitting time increased by 1 hour/day (95% CI 0.6-1.3) in the young and middle-aged adults, and 0.9 hours/day (95% CI 0.4-1.3) in the older adults ($p_{\text{trend}} < 0.001$ for both categories; only data from the 2007-2016 cycles were used). Overall, the prevalence of SB in adults did not seem to decline, and it even increased for some behaviors (Yang et al., 2019).

Du et al. (2019) examined a narrower section of NHANES data, from the 2007-2016 cycles (total $n = 27{,}343$). Here, they defined SB as sitting time, and adults as those age 18+. Overall, SB time increased by 0.7 hours/day ($p_{\text{trend}} < 0.001$), and this trend was observed for all age categories ($p_{\text{trend}} < 0.001$ for all); there was a significant interaction effect of age ($p = 0.01$). However, this significant increase in SB prevalence seems to be due to a spike during the 2013-2014 cycle. The authors stated that "the reasons for this remain unclear and warrant further investigation" (Du et al., 2019, pg. 8). When physical inactivity and SB were jointly analyzed, it was found that the population proportion of the most sedentary (sitting time >6 hours/day) and inactive (not meeting PA guidelines) individuals increased by 2.7% across the eight-year period ($p_{trend} < 0.001$). The authors reported that PA levels did not significantly increase over time; as well, SB increased, showing that both components of daily living need to be addressed (Du et al., 2019).

The prevalence of physical inactivity was assessed in the study of Whitfield and coworkers (2021), which utilized NHANES data from the 2007-2018 cycles. Here, they found a linear decrease in the trend of inactivity (defined as no reported moderate-to-vigorous-intensity activity of at least 10 continuous minutes). In terms of occupational or household PA, there was a quadratic decrease of 5.6% in inactivity. These results are reassuring, but they seem counterintuitive, given that previous studies using most of the same data showed that SB levels were rising within the US. This supports the assertion of van der Ploeg & Hillsdon (2017) that physical inactivity and SB are not entirely equivalent, and that both need to be addressed separately in public health guidelines and recommendations.

Interval Training

Research on IT has proliferated over the last 15 years, heralding it as an effective, time-efficient mode of exercise (Gibala & Jones, 2013). Earlier studies (Hickson et al., 1977; Holloszy, 1967; Romijn et al., 1993; Tremblay et al., 1994) used high-intensity exercise as an effective stimulus to produce favorable adjustments in SM and fuel substrate metabolism. However, it was only recently that IT came to the forefront of exercise physiology research with an intriguing premise: that individuals with both little and much exercise training experience can considerably improve CRF with relatively lower exercise durations at higher intensities (Gibala & Jones, 2013). An increasing body of evidence has demonstrated that IT may even be more effective than MICT at producing improvements in cardiometabolic health (Gibala et al., 2012), as well as central (O'Driscoll et al., 2018) and peripheral (Granata et al., 2017) adaptations to exercise. The infinite variability of IT configurations results in more flexible training with a wide range of possible adaptations (Gibala & Jones, 2013). The traditional dichotomy of IT is (1) HIIT, characterized by longer, "near maximal" exercise bouts performed at ≥80% maximal HR, and (2) SIT, involving shorter, "all-out" exercise bouts (Gibala et al., 2019; MacInnis & Gibala, 2017). Because intensity is a key mediator of the physiological response to exercise (Barnes & Kilding, 2015b; Bishop et al., 2014; Dunham & Harms, 2012; Gibala et al., 2019; Granata et al., 2016b, 2017, 2018; Hamer et al., 2017; Hawley et al., 2014; MacInnis & Gibala, 2017; Matsuo et al., 2014; Milanović et al., 2015; Montero et al., 2015a), a close examination of IT is warranted.

Interval Training and Health

While generally viewed purely as a method of increasing fitness, IT has been shown to effectively improve cardiometabolic health in both healthy and diseased populations (Gibala et al., 2012). This is primarily linked to the relationship between CRF, and health outcomes (Weston et al., 2014), but studies have also reported improvements in cardiovascular health (Batacan et al., 2017; Cassidy et al., 2017; Quindry et al., 2019; Weston et al., 2014), body composition (Batacan et al., 2017; Quindry et al., 2019; Weston et al., 2014), and glucose control (Batacan et al., 2017; Cassidy et al., 2017; Gibala & Little, 2020). For example, the systematic review and meta-analysis of Batacan and colleagues (2017) identified 65 studies (study n range = 5-85) differentiated by short-term (<12 weeks) and long-term ≥12 weeks) interventions. Short-term HIIT decreased both diastolic BP (SMD -0.52, 95% CI -0.89 to -0.16; $p < 0.01$) and fasting glucose (SMD -0.35, 95% CI -0.62 to -0.09; $p < 0.01$). Long-term HIIT decreased waist circumference (SMD -0.20, 95% CI

-0.38 to -0.01; $p < 0.05$), % body fat (SMD -0.40, 95% CI -0.74 to -0.06; $p < 0.05$), resting HR (SMD -0.33, 95% CI -0.56 to -0.09; $p < 0.01$), systolic BP (SMD -0.35, 95% CI -0.60 to -0.09; $p < 0.01$), and diastolic BP (SMD -0.38, 95% CI -0.65 to -0.10; $p < 0.01$). Notably, these effects were only seen in overweight/obese populations; only CRF improved through short- and long-term HIIT in normal weight populations. Furthermore, there was a significant correlation between BMI and $\dot{V}O_{2max}$ increases ($\beta = 0.8366$; $p < 0.05$). These data indicate that those who are overweight or obese can significantly improve health through both short- and long-term HIIT (Batacan et al., 2017). Such findings have been observed in those with other disease risk factors as well.

Weston and colleagues (2014) conducted a systematic review and meta-analysis of 273 patients with lifestyle-induced cardiometabolic diseases (i.e., coronary artery disease, heart failure, HT, metabolic syndrome, and obesity) from 10 studies. Here, rather than changes in various biological markers from baseline, the authors of this study meta-analyzed HIIT and MICT on improvements in $\dot{V}O_{2max}$. The mean difference for this comparison was 3.03 (95% CI 2.00-4.07; $p < 0.001$) in favor of HIIT, equal to nearly double the increase by MICT (19.4% vs. 10.3%). Additionally, the authors concluded from their accumulated studies that blood glucose and triglycerides, oxidative stress, and inflammation were decreased more by HIIT compared to MICT. Furthermore, HIIT more effectively increased high-density lipoprotein cholesterol, nitric oxide availability, and insulin sensitivity. Thus, in those with various cardiometabolic diseases, HIIT was more effective than MICT at improving both fitness and metabolic health profile (Weston et al., 2014). Overall, CRF can be improved in both healthy and diseased populations, while further benefits can be acquired by those with cardiometabolic diseases.

While the efficacy of HIIT has been demonstrated, there remains controversy concerning the safety of such high-intensity exercise, especially in those with cardiac health conditions (Weston et al., 2014). Because vigorous exercise increases the risk of cardiac events (Cassidy et al., 2017; Quindry et al., 2019), it is indeed true that special care must be taken for this population. This thought is reflected in the American College of Sports Medicine's *Guidelines for Exercise Prescription and Testing*, which outlines stringent and detailed pre-exercise screening procedures to ensure minimal risk. In support of this, Quindry et al. (2019) advocate for HIIT as an alternative mode of exercise only when patients are stable and asymptomatic when performing exercise. However, in those with well-controlled or stable conditions, HIIT may be a reasonable alternative to MICT (Cassidy et al., 2017; Rognmo et al., 2012; Weston et al., 2014). The study of Rognmo and coworkers (2012) examined 4,846 patients (mean age 57.8 years) from three cardiac rehabilitation centers, performing a total of 175,820 exercise training hours from both HIIT and MICT. They found that, from 129,456 exercise hours of MICT, only one fatal cardiac arrest was observed; from 46,364 exercise hours of HIIT, only two nonfatal cardiac arrests were observed, with no fatal cardiac arrests. The authors concluded that the number of incidents was too few to make a comparison, and that both modalities are safe for CHD patients. It is worth noting that the patients of this study seemed to have stable conditions, given that they were referred for exercise rehabilitation by their general practitioner or hospital cardiologist (Rognmo et al., 2012); such findings may not be applicable to those with worse disease symptoms (Weston et al., 2014).

Nevertheless, HIIT can be a revolutionary clinical rehabilitation tool due to the supported notion that exercise training is more effectual in those with lower levels of fitness. Furthermore, HIIT may not need supramaximal intensity or long work intervals to be effective. In fact, the traditional Wingate protocol (i.e., "all-out" 30-second cycling sprints; Burgomaster et al., 2005; Granata et al., 2017) may not be safe or tolerable for many (Gibala et al., 2012), let alone those in diseased populations. Recent work has investigated brief vigorous exercise (Gibala & Little, 2020), which has been dubbed as "exercise snacks" in some studies (Francois et al., 2014). Brief vigorous exercise has the benefits of (1) decreasing the sessional exercise duration, and therefore the total time commitment, and (2) implementing exercise into one's day, reducing time spent in SB. This kind of exercise may be better tolerated by cardiac patients due to the much shorter and longer durations of work and rest intervals, respectively. While brief vigorous exercise has been shown to improve CRF (Gibala & Little, 2020), more research is needed to examine the mechanisms behind improvements, as well as effects on other cardiometabolic health factors. Additionally, longitudinal studies are needed to confirm the health benefits of HIIT. Finally, work on SIT and health is limited (Cassidy et al., 2017); studies are needed to elucidate this relationship.

Cardiopulmonary Adaptations to Interval Training

The nature and magnitude of central adaptations induced by IT are not as clear as for peripheral adaptations (O'Driscoll et al., 2018). However, evidence has emerged showing that IT can improve cardiovascular and pulmonary function, even in inactive individuals. The study of O'Driscoll and coworkers recruited 40 highly sedentary men (age 21 ± 1.7 years). Using a randomized crossover design with a four-week washout period, the participants alternated between a two-week HIIT program and a two-week control period. The HIIT protocol consisted of three sessions per week (six sessions total) with 3 x 30 seconds of "all out" cycling and 2 minutes of active rest (intensity not reported). For cardiorespiratory parameters, HIIT increased $\dot{V}O_{2peak}$ ($p < 0.001$) and minute ventilation ($p = 0.009$) compared to baseline. For hemodynamic parameters, HIIT decreased systolic ($p < 0.001$) and diastolic BP ($p = 0.038$) and increased resting SV ($p < 0.001$) compared to baseline. For cardiac autonomic parameters, HIIT decreased resting HR ($p < 0.001$). For cardiac function and structure parameters, HIIT induced improvements in left ventricular systolic and diastolic function, as well as many other autonomic factors ($p < 0.05$ for all). Finally, for left ventricular mechanics, HIIT improved average global longitudinal strain rate ($p = 0.014$). There was no significant increase in left ventricular mass in the HIIT group ($p = 0.80$). This differs from what was observed in the study of Matsuo et al. (2014), where sedentary subjects were also used. However, that study used 3-minute work intervals for the HIIT group, suggesting that the duration of the high-intensity repetitions may impact left ventricular mass more than the intensity. The improvements in cardiac autonomic modulation through HIIT seen within inactive subjects has valuable implications for improving health outcomes in sedentary individuals (O'Driscoll et al., 2018).

The effect of HIIT on pulmonary variables was examined in the study of Dunham & Harms (2012). Here, 15 active young adults were assigned into either a HIIT group or an MICT group to train at three sessions per week for four weeks. The HIIT protocol was 5 x 1-minute bouts at 90% $\dot{V}O_{2max}$ with 3 minutes of active rest at 20 Watts. The MICT protocol was 45 minutes at 60%-70% $\dot{V}O_{2max}$. The participants also completed pre-, during- (at the halfway point), and post-intervention five-mile time trials. Both groups improved $\dot{V}O_{2max}$ and time trial completion time ($p < 0.05$ for both), with no differences between groups ($p > 0.05$). Maximal inspiratory pressure, a correlate of inspiratory muscle strength, was improved in both groups ($p < 0.05$ for both), but more so for the HIIT group ($p < 0.05$). Therefore, pulmonary system function was enhanced through four weeks of HIIT (Dunham & Harms, 2012).

Skeletal Muscle Adaptations to Interval Training

The seminal paper of Burgomaster and colleagues (2005) provided the groundwork for modern IT research. In this paper, eight recreationally active participants (age = 22 ± 1 years) completed six SIT sessions comprising 4-7 30-second "all-out" cycling tests with four minutes of passive or active rest. This study was conducted over two weeks with 1-2 days between sessions to ensure adequate rest. The participants also performed an endurance cycling test to fatigue at ~80% of peak oxygen uptake ($\dot{V}O_{2peak}$). Both mitochondrial volume (as indicated by citrate synthase maximal activity) and resting muscle glycogen content increased as a result of the training ($p < 0.05$ for both). There was no change in $\dot{V}O_{2peak}$; remarkably, time to fatigue increased by nearly 100% in the experimental group (pre-training 26 ± 5 minutes vs. post-training 51 ± 11 minutes). In total, the SIT program consisted of only about 15 minutes of exercise across two weeks. The implications of these results were that very short-term, low-volume IT could improve both mitochondrial volume and cycling endurance capacity in those who were already active (Burgomaster et al., 2005). This seems to undermine the traditional concept that aerobic capacity can only be improved through activities that engage primarily aerobic energy pathways, i.e., low-to-moderate-intensity PA.

MacInnis and coworkers (2017) used a unique within-subjects design to study ten active, male UCS (age 23 ± 1 years). Their approach involved counterweighted single-leg cycling; one leg was randomly assigned to do MICT, the other was assigned to do HIIT. This effectively eliminated any between-person differences in adaptation to exercise training. Like in the previous study (Burgomaster et al., 2005), the participants performed six exercise sessions spread over a two-week period. The HIIT leg protocol was 4 x 5 minutes at 65% peak power (W_{peak}) with 2.5

minutes of active recovery at 20% W_{peak}. The MICT leg protocol was 30 minutes at 50% W_{peak}. The total work was matched between groups ($p = 0.44$). The HIIT leg incurred greater increases in maximal citrate synthase activity (i.e., mitochondrial volume; $p = 0.02$) and mitochondrial respiration than the MICT leg ($p = 0.03$). Single-leg W_{peak} increased in both legs ($p = 0.003$), however, single-leg $\dot{V}O_{2peak}$ did not change in either leg ($p = 0.81$). The findings of this study are similar to those of Burgomaster et al. (2005), where two weeks of three nonconsecutive IT sessions per week significantly increased mitochondrial content, but not peak aerobic capacity. These data indicate that mitochondrial adaptations occur even after short-term IT, whereas improvements in CRF may require a lengthier period of training, a notion which was echoed in an earlier meta-analysis by Milanović et al. (2015). The authors concluded that intensity may be the most important factor regulating SM remodeling (MacInnis et al., 2017).

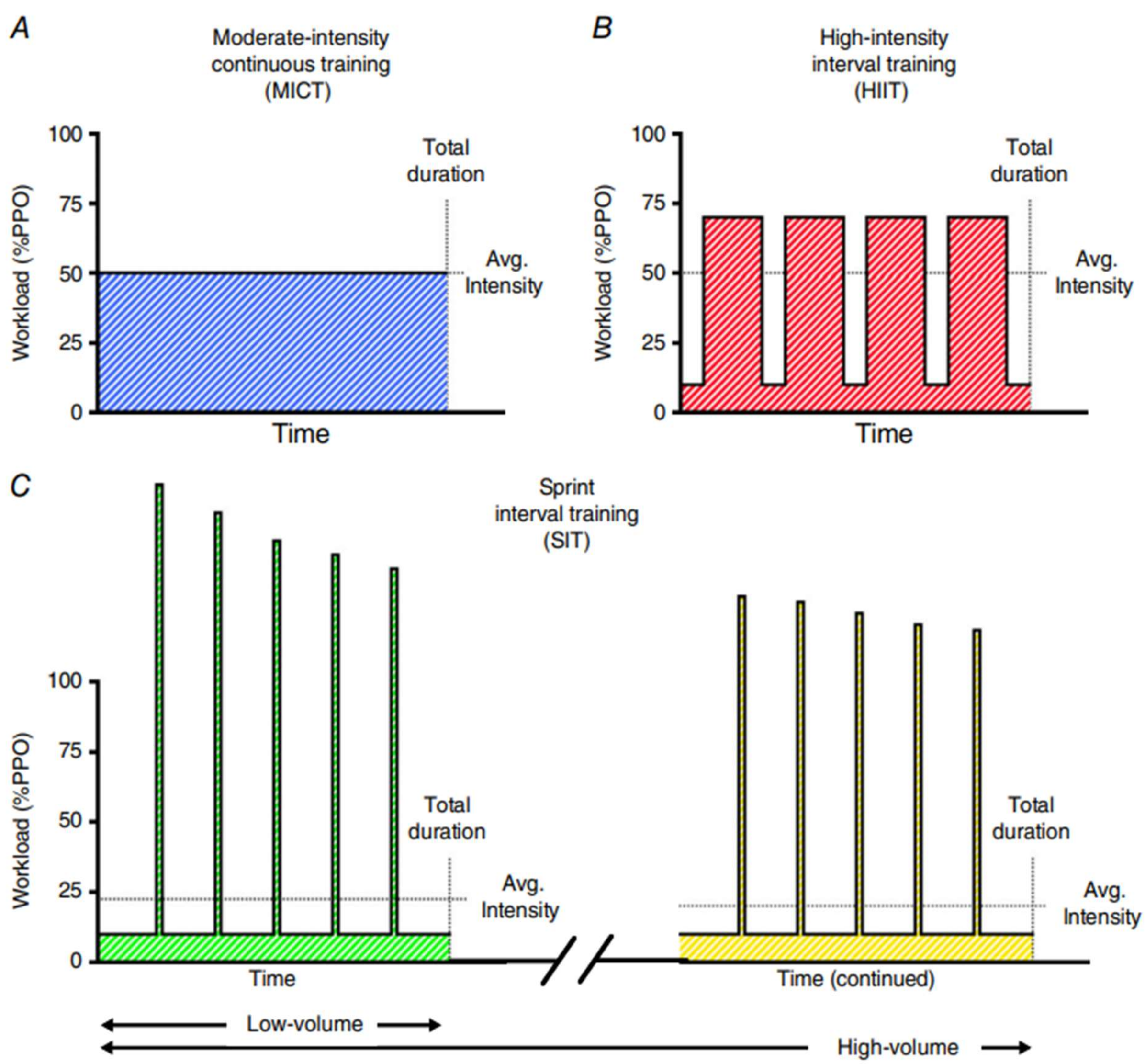
Other studies have explored the effects of SIT on mitochondrial biogenesis, particularly on the content of PGC-1α and other regulatory proteins such as p53 and PHF20. Granata and colleagues (2017) assigned nineteen men (age 21 ± 2 years) to a single bout of either SIT (4 x 30 seconds of "all-out" cycling [rest not reported]) or MICT (24 min at 63% W_{peak}). The authors took muscle biopsies before, immediately after, and three hours after the exercise bouts. The protein content of p53 (nuclear $p = 0.002$, cytosolic $p = 0.012$) and PHF20 (nuclear $p = 0.006$, cytosolic $p < 0.001$) were higher immediately after exercise but were not different between MICT and SIT ($p > 0.05$ for all interactions). Nuclear PGC-1α protein content increased immediately after ($p = 0.043$), but not three hours after ($p = 0.13$), exercise, and this was only observed in the SIT group ($p = 0.046$). Cytosolic PGC-1α did not significantly increase compared to baseline but did compared to MICT ($p = 0.036$). The fact that these adaptations occurred so promptly after exercise in the SIT group demonstrates that intensity is directly related to mitochondrial biogenesis (Granata et al., 2017).

Configurations of Interval Training

Due to IT's endless number of combinations (Gibala & Jones, 2013), a variety of configurations have been employed, resulting in varying physiological adaptations. An example of IT and MICT paradigms is shown in Figure 3. Specific composites have been identified as "representative examples" of the two major components of IT (Matsuo et al., 2014, pg. 42): These are the 4 x 4-minute protocol for HIIT, and the Wingate protocol for SIT. Another configuration that has been frequently used is the 10 x 1-minute protocol (Jung et al., 2014; Poon et al., 2018). However, Vollaard and Metcalfe (2017) argue in their review that IT should focus on fewer and shorter work intervals. They contend that time commitment and overall intensity can be decreased through abbreviated SIT – dubbed as reduced-exertion high-intensity interval training – without substantial attenuation in physiological adaptations.

In support of this, a recent review (Stamatakis et al., 2021) pointed to vigorous intermittent lifestyle PA as a possibly more feasible alternative to planned high-intensity exercise. This would involve PA that occurs as part of daily living, such as climbing stairs or even increasing walking pace. Stamatakis et al. (2019) gave an example of a day marked with sporadic bouts of vigorous-intensity PA: 6 minutes of cycling to and from work, 2 minutes of walking up a hill, and 2 minutes of carrying groceries upstairs, adding up to roughly 100 MET-minutes for the day. Repeating this regime for six days of the week (replacing the active transportation to work with other PA on the weekend days or when not working) would bring the individual up to the 600 MET-minute threshold with a mere 10-minute volume of PA. The authors emphasized that this kind of daily intermittent exercise could be easily performed by people of all ages (Stamatakis et al., 2019). However, there is still a paucity of evidence; there is a need to identify ways for IT to be implemented without unnecessary time commitment, fear of intensity, or overtraining (Stamatakis et al., 2021; Vollaard & Metcalfe, 2017).

Figure 3. Aerobic exercise training program paradigms (retrieved from MacInnis & Gibala, 2017).



Psychological Responses to Physical Activity and Interval Training

Psychological Responses to Physical Activity

The responses to physical work performed by the body are not exclusively physiological. Rather, the psychological component of movement merits consideration because affective responses, enjoyment, and self-efficacy are associated with PA behaviors (Bartlett et al., 2011; Ekkekakis et al., 2011; Jung et al., 2014; Rahmati-Najarkolaei et al., 2015; Thum et al., 2017; Tritter et al., 2013; Williams, 2008). Affect is defined as "the simplest and most phylogenetically and ontogenetically primitive response" (Ekkekakis, 2011, pg. 214). Hence, affective responses to internal and external stimuli are like the building blocks that compose the core of the psychological domain (Ekkekakis, 2011). Out of the three components of PA volume (i.e., duration, frequency, and intensity), intensity is the most important factor mediating affective responses (Ekkekakis et al., 2011). It has been well established that affective responses to exercise worsen as intensity increases, with a sharp inflection point at the anaerobic threshold, also known as the ventilatory threshold or lactate threshold (Ekkekakis, 2003; Ekkekakis et al., 2011; Jung et al., 2014; Poon et al., 2018; Williams, 2008). However, these responses are not rigid and one-dimensional; on the other hand, "there is a difference between what one feels and how one feels at varying intensities of physical work" (Hardy & Rejeski, 1989, pg. 310). For example, as Hardy and Rejeski (1989) point out, two individuals can ascribe the same rating of perceived exertion (RPE) to an intensity, but the response to that same intensity may differ. Therefore, the proper design of LTPA programs requires an examination of individualized perceptions of exercise (Poon et al., 2018).

Designing exercise programs also requires a knowledge of the barriers that discourage individuals from engaging in LTPA. Perceived lack of time has been shown to be the most cited barrier to PA in adults (Justine et al., 2013) and UCS (Daskapan et al., 2006; Rahmati-Najarkolaei et al., 2015). Also noted as common barriers for the two groups were tiredness/lack of energy (Daskapan et al., 2006; Justine et al., 2013) and lack of knowledge (Justine et al., 2013; Rahmati-Najarkolaei et al., 2015). Rahmati-Najarkolaei and colleagues (2015) also identified perceived severity of exercise as a barrier to participation. Therefore, to enhance PA adherence, there is a need to address the barriers of both time and intensity.

Psychological Responses to Interval Training

IT and MICT presumably solve the problems of time and intensity, respectively, but cause the other. The question becomes, which problem is more pertinent to exercise adherence? Crossover-design randomized controlled trials conducted within the last 15 years have examined the psychological response to different configurations of IT. Bartlett and coworkers (2011) examined the enjoyment responses of eight recreationally active men (age = 25 ± 5 years) using a treadmill protocol consisting of 6 x 3 minutes at 90% $\dot{V}O_{2max}$, with 3 minutes of active rest at 50% $\dot{V}O_{2max}$. The IT protocol was compared to 50 minutes of MICT at 70% $\dot{V}O_{2max}$. While RPE was higher during the IT protocol ($p < 0.05$), enjoyment following the IT protocol was also higher ($p < 0.05$). There was no difference in energy expenditure between the two groups ($p = 0.383$), indicating that HIIT is more tolerable than MICT in recreationally active men when total workload is matched (Bartlett et al., 2011). Exercise enjoyment and affect was also investigated by Thum et al. (2017) in recreationally active adults ($n = 12$, age = 29.5 ± 10.7 years), comparing HIIT and MICT using a cycle ergometer. The HIIT protocol consisted of 8 x 1 minute at 85% W_{max} with 1 minute of active rest at 25% W_{max}. The MICT protocol was 20 minutes at 45% W_{max}. Affective responses were less adaptive in the HIIT group compared to MICT ($p < 0.05$). However, HIIT produced greater enjoyment ($p = 0.013$), and 11 of the 12 participants preferred HIIT. The authors proposed that the greater enjoyment may be related to the lower time commitment and the variable stimulus (Thum et al., 2017).

As an "alternative" to moderate-intensity PA, vigorous-intensity continuous exercise (VICT) is recommended in the *Physical Activity Guidelines for Americans* (U.S. Department of Health and Human Services, 2018) in weekly bouts of 75 minutes. However, the greater intensity of VICT may not make it a practical way to meet guideline recommendation. In the repeated-measures study of Jung et al. (2014), three different protocols were assessed on affective responses, self-efficacy, enjoyment, and preference in 44 insufficiently active adults (age: men 30.94 ± 12.54 years, women 35.36 ± 16.96 years) using cycling protocols. For HIIT, participants did 10 x 1 minute at 100% W_{peak} with 1 minute of active rest at 20% W_{peak}; for MICT, 40 minutes at 40% W_{peak}; and for VICT, 20 minutes at 80% W_{peak}. Compared to VICT, not only was HIIT more enjoyable ($p = 0.01$), but over half the participants indicated they would rather engage in HIIT ($p < 0.05$). Furthermore, participants' confidence to do HIIT was just as high as it was for MICT compared to VICT ($p < 0.05$). While the affective response data were varied, the overall results suggest that HIIT is a viable exercise option in adults who are not meeting PA guidelines (Jung et al., 2014). Poon and colleagues (2018) examined the age differences in affective responses and self-efficacy comparing HIIT, MICT, and VICT running exercise. They recruited 12 young (age 24.3 ± 1.7 years) and 12 middle-aged (age 46.8 ± 7.5 years) healthy, insufficiently active males. The HIIT protocol was 10 x 1 minute at 100% $\dot{V}O_{2max}$ with 1 minute of active rest at 50% $\dot{V}O_{2max}$; the MICT protocol was 40 minutes at 65% $\dot{V}O_{2max}$; and the VICT protocol was 20 minutes at 80% $\dot{V}O_{2max}$. In the young adults, surprisingly, affective responses were more positive for HIIT and

VICT compared to MICT ($p < 0.05$ for both). For middle-aged adults, there were more positive responses for HIIT and MICT compared to VICT ($p < 0.05$ for both); self-efficacy was higher for MICT compared to HIIT and VICT ($p < 0.01$); and only 17% preferred HIIT compared to MICT and VICT. From this study, it appears that greater intensities are more well-tolerated by young compared to middle-aged adults (Poon et al., 2018).

Oliveira et al. (2018) meta-analyzed eight studies to investigate the differences in affective and enjoyment responses comparing HIIT to MICT. The psychological metrics were assessed in those studies by the Feeling Scale (FS), the Physical Activity Enjoyment Scale (PACES), and the Exercise Enjoyment Scale (EES). While FS-measured effects were nonsignificant (SMD 0.19, 95% CI -0.17-0.56), results for both the PACES (SMD 0.49, 95% CI 0.11-0.86) and the EES (SMD 0.48, 95% CI 0.22-0.74) were in favor of HIIT. Thus, compared with MICT and VICT, HIIT was shown to be a more enjoyable exercise option. While there was significant data heterogeneity, especially for the FS ($I^2 = 78.9$), the results of this meta-analysis indicate that HIIT is a viable form of exercise for many populations. The authors recommended that rest intervals be longer to preserve positive affect, both for normal-weight and overweight individuals (Oliveira et al., 2018).

SIT is characterized by intervals of shorter duration and higher intensity than in HIIT. In the study by Tritter et al. (2013), the authors tested the effects of varying feedback on self-efficacy and affect responses to SIT. They recruited 74 insufficiently active UCS to perform four 30-second sprint intervals interspersed with 4-minute rest periods. Following each interval, researchers gave either positive (high self-efficacy group), negative (low self-efficacy), or no (control group) feedback on their performance. The high self-efficacy group had less of a decline in self-efficacy from baseline ($p = 0.02$), as well as higher levels of enjoyment ($p = 0.003$) compared to the other two groups. Additionally, the high self-efficacy group experienced greater satisfaction ($p < 0.001$) compared to the low self-efficacy group. These data show that self-efficacy may decrease over the course of a SIT workout, but positive external feedback can be used to maintain self-efficacy levels (Tritter et al., 2013).

Conclusion

This review of literature demonstrates a clear and present need for insufficiently active individuals to increase PA levels with the goal of improving long-term health. PA bestows a wide range of benefits that range from reduction in disease and mortality risk to improvements in physiological and performance parameters. Furthermore, improvements in CRF are also associated with better outcomes in both active and inactive populations, although benefits are more pronounced in those who are less active. SB is an independent risk factor for ACM and various morbidities, and the need for increased PA is complemented by the urgency for reducing time spent in SB. Trends for PA in the United States are positive, but the prevalence of SB has also increased, showcasing the elevation in technology use around the nation. IT has emerged as a time-efficient mode of exercise, which can be employed in a wide variety of configurations that is easily individualized. The reported psychological responses to IT are generally positive but remain equivocal and require further investigation. This thesis study adds to the current literature to help elucidate the relationships between IT and physiological and psychological responses.

CHAPTER THREE: METHODOLOGY

This thesis study aimed to investigate the relationships among training frequencies and CRF improvements within IT exercise modalities, as well as clarify the affective responses to IT, using a randomized controlled design. Participants were recruited from Washington State University's UCS population using convenience sampling. The study consisted of two groups (HIIT1 and HIIT3), to which participants were assigned using a randomization concealment tool (Doig & Simpson, 2005). For the exercise groups (HIIT1 and HIIT3), all exercise was performed on a treadmill. Baseline testing was completed by all subjects prior to the intervention stage of the study, and post-intervention testing was completed following completion of the six-week protocol. Following baseline testing participants came to the Exercise Physiology & Performance Laboratory (EPPL) for the intervention an unequal number of times per week based on their assigned group. Specifically, the HIIT1 group came once per week, and the HIIT3 group came three times per week. This thesis study obtained approval from the Washington State University Institutional Review Board in the summer of 2023 (Figure 4; IRB #20261).

Participants

Fourteen UCSs from Washington State University were recruited for this study (n = 7 per group). Estimated sample size was obtained from a power analysis using a statistical power level of 0.80, alpha value of 0.05, number of groups as 2, number of measurements as 2, and default settings for correlation among repeated measures and nonsphericity correction. Expected effect size was calculated using values retrieved from the studies of Matsuo and colleagues (2014), Burgomaster and colleagues (2005), Granata and colleagues (2016b; 2017), and Dunham and

Harms (2012). These effect sizes were averaged and produced an expected effect size of 0.48. Analysis with these parameters resulted in a sample size of 12 participants needed for sufficient power. Flyers, social media notices, and classroom announcements were used online and around the university as advertisement tools. Prior to study participation, all prospective subjects completed the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003), the Physical Activity Readiness Questionnaire (PAR-Q+; Warburton et al., 2022; Figure 5) and the WHOQOL-BREF questionnaire (WHOQOL Group, 1998) to establish inclusion/exclusion status based on PA level and health status. These questionnaires were housed together within a Qualtrics survey; data were stored and managed on a WSU-provided, HIPAA-compliant cloud platform as well as a secure storage device housed in the EPPL. Inclusion criteria for this thesis study is as follows: that all participants be (1) between 18 and 24 years of age, (2) consistently (≥6 consecutive weeks) doing some weekly aerobic LTPA that is insufficient to meet guidelines, (3) generally healthy, as deemed by the PAR-Q+ and WHOQOL-BREF questionnaires, (4) prescription medication-free, (5) non-smokers, and (6) able to read and speak conversationally in English. Answering "Yes" to any of the questions on the PAR-Q+ resulted in exclusion from the study. Table 1 shows the purpose, validity, reliability, and application of the various measurement tools utilized for this study. To account for sex differences in physiological response to exercise training (Ansdell et al., 2020), study investigators equally stratified by sex. In other words, both males and females were randomized into the different categories. All study participants were compensated for their participation in the study with a $50 gift card.

The timing of the exercise sessions was based flexibly around the participants' schedules, with the HIIT1 group members able to come on any day of the week, and the HIIT3 group members coming on any three days of the week, provided those days were nonconsecutive. Participants were reminded of the exercise sessions at least 12 hours before its occurrence. If, during the exercise intervention or GXTs, a participant was injured and unable to continue in the study, they were immediately excluded from the study and received the $50 gift card compensation. While a sample size of 30 subjects was the objective of this study, we aimed to recruit roughly 50 participants to account for potential dropout and maintain statistical power. Participants were removed from the study if they were unable to come to (1) one or more of the sessions for the HIIT1 group, (2) three or more sessions for the HIIT3 group, or (3) either one of the two GXTs. This was the case regardless of sickness or other personal circumstances.

Table 1

Purpose, validity, reliability, and application of measurement tools

	Purpose	Validity	Reliability	Application
IPAQ[a]	Cross-national monitoring of PA and inactivity	ρ = 0.30	ρ = 0.76	Shown to be a reliable and valid PA measurement tool in 12 countries[a]; cited almost 20,000 times
PAR-Q+[b]	Pre-participation screening tool for PA	r^2 = 0.90	r^2 = 0.98	Used by millions of people worldwide; validity recognized by the American College of Sports Medicine[b]
WHOQOL-BREF[c]	Abbreviated assessment of quality of life and health	r^2 = 0.52	α = 0.82	Validated in a cohort of 11,830 people from 23 countries[c]
RPE[d]	Subjective measure of exertion during exercise	r^2 = 0.76	r^2 = 0.78	One of the most commonly used tools for assessing subjective work rate; used in almost 1,000 studies between 2001 and 2016[e]
FS[f]	11-point bipolar scale assessing the core affective dimension of valence	r^2 = 0.31	r^2 = 0.08	Compared well with HR, ventilation, and $\dot{V}O_2$; used frequently in exercise psychology studies[g]

[a]Craig *et al.* (2019); [b]Warburton *et al.* (2011); [c]Skevington *et al.* (2004); [d]Herman *et al.* (2006); [e]Haddad *et al.* (2017); [f]Hardy & Rejeski (1989); [g]Ekkekakis *et al.* (2011).

Pre-Intervention Procedures

Physiologic and anthropometric data collection took place at the EPPL at Washington State University. Prior to baseline testing, participants were given a liability waiver explaining the minimal risks of the study (e.g., falling while running). Acknowledgement of this liability waiver exempted the laboratory from legal action taken by participants should an injury or adverse event occur. Baseline testing commenced, beginning with anthropometric and resting physiological measurements (i.e., HR, BP, and blood lactate [BL]). Height was assessed using a stadiometer (seca GmbH & Co. Kg., Hamburg, Germany), and body mass was measured by a manual scale (Global Industrial, Port Washington, New York, USA). HR was obtained using Polar Heart Rate Sensor H1 sensors paired with Polar FT7 wristwatches (Polar Electro Oy, Kempele, Finland). BP was taken in a seated position with a manual sphygmomanometer (AliMed, Inc., Dedham, Massachusetts, USA). BL was measured by finger prick with a portable blood lactate analyzer (Nova Biomedical, Waltham, Massachusetts, USA).

Once resting values were obtained, all participants performed a graded (GXT) on a treadmill (Full Vision, Inc., Newton, KS, USA; WOODWAY USA, Waukesha, Wisconsin, USA) until volitional exhaustion. Participants began with a five-minute warmup on the treadmill at ≤6 miles per hour (mph). The subjects then put on a medical mask attached to a two-way rebreathing valve and hose, connected to a metabolic cart. This system captures expired air, which is then analyzed using a connected metabolic measurement system (ParvoMedics, Inc., Salt Lake City, Utah, USA) to assess oxygen consumption ($\dot{V}O_2$) during the GXT. The GXT protocol is displayed in Table 2. During rest periods, HR, BP, and BL measurements were obtained by lab staff. Also, subjects had the opportunity to remove the mask for easier breathing, and to rehydrate. Volitional exhaustion for pre- and post-intervention GXTs was defined as either (1) the participant deliberately ceases running, as indicated by stepping on the sides of the treadmill and grabbing the handrails, or (2) the participant is in danger of falling due to fatigue, at which point the EPPL staff will stop the test. Following completion of the GXT, HR, BP, and BL measurements were taken, and then the participants engaged in a five-minute cool down session on the treadmill at a desired speed. Following this, final measurements were taken for HR, BP, and BL.

Table 2

Pre- and post-intervention GXT protocol

Stage #	Speed (mph)	Grade (%)
1	6	0
2	6	5
3	7	6
4	8	7
5	9	8
6	10	9
7	11	10
8	12	11

Exercise Interventions

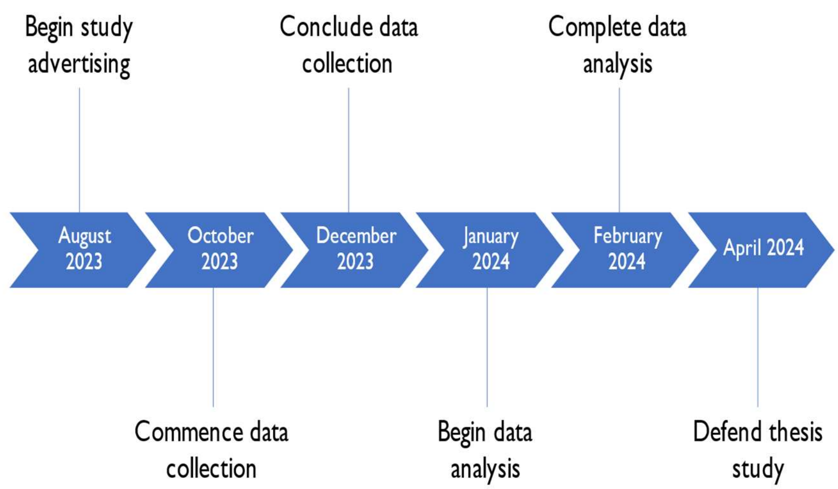
All study-eligible participants who completed pre-intervention testing were randomized (Doig & Simpson, 2005) into HIIT1 and HIIT3 groups. The two exercise groups were matched by work interval intensity and work/rest ratio and differentiated by weekly exercise frequency. Both exercise groups reached a total weekly energy expenditure of 450 MET-minutes, or 7.5 MET-hours (Figure 6). Both groups did a 5-minute warmup and cooldown on the treadmill at 6.1 mph. The HIIT1 group reported to the laboratory once per week. This group had two options for exercise protocols: (1) 8 repetitions of 3-minute work intervals at 8.0 mph with 4-minute rest intervals at 5.2 mph, or (2) 10 repetitions of 3-minute work intervals at 8.0 mph with 3-minute rest intervals at 3.9 mph. The work and rest interval speed and duration were modified if a participant feels uncomfortable with the default protocols, provided the 450-MET-minute threshold is reached. The

HIIT3 group reported to the laboratory three times per week. They performed a 5 x 1-minute protocol with active rest, as follows: 1 minute at 8.0 mph, then 1 minute at 4.9 mph. Immediately following each work interval, RPE was assessed on a 1-10 scale. During rest intervals, participants were able to rehydrate if desired. At the beginning of the cool down stage of each session, participants completed the FS (Hardy & Rejeski, 1989), an 11-point bipolar scale ranging from -5 (Very Bad) to +5 (Very Good).

Post-Intervention Procedures

Following the six-week intervention period, all participants performed a GXT on the treadmill once again to assess pre- and post-intervention differences in $\dot{V}O_{2max}$ and running economy (RE). The protocol for this GXT was identical to the pre-intervention $\dot{V}O_{2max}$ test (Table 2). Immediately following completion of the GXT, the participants were individually debriefed on their pre- and post-intervention GXT performances to discuss the effects of their protocol (HIIT1 vs. HIIT3) on CRF. Finally, they were granted the $50 gift card for participation in the study.

Figure 4. Proposed study timeline.



Data Management & Statistical Analyses

For the pre- and post-intervention GXTs, $\dot{V}O_2$ results were obtained for manual analysis using the metabolic cart's data retrieval feature. $\dot{V}O_{2max}$ was calculated using the five highest consecutive plateaued values reached during the last fully-completed stage. A $\dot{V}O_2$ plateau was defined as no more than a 2 mL/kg/min difference between consecutive values (Astorino, 2009). RE was assessed as the maximal $\dot{V}O_2$ attained for a given stage. If this was not attainable for a stage, a period of 60 seconds was used. This was compared across groups for each work interval, unless there are too few who have reached a certain stage to make a comparison. RPE data were used as a secondary analysis of the perceived intensity of the exercise interventions. The RPE of the last work interval was averaged across the six work sessions in both groups.

One-way analysis of variance (ANOVA) was performed to determine differences between groups for pre-intervention data, which included age (years), height (m), body mass (kg), $\dot{V}O_{2max}$, (mL/kg/min) and RE (mL/kg/min). Repeated-measures ANOVA (RM-ANOVA) was used to assess differences between pre- and post-intervention $\dot{V}O_{2max}$, RE, RPE, and FS scores. For affective responses and RPE, scores were analyzed in two ways. Firstly, they were averaged for each session, then assessed across the intervention at one-week time intervals (i.e., every session for HIIT1 and the average of every three sessions for HIIT3). Statistical significance was set at $p < 0.05$. All statistical analysis was performed using the SPSS v.28 software package (IBM Inc., Chicago, IL, USA).

Figure 6. Calculations of weekly energy expenditure in the exercise groups (example protocol shown for HIIT1).

HIIT1

Work: 8.0 mph running = 11.8 METs
Rest: 5.2 mph running = 9.03 METs
Warmup and cooldown: 6.1 mph running = 10.0 METs

(11.8 METs × 3-minute work intervals) + (9.03 METs × 3-minute rest intervals) = 62.5 MET-minutes

62.5 MET-minutes × 8 repetitions = 500 MET-minutes

Warmup and cooldown: 10.0 METs× 5 minutes × 2 = 100 METs

500 MET-minutes + 100 MET-minutes = 600 MET-minutes per session

600 MET-minutes per session × 1 session/week

= 600 MET-minutes (10 MET-hours) per week

HIIT3

Work: 8.0 mph running = 11.8 METs
Rest: 4.9 mph running = 8.2 METs
Warmup and cooldown: 6.1 mph running = 10.0 METs

(11.8 METs × 1-minute work intervals) + (9.6 METs × 1-minute rest intervals) = 20 MET-minutes

20 MET-minutes × 5 repetitions = 100 MET-minutes

Warmup and cooldown: 10.0 METs× 5 minutes × 2 = 100 METs

100 MET-minutes + 100 MET-minutes = 200 MET-minutes per session

200 MET-minutes per session × 3 sessions/week

= 600 MET-minutes (10 MET-hours) per week

MET values retrieved from Ainsworth *et al.* (2011)

CHAPTER FOUR: MANUSCRIPT

Effects of blocked and periodic interval training on cardiorespiratory fitness and affective responses among college students

Abstract

Physical activity (PA), defined as any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above a basal level, is negatively associated with adverse health outcomes and positively associated with health and fitness. However, 46% of all American adults are not meeting aerobic PA guidelines (i.e., 150 minutes of moderate-intensity activity, 75 minutes of vigorous-intensity activity, or equivalent combination), and of those not meeting guidelines, more than half do not engage in any purposeful aerobic PA whatsoever. Perceived lack of time is the most cited barrier to PA in young adults and may partially explain the above findings. Interval training (IT) has emerged as an effective, time-efficient mode of exercise to potentially attenuate the time barrier, thus enabling young adults to meet PA guidelines. The purpose of this study was to compare different weekly frequencies of interval training on cardiorespiratory fitness adaptations and affective responses among university students. Fourteen students were recruited and randomly assigned into a six-week exercise intervention group. The "blocked" group (HIIT1) performed the weekly recommended exercise volume in one session every week. The "periodic" group (HIIT3) performed the same volume spread out across three weekly sessions. The intensity of the intervention sessions was set at 80% of $\dot{V}O_{2max}$ for each participant. Baseline and post-intervention graded exercise testing were conducted to compare differences in cardiorespiratory fitness ($\dot{V}O_{2max}$) improvements. Affective responses were assessed by rating of perceived exertion (RPE) and the Feeling Scale (FS) and were measured within the intervention. Both groups experienced significant ($p < 0.05$) increases in $\dot{V}O_{2max}$, with the greatest effect observed in the HIIT3 group (HIIT1, +8.2% ± 6.8%; HIIT3, +11.3% ± 9.2%; $p = 0.04$). RPE average across the intervention was significantly higher in the HIIT1 group (HIIT1: 6.3 ± 2.1, HIIT3: 3.2 ± 2.3, $p < 0.001$). FS score session averages, on the other hand, were lower for HIIT1 than HIIT3 (HIIT1: -0.2 ± 1.4, HIIT3: 3.5 ± 0.6, $p < 0.001$). Interestingly, neither RPE nor FS scores changed across the intervention in the HIIT3 group ($p > 0.05$ for both), whereas the HIIT1 group experienced decreases in RPE (-2.4 ± 0.4, $p = 0.02$) and increases in FS score (+3.6 ± 0.8, $p = 0.008$). The present study demonstrated that the $\dot{V}O_{2max}$ improvement was greater in the HIIT3 group compared to the HIIT1 group even with matched relative intensity and weekly exercise volume. Additionally, the HIIT3 group had more adaptive affective responses throughout the intervention. These findings suggest that spreading a weekly volume of exercise across multiple days may be superior to completing it in one session in terms of both cardiorespiratory fitness improvement and affective responses.

Introduction

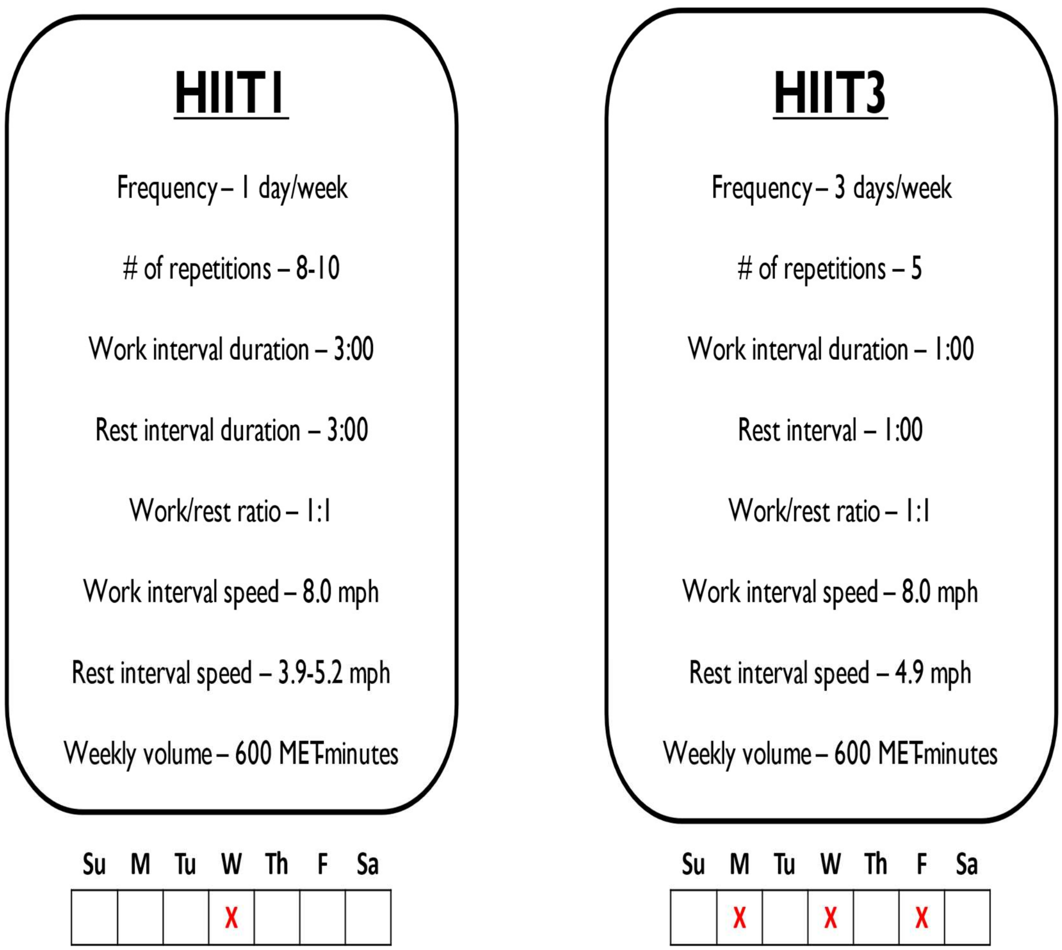
Physical activity (PA) has been defined by the U.S. Department of Health and Human Services as any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above a basal level (U.S. Department of Health and Human Services, 2018, pg. 29). Numerous studies have demonstrated that PA is negatively associated with adverse health outcomes (Aune et al., 2015; Eijsvogels et al., 2016; Fan et al., 2013; Fletcher et al., 1996; Kelly et al., 2014; Lee, 2003; Morris et al., 1953; Sattelmair et al., 2011; Stewart et al., 2017; Thompson et al., 2003) and positively associated with health and fitness (Chastin et al., 2020; Eijsvogels et al., 2016; Fletcher et al., 1996; Thompson et al., 2003). Cardiorespiratory fitness (CRF) can be improved through PA and is itself negatively associated with morbidity and mortality (Lee et al., 2011; Ross et al., 2016).

The current *Physical Activity Guidelines for Americans* recommend that adults perform 150 minutes per week of moderate-intensity or 75 minutes per week of vigorous-intensity aerobic PA (U.S. Department of Health and Human Services, 2018). However, National Health Interview Survey (NHIS) data, published by the Centers for Disease Control and Prevention (2022), suggests 46% of all American adults did not meet aerobic PA guidelines. Furthermore, of those not meeting guidelines, 55% (i.e., 25% of all American adults) did not engage in any purposeful aerobic PA whatsoever. Given the cumulative health benefits of PA as well as the specific relationships previously shown with disease and mortality, these are startling findings. There is an urgent need for a nationwide elevation in PA levels, particularly given that sedentary behavior (SB) has increased over the last twenty years (Yang et al., 2019). SB is positively associated with morbidity and mortality risk (Biswas et al., 2015; Ekelund et al., 2016; Fletcher et al., 1996; Grøntved & Hu, 2011; Matthews et al., 2015; Patterson et al., 2018). National Health and Nutrition Survey (NHANES) data for the years 2007-2016 showed an increase in total sitting time across all age groups (Du et al., 2019; Yang et al., 2019). Moreover, there was a concomitant increase in total computer usage outside school or work for all age groups (Yang et al., 2019). Despite these alarming trends, it appears that replacing SB with PA can attenuate (Ekelund et al., 2016; Matthews et al., 2015) or possibly eliminate (Ekelund et al., 2016) the negative effects of SB.

Recent NHANES data (2017-2018 cycle) revealed that the young adult subpopulation (age 18-24 years) was the most active, with 55.2% meeting the aerobic PA guideline (Whitfield et al., 2021). Unfortunately, inactivity levels have increased within this subgroup by 2.0% over the past 15 years, suggesting at the very least that SB among young adults has not improved within the last decade. This likely results from various barriers that specifically affect young adults, often seen among university and college students (UCS). These barriers include perceived lack of time, energy, motivation, and resources (Daskapan et al., 2006). Furthermore, students likely incur high levels of stress from sources such as academic endeavors, moving to a new location, and financial independence. These stressors have been reported to predispose UCS to poorer PA and nutrition behaviors (Plotnikoff et al., 2015). Because lifestyle behavior improvements can lower non-communicable disease risk (Plotnikoff et al., 2015), it is crucial that interventions to improve PA levels target specific barriers and lifestyle factors. As the most commonly reported barrier to PA in UCS, perceived lack of time may be an ideal intervention target (Daskapan et al., 2006).

Interval training (IT) has emerged as an effective, time-efficient mode of exercise within the last fifteen years (Gibala & Jones, 2013). Research on this topic has questioned the popular notion that aerobic exercise should be submaximal and lengthy, while promoting instead that both untrained and recreationally active people can substantially improve fitness with relatively lower exercise durations at higher intensities (Gibala & Jones, 2013). Recent work has even shown that IT is superior to traditional moderate-intensity continuous training (MICT) for both central (O'Driscoll et al., 2018) and peripheral (Granata et al., 2017) exercise-induced adaptations. Moreover, IT is advantageous in that it is "almost infinitely variable" (Gibala & Jones, 2013, pg. 51), effectively being organized into many configurations of varying duration and intensity. Most previous studies comparing traditional moderate-intensity continuous training (MICT) and IT interventions have used matched frequencies (e.g., three days per week). What remains unclear is whether IT-induced physiological adaptations differ when energy expenditure is matched but frequency is unmatched (e.g., 150 minutes of moderate-intensity aerobic exercise spread out over one vs. three days per week; Figure 1).

Figure 1. Overview of experimental protocol.



Psychological responses to IT have also been investigated. According to the Dual-Mode Theory, exercise intensities exceeding the anaerobic threshold are related to negative affective responses (Ekkekakis, 2003; Ekkekakis et al., 2011). Because IT is generally characterized by intensities that exceed the anaerobic threshold, it is reasonable to postulate that IT would produce unfavorable psychological states compared with MICT. However, other work has shown that IT can produce greater exercise enjoyment in both sedentary (Oliveira et al., 2018) and recreationally active (Bartlett et al., 2011; Thum et al., 2017) individuals, likely due to a lower time commitment (Oliveira et al., 2018; Thum et al., 2017). Furthermore, in their study of untrained adults, Jung and colleagues (2014), reported that the majority of participants preferred HIIT to MICT. While studies such as these have reported positive outcomes, the psychological responses to IT remain ambiguous (Poon et al., 2018; Thum et al., 2017), which could be the result of varying study methodology (Oliveira et al., 2018).

The primary aim of this study was to determine the relationship between exercise frequency and CRF improvements. We hypothesized that periodic exercise (three days/week) would more effectively improve maximal oxygen uptake and RE compared to energy expenditure-matched blocked exercise (one day/week). The secondary aim of this study was to examine the correlation of core affective responses with exercise adherence in different types of IT. We postulated that periodic exercise would produce more adaptive affective responses compared to blocked exercise.

Methodology

Participants

Fourteen UCSs from Washington State University were recruited for this study (n = 7 per exercise group). Estimated sample size was obtained from a power analysis using a statistical power level of 0.80, alpha value of 0.05, number of groups as 2, number of measurements as 2, and default settings for correlation among repeated measures and nonsphericity correction. Expected effect size was calculated using values retrieved from the studies of Matsuo and colleagues (2014 [Cohen's d = 0.63]), Burgomaster and colleagues (2005 [Cohen's d = 0.35]), Granata and colleagues (2016b [Cohen's d = 0.71]; 2017 [Cohen's d = 0.43]), and Dunham and Harms (2012 [Cohen's d = 0.28]). These effect sizes were averaged to produce an expected effect size of 0.48. Analysis using these parameters resulted in a sample size of 12 participants needed for sufficient power. Prior to study participation, all prospective subjects completed the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003), the Physical Activity Readiness Questionnaire (PAR-Q+; Warburton et al., 2022) and the WHOQOL-BREF questionnaire (WHOQOL Group, 1998) to establish inclusion/exclusion status based on PA level and health status. Demographic and participant characteristics of interest included age, sex, race/ethnicity, weight status, and weekly alcohol intake (based off the cutoff points given by Du et al. [2019]). Inclusion criteria for this thesis study were as follows: that all participants be (1) between 18 and 24 years of age, (2) consistently (≥6 consecutive weeks) doing some weekly aerobic PA, but that was insufficient to meet guidelines, (3) generally healthy, as deemed by the PAR-Q+ and WHOQOL-BREF questionnaires, (4) prescription medication-free, (5) non-smokers, and (6) able to read and speak conversationally in English. Answering "Yes" to any of the questions on the PAR-Q+, or a score lower than 80 on the WHOQOL-BREF, resulted in exclusion from the study. The experimental protocol and recruitment procedures of this study were approved by the Washington State University Institutional Review Board (IRB #20621).

All study participants completed baseline and post-intervention graded exercise testing (GXT) and were randomly assigned into an exercise intervention group (HIIT1 vs. HIIT3). To account for sex differences in physiological response to exercise training (Ansdell et al., 2020), study investigators equally stratified by sex with both males and females were randomized into the different groups. The timing of the intervention exercise sessions was scheduled according to participant weekly availability, with the HIIT1 group members able to come on any day of the week, and the HIIT3 group members coming on any three days of the week. To the best of the researchers' ability, those three days of the week were nonconsecutive; in cases where this misaligned with participants' schedules, consecutive exercise sessions were allowed. Participants were reminded via email of exercise sessions at least 12 hours before occurrence. If, during the exercise intervention or GXTs, a participant was injured and unable to continue in the study, they were immediately excluded from the study and received $50 gift card compensation. Participants were removed from the study if they were unable to come to (1) one or more of the sessions for the HIIT1 group, (2) three or more sessions for the HIIT3 group, or (3) either baseline or post-intervention GXTs. This was the case regardless of sickness or other personal circumstances.

Anthropometrics & Graded Exercise Testing

Physiologic and anthropometric data collection took place at the EPPL at Washington State University. Prior to baseline testing, participants were given a liability waiver explaining the minimal risks of the study (e.g., falling while running). Acknowledgement of this liability waiver exempted the laboratory from legal action taken by participants should an injury or adverse event occur. Baseline testing commenced, beginning with anthropometric and resting physiological measurements (i.e., heart rate [HR], blood pressure [BP], and blood lactate [BL]). Height was assessed using a stadiometer (seca GmbH & Co. Kg., Hamburg, Germany), and body mass was measured by a manual scale (Global Industrial, Port Washington, New York, USA). HR was obtained using Polar Heart Rate Sensor H1 sensors paired with Polar FT7 wristwatches (Polar Electro Oy, Kempele, Finland). BP was taken in a seated position with a manual sphygmomanometer (AliMed, Inc., Dedham, Massachusetts, USA). BL was measured by finger prick with a portable blood lactate analyzer (Nova Biomedical, Waltham, Massachusetts, USA).

Once resting values were obtained, all participants performed a graded (GXT) on a treadmill (Full Vision, Inc., Newton, KS, USA; WOODWAY USA, Waukesha, Wisconsin, USA) until volitional exhaustion. Participants began with a five-minute warmup on the treadmill at ≤6 miles per hour (mph). The subjects then put on a medical mask attached to a two-way rebreathing valve and hose, which was connected to a metabolic measurement system (ParvoMedics, Inc., Salt Lake City, Utah, USA) to assess oxygen consumption ($\dot{V}O_2$) during the GXT (Table 1). During rest periods, HR, BP, and BL measurements were obtained by lab staff. Also, subjects had the opportunity to remove the mask for easier breathing, and to rehydrate. Volitional exhaustion for pre- and post-intervention GXTs was defined as either (1) the participant deliberately ceases running, as indicated by stepping on the sides of the treadmill and grabbing the handrails, or (2) the participant is in danger of falling due to fatigue, at which point the EPPL staff stopped the test. Following completion of the GXT, HR, BP, and BL measurements were taken, and then the participants engaged in a five-minute cool down session on the treadmill at a desired speed. Following this, final measurements were taken for HR, BP, and BL.

Table 2

Pre- and post-intervention GXT protocol

Stage #	Speed (mph)	Grade (%)
1	6	0
2	6	5
3	7	6
4	8	7
5	9	8
6	10	9
7	11	10
8	12	11

Exercise Intervention

All study-eligible participants who completed pre-intervention testing were randomized (Doig & Simpson, 2005) into HIIT1 and HIIT3 groups. The two exercise groups were matched by work interval intensity and work/rest ratio and differentiated by weekly exercise frequency. Both exercise groups reached a total weekly energy expenditure of 450 MET-minutes, or 7.5 MET-hours. For every intervention session, both groups completed a 5-minute warmup and cooldown on the treadmill at 6.1 mph. The HIIT1 group reported to the laboratory once per week. This group performed 8 repetitions of 3-minute work intervals at 80% $\dot{V}O_{2max}$ with 4-minute rest intervals at an intensity which resulted in collectively attaining the 450-MET-minute threshold. The HIIT3 group reported to the laboratory three times per week. They performed 5 repetitions of 1-minute work intervals at 80% $\dot{V}O_{2max}$ with 1-minute rest intervals similarly at an intensity that collectively resulted in reaching the necessary weekly exercise volume. For both groups, immediately following each work interval, RPE was assessed on a 1-10 scale. During rest intervals, participants hydrated if desired. Prior to the cool down stage of each session, participants completed the FS (Hardy & Rejeski, 1989), an 11-point bipolar scale ranging from -5 (Very Bad) to +5 (Very Good).

Following the six-week intervention period, all participants performed a GXT on the treadmill once again to assess pre- and post-intervention differences in $\dot{V}O_{2max}$ and RE. The protocol for this GXT was identical to the pre-intervention $\dot{V}O_{2max}$ test (Table 2). The participants were then individually debriefed on their pre- and post-intervention GXT performances to discuss the effects of their protocol (HIIT1 vs. HIIT3) on CRF. They were then given their compensation to conclude their participation in the study.

Data Management

For the pre- and post-intervention GXTs, $\dot{V}O_2$ results were obtained for manual analysis using the metabolic cart's data retrieval feature. $\dot{V}O_{2max}$ was calculated using the five highest consecutive plateaued values reached during the last fully-completed stage. A $\dot{V}O_2$ plateau was defined as no more than a 2 mL/kg/min difference between consecutive values (Astorino, 2009) for a period of at least 75 seconds. If this was not attainable for a stage, a period of 60 seconds was used. RE was assessed as the maximal $\dot{V}O_2$ attained for a given stage and was calculated using the same method as for $\dot{V}O_{2max}$. This was compared across groups for each work interval, unless there are too few who reached a certain stage to make a comparison. The Study Coordinator thoroughly explained the RPE scale (1-10) and the FS (-5 to +5) prior to the first exercise sessions. These two metrics were assessed at the end of every work interval; the researchers verbally requested the information as soon as possible following the onset of the rest interval. This process repeated until all the repetitions were completed.

Statistical Analysis

One-way analysis of variance (ANOVA) was performed to determine differences between groups for pre-intervention data, which included age (years), height (m), body mass (kg), $\dot{V}O_{2max}$, (mL/kg/min) and RE (mL/kg/min). This process also determined whether statistical assumptions were met for hypothesis testing, that is, normal distribution of the data and homogeneity of variance. To determine the significance of changes in values measured pre- and post-intervention, paired Student's *t*-tests were utilized. Repeated-measures ANOVA (RM-ANOVA) was used to assess differences between pre- and post-intervention $\dot{V}O_{2max}$, RE, RPE, and FS scores. For RPE and the FS, scores were analyzed in two ways. Firstly, they were averaged for each session, then assessed across the intervention at one-week time intervals (i.e., every session for HIIT1 and the average of every three sessions for HIIT3). Secondly, values for the first and last session of every participant were averaged within each group and compared. For the RM-ANOVA models, each of the dependent variables (e.g., $\dot{V}O_{2max}$) was placed as the within-subjects factor, with pre- and post-intervention timepoints as the two levels. Partial η^2 was used as an effect size (ES) index for dependent variables. Statistical significance was set at $p < 0.05$. All statistical analysis was performed using the SPSS v.28 software package (IBM Inc., Chicago, IL, USA).

Results

Cardiorespiratory Fitness

Seventeen students were recruited for the study. Though all were determined as safe to participate by the PAR-Q+ and the WHOQOL-BREF questionnaires, three withdrew due to injury, sickness, or personal reasons, resulting in a total sample size of 14 participants ($n = 7$ per group). Table 3 shows means (M), standard deviations (SD), ANOVA statistics (F), and p-values of participant characteristics at pre-intervention testing. Pre-intervention $\dot{V}O_{2max}$ was found to be approximately normally distributed for both groups by a Shapiro-Wilk's test ($p > 0.05$) as well as visual inspection of their histograms, Q-Q plots, and box plots, with a skewness of 0.786 (standard error [SE] = 0.794) and a kurtosis of -0.745 (SE = 1.587) for HIIT1 and a skewness of 1.079 (SE = 0.794) and a kurtosis of 0.147 (SE = 1.587) for HIIT3. Levene's test demonstrated that the variances in pre-intervention $\dot{V}O_{2max}$ were not significantly different between HIIT1 and HIIT3 [$F(1,13) = 3.048$, $p = 0.106$]. There were no significant outliers, that is, no values were more than three SDs away from the mean. One-way ANOVA was conducted to determine differences between groups; results indicated a non-significant effect at the 0.05 alpha level (HIIT1 M ± SD = 48.2 ± 6.3, HIIT3 M ± SD = 47.2 ± 7.0 [$F(1, 13) = 1.49$, $p = 0.245$]).

Table 3

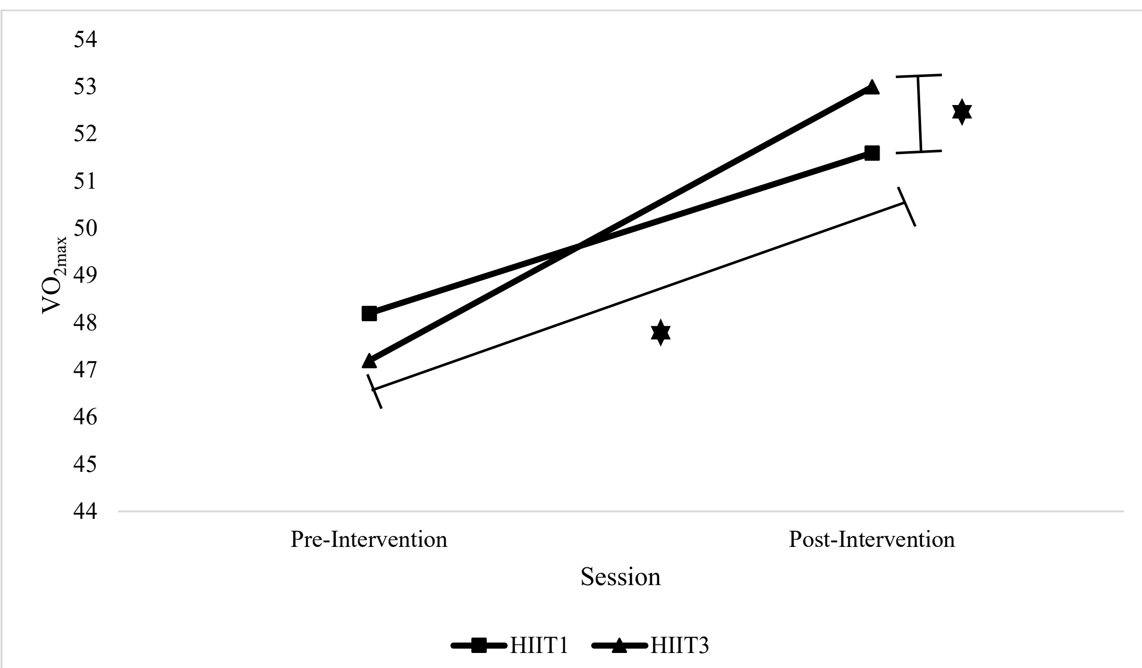
Participant baseline characteristics

	HIIT1 (*n* = 7)	HIIT3 (*n* = 7)	ANOVA, *F*(1,13)	ANOVA, *p*
Age (yr)	21.3 ± 2.3	20.1 ± 1.9	1.15	0.34
Height (cm)	175.4 ± 7.3	173.8 ± 5.4	0.943	0.47
Body mass (kg)	59.1 ± 8.1	64.6 ± 7.4	1.38	0.29
$\dot{V}O_{2max}$ (mL/kg/min)	48.2 ± 6.3	47.2 ± 7.0	1.49	0.25
Stage 1 $\dot{V}O_2$ (mL/kg/min)	26.8 ± 5.3	29.1 ± 3.9	0.936	0.48
Stage 2 $\dot{V}O_2$ (mL/kg/min)	38.1 ± 4.4	37.5 ± 6.0	0.319	0.79

Post-intervention $\dot{V}O_{2max}$ data were approximately normally distributed for both groups (Shapiro-Wilk test $p > 0.05$), with a skewness of -0.589 (SE = 0.794) and a kurtosis of -0.157 (SE = 1.587) for HIIT1, and a skewness of 1.359 (SE = 0.794) and a kurtosis of 0.875 (SE = 1.587) for HIIT3. Levene's test showed that variances were not significantly different between groups [$F(1,13) = 0.425$, $p = 0.527$]. Significant increases in $\dot{V}O_{2max}$ were observed in both groups (HIIT1:

+8.2% ± 5.6%, $p = 0.003$; HIIT3: +12.8% ± 7.3%, $p < 0.001$) as assessed by Student's independent *t*-tests. $\dot{V}O_{2max}$ increased by ≥5% in twelve out of the fourteen subjects. In HIIT1, three out of the seven subjects (43%) experienced $\dot{V}O_{2max}$ increases of ≥10%, while four of the seven HIIT3 subjects (57%) experienced such an increase. RM-ANOVA for pre- and post-intervention $\dot{V}O_{2max}$ revealed significant within-subjects [$F(1,13) = 2.219$, $p = 0.02$, partial $\eta^2 = 0.086$] and between-subjects [$F(1,13) = 15.845$, $p < 0.001$, partial $\eta^2 = 0.156$] effects (Mauchly's test of sphericity $p = 0.306$; Figure 6). Medium effect sizes were found for both HIIT1 (partial $\eta^2 = 0.063$) and HIIT3 (partial $\eta^2 = 0.109$), and there was a significant interaction between group (HIIT1 vs. HIIT3) and time (pre- vs. post-intervention), on the improvement in $\dot{V}O_{2max}$ [$F(1,13) = 6.215$, $p = 0.003$, partial $\eta^2 = 0.121$].

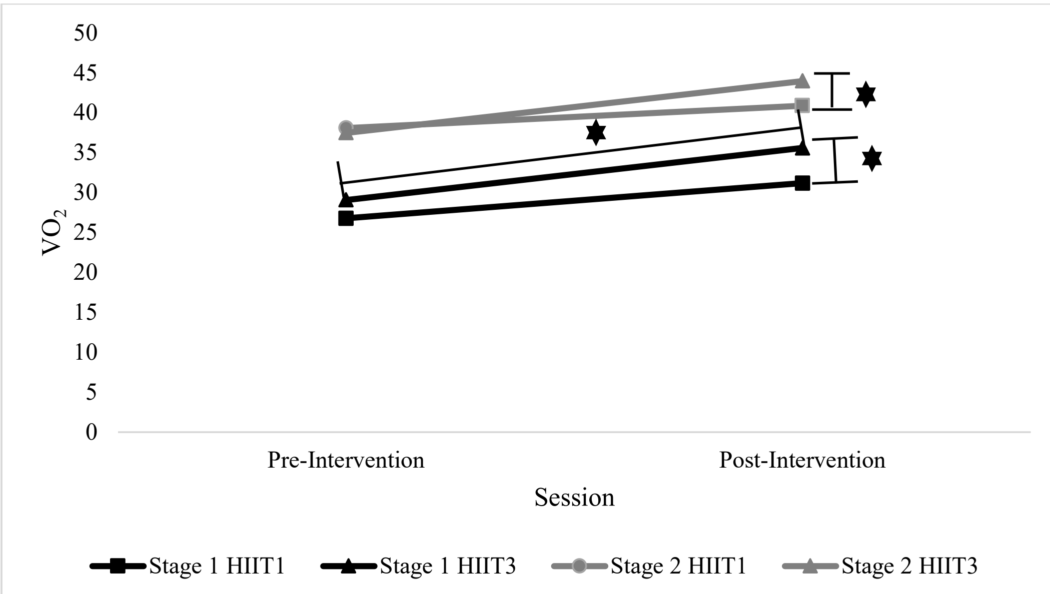
Figure 6. Interaction effect of group and time on $\dot{V}O_{2max}$



* Significant effect at $p < 0.05$.

RE data were found to be approximately normally distributed (Shapiro-Wilk's test $p > 0.05$ for all) and with homogeneity of variance (Levene's test $p > 0.05$ for all) for both groups in stages 1 and 2 of the GXT. For stage 1 of the pre-intervention GXT, HIIT1 had a skewness of -0.638 (SE = 0.794) and a kurtosis of 1.009 (SE = 1.587), and HIIT3 had a skewness of 0.349 (SE = 1.132) and a kurtosis of -0.158 (SE) = 1.587). For stage 2, HIIT1 had a skewness of 1.009 (SE = 1.532) and a kurtosis of 1.690 (SE = 0.901), and HIIT3 had a skewness of -1.127 (SE = 1.587) and a kurtosis of -0.328 (SE = -1.194). For stage 1 of the post-intervention GXT, HIIT1 had a skewness of 1.248 (SE = 0.887) and a kurtosis of 0.109 (SE = -1.587), and HIIT3 had a skewness of 0.279 (SE = 0.013) and a kurtosis of 0.211 (SE = -0.891). For stage 2, HIIT1 had a skewness of -1.009 (SE = 0.794) and a kurtosis of -0.782 (SE = 0.909), and HIIT3 had a skewness of 0.508 (SE = 0.891) and a kurtosis of 0.503 (SE = 0.746). Surprisingly, for the first two GXT stages of the GXT, Student's independent *t*-tests showed oxygen consumption increases in both HIIT1 (stage 1 p = 0.005]; stage 2: $p = 0.009$]) and HIIT3 (stage 1 $p = 0.03$]; stage 2 $p = 0.002$]). RM-ANOVA for pre- and post-intervention stage 1 RE produced significant between-subjects [$F(1,13) = 1.748$, p = 0.04, partial $\eta^2 = 0.048$] and within-subjects [$F(1,13) = 3.713$, $p = 0.03$, partial $\eta^2 = 0.052$] effects (Mauchly's test of sphericity $p = 0.238$), and there was a significant group × time interaction on RE [$F(1,13) = 2.018$, $p = 0.03$, partial $\eta^2 = 0.050$]. For stage 2, a significant between-subjects effect was found ([$F(1,13) = 4.498$, $p = 0.02$, partial $\eta^2 = 0.067$]; Mauchly's test of sphericity $p = 0.313$). No significant interaction effect was observed. Main effects of group with time on stage-specific running economy are shown in Figure 7. Fewer than half of the participants completed later GXT stages, so comparisons were not made beyond stage 2. Overall changes in oxygen consumption between pre- and post-intervention testing are given in Table 4.

Figure 7. Main effects of group and time on GXT stage 1 and 2 $\dot{V}O_2$



* Significant effect at $p < 0.05$. Vertical line intervals denote significant between-subjects effects, horizontal line intervals denote significant within-subjects effects.

Table 4

Comparison of changes in oxygen consumption

	Pre-Intervention		Post-Intervention	
	HIIT1 (n = 7)	HIIT3 (n = 7)	HIIT1 (n = 7)	HIIT3 (n = 7)
$\dot{V}O_{2max}$ (mL/kg/min)	48.2 ± 6.3	47.2 ± 7.0	51.6 ± 7.8*	53.0 ± 6.4†
Stage 1 $\dot{V}O_2$ (mL/kg/min)	26.8 ± 5.3	29.1 ± 3.9	31.2 ± 4.0*	35.6 ± 7.6†
Stage 2 $\dot{V}O_2$ (mL/kg/min)	38.1 ± 4.4	37.5 ± 6.0	40.9 ± 3.8*	44.0 ± 5.3†

* Significantly different from pre-intervention value at $p < 0.05$.
† Significantly different from pre-intervention value and HIIT1 value at $p < 0.05$.

Affective Responses

In the first part of the analysis, RPE and FS scores were averaged across each intervention session (i.e., average of 8 repetition values for HIIT1 and 5 repetition values for HIIT3) for each participant, then combined within groups for analysis. Because the number of HIIT3 sessions was three times greater than the number of HIIT1 sessions, HIIT3 values were averaged across three sessions, corresponding to the weekly session of HIIT1. Both RPE and FS averages were approximately normally distributed for both groups (Shapiro-Wilk test $p > 0.05$). Levene's test indicated homogeneity of variance for both groups' data ($p > 0.05$). Values for six time points were placed into the RM-ANOVA with 'group' (i.e., HIIT1 vs. HIIT3) as the between-subjects variable. RM-ANOVA indicated significant main effects for RPE [$F(1,13) = 27.491$, $p < 0.001$, partial $\eta^2 = 0.163$, Mauchly's test of sphericity $p = 0.200$] and FS [$F(1,13) = 36.388$, $p < 0.001$, partial $\eta^2 = 0.189$, Mauchly's test of sphericity $p = 0.345$] scores, with significant group × time interactions for both (RPE: [$F(1,13) = 16.392$, $p < 0.001$, partial $\eta^2 = 0.144$]; FS: [$F(1,13) = 18.919$, $p < 0.001$, partial $\eta^2 = 0.153$]. Student's independent *t*-tests revealed that RPE session averages were significantly greater for HIIT1 than HIIT3 (HIIT1: 6.3 ± 2.1, HIIT3: 3.2 ± 2.3, $p < 0.001$); FS session averages, on the other hand, were significantly lower for HIIT1 than HIIT3 (HIIT1: -0.2 ± 1.4, HIIT3: 3.5 ± 0.6, $p < 0.001$).

The second part of the analysis involved comparison between the first and last sessions to identify changes across the six-week period. As with the cardiorespiratory fitness variables, Student's independent *t*-tests were used to assess differences between the beginning and end of the intervention. Neither RPE nor FS scores changed across the intervention in the HIIT3 group (RPE $p = 0.102$, FS $p = 0.249$), but the HIIT1 group experienced decreases in RPE (-2.4 ± 0.4, $p = 0.02$) and increases in FS scores (+3.6 ± 0.8, $p = 0.008$). RPE and FS scores across the intervention are given in Figures 8 and 9, respectively. Also, within-session RPE and FS scores (i.e., scores on the first repetition vs. the last repetition) were not different in the HIIT1 group ($p = 0.09$), whereas RPE increased (4.7 ± 1.2 to 8.8 ± 2.6, $p = 0.01$) and FS score decreased (1.9 ± 0.9 to -2.3 ± 1.6, $p = 0.04$). Overall changes in RPE and FS are shown in Table 5.

Figure 8. Changes in RPE across the intervention

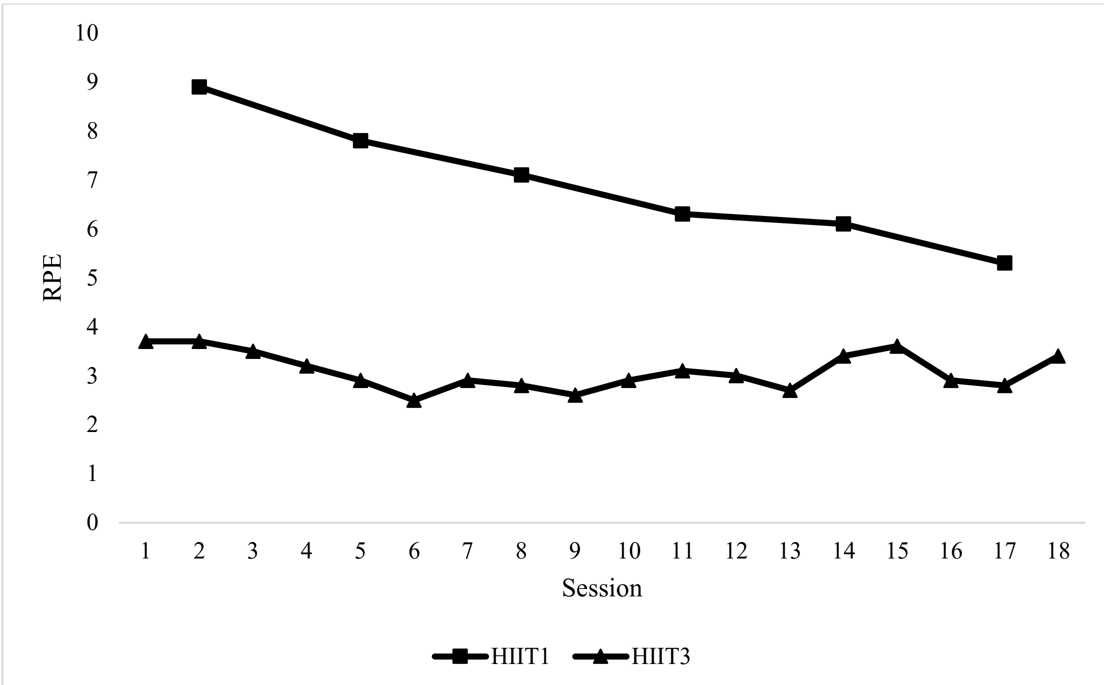


Figure 9. Changes in FS scores across the intervention

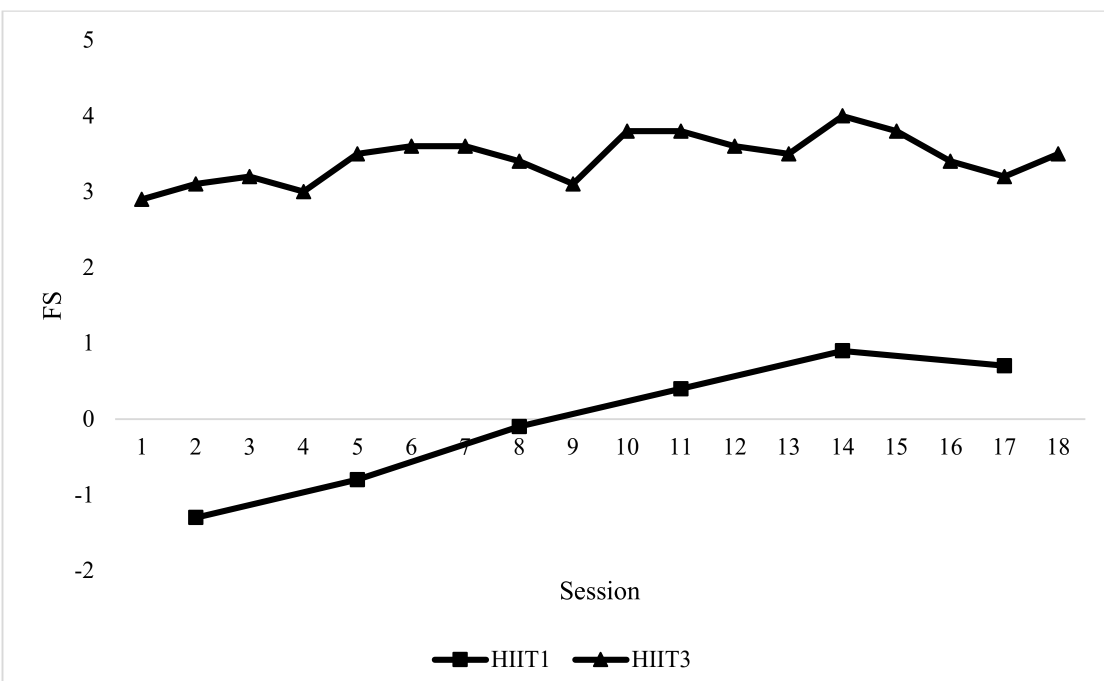


Table 5

Comparison of changes in psychological metrics

	First Session		Last Session	
	HIIT1 (*n* = 7)	HIIT3 (*n* = 7)	HIIT1 (*n* = 7)	HIIT3 (*n* = 7)
RPE	8.9 ± 1.5	3.7 ± 2.0†	5.3 ± 2.8*	3.4 ± 1.4†
FS	-1.3 ± 0.4	2.9 ± 1.0†	0.7 ± 1.8*	3.8 ± 2.3†

* Significantly different from pre-intervention value at $p < 0.05$.
† Significantly different from HIIT1 at $p < 0.05$.
RPE, rating of perceived exertion, FS, Feeling Scale.

Discussion

Cardiorespiratory Fitness

The present study compared two energy expenditure-matched interval training protocols, with different weekly training frequencies, on CRF and affective responses in insufficiently active college students. Significant increases in $\dot{V}O_{2max}$ were observed in both groups following the intervention period, as well as a significant time-group interaction. The percentage change in the HIIT3 group (+12%) was significantly larger than that of the HIIT1 group (+7%) (Table 3). Surprisingly, RE decreased in Stages 1 and 2 of the GXT for both groups, with a greater decrement in the HIIT1 group. These findings are in line with our hypotheses, which were that the HIIT1 group would experience greater improvements in CRF and RE compared to the HIIT3 group.

The role of intensity in modulating CRF improvements has already been investigated numerous times (Matsuo et al., 2014). Yet, to our knowledge, no studies have examined the specific role of weekly IT frequency on CRF. More recent studies on exercise frequency have explored a population known as “weekend warriors,” defined as those who perform one or two prolonged bouts of exercise per week which collectively meet exercise guidelines (i.e., energy expenditure ≥1,000 kcal/week; Lee et al., 2004). However, these studies have been primarily epidemiological in nature (Lee et al., 2004; O'Driscoll et al., 2017), with health rather than fitness outcomes as the variables of interest. Positively, O'Driscoll and colleagues (2017) reported significantly lower risks for all-cause and CVD mortality in "weekend warriors" compared to sedentary individuals. However, Lee and coworkers (2004) found that "weekend warriors" were at a greater risk compared to those in the regularly active group. Hence, although these findings are not directly related to CRF, it appears that there may be a positive relationship between exercise frequency and physiological changes.

Our hypothesis that the HIIT3 group would exceed the HIIT1 group in CRF improvements also stems from the idea that exercise presents a physiological disturbance to the body and its systems that provokes both acute and chronic responses (Hawley, 2002; Hawley et al., 2014). With a greater exercise frequency comes more frequent homeostatic disturbances, which could perhaps be seen as more "opportunities" for the biological systems to respond and adapt. In the present study, the HIIT1 group exercised once per week, meaning that six days of the week were presumably spent not doing any aerobic exercise. Admittedly, we did not formally assess daily PA levels by means of a survey or other validated tool, but qualitative feedback indicated that the participants did not do any organized aerobic PA outside of the intervention. We predicted that the cellular signaling pathways for physiological adaptation associated with exercise training would be attenuated by the long gap in intervention sessions compared to that of the thrice-per-week HIIT3 group, even though the weekly energy expenditure was matched. The HIIT3 group improved in CRF by 12.8% (partial $\eta^2 = 0.109$), which was significantly greater than the 8.2%

(partial $\eta^2 = 0.063$) increase observed in the HIIT1 group. Our findings that both CRF and RE were superiorly improved in the HIIT3 group are in agreement with this prediction.

IT can be organized into many configurations of varying duration and intensity, making it a flexible mode of exercise (Gibala & Jones, 2013). A number of “standard” IT protocols have been created, including the 4 x 4 protocol (typically classified as HIIT) and Wingate protocol (typically classified as SIT). In a review concerning the different configurations of SIT, Vollaard and Metcalfe (2017) argue that, although classic SIT is purported to help solve the “perceived lack of time” barrier, the training sessions can still be somewhat lengthy. Therefore, combined with the increased intensity, classic SIT may not be a good alternative to MICT. The authors proposed that a decreased number and duration of intervals can result in health and fitness improvements similar to classic SIT. The authors contend that this may serve as a more potent solution to exercise barriers in the general population. In this study, both groups performed the same weekly exercise volume at the same relative intensity, but with variation in weekly frequency, number of repetitions, and duration of repetitions. The HIIT1 protocol more closely mimics the typical HIIT configurations, whereas the HIIT3 protocol is more similar to SIT configurations. The fact that the HIIT3 group experienced greater improvements in CRF may indicate that fewer and shorter intervals are at least equivalent, if not superior, to more and longer intervals. However, because there were group discrepancies in both weekly frequency and interval configuration, it is difficult to identify the role of each factor individually.

RE is a measure of the ratio of work done while running to the energy expended (Barnes & Kilding, 2015b), and can be affected by cardiorespiratory, biomechanical, neuromuscular, and metabolic responses and adaptations (Barnes & Kilding, 2015a). Traditionally, RE has been assessed within time intervals of 3 to 15 minutes for various submaximal intensities (Barnes & Kilding, 2015b), although intervals as short as 30 seconds have also been employed (Barnes et al., 2013). Analysis of previous GXTs performed in our lab have demonstrated that steady-state – indicated by a plateau in the $\dot{V}O_2$ curve – is generally reached after roughly one and a half minutes of a submaximal stage, leaving an additional one and a half minutes of plateaued $\dot{V}O_2$ values. A plateau has been defined generally as either a maximum difference between consecutive values in a time interval (e.g., ≤2 mL/kg/min, given by Astorino [2009]) or by the slope of the $\dot{V}O_2$ curve in the latter portion of a GXT (Yoon et al., 2007). We decided to use the consecutive values method with a maximum $\dot{V}O_2$ difference of ≤2 mL/kg/min and 15-second recordings since that has been used in our lab previously. This use of 15-second recordings is supported by Astorino (2009), who demonstrated that a $\dot{V}O_2$ plateau was more consistently reached with interval times shorter than one minute. Hence, with presumably one and a half minutes at steady-state, and 15-second $\dot{V}O_2$ recordings, six $\dot{V}O_2$ values can be used for RE analysis. However, we observed from previous GXTs in our lab that sometimes it is not the case that six consecutive plateaued values are reached. To account for this, we decided to reduce the necessary number of 15-second intervals to five, resulting in a one minute and fifteen-second analysis period at the end of the GXT. This specific value of 1:15 did not appear in any studies the researchers found on running economy, however, given the apparent flexibility of running economy analysis time intervals (Barnes & Kilding, 2015b), we felt that this value would allow us to obtain accurate and consistent RE data while accounting for those with less time at steady state.

One surprising finding of this study is that RE decreased in both groups for stages 1 and 2 of the GXT. Therefore, another consideration with the assessment of $\dot{V}O_2$ is the possibility of mechanical error. The instrument used for this study in question, the ParvoMedics TrueOne 2400, has been validated as an accurate and reliable computerized metabolic system, even compared to the criterion Douglas bag method (Crouter et al., 2006). In fact, this system has been utilized as a gold standard to compare against more recent technological advancements (McClung et al., 2023). Regardless, Howley and coworkers (1995) estimated that around 10% of $\dot{V}O_2$ measurement error is related to technical issues, which is supported by McClung and colleagues (2023), who give a range of 4%-14% error rate for $\dot{V}O_2$ assessment. Howley and others (1995) did indicate that variations in measurement can be reduced with shorter sampling intervals (i.e., an average across 15-20 seconds), which is what we utilized for this study.

Other problems with the system could arise from operator error or neglect. However, prior to conducting the study we ensured that all worn parts, including drying lines and drying loops, were replaced and that calibration was properly completed before every test. Specifically, change values in gas and Flowmeter calibration were set at no more than ±1%. The Study Coordinator supervised every calibration to make sure that it was done correctly. Additionally, external equipment such as mask supplies and gas tubes were thoroughly cleaned prior to usage, tasks such as placement of the mask on the participants' heads were done carefully to avoid slippage and potential breath leaks. Thus, it is mysterious as to why oxygen consumption tended to increase for a given stage in the post-intervention test compared to pre-intervention.One possibility is the environmental changes that occurred with the seasonal shifts. Chen et al. (2020) indicated that environmental factors, such as air composition, can affect accuracy in metabolic measurement systems such as the ventilated hood method. Woods and colleagues (2016) add to this by saying that even ambient noise and lighting can affect results. It is possible that the volatile weather changes that occur in Eastern Washington in the late winter and early spring may have influenced the metabolic cart's ability to analyze gas exchange. While these factors are largely out of our control, we minimized this type of error by calibrating the system with the same equipment each time, regularly maintaining the equipment, and requiring sufficient familiarization with the protocol before contribution. Another possible source of error is an improperly placed mask that was not reported by the participant. To remedy this, we closely visually monitored the position of the mask to ensure there was minimal movement around the face throughout the GXT, and we inquired about the fit and tightness at the end of every stage. Currently, it is unclear why the degree of RE decrease was so pronounced in both groups; it is also worth mentioning that our sample, being small, may not be entirely representative of the UCS population.

Affective Responses

We observed psychological responses during the intervention in favor of the HIIT3 group. When scores were averaged across the intervention, the HIIT3 group had lower RPE scores (Figure 2) and higher FS scores (Figure 3) compared to the HIIT1 group (RPE – HIIT1: 6.3 ± 2.1, HIIT3: 3.2 ± 2.3, $p < 0.001$; FS – HIIT1L: -0.2 ± 1.4, HIIT3: 3.5 ± 0.6, $p < 0.001$) ; this also was in line with our hypothesis. Due to the untrained nature of the sample, we predicted that the dramatic increase in session volume of PA would not be very tolerable in the HIIT1 group. Qualitatively speaking, the participants in this group often struggled to get through each session, especially in the beginning of the intervention. Furthermore, adherence to the intervention was lower compared to the HIIT3 group, since all three of the participants who withdrew from the study were in the HIIT1 group. Thus, this particular IT protocol consisting of a single session of aerobic exercise equivalent to the PA guideline may not be suitable for insufficiently active college students.

One intriguing finding is that, in terms of intervention-wide trends, affective responses improved across the intervention only in the HIIT1 group, indicated by decreases in RPE scores (-2.4 ± 0.4, $p = 0.02$) and increases in FS scores (+3.6 ± 0.8, $p = 0.008$) across the six sessions. The participants in this group reported that each session was easier than the last, and most continued to improve in their adaptive responses throughout the six weeks. This is likely due to the fact that, since the participants were not used to such a high single-session volume of exercise, the first intervention session would be physiologically and psychologically more stressful compared to the HIIT3 group. As the HIIT1 group participants continued in the intervention, it made sense that there would be a steeper rate of adaptation as a result of the harsher baseline. However, the steeper rate of improvement may not exonerate this particular IT protocol, as most participants in this group still felt that they overall did not enjoy this type of aerobic PA. The HIIT3 group, although not experiencing a significant improvement in either psychological metric, reported an overall greater desire to continue IT following completion of the study.

Exercise intensities exceeding the anaerobic threshold are related to negative affective responses (Ekkekakis, 2003; Ekkekakis et al., 2011). Interval training by nature brings the body above this threshold, thereby challenging the body's physiological systems and worsening affect scores. However, studies have shown that IT may still be more enjoyable than (Bartlett et al., 2011; Oliveira et al., 2018; Thum et al., 2017) and preferable to (Jung et al., 2014) MICT in various populations. In this study, one "HIIT-like" protocol and one "SIT-like" protocol were compared on RPE and FS scores during the exercise intervention. The HIIT1 protocol, although being an IT configuration, was characterized by a very high session volume of exercise (~1 hour). Comparatively, the HIIT3 group's sessions were only about 20 minutes in length. Therefore, the duration of an exercise session may be an important modulator of affect. This is in line with the commentary of Vollaard and Metcalfe (2017), who argued that a lower volume of IT, accomplished by fewer and shorter intervals, can be just as effective as classic SIT in improving CRF and be more psychologically sustainable.

Strengths and Limitations

This study is strengthened by its use of blocked concealed randomization and relative intensity for the exercise interventions. The randomization scheme used (Doig & Simpson, 2005) has been widely cited and is therefore a valid tool for ensuring proper group sampling. This method was also useful in its ability to stratify by different groups. In this case, male and female college students could be allocated separately to account for sex differences in physiological adaptation to exercise training (Ansdell et al., 2020). The use of relative over absolute intensity is common across virtually all IT studies and is important because it applies the same stimulus to the participants equally. Within this, unfortunately, there is an inherent limitation, as the relative intensity was determined by performance on an objectively-measured GXT. Should a participant perform worse than their true fitness capacity, that would result in a relative intensity that is lower than that of other participants, potentially skewing the results. As an alternative to this, Eston and coworkers (2012) proposed the usage of a perceptually regulated GXT that correlates HR and RPE with $\dot{V}O_{2max}$. Their study also indicated that familiarity with an exercise protocol, or exercise in general, can significantly affect CRF assessment. While traditional GXT has been used in untrained and sedentary populations in the past, it may be that more subjective tools for assessing CRF are superior in these individuals. It also may be that this problem is avoided with a large enough sample size, as there would potentially be regression to the mean. Because we acquired the necessary sample size, it is expected that this problem was avoided. Nevertheless, it may be more appropriate to use more submaximal measures, in at-risk populations such as the non-athletic, elderly, or patient (Eston et al., 2012).

Other limitations of this study include a relatively low sample size, lack of a method to track PA across the intervention, and non-specificity of the intervention to the GXT. While studies with sample sizes as low as eight people have been published (Bartlett et al., 2011), it is likely that more participants are needed to detect a true difference. Additionally, although participants were told to refrain from aerobic PA apart from the intervention, this study did not use logs or other means to track PA throughout. Participant self-report indicated that the participants fulfilled this requirement, but a surveillance system may be needed to confirm this in future studies. Finally, the intervention exercise was non-specific to the GXT; the former was entirely flat, but the latter had dramatic increases in incline. In fact, many of the participants reported feeling that their intolerance of the incline was the limiting factor in their post-intervention GXT performance. Porszasz and others (2003) in their paper point out that increases in treadmill speed mainly modify the speed and efficiency at which the legs move, whereas early increases in incline raise the initial metabolic cost. Hence, even though the objective energy expenditure of two protocols (e.g., 8 mph, 0% incline vs. 6 mph, 5% incline) may be equivalent, both perception and performance can be influenced by the factors of speed and incline. Specificity, as a primary attribute of exercise training (Fahey et al., 2019), applies not just to training but to performance as well. For maximal performance, it is necessary for there to be translation from intervention to GXT. Therefore, future studies using treadmill running as the modality should develop or utilize an existing protocol which reflects the nature of the intervention exercise.

Applications

It has been shown that not enough UCS are completing the recommended PA volume for good health (Centers for Disease Control and Prevention, 2022), and that perceived lack of time is a major barrier in the way of solving this issue (Daskapan et al., 2006). This two-fold problem poses a difficult question: How can UCS get the required PA with their busy academic and occupational schedules, and can they do so in a psychologically sustainable way? In response to this query, several studies have indicated that a lower time commitment may be key in exercise program adherence (Oliveira et al., 2018; Thum et al., 2017). Other work (e.g., Jung et al., 2014) has indicated that IT may be preferable to MICT in various populations. However, appropriate IT programming requires that the protocol not be too fatiguing, as may be the case with protocols characterized by longer and more intervals (Vollaard & Metcalfe, 2017). This study compared two IT configurations: one with a relatively higher exercise volume/session ratio, and with a lower ratio. The results demonstrated adaptive affective responses in the group with the relatively lower volume, along with superior improvements in CRF. This supports the recent push in IT research to taper exercise volume based on the notion that physiological adaptation may not be sacrificed (Vollaard & Metcalfe, 2017). Increasing PA levels in the general population is crucial for the preservation of public health, and the low-volume IT protocol utilized in this study, as an example, may be a strong means of doing so.

Conclusion

In summary, our hypotheses were supported by the greater increases in CRF and running economy, as well as the more adaptive affective responses, in the HIIT3 group compared with the HIIT1 group. The two groups were matched on weekly exercise volume and relative intensity.

These findings suggest that exercise frequency within the context of treadmill-based IT may play a role in mediating physiological adaptation and psychological experiences and may at least suggest a positive relationship between the weekly number of days doing aerobic exercise and improvements in CRF. While it is unclear whether these results can be translated to other exercise modalities such as cycling and rowing, these results may have valuable implications for running. Additionally, traditional IT protocols characterized by a greater number of longer repetitions may be superseded by protocols characterized by fewer and shorter repetitions in terms of affect and adherence. Future investigations are needed to confirm these findings and identify mechanisms underlying the discrepancy in physiological and psychological responses.

Disclosure Statement

The authors declare that they have no conflict of interest.

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CHAPTER FIVE: CONCLUSION

This thesis study aimed to identify the effects of different frequencies of IT on CRF and affective responses in insufficiently active UCS. An expansive body of literature has elucidated the role of intensity, interval duration, and other factors in mediating fitness adaptations, yet little is known about the role of weekly frequency. To our knowledge, this is the first study specifically investigating weekly IT frequency. Here, frequencies of once per week and thrice per week were utilized, with both groups performing a weekly exercise volume equivalent to the guideline for aerobic PA. The results of the study indicate that a thrice-per-week IT intervention was more effective than a once-per-week intervention, with a matched exercise volume, at increasing CRF. Furthermore, three weekly sessions of IT improved running economy compared to one weekly session. Additionally, one session per week was more psychologically sustainable, as indicated by lower RPE and higher FS scores.

The present study was potentially limited by its relatively low sample size, lack of experimental control with regard to PA tracking across the intervention, and non-specificity to the pre- and post-intervention GXT. While these limitations exist, the present study adds to the body of PA and IT literature by identifying a potential modulatory effect of weekly frequency on CRF and affective responses among UCS. This study is strengthened by its use of blocked concealed randomization and relative intensity for the exercise interventions. Future studies should aim to recruit more participants, identify and implement methods to monitor PA, and match the GXT to the exercise intervention. Other investigations could examine the role of IT frequency in other populations, such as older adults.

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APPENDIX

APPENDIX A: Washington State University IRB Approval

Christopher and William,

Please see the attached for the approved files for use and stamped consent form associated with the approved IRB # 20261-001, "Effects of blocked and periodic interval training on cardiorespiratory fitness and affective responses among college students."

Additionally, these files can be accessed and downloaded via the MyResearch database by following the instructions and link outlined in the approval notice.

Best regards,

JULIE ANNE SCHEID
HUMAN SUBJECTS RESEARCH COMPLIANCE SPECIALIST
Human Research Protection Program-ORA
Washington State University
Office: irb@wsu.edu
Email: Julie.Scheid@wsu.edu

From: irb@wsu.edu <irb@wsu.edu>
Sent: Thursday, December 21, 2023 3:01 PM
To: Scheid, Julie <julie.scheid@wsu.edu>
Subject: IRB Approved New: IRB Number #20261-001
Importance: High

MEMORANDUM

TO: Christopher Connolly

FROM: Coordinator - Julie Anne Scheid (for) Chris Barry, Ph.D, and Andrea Lazarus, Ph.D, Chairs, WSU Institutional Review Board (3143)

DATE: 12/21/2023

SUBJECT: Approved Human Subjects New, IRB Number #20261-001

FWA: Washington State University is covered under Human Subjects Assurance Number FWA00002946 which is on file with the Office for Human Research Protections.

FUNDING INFORMATION:
ORSO No.: N/A
Agency: N/A

Dear Christopher Connolly:

Your human subjects application and additional information provided for the proposal titled "Effects of blocked and periodic interval training on cardiorespiratory fitness and affective responses among college students", IRB 20261-001 was reviewed for the protection of the participants in the study. Based on the information reviewed, the WSU Institutional Review Board approved your protocol on 12/21/2023.

Your study has been determined to be of minimal risk and also meet the regulatory guidelines for Expedited review category at:

45 CFR 46.110(b)(4) - Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves.

45 CFR 46.110(b)(6) - Collection of data from voice, video, digital, or image recordings made for research purposes other than transcription.

45 CFR 46.110(b)(7) - Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

The study is approved for enrollment of:
30 total participants; 2 groups of 15 people, all aged between 18-24 years.

Continuing review of this protocol is not required, per 45 CFR 46.109(f)(1). The stamp on the consent document will remain valid until the project is closed and will not require re-stamping unless changes are made.

Materials reviewed and approved as of 12/21/2023 include:
20261-001-Connolly-NP-Yaku Human Subject Non-Exempt Application
20261-001-Connolly-NP-Yaku Addendum Confidentiality Agreement
20261-001-Connolly-NP-Yaku Addendum FDA
20261-001-Connolly-NP-YYAKU Final
20261-001-Connolly-NP-aku Recruitment Materials
20261-001-Connolly-NP-Yaku Informed Consent Form STAMPED
20261-001-Connolly-NP-WHOQOL-BREF IRB Submission
20261-001-Connolly-NP-2022 PAR-Q+
20261-001-Connolly-NP-Feeling Scale
20261-001-Connolly-NP-Physiological Variable Data Sheet
20261-001-Connolly-NP-Yaku Debriefing Form

Please visit https://myresearch.wsu.edu/IRB.aspx?HumanActivityID=70105 to download the approved materials as a PDF file by clicking on "Image" in the "uploading approved materials" line in the activity log.

The following conditions apply to the project:

a) Use only the approved study materials (IRB stamped consent form with a valid date) and procedures in your research.

b) All participants on this project must sign the appropriate approved consent forms stamped by IRB unless a waiver has been granted.

c) In accordance with federal regulations, this approval letter and a copy of the approved protocol must be kept with any copies of signed consent forms by the principal investigator for THREE years after completion of the project. HIPAA forms must be retained for SIX years. HIPAA forms must be retained for TEN years if the data are research and a medical record. Any research records related to a federally funded grant or contract are recommended to be kept 6 years after completion/closeout of the grant, and 3 years after completion of the research protocol at a minimum.

d) IRB approval indicates that the WSU IRB has determined your protocol is compliant with federal and state regulations and WSU policies governing human subjects research and is appropriately designed to protect the rights and welfare of the participants enrolled.

e) You will need to submit an Annual Check-in/Closeout form. This form is available at https://irb.wsu.edu/forms/ and is next due 12/21/24.

f) Upon completion of the project, please submit an Annual Check-in/Closeout form (https://irb.wsu.edu/forms/) to officially close the project.

g) Any unanticipated or adverse event encountered that poses actual or potential risks to participants must be reported to the IRB in writing immediately with the HRPP Reporting form (https://irb.wsu.edu/forms/).

h) Procedural changes, amendments to the protocol and consent forms revisions must be approved by the IRB before implementation with an Amendment Request form (https://irb.wsu.edu/forms/).

i) IRB approval does not supersede required compliance with any Federal, State or Local laws or regulations or contractual terms (including Material Transfer Agreements and Data Use Agreements), nor the policies and guidelines of any funding agency or Washington State University. The PI is ultimately responsible for conveying to the IRB any contractual, legal or funding agency requirement related to their IRB protocol to ensure that IRB approval is consistent with these requirements. IRB approval does not constitute approval by other oversight bodies (including IBC, RSC and IACUC), the PI is ultimately responsible for securing any other approvals required to conduct the research (e.g., oversight committee, agency/institutional, and sponsor approvals).

j) In the absence of a cooperative agreement (reliance agreement), review and approval of this protocol does not extend to non-WSU collaborators. For more information about collaborative agreements, please visit (https://irb.wsu.edu/external-collaborations/).

If you have questions, please contact the Human Research Protection Program at irb@wsu.edu.

Thank You,

Julie Anne Scheid

Human Subjects Research Compliance Specialist
Human Research Protection Program
Office of Research Assurances
Washington State University

On behalf of the Human Research Protection Program (HRPP) and WSU Institutional Review Board (IRB)

APPENDIX B: Confidentiality Agreement Form Addendum

WASHINGTON STATE UNIVERSITY

Human Research Protection Program (HRPP) - Office of Research Assurances
PO Box 643143 Neil Hall 427 Pullman, WA 99164-3143
Telephone: (509)335-7646 Email: irb@wsu.edu Web site: www.irb.wsu.edu

DO NOT DELETE OR ALTER ANY PART OF THIS FORM

Principal Investigator:	Dr. Christopher P. Connolly
Study Title:	Effects of blocked and periodic interval training on cardiorespiratory fitness and affective responses among college students
IRB #:	

ADDENDUM: CONFIDENTIALITY AGREEMENT FORM

By signing below, you agree to the to the following:

1. I understand that I will have access to research data for transcription and/or data entry and management that is strictly confidential. The individuals who participated in this research project have revealed the information on good faith that the information would remain strictly confidential.
2. I agree to the following:
   - Keep all the research information shared with me confidential by not discussing or sharing the research information in any form or format (e.g., recordings, transcripts, data sets) with anyone other than the researcher(s).
   - Keep all research information in any form or format (e.g., recordings, transcripts, data sets) secure while it is in my possession.
   - Return all research information in any form or format (e.g., recordings, transcripts, data sets) to the researcher(s) when I have completed the research tasks.
   - After consulting with researcher(s), erase or destroy all research information in any form or format regarding this research project that is not returnable to the researcher(s) as described in the non-exempt application.

Any violation of this agreement would constitute a serious breach of ethical standards, and I pledge not to do so.

This study has been reviewed and approved for human subject participation by WSU IRB. If you have questions or concerns about this study, please contact the principal investigator.

Name: Will Yaku
Date: September 22nd, 2023

Version 10/01/21 Page 1 of 2

APPENDIX C: FDA Addendum

WASHINGTON STATE UNIVERSITY

Human Research Protection Program (HRPP) - Office of Research Assurances
PO Box 643143 Neil Hall 427 Pullman, WA 99164-3143
Telephone: (509)335-7646 Email: irb@wsu.edu Web site: www.irb.wsu.edu

DO NOT DELETE OR ALTER ANY PART OF THIS FORM

Principal Investigator:	Dr. Christopher P. Connolly
Study Title:	Effects of blocked and periodic interval training on cardiorespiratory fitness and affective responses among college students
IRB #:	

ADDENDUM: FDA - DRUGS, DEVICES, & BIOLOGICS/ COLLECTION OF BIOLOGICAL SPECIMENS

Instructions:

- Read the guidance provided below before answering the questions.
- Do not leave questions/[REQUIRED FIELD] blank; write or check "**N/A**" if not applicable.

Guidance:

- **Investigational new drugs (IND):** Defined as a new drug or biological drug that is used in a clinical investigation. The term also includes a biological product that is used in vitro for diagnostic purposes. The terms ''investigational drug'' and ''investigational new drug'' are deemed to be synonymous for purposes of determining whether a Notice of Claimed Investigational Exemption for a New Drug must be submitted to the US Food and Drug Administration (FDA).
- **Medical devices:** Defined, in part, as any health care product that does not achieve its primary intended purposes by chemical action or by being metabolized. Medical devices include, among other things, surgical lasers, wheelchairs, sutures, pacemakers, vascular grafts, intraocular lenses, and orthopedic pins. Medical devices also include diagnostic aids such as reagents and test kits for in vitro diagnosis (IVD) of disease and other medical conditions such as pregnancy.

  Further FDA guidance on investigational drugs, other drugs, and devices can be found at: http://www.fda.gov/

- **Blood, tissue, bodily fluids, or other biological specimens:** If you are using blood, tissue, bodily fluids or other biological specimens, you may also need to seek Institutional Biosafety Approval before you begin the research. Contact the WSU Biosafety Coordinator at 509-335-7195 or ibc@wsu.edu.

SECTION 1. RESEARCH UTILIZING INVESTIGATIONAL NEW DRUGS (IND)

1. **Does this research utilize investigational new drugs (IND)?**
   ☒ **No**
   ☐ **Yes**
   If yes, complete (a-f).

   a. **Provide the name and source of the drug(s):** N/A

   b. **Provide available toxicity data on the drug(s):** N/A

   c. **Describe previous studies on humans:** N/A

   d. **Provide any available literature for review:** N/A

   e. **If this is a Phase I study, please provide available reports of the animal studies:** N/A

   f. **Address whether this study will have a Data Safety Monitoring Board in place:** N/A

SECTION 2. RESEARCH UTILIZING BIOLOGICS (NON-IND & OTHER DRUGS)

2. **Does this research utilize Biologics (non-IND & other drugs)?**
   ☒ **No**
   ☐ **Yes**
   If yes, complete (a-g).

   a. **Provide the name and source of the drug(s):** N/A

   b. **Describe if the drug(s) is FDA approved and its classification (e.g., over the counter/prescription):** N/A

   c. **Describe the planned dosage of the drug(s):** N/A

   d. **Provide any relevant toxicity data on the drug(s):** N/A

   e. **Describe the relevant previous studies on humans in relation to the proposed research and this drug:** N/A

   f. **Provide any available literature for review in relation to the proposed research and this drug:** N/A

   g. **Address whether this study will have a data safety monitoring board in place:** N/A

SECTION 3. RESEARCH UTILIZING INVESTIGATIONAL DEVICES (IDE)

3. **Does this research utilize investigational devices (IDE)?**
   ☒ **No**
   ☐ **Yes**
   If yes, complete (a-d).

   a. **Provide the name and source of the device(s):** N/A

   b. **Provide the current FDA status of the device(s) and IDE number:** N/A

   c. **Address the associated risks of the device:** N/A

   d. **Clarify the risk level assignment as determined by the sponsor (e.g., non-significant or significant risk):** N/A

SECTION 4. BIOSPECIMENS

4. **Does this research utilize the collection of blood, tissue, bodily fluids, or other biological specimens?**
   ☐ **No**
   ☒ **Yes**
   If yes, complete (a-c).

   a. **Will any of the blood, tissue, bodily fluids, or other biological specimens be used for genetic testing? If so, please describe:** The blood samples acquired for this study will not be used for genetic testing; they will be used solely for assessing the body's response to exercise at gradually increasing intensities. The blood samples will be disposed of immediately in a biohazard waste bag following analysis. This disposal process is in accordance with the guidelines set by the Washington State University Institutional Biosafety Committee. These samples will not be used again for any purpose.

   b. **Will your studies involve the analysis of genes known to be implicated in the disorder(s), syndrome(s) or condition(s) you are studying? If so, please describe what genes you will be studying:** This study will not involve gene analysis, therefore N/A.

   c. **Will your studies involve finding the gene(s) that may cause the condition or genetic markers that co-segregate with this condition? If so, please describe:** N/A

APPENDIX D: IRB-Approved Recruitment Flyer

College of Education
Washington State University

This study (IRB# 20261) has been approved by the WSU Human Research Protection Program

EPPL
Exercise Physiology & Performance Laboratory

JOIN OUR STUDY

BE PHYSICALLY ACTIVE

Overview:
-Participate in **six weeks** of **1 on 1** exercise sessions on a treadmill
-Meet 2018 physical activity guidelines from the U.S. Department of Health and Human Services
-Participants will complete an 11-point feeling scale after each session
-Will receive **free** pre and post intervention **VO2 max testing**
-Participants will recieve a **$50 giftcard** as compensation

Does blocked or periodic exercise of the same volume produce more adaptions?

Elligble participants are:
-College students
-Lightly active
-Willing to engage in structured cardio
-Not taking any medication
-No outstanding medical conditions
-Not pregnant

william.yaku@wsu.edu
(206) 637-9911

Want to participate or have any Questions? Scan the QR code to the right or contact us above

APPENDIX E: IRB-Approved Recruitment Script

Improve your fitness! Meet exercise guidelines!

Come to the Exercise Physiology and Performance Laboratory (located in Smith Gym 70) to engage in running interval training on the treadmill to improve your cardiorespiratory fitness and meet physical activity guidelines! This is a six-week intervention with pre- and post-intervention testing in the weeks immediately prior to and after the intervention, respectively. Within the exercise intervention, you will perform a weekly volume of exercise that exactly matches the physical activity guidelines set by the U.S. Department of Health and Human Services. Participation in this study will likely improve your cardiorespiratory fitness and may help you to enjoy aerobic exercise more than you expected. If you feel like you are not doing enough cardio, come participate in this study!

Requirements:

- Doing less than 150 minutes per week of moderate-intensity aerobic exercise
- Between 18-24 years of age
- Not taking any prescription medication
- No chronic medical conditions (e.g., cardiovascular disease, respiratory issues)

You may not participate in this study if:

- You are meeting physical activity guidelines (≥150 minutes per week of moderate-intensity aerobic exercise)
- You are under 18 or above 24 years of age
- You are taking prescription medication
- You have an existing chronic medical condition (such as those listed above)
- You are pregnant

For any questions, please contact Will Yaku at will.yaku@wsu.edu, or Dr. Christopher Connolly at c.connolly@wsu.edu

Social Media Script

*The script for posting on the WSU Exercise Physiology and Performance Laboratory were identical to the classroom announcement script above. The picture used for the post were identical to the recruitment flyers posted around campus.

APPENDIX F: IRB-Approved Informed Consent Form

WASHINGTON STATE UNIVERSITY
Department of Kinesiology and Educational Psychology

Research Study Consent Form

Study Title: Effects of blocked and periodic interval training on cardiorespiratory fitness and affective responses among college students

Researchers:

Principal Investigator: Dr. Christopher Connolly, Associate Professor, Washington State University, (509) 335-7605

Co-Investigator/Study Coordinator: Will Yaku, M.S. Student, Washington State University, (206) 637-9911

Emergency Phone Number: (509) 332-2521 (WSU Police)

What you should know

You are being asked to take part in a research study carried out by Dr. Christopher Connolly and Will Yaku. This form explains the research study and your part in it if you decide to join the study. Please read the form carefully, taking as much time as you need. Contact the researcher at c.connolly@wsu.edu to explain anything you don't understand. You may decide not to join the study. If you join the study, you can change your mind later and quit at any time. You may refuse any question, test, or procedure. There will be no penalty or loss of services or benefits if you decide to not take part in the study or quit later. This study has been reviewed and approved for human subject participation by the Washington State University Institutional Review Board.

What is the purpose of this study?

This research study is being done primarily to determine how the weekly exercise frequency affects improvements in aerobic fitness in college students who are not meeting physical activity guidelines. The secondary purpose of the study is to identify whether a higher or lower exercise session volume is psychologically more positive and sustainable for insufficiently active college students. You are being asked to take part because you are not currently meeting those physical activity guidelines and are seeking to do so. You will not be allowed to participate in this study if you (1) are under 18 or over 24 years of age, (2) are currently meeting the 2018 *Physical Activity Guidelines for Americans*, (3) have a medication prescription, (4) are deemed unable to participate in vigorous exercise due to presence of a chronic disease or medical condition, or (5) are pregnant.

What will I be asked to do if I am in this study?

You will first be assessed to see whether you can participate. This will be done through (1) the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and (2) the World Health Organization Quality of Life Questionnaire, Brief Edition (WHOQOL-BREF). The PAR-Q+ will ask questions about any existing medical conditions, such as cardiovascular disease or respiratory issues, which may prevent you from engaging in high-intensity exercise. The WHOQOL-BREF will assess your overall quality of life to determine whether the introduction of high-intensity exercise into your life will be harmful rather than beneficial. You will also be verbally asked about your physical activity levels to identify whether you are or are not meeting aerobic physical activity guidelines. These guidelines are to partake in either 150 minutes per week of moderate-intensity activity, 75 minutes per week of vigorous-intensity activity, or an equivalent combination. Once you have been approved for participation, you will then be asked to provide informed consent to participate in this study. You will complete a pre-intervention graded exercise test, which involves gradually increasing intensities of exercise until volitional exhaustion; this is designed to directly assess cardiorespiratory fitness. Height and weight will be determined prior to the exercise test. The assessment of these factors will contribute to the calculation of your cardiorespiratory fitness. Heart rate, blood pressure, and blood lactate concentration will be measured to monitor your body's response to high-intensity exercise. Heart rate and blood pressure will be measured during every rest period and before and after the test, while blood lactate measurements will be taken immediately before and after the test only. Blood lactate will be measured using a finger prick tool and blood lactate analyzer. The amount of pain incurred by the finger prick tool is almost unnoticeable, and only a small drop of blood will be obtained for analysis. These instruments will be operated by trained laboratory staff; up to this point, no incidents involving excessive pain or bleeding have occurred. For the measurement of oxygen consumption, which is the major purpose of the test, you will wear a mask attached to a tube which feeds into a metabolic measurement system. To hold the mask on your face, a network of head straps will be placed in a way that is firm but not uncomfortable. Running with the mask on may feel unfamiliar but will not inhibit your ability to breathe. Upon volitional exhaustion, the test will conclude, and you will be debriefed about your performance. You will be given a copy of the test results for your records. If you have questions about the values listed on the results page, lab staff will provide the requested information. You will then be informed about which group you were randomly assigned to, which is either the one-session-per-week ("blocked") group or the three-sessions-per-week ("periodic") group. In the following week you will report to the lab either one or three times weekly, depending on your assigned group, to engage in ~60 or ~20 minutes of exercise for the "blocked" or "periodic" groups, respectively. Within these exercise sessions, you will engage in repeated bouts of high-intensity running exercise on the treadmill, with alternating work and rest periods. During the rest periods, the research staff members will assess your psychological response to the high-intensity exercise with the Feeling Scale (FS), a bipolar 11-point scale which simply assesses how you felt during the exercise bout. To avoid the confounding factors of external physical activity, we ask you not to engage in cardiorespiratory endurance exercise, such as running, cycling, and swimming, aside from exercise training within the study. Following the six-week intervention, you will complete a post-intervention exercise test, the procedure of which is identical to the pre-intervention exercise test. After the post-intervention exercise test is completed, you will be compensated with a $50 gift card for your participation. The study will take place over the timeline of about eight weeks; a basic timeline for the three major sections of the study is given below.

- Week 1: Pre-intervention exercise test
  - Group will be assigned
- Weeks 2-7: Exercise intervention
  - "Blocked": One day per week
  - "Periodic": Three days per week
- Week 8: Post-intervention exercise test
  - Compensation

In total, approximately 30 participants will be recruited for this study.

Are there any benefits to me if I am in this study?

The potential benefits to you for taking part in this study include improvement of cardiorespiratory fitness and identification of a sustainable exercise protocol that helps you meet exercise guidelines. If you take part in this study, you may have a greater likelihood of meeting exercise guidelines by continuing to engage in the interval training protocols employed in the study.

Are there any risks to me if I am in this study?

The potential risks from taking part in this study are:

- Discomfort or fatigue during the exercise tests or intervention interval training
  - To minimize your discomfort and fatigue we will allow you to hydrate during the rest intervals. We will also have you do a five-minute warmup and cool down prior to and after every session,

respectively. This will likely reduce the risk of injury or soreness that can come with high-intensity exercise. The option to withdraw from this study is always available to you.

- A fall during the exercise tests or intervention interval training
  - For all sessions, including the pre- and post-intervention tests, there will be at least two "spotters" behind you while you are running, to catch you should you fall. If available, a third spotter will be utilized as an extra safety precaution. All lab personnel are CPR-certified and are equipped to handle emergency situations. The lab carries a first aid kid and functional AED unit in case of injury or cardiac dysfunction.
- Breach of data confidentiality
  - Your informed consent will be kept in the locked laboratory of the PI. If the data leaked and is somehow linked to you we will notify you, the proper authorities (because it will mean that the PI's office was unlawfully intruded upon) and IRB immediately.

If you are injured as a result of falling onto or off the treadmill, please let the research staff know, and your physical condition will be assessed immediately. If the injury is severe (difficulty breathing, fainting, cardiac event), the researcher will contact 911 for an emergency response. Should you become injured in any way, you may contact the two WSU faculty members who lead the university athletic training program and have extensive experience with physical activity-related injury:

- Dr. Kasee Hildenbrand (Director, WSU Athletic Training Program) (509) 335-8834
- Mrs. Katy Pietz (Clinical Coordinator, WSU Athletic Training Program) (509) 335-6230

As with any experimental procedure, there may be adverse events or side effects that are currently unknown and it is possible these unknown risks could be permanent, severe, or life-threatening.

Will my information be kept private?

The data for this study will be kept confidential to the extent allowed by federal and state law. No published results will identify you, and your name will not be associated with the findings. Under certain circumstances, information that identifies you may be released for internal and external reviews of this project. Your privacy during data collection will be maintained with laboratory testing only being conducted with necessary researchers present and the lab door locked from intrusion. Data will be stored on computers in the lab and offices that can only be accessed by the data custodians of this project, that is, Dr. Christopher Connolly and Will Yaku. The results of this study may be published or presented at professional meetings, but the identities of all research participants will remain anonymous. The data for this study will be kept for three years and then destroyed. If you do not agree to this, you may choose not to join the study.

Are there any costs or payments for being in this study?

There will be no costs to you for taking part in this study. In the unlikely event of a study-related injury, no compensation will be provided for medical treatment. You will bear the cost of any required medical treatment.

You will receive a $50 gift card for taking part in this study. The funding for this study comes from (1) the Washington State University Department of Kinesiology Student Development Fund ($1,000), and (2) the American College of Sports Medicine Northwest Student Research Grant ($500). If you decide to quit the study you will receive this gift card as if you fully completed study participation. You will be asked to provide your name and email address so that we can send you the link/code for this gift card after you finish participating in this study. You will not receive compensation if you are removed from this study for inappropriate behavior.

Who can I talk to if I have questions?

If you have questions about this study or information on this webpage, please contact the principal investigator, Dr. Christopher Connolly at (509) 335-7605 or email c.connolly@wsu.edu. If you have questions about your rights as a research participant or would like to report a concern or complaint about this study, please contact the Washington State University Institutional Review Board at (509) 335-3668, or email irb@wsu.edu, or regular mail at: Neill 427, PO Box 643143, Pullman, WA 99164-3143.

What are my rights as a research study volunteer?

Your participation in this research study is completely voluntary. You may choose not to be a part of this study at any time. There will be no penalty to you if you choose not to take part. You may choose not to answer specific questions or to discontinue participating at any time. You will be provided with a copy of the consent form for your records.

What does providing consent mean?

Your signature below indicates that:

- You understand the information given to you on this document
- You have been able to ask the researcher questions and state any concerns
- The researcher has responded to your questions and concerns
- You believe you understand the research study and the potential benefits and risks that are involved.

Statement of Consent

I give my voluntary consent to take part in this study. I will be given a copy of this consent document for my records.

________________________________ ____________________

Signature of Participant Date

____

Printed Name of Participant

Do you agree to have your image and actions photographed? (initial here if yes) _________

Statement of Person Obtaining Informed Consent

I have carefully explained to the person taking part in the study what they can expect.

I certify that when this person signs this form, to the best of my knowledge, they understand the purpose, procedures, potential benefits, and potential risks of participation.

I also certify that they:

- Speak the language used to explain this research
- Read well enough to understand this form or, if not, this person is able to hear and understand when the form is read to them
- Does not have any problems that could make it hard to understand what it means to take part in this research.

Signature of Person Obtaining Consent | Date

Printed Name of Person Obtaining Consent | Role in the Research Study

APPENDIX G: IRB-Approved Debriefing Form

WASHINGTON STATE UNIVERSITY
Department of Kinesiology and Educational Psychology

DEBRIEFING FORM

Study Title: Effects of blocked and periodic interval training on cardiorespiratory fitness and affective responses among college students

Study Purpose:

Thank you for your participation in this research study carried out by Dr. Christopher Connolly. The purpose of this study was to determine how the weekly exercise frequency affects improvements in aerobic fitness in college students who are not meeting physical activity guidelines, as well as to identify whether a higher or lower exercise session volume is psychologically more positive and sustainable for insufficiently active college students.

Your Right to Withdraw Data:

If you would like to withdraw the research data you provided, please contact the research team at (509) 335-9658 or email eppl@wsu.edu.

For Questions or Concerns:

If you have any follow-up questions or concerns about the research, please reach out to the study investigator, Dr. Christopher Connolly, at (509) 335-7605 or email c.connolly@wsu.edu. If you have any questions or concerns about your rights as a research participant, please contact the WSU Institutional Review Board at irb@wsu.edu, or 509-335-7646.

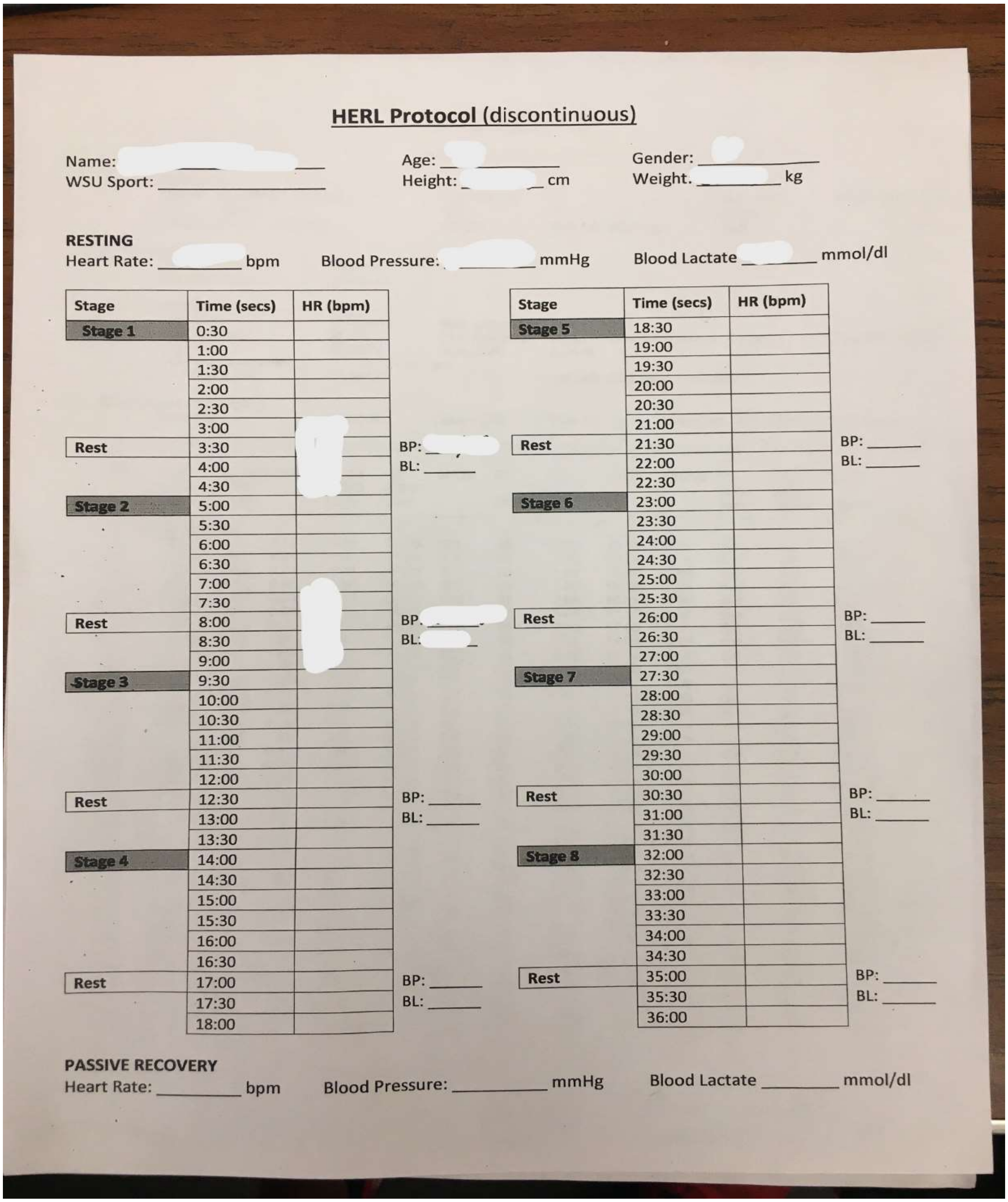
Participant Signature:

Your signature below indicates that you have been debriefed and that your questions have been answered.

___________________________	_________________________	_________
Name of Participant	Signature	Date
___________________________	_________________________	__________
Name of Researcher	Signature	Date

Thank you for your time spent participating in this research.

APPENDIX H: Graded Exercise Test Data Sheet



HERL Protocol (discontinuous)

Name: ________ Age: ________ Gender: ________
WSU Sport: ________ Height: ________ cm Weight: ________ kg

RESTING
Heart Rate: ________ bpm Blood Pressure: ________ mmHg Blood Lactate ________ mmol/dl

Stage	Time (secs)	HR (bpm)	
Stage 1	0:30		
	1:00		
	1:30		
	2:00		
	2:30		
	3:00		
Rest	3:30		BP: ______
	4:00		BL: ______
	4:30		
Stage 2	5:00		
	5:30		
	6:00		
	6:30		
	7:00		
	7:30		
Rest	8:00		BP: ______
	8:30		BL: ______
	9:00		
Stage 3	9:30		
	10:00		
	10:30		
	11:00		
	11:30		
	12:00		
Rest	12:30		BP: ______
	13:00		BL: ______
	13:30		
Stage 4	14:00		
	14:30		
	15:00		
	15:30		
	16:00		
	16:30		
Rest	17:00		BP: ______
	17:30		BL: ______
	18:00		

Stage	Time (secs)	HR (bpm)	
Stage 5	18:30		
	19:00		
	19:30		
	20:00		
	20:30		
	21:00		
Rest	21:30		BP: ______
	22:00		BL: ______
	22:30		
Stage 6	23:00		
	23:30		
	24:00		
	24:30		
	25:00		
	25:30		
Rest	26:00		BP: ______
	26:30		BL: ______
	27:00		
Stage 7	27:30		
	28:00		
	28:30		
	29:00		
	29:30		
	30:00		
Rest	30:30		BP: ______
	31:00		BL: ______
	31:30		
Stage 8	32:00		
	32:30		
	33:00		
	33:30		
	34:00		
	34:30		
Rest	35:00		BP: ______
	35:30		BL: ______
	36:00		

PASSIVE RECOVERY
Heart Rate: ________ bpm Blood Pressure: ________ mmHg Blood Lactate ________ mmol/dl

APPENDIX I: 2022 Physical Activity Readiness Questionnaire for Everyone

2022 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1) Has your doctor ever said that you have a heart condition ☐ **OR** high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** ______	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it **does not limit your current ability** to be physically active. **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Global Physical Activity Guidelines for your age (https://www.who.int/publications/i/item/9789240015128).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION
If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ______ DATE ______

SIGNATURE ______ WITNESS ______

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

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2022 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?
If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐

2. Do you currently have Cancer of any kind?
If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? This Includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm
If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐

4. Do you currently have High Blood Pressure?
If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐

5. Do you have any Metabolic Conditions? This Includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes
If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

2022 PAR-Q+

6. Do you have any Mental Health Problems or Learning Difficulties? This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome

If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7

6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	YES ☐ NO ☐

7. Do you have a Respiratory Disease? *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*

If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8

7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐

8. Do you have a Spinal Cord Injury? *This includes Tetraplegia and Paraplegia*

If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9

8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐

9. Have you had a Stroke? *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*

If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10

9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐

10. Do you have any other medical condition not listed above or do you have two or more medical conditions?

If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations

10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: ____________________

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

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2022 PAR-Q+

If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ______________________________ DATE ______________________________

SIGNATURE ______________________________ WITNESS ______________________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________________

For more information, please contact

www.eparmedx.com

Email: eparmedx@gmail.com

Citation for PAR-Q+

Warburton DER, Jamnik VK, Bredin SSD, and Gledhill N on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

Key References

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01-11-2021

APPENDIX J: World Health Organization Quality of Life Questionnaire – Brief Version

WHOQOL-BREF

Field Trial Version
December 1996

PROGRAMME ON MENTAL HEALTH
WORLD HEALTH ORGANIZATION
GENEVA

For office use only

	Equations for computing domain scores	Raw score	Transformed scores*	
			4-20	0-100
Domain 1	(6-Q3) + (6-Q4) + Q10 + Q15 + Q16 + Q17 + Q18 ☐ + ☐ + ☐ + ☐ + ☐ + ☐ + ☐	=		
Domain 2	Q5 + Q6 + Q7 + Q11 + Q19 + (6-Q26) ☐ + ☐ + ☐ + ☐ + ☐ + ☐	=		
Domain 3	Q20 + Q21 + Q22 ☐ + ☐ + ☐	=		
Domain 4	Q8 + Q9 + Q12 + Q13 + Q14 + Q23 + Q24 + Q25 ☐ + ☐ + ☐ + ☐ + ☐ + ☐ + ☐ + ☐	=		

WHOQOL-BREF
Page 2

ABOUT YOU

I.D. number

Before you begin we would like to ask you to answer a few general questions about yourself: by circling the correct answer or by filling in the space provided.

What is your **gender?** — **Male** **Female**

What is you **date of birth?** — ______ / ______ / ______
Day / Month / Year

What is the highest **education** you received?
- None at all
- Primary school
- Secondary school
- Tertiary

What is your **marital status?**
- Single
- Married
- Living as married
- Separated
- Divorced
- Widowed

Are you currently **ill?** Yes No

If something is wrong with your health what do you think it is?________________________ illness/ problem

Instructions

This assessment asks how you feel about your quality of life, health, or other areas of your life. **Please answer all the questions.** If you are unsure about which response to give to a question, **please choose the one** that appears most appropriate. This can often be your first response.

Please keep in mind your standards, hopes, pleasures and concerns. We ask that you think about your life **in the last two weeks.** For example, thinking about the last two weeks, a question might ask:

		Not at all	Not much	Moderately	A great deal	Completely
	Do you get the kind of support from others that you need?	1	2	3	4	5

You should circle the number that best fits how much support you got from others over the last two weeks. So you would circle the number 4 if you got a great deal of support from others as follows.

		Not at all	Not much	Moderately	A great deal	Completely
	Do you get the kind of support from others that you need?	1	2	3	(4)	5

You would circle number 1 if you did not get any of the support that you needed from others in the last two weeks.

Please read each question, assess your feelings, and circle the number on the scale for each question that gives the best answer for you.

		Very poor	Poor	Neither poor nor good	Good	Very good
1(G1)	How would you rate your quality of life?	1	2	3	4	5

		Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
2 (G4)	How satisfied are you with your health?	1	2	3	4	5

The following questions ask about **how much** you have experienced certain things in the last two weeks.

		Not at all	A little	A moderate amount	Very much	An extreme amount
3 (F1.4)	To what extent do you feel that physical pain prevents you from doing what you need to do?	1	2	3	4	5
4(F11.3)	How much do you need any medical treatment to function in your daily life?	1	2	3	4	5
5(F4.1)	How much do you enjoy life?	1	2	3	4	5
6(F24.2)	To what extent do you feel your life to be meaningful?	1	2	3	4	5

		Not at all	A little	A moderate amount	Very much	Extremely
7(F5.3)	How well are you able to concentrate?	1	2	3	4	5
8 (F16.1)	How safe do you feel in your daily life?	1	2	3	4	5
9 (F22.1)	How healthy is your physical environment?	1	2	3	4	5

The following questions ask about **how completely** you experience or were able to do certain things in the last two weeks.

		Not at all	A little	Moderately	Mostly	Completely
10 (F2.1)	Do you have enough energy for everyday life?	1	2	3	4	5
11 (F7.1)	Are you able to accept your bodily appearance?	1	2	3	4	5
12 (F18.1)	Have you enough money to meet your needs?	1	2	3	4	5
13 (F20.1)	How available to you is the information that you need in your day-to-day life?	1	2	3	4	5
14 (F21.1)	To what extent do you have the	1	2	3	4	5

		Very poor	Poor	Neither poor nor good	Good	Very good
15 (F9.1)	How well are you able to get around?	1	2	3	4	5

The following questions ask you to say how **good or satisfied** you have felt about various aspects of your life over the last two weeks.

		Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
16 (F3.3)	How satisfied are you with your sleep?	1	2	3	4	5
17 (F10.3)	How satisfied are you with your ability to perform your daily living activities?	1	2	3	4	5
18(F12.4)	How satisfied are you with your capacity for work?	1	2	3	4	5
19 (F6.3)	How satisfied are you with yourself?	1	2	3	4	5
20(F13.3)	How satisfied are you with your personal relationships?	1	2	3	4	5
21(F15.3)	How satisfied are you with your sex life?	1	2	3	4	5
22(F14.4)	How satisfied are you with the support you get from your friends?	1	2	3	4	5
23(F17.3)	How satisfied are you with the conditions of your living place?	1	2	3	4	5
24(F19.3)	How satisfied are you with your access to health services?	1	2	3	4	5
25(F23.3)	How satisfied are you with your transport?	1	2	3	4	5

The following question refers to **how often** you have felt or experienced certain things in the last two weeks.

		Never	Seldom	Quite often	Very often	Always
26 (F8.1)	How often do you have negative feelings such as blue mood, despair, anxiety, depression?	1	2	3	4	5

Did someone help you to fill out this form?..

How long did it take to fill this form out?..

Do you have any comments about the assessment?

....

....

THANK YOU FOR YOUR HELP

APPENDIX K: Feeling Scale

+5	Very Good
+4	
+3	Good
+2	
+1	Fairly Good
0	Neutral
- 1	Fairly Bad
- 2	
- 3	Bad
- 4	
- 5	Very Bad

APPENDIX L: 2023 ACSM Northwest Chapter Student Research Grant Award

ACSM
NORTHWEST

July 14th, 2023

Dear Will Yaku,

Thank you for your recent application to the ACSM Northwest Research Grant Program. We received many competitive submissions from students across the region, but I am pleased to inform you that after reviewing your proposal "The effects of blocked and periodic interval training on cardiorespiratory fitness and affective responses among college students", the grant review committee has decided to award you with $500 to help fund your research study!

On behalf of the ACSM Northwest Chapter, we congratulate you on this wonderful accomplishment! Attached to this email is a student contract for receiving funds. Please complete this contract and return it back to us. Once completed, we will work with Matt Laye, the ACSM Northwest Treasurer to begin the process of distributing your funds.

Again, congratulations and we look forward to hearing about your research at our Annual Meeting!

Sincerely,

Ariel Aguiar Bonfim Cruz

Ariel Aguiar Bonfim Cruz
ACSM Northwest National Student Representative