5-2021

Effects of High Intensity Interval Training on Cardiorespiratory Fitness and Body Composition in Women: A Review

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Recommended Citation

Dykstra, Rachel Marie, "Effects of High Intensity Interval Training on Cardiorespiratory Fitness and Body Composition in Women: A Review" (2021). *Dissertations*. 3709.
https://scholarworks.wmich.edu/dissertations/3709

EFFECTS OF HIGH INTENSITY INTERVAL TRAINING ON CARDIORESPIRATORY FITNESS AND BODY COMPOSITION IN WOMEN: A REVIEW

by

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A dissertation submitted to the Graduate College
in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
Education and Human Development
Western Michigan University
May 2021

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Rachel Marie Dykstra, Ph.D.

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Background: A growing body of literature indicates that women, in comparison to men, report significantly more barriers to exercise, often times related to perceived lack of time due to their social roles (e.g. family responsibility, childcare). Therefore, it has been considered that exercise programs that require less time commitments would be more attractive for women to alleviate this concern. **Objective:** This review was conducted to comprehensively understand the present literature surrounding women and such a time-efficient protocol: high intensity interval training (HIIT). The primary aim was to determine the impact of HIIT on both cardiorespiratory fitness (CRF) and body composition. The secondary aim was to identify what variables, if any, influence the effect of HIIT on changes in CRF and body composition. **Methods:** A database search was conducted in MEDLINE (PubMed), CENTRAL (Cochrane), and ESCO (SPORTdiscus) to obtain all peer-reviewed publications up until November 2020. Studies were included if HIIT protocols were aerobic-based, a minimum of two weeks in duration, participants were between the ages of 18-65 years and free from cardiovascular, metabolic, or renal disease and cancers. Comparisons were made for changes in maximal or peak oxygen consumption (VO_2max *or* VO_2peak), fat mass (FM), fat-free mass (FFM), and body fat percentage (BF%). **Results:** 41 studies were included in this review, involving a total of 628 female subjects who were predominantly younger (582 subjects between ages 18-35 years) and overweight (body mass index ranging from 20.3-35.7 $kg \cdot m^{-2}$). Exercise intervention duration ranged from 2-15 weeks (7.8±3.7 weeks), utilizing between 2-5 sessions (3.1±0.4 visits) per week. Of the 37 studies with CRF as an outcome measures, 34 reported improvements. 35 studies reported pre- and post-intervention assessments surrounding body composition. 14 determined significant improvements in BF% and 12 studies reported a significant decrease in FM, six showed significant increases in FFM. **Conclusion:** It is suggested that HIIT can significantly improve CRF in women, irrespective of age, training status, BMI, and training frequency. However, exercise intervention duration, in conjunction with the appropriate intensity of exercise may influence the improvements. HIIT interventions that are shorter in duration (≤7 week) should consider utilizing intensities >100% VO_2max (supramaximal) to elicit improvements in CRF. Intensities ranging from 85-95% VO_2max are sufficient to augment CRF in interventions exceeding 7 weeks. The effect of HIIT on body composition is less clear. Excess post-exercise oxygen consumption (EPOC) and energy expenditure greatly exceeding 1000 MET-minutes per week may account for reductions in FM. However, there is no guarantee that these reasons alone account for all reductions in FM. There were improvements in FFM across very few studies (*n* = 6). It is suggested that aerobic-based HIIT be supplemented with resistance training to generate superior improvements in FFM. Furthermore, lack of controlled diet across all studies makes it difficult to determine if caloric intake could account for any changes in body composition. While HIIT may be an effective and time-efficient protocol for women, future research should focus on ecological validity and women's adherence to such vigorous training, specifically within non-athletic and sedentary subgroups.

ACKNLOWLEDGEMENTS

I would like to start by thanking my doctoral advisor, Dr. Nicholas Hanson, for the mentorship he has provided me over the past several years. Dr. Hanson, you continuously generated opportunities that facilitated my professional growth, to which I am incredibly grateful. I am especially appreciative that you held me to a high standard and challenged me. I was able to exceed all expectations I had for myself. It has been a privilege to learn from you.

I would also like to thank Dr. Timothy Michael and Dr. Carol Weideman, who have undoubtably supported me throughout my graduate studies. Dr. Michael and Dr. Weideman, your encouragement and advisement has contributed to many of my academic, professional, and personal successes. Thank you both for never allowing me to underestimate myself. You have both played invaluable roles throughout my experience. Dr. Michael Miller and Dr. Ya Zhang, thank you both for serving on my committee and assisting me throughout this process. It has been a pleasure to collaborate and receive such positivity and encouragement from both of you.

Additionally, I would like to express the immeasurable appreciation I have for my mother and brother. Over the seemingly hundreds of years I have been in school, you both have, for lack of better words, dealt with me. There are not enough words to express my gratitude and how much I love you both. Mom, I cannot thank you enough for all the sacrifices you have made for me along the way. I know that through anything, I can always count on you. Chris, thank you for keeping me grounded and taking the time to remind me that life exists outside academia. Through every stressful moment, you continuously reminded me that it will all be worth it and I am here to say, you were right.

Acknowledgements–Continued

To my incredibly loving husband, Jordan. First and foremost, you are by far the most patient human being on this earth. Since the beginning of this journey, you have been my number one fan. You never stop motivating me to persevere. There have been many long days and nights, but through every one, you have always been there to ensure my happiness. You undeniably care for my well-being and it shows through your selflessness. Not a day goes by where I do not appreciate and love you immensely.

Lastly, I would like to dedicate this dissertation to my late father, Joseph Maceri. It was by watching him that I learned to dream big, to work hard, and to always remain humble. It is because of his inspiration and unconditional love that I have become the person I am today. Dad, I know you would have been so incredibly proud of my accomplishments over this past year and I only wish I had gotten to share them with you. Whatever I do, wherever life takes me, I still always have you to thank. I love you.

Rachel Dykstra

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LIST OF ABBREVIATIONS

BF% – body fat percentage

BIA – bioelectrical impedance analysis

BMI – body mass index

CRF – cardiorespiratory fitness

CVD – cardiovascular disease

DXA – dual energy x-ray absorptiometry

FFM – fat free mass

FM – fat mass

HIIT – high intensity interval training

HR_{max} – maximal heart rate

HR_{peak} – peak heart rate

MICT – moderate intensity continuous training

VO_2max – maximal oxygen consumption

VO_2peak – peak oxygen consumption

CHAPTER I: INTRODUCTION

A growing body of literature indicates that exercise motives differ between men and women (1). While men are more likely motivated to exercise for social or competitive reasons (1), women tend to exercise striving for an “ideal” or “attractive” physical appearance (e.g. slimmer aesthetic, lower body fat) (1). Studies have also noted that sex influences habitual participation in exercise programs (1, 2). Women tend to report more barriers to physical activity, often times associated with their social roles (2). Family responsibility (e.g. care-giving), or more specifically, motherhood, is often a perceived barrier that greatly effects exercise participation (2). Perceived time devoted to exercise is viewed as unfavorable, seeing that time spent exercising is less conducive than partaking in family commitments (e.g. familial errands, childcare, etc.) (2). It is not surprising that women, specifically those in a childcare role, commonly report lack of time as a perceived barrier (3-5) to exercise. Even for women whose lifestyles do not necessitate childcare, lack of time has been identified as a more significant barrier to exercise in comparison to men (2, 4). Consequently, this barrier can make it difficult for women to prioritize their health.

Correspondingly, irrespective of age, prevalence of physical inactivity remains highest within women (6). Physical inactivity has been continuously recognized through research as a considerable risk factor associated with all-cause mortality in adults (7, 8). Alternatively, regular participation in exercise has been shown to reduce relative risk of death (9) and improve multiple aspects of health, such as cardiorespiratory fitness (CRF) (10, 11), adiposity (12), and glucose tolerance (10), which in combination, often contribute to chronic disease (9, 10). While the Center for Disease Control (CDC) and American College of Sports Medicine (ACSM) have created physical activity guidelines to maintain or further, improve health in adults (11, 13) and combat health conditions associated with physical inactivity (e.g. cardiovascular disease [CVD], type-II diabetes, and hypertension) (10, 11, 14-16), still the majority of women still fail to reach or maintain recommended guidelines (17).

Therefore, researchers have sought to consider lack of time as a barrier for participation in physical activity, explicitly among women (18), with the intent of establishing not only effective, but more attainable exercise programs that will account for these deterrents and offset negative health consequences. The provision of tailored exercise programs that work around this perceived obstacle, may improve women's initiation and adherence to exercise programs, thereby improving their health (18-20). It has been considered that exercise programs characterized by shorter durations may be more attractive for women in order to alleviate their concerns for time (8).

High Intensity Interval Training

With considerable interest in identifying an exercise protocol that optimizes physiological benefits, but minimizes time requirements (17, 21), a modified exercise protocol emerged. This protocol has been deemed as both time-efficient (17, 21) and has potential to elicit similar, or superior benefits on cardiovascular health, more so than conventional endurance training (22); this protocol is known as high intensity interval training (HIIT). HIIT is generally characterized by alternating periods of brief, but vigorous aerobic exercise, followed by periods of rest or low intensity recovery (14, 23). To date, there is a lack of standardization for HIIT (24), as protocols can vary in duration (25), number of intervals completed (25, 26), and/or length and type of recovery periods (27). However, a key factor that is comprehensively agreed upon for conventional HIIT, is the classification of intensity (24, 28): the target intensity is between 80-100% of an individual's maximum heart rate (HR_{max}) or maximum oxygen consumption

(VO_2max) (22, 28). Though, more recently, a new branch of HIIT emerged: sprint interval training (SIT) (29). This type of interval training can be distinguished from conventional HIIT characterizations (30, 31) as the target intensity is supramaximal (29), meaning that training involves exercising at workloads greater than what is required to elicit 100% of VO_2max (28). Moreover, energy production exceeds what can be sustained by purely oxidative metabolism (22, 31); this indicates that supramaximal exercise requires anaerobic metabolism as well (32).

It has been recognized that both HIIT and SIT are not only time-efficient, but may elicit advantageous physiological adaptations (e.g. improved CRF) (24). Previous research has shown that as little as six SIT sessions over the span of two weeks can augment aerobic capacity (24). Similarly, a total of eight sessions over four weeks of conventional HIIT at 95% HR_{max} can improve aerobic capacity, with a 7.4% increased improvement in VO_2max (33). Additionally, recent evidence has supported HIIT and SIT as effective training protocols to induce reductions in fat-mass (FM) and increases in fat-free mass (FFM) (8). Favorable changes in body composition were documented after six weeks (three visits per week) of SIT (31). A recent meta-analysis reported that after approximately 10 weeks of conventional HIIT (intensity defined as >85% HR_{max} or >80% VO_2max), FM decreased by 6% (8). Though the literature supporting conventional HIIT and SIT for improving numerous health- and fitness-related components continues to grow (28, 34), two limitations have surfaced: 1) the majority of exercise-related studies have been performed on young, healthy men and results are generalized to other healthy populations (35, 36), and 2) a limited number of studies have tested different moderating variables (e.g. duration of intervention, duration of recovery periods, type of recovery, etc.) can influence the effectiveness of HIIT on essential components of health and fitness in women.

These limitations indicate that exercise interventions are developed on a basis of male responses to exercise and also that moderating variables are highly overlooked. Yet, the premise that "one size fits all" within exercise prescription is highly outdated, but unfortunately still used (36). Continuing to ignore the potential sex-specific differences is quite a disservice (37), as there is considerable research surrounding exercise that report copious differences between men and women in regard to morphology, physiology, barriers, and preferences (25, 35). This highlights the necessity to analyze data from men and women independently to account for differences (36), rather than generalizing results. Additionally, it is appropriate to identify specific subgroups in order to identify further insight into the effectiveness of HIIT programs with distinct moderating variables (e.g. differences in intervention duration, dissimilar intensities) (8). Thereafter, with consideration to these factors, health professionals can better formulate individualized HIIT programs for clients, based on the population, personalized goals, distinctive outcomes measures, and desired adaptations (25, 36, 38).

Focus on Women

Although HIIT protocols were not generated to tailor to women's distinct perceived time constraints, it seems as though this exercise intervention could be an ideal option for women, as it does mitigate common obstacles (e.g. lack of time) that avert women from regular participation in physical activity. Additionally, HIIT can potentially improve areas of health that are of great concern to women: CVD and obesity (11, 39). It is imperative to continually examine this training protocol, as it can potentially reduce the prevalence of the aforementioned diseases and their associated risk factors through improvements in specific physical fitness components (e.g. CRF and body composition) (11, 39).

Cardiorespiratory Fitness and Body Composition

Considering that CVD is the leading cause of death in women today (40), further evaluating the effectiveness of any exercise intervention that could decrease the risk of this disease is highly advantageous for women's health. CRF, measured by VO_2max, is a powerful predictor of overall health, quality of life, and longevity (11, 39). Moreover, CRF is inversely related to all-cause mortality (13, 22) and improvements in this component of physical fitness can decrease risk factors associated with CVD (11, 39). In order to improve CRF, individuals need to continuously participate in exercise that aims to improve aerobic capacity (13); researchers suggest that HIIT could be an exemplary form of training contributing to this physiological adaptation (41).

Additionally, obesity, defined as an abnormal or excessive fat accumulation that presents health risks (42), has become a serious public health issue and a leading risk factor for CVD (40). In 1997, The World Health Organization listed obesity as a global epidemic (43), with the incident rate still, today, drastically increasing worldwide (5). Moreover, obesity rates are significantly greater in women in comparison to men (2). With respect to this, participation in an effective exercise strategy to help combat obesity (e.g. decrease fat mass) within this population is vital (2). Again, HIIT may be an effective training method to induce adaptations in body composition (5, 16).

Purpose Statement

Like men and women's physiological responses and reported barriers to exercise, HIIT protocols are not all one in the same (25). Moreover, there is still an incomplete understanding of how exercise intervention parameters (e.g. exercise, rest and intervention duration, modality, etc.) influences the effect of HIIT on both CRF and body composition (25). It has also been suggested that other factors such as age, training status, and modality could be potential moderating variables. Largely missing from the literature are analyses focusing on exercise parameters and how each may influence the effect HIIT has on women, specifically. Therefore, the primary purpose of this review is to comprehensively understand the present literature focusing on the effects of HIIT on CRF and body composition in women. Subsequently, the secondary aim of this study is to determine what moderating variables (e.g. duration of intervention, intervention sessions per week, intensity of training sessions, length of training sessions, length of recovery periods, type of recovery periods, modality, age of participants), if any, play a role in the effectiveness of HIIT on these essential components of physical fitness.

Aims of the Study

1. The **primary** purpose of this review is to comprehensively analyze the present literature focusing on the effects of HIIT on CRF and body composition in women.
2. The **secondary** aim is to identify what variables, if any, influence the effect HIIT has on changes in CRF and body composition.

Research Questions

1. Is high intensity interval training effective in improving cardiorespiratory fitness and body composition in women?
2. What variables, if any, influence the effect of high intensity interval training on changes in cardiorespiratory fitness and body composition?

Definition of Terms

Cardiorespiratory Fitness: A component of physiologic fitness that relates to the ability of the circulatory and respiratory systems to supply oxygen during prolonged physical activity or exercise. It is also referred to as aerobic capacity (44). The most widely accepted measure of cardiorespiratory fitness is maximal oxygen consumption, or VO_2max (44, 45). An individual's VO_2max refers to the maximum amount of oxygen an individual utilizes during maximal exercise (44). A VO_2max test is an incremental exercise test where the workload is progressively increased. These tests are primarily completed on a cycle ergometer or treadmill, and typically require individuals to bike or run until volitional exhaustion.

Operational Definition: Values or "scores" from pre- and post-intervention VO_2max tests.

Body Composition: A component of physical fitness used to break down the body into core components: fat, protein, minerals, and body water (46). Moreover, it is used to identify the amount of fat mass and lean (muscle) mass an individual has, as well as their body fat percentage (13). Commonly accepted methods used to measure body composition are bioelectrical impedance analysis (BIA), skinfolds, dual energy x-ray absorptiometry (DXA), hydrostatic (underwater) weighing, and air displacement plethysmography (ADP).

Operational Definition: Body fat percentage values from pre- and post-intervention measurements.

Conventional Endurance Training: Also referred to as moderate intensity continuous training (MICT), this traditional aerobic exercise training protocol allows individuals to exercise continuously at a steady state for an established duration (typically 20-60 minutes) (22).

Operational Definition: Exercising at a continuous, moderate intensity for a minimum of 20 minutes. Moderate intensity can be expressed as any of the following: 1) 40-59% of heart rate reserve (HRR), 2) 64-76% HR_{max}, or 3) 46-63% VO_2max (13).

High Intensity Interval Training: Characterized by alternating between short periods of high or near maximal intensity exercise and periods of active or passive recovery (22).

Operational Definition: Exercising at a high or near maximal intensity. High intensity can be represented by any of the following: 1) ≥60% HRR, 2) ≥77% HR_{max}, or 3) ≥64% VO_2max (13). Exercise bouts range from 60-240 seconds and recovery periods range from 30 seconds to several minutes.

Sprint Interval Training: Characterized by alternating between short periods of supramaximal or "all out" exercise (i.e. sprints) and periods of active or passive recovery (22).

Operational Definition: Exercising at a supramaximal intensity (a workload greater than what is required to elicit 100% of VO_2max). Exercise bouts range from 8-30 seconds and recovery periods range from 30 seconds to several minutes.

CHAPTER II: LITERATURE SEARCH METHODOLOGY

Eligibility Criteria

Study eligibility criteria applied were: 1) published in a peer-reviewed journal prior to November 2020, 2) included a minimum of means and standard deviations for participant outcome measures for a) cardiorespiratory fitness using VO_2max or VO_2peak *and/or* b) body composition using FM, FFM, *and/or* body fat percentage (BF%), 3) participants were female *or* the study included males, but separated data between sexes 4) participants had various body mass indexes (BMI) (e.g. normal, overweight, obese), 5) participants were free from cardiovascular, metabolic, and renal disease and cancers, 6) exercise intervention used was HIIT or SIT, 7) exercise interventions were a minimum of two weeks in duration, with at least two visits per week, and 8) exercise interventions were aerobic-based (e.g. running, cycling, rowing, etc.). Abstracts and manuscripts with insufficient data were not included in this review. Studies using adolescents (ages < 18 years) and older (ages > 65 years) female participants were also excluded from this review.

Information Sources

A search of electronic databases was conducted to identify all publications up to November 2020. MEDLINE (PubMed/PubMed Central interface), CENTRAL (Cochrane Central Register of Controlled Trials), and ESCO (SPORTdiscus) were the primary databases used to locate studies.

Search Strategies

Keywords used for searches included terms that were synonymous with, or directly related to *high intensity interval training* (e.g. high intensity interval exercise [HIIE], HIIT, sprint interval exercise [SIE], sprint interval training [SIT]), *women* (e.g. females), *cardiorespiratory fitness* (e.g. maximal oxygen consumption, VO_2max, VO_2peak, aerobic capacity), and *body composition* (e.g. body fat percentage, BF, FM, FFM). Boolean operators (i.e. and, or) were also used to refine searches and maximize relevant results. In addition, reference tracing was conducted on all studies identified through searches to locate additional studies.

Study Selection

Studies were screened using the eligibility criteria above. The search yielded an initial set of *n* = 221 studies, potentially relevant to the review. Thereafter, a reference management software (EndNote) was used to filter duplicates from initial screening. Titles and abstracts of all remaining studies were reviewed to eliminate unrelated manuscripts. Reference tracing produced an additional *n* = 15 studies. The final pool of studies selected was *n* = 41. A flow diagram of the literature selection process is shown in Figure 1.

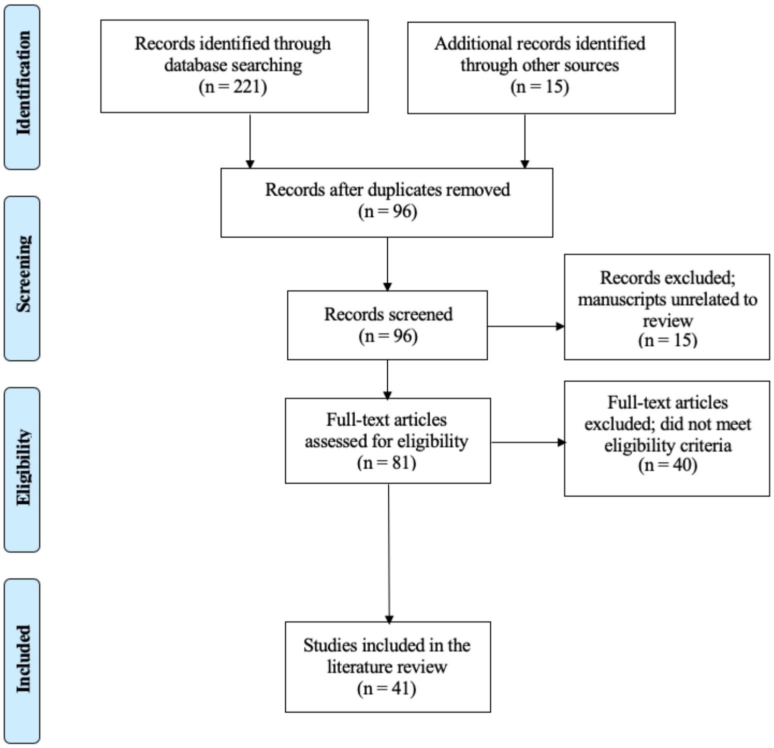

Figure 1. Flow diagram of the literature selection process.

CHAPTER III: RESULTS

Subject Characteristics

Subject characteristics are summarized in Table 1. There was a total of *n* = 628 subjects across all 41 studies. Subject's ages ranged from 18-55 years. According to ACSM's BMI classifications (13), 30.4% of subjects were normal weight (23, 26, 27, 29, 30, 33, 47-51), 31.1% were considered overweight (5, 11, 14, 15, 17, 19, 52-59), 12.3% were obesity class I (10, 60-63), and 2.2% were obesity class II (64). 24.1% of the studies did not determine subject's BMI nor reported sufficient anthropometric data (i.e. body weight and height) to compute this variable (16, 31, 43, 65-71). 10 studies (27, 31, 33, 47, 65, 67-71) used subjects who were considered 'recreationally active' or 'trained', but defining characteristics for these terms varied across studies. 25 studies (5, 10, 11, 15-17, 19, 26, 29, 48-58, 60, 61, 63, 64, 66) included sedentary (physically inactive) or untrained, but otherwise healthy subjects. The remainder of the studies (14, 23, 30, 43, 59, 62) did not report data pertaining to subject's physical activity status.

Table 1. Subject characteristics

Study, year	Sample size	Age (years)	BMI (kg·m^{-2})	Physical activity status
Alves et al., 2017 (52)	LID: 10 SID: 10	LID: 25.0±5.0 SID: 25.0±5.0	LID: 25.4±3.9 SID: 26.0±4.4	Untrained Untrained
Arad et al., 2015 (60)	9	29.0±4.0	32.5±3.6	Sedentary (exercising <3 days per week, 60 minutes per session)
Astorino et al., 2011 (71)	9	25.2±3.1	NR	Recreationally active (vigorous exercise 4 hours per week for a minimum of 3 years)
Astorino et al., 2013 (53)	11	22.7±5.4	25.3.±4.3	Sedentary (<60 minutes of exercise per week)
Bagley et al., 2016 (30)	17	41±3.2	22.2±0.7	NR

Table 1. (continued)

Study, year	Sample size	Age (years)	BMI (kg·m^{-2})	Physical activity status
Bhati et al., 2017 (26)	LV: 17 HV: 15	LV: 22.0±0.5 HV: 22.0±3.0	LV: 20.3±0.4 HV: 22.4±0.5	Sedentary (<20 minutes of low intensity exercise or sport per week for both groups
Brown et al., 2018 (47)	6	22.0±2.8	24.7±2.4	Recreationally active (at least 1-3 hours of physical activity per week for the preceding month)
Chidnok et al., 2020 (48)	11	21.3±0.7	21.3±3.9	Not involved in regular physical activity
Connolly et al., 2017 (54)	15	44.0±7.0	25.2±4.9	Physically inactive (no participation in physical activity for the preceding 2 years)
Edge et al., 2006 (70)	8	20.0±1.0	NR	Recreationally active (various team sports)
Eimarieskandari et al., 2012 (55)	7	22.3±0.9	29.2±0.8	Not involved in regular physical activity for the preceding 6 months
Fereshtian et al., 2017 (69)	21	20.0±4.0	NR	Incline speed skaters with 3 years of experience
Forbes et al., 2016 (23)	8	23.4±4	23.4±2.4	NR
Ghasemi & Nayebifar, 2019 (56)	10	23.6±2.2	27.3±1.3	Sedentary
Gillen et al., 2013 (19)	8	27.0±7.0	29.0±3.0	Sedentary (exercise frequency/duration <2 days per week, <30 minutes per session)
Harris et al., 2014 (29)	6	22.0±2.0	23.6±1.8	Low-moderately active (attending 0-2 structured exercise sessions per week)
Hazell et al., 2014 (31)	10	22.9±3.6	NR	Recreationally active (not participating in more than 2 structured exercise training sessions per week)
Higgins et al., 2016 (61)	23	20.4±1.5	30.3±4.5	Sedentary (exercise frequency/duration ≤2 days per week, <30 minutes per session)

Table 1. (continued)

Study, year	Sample size	Age (years)	BMI ($kg·m^{-2}$)	Physical activity status
Kong et al., 2016 (a) (11)	13	21.5±4.0	25.8±2.6	Sedentary (reporting <60 minutes of exercise per week for the preceding 6 months)
Kong et al., 2016 (b) (17)	10	19.8±0.8	25.5±2.1	Physically inactive (<90 minutes of moderate-intensity exercise per week for the preceding 6 months)
Mallol et al., 2020 (33)	R: 7 C: 7	R: 41.0±7.0 C: 43.0±13.0	R: 22.6±2.3 C:21.8±4.5	Habitual active runners (≥2 running session per week; able to run 10km in <70 minutes)
Mazurek et al., 2014 (49)	24	19.5±0.6	21.6±2.1	Untrained
Mirghani et al. 2019 (62)	G60: 8 G30: 8	G60: 33.8±5.3 G30: 32.9±5.3	G60:32.2±3.8 G30: 28.1±3.3	NR
Nayebifar et al., 2016 (57)	10	22.4±3.2	28.4±2.4	Sedentary (no aerobic based exercise for preceding 6 months
Naves et al., 2018 (27)	SIT: 24 HIIT: 25	SIT: 29.8±6.4 HIIT: 31.0±6.0	SIT: 24.5±3.3 HIIT: 25.2±3.2	Physically active (≥150 minutes of aerobic activity per week)
Nie et al., 2019 (58)	SIT: 11 HIIT: 12	SIT: 20.5±1.6 HIIT: 20.0±1.0	SIT: 27.9±4.3 HIIT: 27.0±2.8	Physically inactive Physically inactive
Panissa et al., 2016 (59)	11	28.4±12.5	25.9±4.1	NR
Renteria et al., 2019 (50)	9	22.0±1.0	24.2±2.2	Sedentary
Rowan et al., 2012 (68)	11	19.5±0.9	NR	Division III collegiate soccer team players
Rowley et al., 2017 (63)	8	33.6±1.7	31.3±6.8	Physically inactive (inactive for the preceding 3 months)
Sijie et al., 2012 (14)	17	19.8±1.0	27.7±1.9	NR
Smith-Ryan et al., 2016 (10)	1 min: 11 2 min: 10	1 min: 33.2±12.8 2 min: 33.6±11.6	1 min: 33.9±6.1 2 min: 28.6±3.7	Sedentary Sedentary
Sun et al., 2019 (15)	SIT: 14 HIIT: 14	SIT: 21.4±1.1 HIIT: 21.5±1.8	SIT: 26.0±2.5 HIIT: 26.3±2.3	Physically inactive (no engagement in aerobic activity for the preceding 6 months)
Talanian et al., 2007 (67)	8	22±1	NR	Recreationally active (engaged in aerobic activity for a minimum of 2-3 days per week)

Table 1. (continued)

Study, year	Sample size	Age (years)	BMI (kg·m^{-2})	Physical activity status
Tong et al., 2018 (66)	SIT: 16 HIIT: 16	SIT/HIIT: 18-23 (no mean±SD reported)	SIT/HIIT: NR	Physical inactive (exception of participating in physical education courses 2 days per week)
Trapp et al., 2008 (51)	15	22.4±0.7	24.2±1.5	Physically inactive
Trilk et al., 2011 (64)	14	30.1±6.8	35.7±6.3	Sedentary (exercise frequency ≤1 day per week)
Walter et al., 2010 (65)	19	21.5±2.4	ND	Recreationally active (aerobic-based activity 1-5 days hours per week)
Zeng et al., 2020 (43)	18	22.1±1.3	NR	NR
Zhang et al., 2015 (5)	12	21.0±1.0	25.8±2.7	Physically inactive (exception of participating in physical education courses 2 days per week)
Zhang et al., 2017 (16)	15	18-22 years; no mean±SD reported	NR	Physically inactive (exception of participating in physical education courses 2 days per week)

Note. All values for age are reported using mean±standard deviation. *NR* not reported, *SIT* sprint interval training, *HIIT* high intensity interval training, *BMI* body mass index, *LID* longer interval duration, *SID* shorter interval duration, *LV* low volume, *HV* high volume, *R* running, *C* cycling, *G60* group with 60 second intervals, *G30* group with 30 second intervals, *1 min.* group with 1 minute intervals, *2 min.* group with 2 minute intervals.

Intervention Characteristics

Exercise intervention characteristics are summarized in Table 2. From the 41 studies, 24 utilized HIIT protocols (5, 10, 14, 16, 19, 26, 33, 43, 47, 48, 50, 52-57, 59, 60, 62, 65, 67, 69, 70), while 13 employed SIT (11, 17, 23, 29-31, 49, 51, 61, 63, 64, 68, 71), and the remaining four studies (27, 58, 66, 72) compared both HIIT and SIT interventions. The most commonly used mode for all interventions was cycle ergometry (*n* = 28) (10, 11, 15-17, 23, 27, 29, 30, 43, 48-54, 58-61, 64-67, 70, 71, 73), followed by treadmill (*n* = 7) (5, 26, 31, 55, 62, 63, 69), indoor track or outdoor running (*n* = 4) (14, 56, 57, 68), and rowing ergometry (*n* = 1) (47). One additional study compared outdoor running *and* cycle ergometry HIIT protocols (33). Exercise intervention duration ranged from 2-15 weeks (7.8±3.7 weeks) with 12 weeks being the most common ($n = 14$). Exercise sessions were performed between 2-5 times per week for an average of 23.9±12.1 total sessions. Exercise bouts lasted anywhere between 6-240 seconds, interspersed with rest periods ranging from 9-300 seconds; passive recovery (i.e. complete rest) was used within 13 studies (11, 16, 17, 29, 47, 54, 56-58, 65-67, 72) with an average of 170.6±88.8 seconds of rest. The remaining 28 (5, 10, 14, 19, 23, 26, 27, 30, 31, 33, 43, 48-53, 55, 59-64, 68-71) studies used active recovery methods that lasted an average of 107.1±73.5 seconds. For all training interventions, exercise intensity was prescribed as percentages of VO_2max, VO_2peak, HR_{max}, HR_{peak}, HRR, lactate threshold (LT) *or* categorized as 'all out' or 'maximal effort' bouts/sprints.

Outcome Measures

Effects of HIIT on Cardiorespiratory Fitness

From the 41 studies included in this review, 37 assessed CRF before and after the exercise intervention. The majority of these studies ($n = 35$ (5, 10, 11, 14-17, 19, 23, 26, 27, 29-31, 33, 47-49, 53, 54, 56-58, 60, 61, 63-71)) had subjects complete a maximal graded exercise test to determine VO_2max *or* VO_2peak, while the remaining studies ($n = 2$ (52, 59)) had subjects complete a submaximal graded exercise test used to predict VO_2max. Amid the 37 studies, 34 (5, 11, 14-17, 19, 23, 26, 27, 29-31, 33, 47-49, 52-54, 56-59, 61, 63-68, 70, 71) reported significant increases in VO_2max *or* VO_2peak after HIIT interventions, while only three studies (10, 60, 69) reported non-significant differences between pre- and post-VO_2max *or* VO_2peak results. The average percentage change (% change) for VO_2max and VO_2peak was 15% $mL \cdot kg^{-1} \cdot min^{-1}$. Table 3 outlines assessment and outcome measures surrounding CRF.

Effects of HIIT on Body Composition

With respect to body composition, 30 studies reported pre- and post-intervention assessments. Body composition was assessed using one of the following methods: bioelectrical impedance analysis (BIA) (*n* = 6 (5, 26, 43, 50, 55, 58)); skinfold assessment (*n* = 7 (52, 53, 56, 57, 59, 62, 71)); dual X-ray absorptiometry (DEXA) (*n* = 14 (5, 10, 11, 14, 17, 19, 23, 30, 47, 51, 60, 61, 63, 66)); and air displacement plethysmograph (ADP) (*n* = 3 (31, 54, 65)). 19 studies reported FM (5, 10, 11, 16, 17, 19, 23, 26, 31, 43, 51, 52, 54, 55, 58-61, 66), with 12 of these studies reporting significant decreases after HIIT interventions (5, 16, 19, 26, 31, 43, 51, 52, 58, 59, 61, 66). 13 reported FFM (10, 11, 19, 23, 26, 31, 43, 52, 54, 55, 59, 60, 65) with just five reporting significant increases after HIIT interventions (26, 31, 43, 59, 65). Of the 28 studies that reported BF% (5, 10, 11, 14, 16, 17, 19, 23, 26, 30, 31, 43, 47, 50, 53-63, 65, 66, 71), about half (*n* = 14) reported significant decreases (5, 14, 16, 19, 26, 31, 43, 56, 58, 59, 61-63, 65). Table 4 depicts body composition assessments and outcomes after HIIT interventions.

Table 2. Exercise intervention characteristics

Study, year	Type	Mode	Session details	Frequency (per week)	Intervention duration (weeks)
Alves et al., 2017 (52)	HIIT	Cycling	LID: 1 minute of work at 90% HR_{max} followed by 30 seconds of active recovery; 15 intervals per session SID: 20 seconds of work at 90% HR_{max} followed by 10 seconds of active recovery; 45 intervals per session	3	6
Arad et al., 2015 (60)	HIIT	Cycling	30-60 seconds of work at 75-95% HRR followed by 180-210 seconds of active recovery; 4 intervals per session	3	14
Astorino et al., 2011 (71)	SIT	Cycling	30 second Wingate followed by 5 minutes of active recovery; 4 intervals per session	2-3 (6 total)	2-3 (dependent on frequency)
Astorino et al., 2013 (53)	HIIT	Cycling	60 seconds of work at 85-100% HR_{max} followed by 75 seconds of active recovery; gradual progression from 6-10 intervals per session	3	12
Bagley et al., 2016 (30)	SIT	Cycling	20 second sprints at 175% of workload attained in VO_2max test followed by 2 minutes of active recovery; 4 intervals per session	3	12
Bhati et al., 2017 (26)	HIIT	Treadmill	LV: 4 minute bout at 85-95% HR_{max} followed by 3 minutes of active recovery; 1 interval per session HV: 4 minute bout at 85-95% HR_{max} followed by 3 minutes of active recovery; 4 intervals per session	3	6
Brown et al., 2018 (47)	HIIT	Rowing	60 second bout at >90% HR_{max} followed by 3 minutes of passive recovery; 6 intervals per session	3	12
Chidnok et al., 2020 (48)	HIIT	Cycling	1 minute bout at 80% HR_{max} followed by 2 minutes of active recovery; 5 intervals per session	3	6

Table 2. (continued)

Study, year	Type	Mode	Session details	Frequency (per week)	Intervention duration (weeks)
Connolly et al., 2017 (54)	HIIT	Cycling	1 minute bouts increasing from 30% maximal effort to >90% maximal effort (self-paced) followed by 2 minutes of passive recovery; 5 intervals per session	3	12
Edge et al., 2006 (70)	HIIT	Cycling	2 minute bouts ranging from 120-140% of LT followed by 1 minute bouts of active recovery; gradual progress from 6-10 intervals per session	3	5
Eimarieskandari et al., 2012 (55)	HIIT	Treadmill	4 minutes at 80-90% VO_2peak followed by 3 minutes of active recovery; 4 intervals per session	3	8
Fereshtian et al., 2017 (69)	HIIT	Treadmill	60 seconds at 100%, 115%, or 130% vVO_2max (dependent on group placement) followed by 3 minutes of active recovery; gradual progression from 6-10 intervals per session	3	3
Forbes et al., 2016 (23)	SIT	Cycling	30 second Wingate followed by 4 minutes of active recovery; gradual progression from 4-6 intervals per session	3	4
Ghasemi & Nayebifar, 2019 (56)	HIIT	Running	40 meter shuttle run at 85-95% HR_{max} followed by 30 seconds of passive recovery; gradual progression from 4-8 intervals per session	3	10
Gillen et al., 2013 (19)	HIIT	Cycling	60 seconds at 90% of HR_{max} followed by 60 seconds of active recovery; 10 intervals per session	3	6
Harris et al., 2014 (29)	SIT	Cycling	30 second Wingate followed by passive recovery (specific time ND); 4 intervals per session	3	4
Hazell et al., 2014 (31)	SIT	Treadmill	30 second, maximal effort sprint followed by 4 minutes of activity recovery; 4 intervals per session	3	6

Table 2. (continued)

Study, year	Type	Mode	Session details	Frequency (per week)	Intervention duration (weeks)
Higgins et al., 2016 (61)	SIT	Cycling	30 second, maximal effort sprint followed by 4 minutes of activity recovery; gradual progression from 5-7 intervals per session	3	6
Kong et al., 2016 (a) (11)	SIT	Cycling	8 second maximal effort sprint followed by 12 seconds of passive recovery; 60 intervals per session	4	5
Kong et al., 2016 (b) (17)	SIT	Cycling	8 second maximal effort sprint followed by 12 seconds of passive recovery; 60 intervals per session	4	5
Mallol et al., 2020 (33)	HIIT	Cycling or Running	2 minute bout at 95% HR_{max} followed by 90 seconds of active recovery *and* 1 minute maximal effort sprint followed by 120 seconds of active recovery; 6 intervals at 95% HR_{max} and 4 intervals per session at maximal effort	2	4
Mazurek et al., 2014 (49)	SIT	Cycling	10 second maximal effort sprint followed by 1 minute active recovery; 10 intervals per session	3	8
Mirghani et al., 2019 (62)	HIIT	Treadmill	G60: 1 minute run at 80% HRR followed by 1 minute active recovery; gradual progression from 4-10 intervals per session G30: same as above, with the exception of 30 second active recovery periods, rather than 60 second	3	4
Naves et al., 2018 (27)	SIT and HIIT	Cycling	SIT: 30 second maximal effort sprint followed by 4 minutes of active recovery; 4 intervals per session HIIT: 4 minute bout at 90-95% HR_{peak} followed by 3 minutes of active recovery	3	8
Nayebifar et al., 2016 (57)	HIIT	Running	30 second maximal effort sprint followed by 30 seconds of passive recovery; gradual	3	10
Nie et al., 2019 (58)	SIT and HIIT	Cycling	HIIT: 4 minutes at 90% VO_2max followed by 3 minutes of passive recovery; repeated until reaching 200 kJ. SIT: 1 minute at 120% VO_2max followed by 90 seconds of passive recovery; repeated until reaching 200 kJ.	3-4 (44 total)	12

Table 2. (continued)

Study, year	Type	Mode	Session Details	Frequency (per week)	Interval Duration (weeks)
Panissa et al., 2016 (59)	HIIT	Cycling	1 minute at 90% HR_{max} followed by a 30 second active recovery; 14 intervals per session	3	6
Renteria et al., 2019 (50)	HIIT	Cycling	30 seconds at 80% maximal aerobic power followed by 4 minutes of active recovery; gradual progression from 3-5 intervals per session	3	4
Rowan et al., 2012 (68)	SIT	Running	30 seconds at 80% maximal aerobic power followed by 4 minutes of active recovery; gradual progression from 3-5 intervals per session	3	4
Rowley et al., 2017 (63)	SIT	Treadmill	30 second maximal effort sprints followed by 4 minutes of active recovery; gradual progression from 4-10 intervals per session	3	12
Sijie et al., 2012 (14)	HIIT	Running	3 minute bout at 85% VO_2max followed by 3 minute active recovery; 5 intervals per session	5	12
Smith-Ryan et al., 2016 (10)	HIIT	Cycling	1 min. group: 1 minute bout at 90% VO_2peak followed by 1 minute of active recovery; 10 intervals per session 2 min. group: 2 minute bout at 80%-100% VO_2peak followed by 1 minute of active recovery; 5 intervals per session	3	12
Sun et al., 2019 (15)	SIT and HIIT	Cycling	4 minute bout at 90% VO_2peak followed by 3 minutes of passive recovery; repeated until reaching 200-300 kJ	3	12
Talanian et al., 2007 (67)	HIIT	Cycling	4 minute bout at 90% VO_2peak followed by 2 minutes of passive recovery; 10 intervals per session	7 total	2

Table 2. (continued)

Study, year	Type	Mode	Session Details	Frequency (per week)	Interval Duration (weeks)
Tong et al., 2018 (66)	SIT and HIIT	Cycling	SIT: 6 second, maximal effort sprint followed by 9 seconds of passive recovery; 80 intervals per session HIIT: 4 minute bout at 90% VO_2max followed by 3 minutes of passive recovery; repeated until reaching 200-400 kJ	3	12
Trapp et al., 2008 (51)	SIT	Cycling	8 second maximal effort sprint followed by 12 seconds of active recovery; 60 intervals per session	3	15
Trilk et al., 2011 (64)	SIT	Cycling	30 second maximal effort sprint followed by 4 minutes of active recovery; gradual progression from 4-7 intervals per session	3	4
Walter et al., 2010 (65)	HIIT	Cycling	2 minute bout ranging from 80-110% VO_2peak followed by 1 minute of passive recovery; 5 intervals per session	3	6
Zeng et al., 2020 (43)	HIIT	Cycling	4 minute bout at 90% VO_2max followed by 4 minute active recovery; 5 intervals per session	3	12
Zhang et al., 2015 (5)	HIIT	Treadmill	4 minute bout between 85-95% HR_{peak} followed by 3 minutes of active recovery and thereafter, 7 minutes of passive recovery; 4 intervals per session	4	12
Zhang et al., 2017 (16)	HIIT	Cycling	4 minute bout at 90% VO_2max followed by 3 minutes of passive recovery; repeated until reaching 200-300 kJ	3	12

Note. *SIT* sprint interval training, *HIIT* high intensity interval training, *LID* longer interval duration, *SID* shorter interval duration, *LV* low volume, *HV* high volume, *R* running, *C* cycling, *G60* group with 60 second intervals, *G30* group with 30 second intervals, *1 min.* group with 1 minute intervals, *2 min.* group with 2 minute intervals, HR_{max} age-predicated maximal heart rate, *HRR* heart rate reserve, VO_2max maximal oxygen consumption, *LT* lactate threshold, vVO_2max velocity at maximal oxygen consumption, VO_2peak peak oxygen consumption, HR_{peak} peak heart rate.

Table 3. Cardiorespiratory fitness outcomes after high intensity interval training interventions

Study, year	Type	Assessment – Mode	Outcome measure	Results	
				Pre/post (mL·kg^{-1}·min^{-1})	Percent change
Alves et al., 2017 (52)	HIIT	Submaximal – cycle ergometer	Predicted VO$_2$max	*LID: 27.9±6.0/36.2±9.9 *SID: 33.9±8.5/41.5±11.6	*29.7% *22.4%
Arad et al., 2015 (60)	HIIT	Maximal – cycle ergometer	VO$_2$peak	23.1±4.9/24.9±5.5	7.8%
Astorino et al., 2011 (71)	SIT	Maximal – cycle ergometer	VO$_2$max	*41.4±6.1/43.9±5.7	*6.0%
Astorino et al., 2013 (53)	HIIT	Maximal – cycle ergometer	VO$_2$max	NR	*21.9%
Bagley et al., 2016 (30)	SIT	Maximal – cycle ergometer	VO$_2$max	*33.6±9.4/39.8±9.2	*18.7%
Bhati et al., 2017 (26)	HIIT	Maximal – cycle ergometer	VO$_2$max	*LV: 20.4±2.5 *HV: 20.±2.5	*13.2% *8.1%
Brown et al., 2018 (47)	HIIT	Maximal – cycle ergometer	VO$_2$max	*28.8±8.3/32.1±6.3	*11.6%
Chidnok et al., 2020 (48)	HIIT	Maximal – cycle ergometer	VO$_2$max	*20.1±4.3/24.3±5.7	*21.1%
Connolly et al., 2017 (54)	HIIT	Maximal – cycle ergometer	VO$_2$peak	*26.1±5.9/30.2±6.5	*15.7%
Edge et al., 2006 (70)	HIIT	Maximal – cycle ergometer	VO$_2$max	NR	*14.0%
Eimarieskandari et al., 2012 (55)	HIIT	NR	NR	NR	NR

Table 3. Cardiorespiratory fitness outcomes after high intensity interval training interventions

Study, year	Type	Assessment	Outcome measure	Results	
				Pre/post (mL·kg^{-1}·min^{-1})	Percent change
Fereshtian et al., 2017 (69)	HIIT	Maximal – treadmill	VO_2max	*110%: 42.4±5.3/45.7±8.9 *115%: 41.8±7.6/44.4±9.7 130%:: 42.0±4.5/42.4±5.7	*110%: 7.9% *115%: 6.2% 130%: 0.9%
Forbes et al., 2016 (23)	SIT	Maximal – cycle ergometer	VO_2max	*38.9±4.1/42.4±4.0	*9.0%
Ghasemi & Nayebifar, 2019 (56)	HIIT	Maximal – treadmill	VO_2max	NR	*15.9%
Gillen et al., 2013 (19)	HIIT	Maximal – cycle ergometer	VO_2peak	*28.2±6.1/34.3±5.2	*21.6%
Harris et al., 2014 (29)	SIT	Maximal – cycle ergometer	VO_2max	NR	NR
Hazell et al., 2014 (31)	SIT	Maximal – treadmill	VO_2max	NR	*8.7%
Higgins et al., 2016 (61)	SIT	Maximal – cycle ergometer	VO_2peak	*29.1±4.8/33.2±4.4	*14.1%
Kong et al., 2016 (a) (11)	SIT	Maximal – cycle ergometer	VO_2peak	*32.0±6.6/34.3±7.5	*7.2%
Kong et al., 2016 (b) (17)	SIT	Maximal – cycle ergometer	VO_2peak	*34.1±5.7/36.6±6.6	*7.3%
Mallol et al., 2020 (33)	HIIT	Maximal – treadmill	VO_2max	*R: 42.1±4.9/45.2±5.2 *C: 41.0±5.3/41.8±6.5	*R: 7.4% *C: 2.0%
Mazurek et al., 2014 (49)	SIT	Maximal – cycle ergometer	VO_2max	*36.2±7.2/41.7±7.1	*15.2%

Table 3. Cardiorespiratory fitness outcomes after high intensity interval training interventions

Study, year	Type	Assessment	Outcome measure	Results	
				Pre/post (mL·kg^{-1}·min^{-1})	Percent change
Mirghani et al., 2019 (62)	HIIT	NR	NR	NR	NR
Naves et al., 2018 (27)	SIT and HIIT	Maximal – cycle ergometer	VO_2peak	*SIT: 32.0±7.2/36.5±6.7 *HIIT: 37.7±7.2/42.1±5.5	*SIT:14.1% *HIIT: 11.7%
Nayebifar et al., 2016 (57)	HIIT	Maximal – treadmill	VO_2max	*33.4±0.0/48.9±0.0	*46.3%
Nie et al., 2019 (58)	SIT and HIIT	Maximal – cycle ergometer	VO_2max	*SIT: 26.2±4.4/35.2±5.8 *HIIT: 28.5±2.2/36.7±4.2	*SIT: 34.4% *HIIT: 28.8%
Panissa et al., 2016 (59)	HIIT	Submaximal – cycle ergometer	Predicted VO_2max	*26.5±7.3/34.8±10.5	*31.3%
Renteria et al., 2019 (50)	HIIT	NR	NR	NR	NR
Rowan et al., 2012 (68)	SIT	Maximal - treadmill	VO_2max	*50.7±3.52/52.7±3.2	*4.0%
Rowley et al., 2017 (63)	SIT	Maximal - treadmill	VO_2max	NR	NR
Sijie et al., 2012 (14)	HIIT	Maximal - treadmill	VO_2max	*33.3±3.9/36.1±3.1	*8.4%
Smith-Ryan et al., 2016 (10)	HIIT	Maximal – cycle ergometer	VO_2peak	1 min: 23.2±6.0/25.0±6.1 2 min: 25.0±5.8/27.3±6.0	1 min: 8.0% 2 min: 9.0%

Table 3. Cardiorespiratory fitness outcomes after high intensity interval training interventions

Study, year	Type	Assessment	Outcome measure	Results	
				Pre/post ($mL \cdot kg^{-1} \cdot min^{-1}$)	Percent change
Sun et al., 2019 (15)	SIT and HIIT	Maximal – cycle ergometer	VO_2peak	*SIT: 31.3±3.6/38.9±5.0 *HIIT: 31.5±2.2/39.9±4.7	*SIT: 24.3% *HIIT: 26.7%
Talanian et al., 2007 (67)	HIIT	Maximal – cycle ergometer	VO_2peak	*36.3±3.7/40.9±3.2	*12.7%
Tong et al., 2018 (66)	SIT and HIIT	Maximal – cycle ergometer	VO_2max	*SIT: 30.7±3.5/38.5±4.8 *HIIT: 30.2±4.4/34.3±4.6	*SIT: 25.4% *HIIT: 13.6%
Trapp et al., 2008 (51)	SIT	Maximal – cycle ergometer	VO_2peak	*28.8±2.1/36.4±2.5	*26.4%
Trilk et al., 2011 (64)	SIT	Maximal – cycle ergometer	VO_2max	*21.6±1.1/24.5±1.1	*13.4%
Walter et al., 2010 (65)	HIIT	Maximal – cycle ergometer	VO_2max	*30.5±5.8/35.4±5.4	*16.1%
Zeng et al., 2020 (43)	HIIT	NR	NR	NR	NR
Zhang et al., 2015 (5)	HIIT	Maximal - treadmill	VO_2max	*33.1±3.0/37.7±3.0	*13.9%
Zhang et al., 2017 (16)	HIIT	Maximal – cycle ergometer	VO_2max	*31.6±2.2/40.0±4.5	*26.6%

Note. All values are reported as mean±SD (standard deviation). * depicts a significant difference ($p<.05$) in pre and post measures. *NR* not reported, *SIT* sprint interval training, *HIIT* high intensity interval training, *LID* longer interval duration, *SID* shorter interval duration, *LV* low volume, *HV* high volume, *R* running, *C* cycling, *G60* group with 60 second intervals, *G30* group with 30 second intervals, *1 min.* group with 1 minute intervals, *2 min.* group with 2 minute intervals, VO_2max maximal oxygen consumption, VO_2peak peak oxygen consumption.

Table 4. Body composition outcomes after high intensity interval training interventions

Study, year	Type	Assessment	FM (pre/post)	FFM (pre/post)	BF% (pre/post)
Alves et al., 2017 (52)	HIIT	7-site skinfold	*LID: 20.4±7.5/18.8±7.3 *SID: 24.1±9.5/22.1±8.9	*LID: 37.0±7.1/39.5±6.1 *SID:37.9±9.6/40.2±9.7	NR
Arad et al., 2015 (60)	HIIT	DXA	39.3±7.7/38.5±8.9	50.3±6.5/50.6±6.2	45.4±3.7/44.5±4.0
Astorino et al., 2011 (71)	SIT	3-site skinfold	NR	NR	18.1±5.1/18.3±5.8
Astorino et al., 2013 (53)	HIIT	3-site skinfold	NR	NR	25.5±6.1/NR
Bagley et al., 2016 (30)	SIT	DXA	NR	NR	31.2±7.0/31.3±6.6
Bhati et al., 2017 (26)	HIIT	BIA	*LV: 15.7±4.5/15.1±3.7 *HV: 17.7±3.3/17.3±3.3	*LV: 32.1±2.5/33.6±2.5 *HV: 34.4±9.1/35.2±2.9	*LV: 32.3±5.8 *HV: 31.1±5.4
Brown et al., 2018 (47)	HIIT	DXA	NR	NR	36.2±6.1/35.0±6.5
Chidnok et al., 2020 (48)	HIIT	BMI	NR	NR	NR
Connolly et al., 2017 (54)	HIIT	ADP	24.3±11.6/24.0±13.2	42.5±4.2/42.3±4.1	35.0±9.1/33.9±10.0
Edge et al., 2006 (70)	HIIT	NR	NR	NR	NR
Eimarieskandari et al., 2012 (55)	HIIT	BIA	27.5±1.6/27.6±1.5	49.4±1.4/49.1±1.4	35.6±0.8/35.8±0.7

Table 4. Body composition outcomes after high intensity interval training interventions

Study, year	Type	Assessment	FM (pre/post)	FFM (pre/post)	BF% (pre/post)
Fereshtian et al., 2017 (69)	HIIT	NR	NR	NR	NR
Forbes et al., 2016 (23)	SIT	DXA	15.7±4.4/16.3±5.1	47.9±6.1/47.5±5.6	23.4±3.9/24.2±4.4
Ghasemi & Nayebifar, 2019 (56)	HIIT	3-site skinfold	NR	NR	*33.6±1.4/29.6±1.9
Gillen et al., 2013 (19)	HIIT	DXA	*30.3±7.9/29.7±7.9	43.5±8.2/44.1±7.8	*40.9±5.8/40.1±5.4
Harris et al., 2014 (29)	SIT	BMI	NR	NR	NR
Hazell et al., 2014 (31)	SIT	ADP	*15.1±3.6/13.9±3.4	*45.7±3.5/46.3±2.9	*24.7±4.9/23.0±4.6
Higgins et al., 2016 (61)	SIT	DXA	*33.7±7.9/32.5±7.1	NR	*42.4±4.8/41.2±4.8
Kong et al., 2016 (a) (11)	SIT	DXA	24.6±5.9/24.9±5.4	24.3±2.6/24.6±2.7	35.2±4.0/35.4±3.4
Kong et al., 2016 (b) (17)	SIT	DXA	25.3±6.0/26.0±6.4	NR	36.7±4.8/37.4±5.6
Mallol et al., 2020 (33)	HIIT	NR	NR	NR	NR
Mazurek et al., 2014 (49)	SIT	BMI	NR	NR	NR

Table 4. Body composition outcomes after high intensity interval training interventions

Study, year	Type	Assessment	FM (pre/post)	FFM (pre/post)	BF% (pre/post)
Mirghani et al., 2019 (62)	HIIT	7-site skinfold	NR	NR	*G30: 41.8±0.7/41.2±0.7 *G60: 40.9±0.8/40.4±0.9
Naves et al., 2018 (27)	SIT and HIIT	BMI	NR	NR	NR
Nayebifar et al., 2016 (57)	HIIT	3-site skinfold	NR	NR	*55.5±1.4/41.3±3.0
Nie et al., 2019 (58)	SIT and HIIT	BIA	*SIT: 25.2±6.7/22.9±6.8 *HIIT: 24.3±3.8/19.9±4.1	NR	*SIT: 33.4±3.7/31.5±4.4 *HIIT: 33.4±2.8/30.0±3.5
Panissa et al., 2016 (59)	HIIT	7-site skinfold	*21.4±7.8/19.4±7.7	*38.1±7.7/40.5±6.6	*30.4±6.2/27.5±6.2
Renteria et al., 2019 (50)	HIIT	BIA	NR	NR	27.4±4.5/27.7±4.1
Rowan et al., 2012 (68)	SIT	NR	NR	NR	NR
Rowley et al., 2017 (63)	SIT	DXA	NR	NR	*44.6±4.1/42.9±4.0
Sijie et al., 2012 (14)	HIIT	DXA	NR	NR	*40.6±4.0/36.6±4.3
Smith-Ryan et al., 2016 (10)	HIIT	DXA	SIT: 35.5±10.1/33.4±9.3 HIIT: 31.7±7.5/31.0±6.8	SIT: 56.0±5.7/57.9±5.7 HIIT: 51.1±5.5/53.5±5.8	SIT: 38.2±5.6/36.0±5.0 HIIT: 37.9±3.7/36.4±3.1

Table 4. Body composition outcomes after high intensity interval training interventions

Study, year	Type	Assessment	FM (pre/post)	FFM (pre/post)	BF% (pre/post)
Sun et al., 2019 (15)	SIT and HIIT	BMI	NR	NR	NR
Talanian et al., 2007 (67)	HIIT	NR	NR	NR	NR
Tong et al., 2018 (66)	SIT and HIIT	DXA	*SIT: 25.7±3.5/23.7±3.3 *HIIT: 26.6±6.1/23.8±5.0	NR	SIT: 38.4±2.3/38.2±2.4 HIIT: 38.2±2.4/38.2±2.4
Trapp et al., 2008 (51)	SIT	DXA	NR (p<0.05)	NR	NR
Trilk et al., 2011 (64)	SIT	NR	NR	NR	NR
Walter et al., 2010 (65)	HIIT	ADP	NR	*47.6±4.8/48.3±5.2	*29.3±5.7/28.1±5.7
Zeng et al., 2020 (43)	HIIT	BIA	*21.6±2.7/11.9±1.4	*49.5±5.3/53.7±6.1	*30.3±0.8/22.2±1.3
Zhang et al., 2015 (5)	HIIT	BIA	*19.4±5.9/17.5±4.8	NR	*31.3±3.6/28.2±3.9
Zhang et al., 2017 (16)	HIIT	DXA	*25.7±3.3/22.9±3.1	NR	*38.1±2.3/35.6±2.0

Note. All values are reported as mean±SD (standard deviation). * depicts a significant difference (p<.05) in pre and post measures. *NR* not reported, *SIT* sprint interval training, *HIIT* high intensity interval training, *LID* longer interval duration, *SID* shorter interval duration, *LV* low volume, *HV* high volume, *G60* group with 60 second intervals, *G30* group with 30 second intervals.

CHAPTER IV: DISCUSSION

To our knowledge, this is the first literature review focusing on the effects of HIIT on CRF and body composition, specifically in women. The review included 41 studies involving a total of 628 female subjects who were predominantly younger (18-35 years of age) and overweight (BMI ranging from 20.3-35.7 $kg\cdot m^{-2}$). Firstly, the results suggest that HIIT exercise interventions significantly improve CRF in women, irrespective of age, training status, BMI, and training frequency. However, exercise intervention duration in conjunction with the intensity of exercise may influence the effect of HIIT on CRF. Secondly, results revealed that the effect of HIIT on body composition is less clear. Nonetheless, these findings have implications for optimizing HIIT exercise interventions specific to women.

Cardiorespiratory Fitness

There is a growing body of literature that supports HIIT and SIT as time-efficient, exercise interventions that can produce similar, or in some cases superior, training adaptations in comparison to conventional endurance training (28, 34). This review corroborates previous research showing that HIIT is effective for enhancing CRF within the female population. Over 90% (n = 34) of the reviewed studies that analyzed the effect of HIIT on CRF showed significant improvements. Although the remaining studies (n = 3 (10, 60, 69)) reported no significant changes, they revealed patterns that could potentially explain differences in intervention characteristics responsible for influencing improvements in CRF.

Relationship Between Intervention Duration and Exercise Intensity

A study conducted by Smith-Ryan et al. (10) used a three week HIIT intervention (3x per week) in an attempt to improve cardiometabolic risk factors in sedentary, overweight/obese women (BMI between 28.6±3.7 and 33.9±6.1 $kg\cdot m^{-2}$). Women were separated into one of three groups: 1) 10 repetitions of 1 minute bouts at 90% VO_2peak, followed by 1 minute of active recovery, 2) 5 repetitions of 2 minute bouts between 80-100% VO_2peak, followed by 1 minute of active recovery, or 3) a control group. While VO_2peak increased slightly after the nine exercise sessions for both the 1- and 2-minute groups, the magnitude of change was not significant for either group. Similarly, Arad et al. (60) conducted a 14-week intervention using sedentary, obese (BMI 32.5±3.6 $kg \cdot m^{-2}$) subjects. While the intervention duration was determined to be 14 weeks, only 50% of the weeks involved sessions that were considered *high-intensity*; therefore, the true length of the HIIT intervention was only seven weeks. For the high-intensity portion of the intervention, subjects completed four, 60 second intervals on a cycle ergometer at 90% HRR, followed by 3 minutes of active recovery. Similar to the results of Smith-Ryan et al. (10), VO_2peak increased as a group, but the results were not statistically significant. Yet, preceding studies (14, 16, 43, 58, 66, 72) using comparable training intensities to the aforementioned studies (10, 60) have been conducted, all reporting significant improvements in VO_2max or VO_2peak. However, these studies implemented training interventions that were all 12 weeks in length. Thus, it is plausible to infer that in order to augment VO_2max or VO_2peak using a training intensity that does not exceed 100% VO_2peak or 90% HRR, training duration must exceed 7 weeks.

Inversely, if shorter training interventions (≤7 weeks) are utilized, significant improvements in VO_2max or VO_2peak can occur, given the appropriate intensity. With the exception of Smith-Ryan et al. (10) and Arad et al. (60), all studies included that used short interventions (11, 17, 23, 29, 64, 68, 70, 71) showed significant improvements in CRF, using supramaximal intensities (e.g. SIT). Moreover, the exercise bouts within each study included maximal effort sprints or intensities defined as “supramaximal,” exceeding 100% VO_2max workload. Accordingly, training intervention duration is not the only variable that can influence the effect of HIIT on CRF, as the accompanying intensity must be suitable to elicit significant improvements.

Previous research has provided a wide range of variables for use in prescribing exercise intensities during HIIT (e.g. %VO_2max, %HRR, %HR_{max}, METs, RPE), that lead to further improvements in VO_2max. However, there are still some measures that have been questioned. An individual's velocity at VO_2max (i.e. vVO_2max) represents the minimum running velocity required to achieve maximal oxygen uptake (69). Previous literature has suggested that training at a certain percentage of an individual's vVO_2max is a highly effective training method to improve markers of athletic performance, such as running efficiency (41, 74). While HIIT performed using this marker of intensity has been shown to improve *performance* for numerous athletes, using this intensity marker may not necessarily contribute to improvements in VO_2max (74). Thus, using this as the intensity marker when creating a HIIT may not be beneficial if the goal is to improve CRF.

One study in the current review utilized vVO_2max as the prescribed marker of intensity. Fereshtian et al. (69) used trained female speed skaters as subjects. They were separated into one of three HIIT groups, who performed 10, 60 second bouts of exercise at either 100%-, 115%- or 130%-vVO_2max, three times per week for three weeks. Significant improvements in VO_2max were only seen in groups exercising at 100%- and 115-vVO_2max; there was no change in VO_2max in the group training at 130%-vVO_2max.

Although it seems the strenuous nature of all supramaximal intensities should result in significant improvements in VO_2max, there may be an optimal intensity that is necessary to augment VO_2max, and exceeding this may lead to unexpected results. Accordingly, research generating a more clear understanding of the critical velocity at which improvements in VO_2max cease to occur is necessary.

Body Composition

Energy Expenditure and Fat Mass

While HIIT and SIT have certainly been supported as suitable interventions to augment CRF (13), the effectiveness of these protocols on changes in FM still remains unclear. Research on more common exercise protocols (e.g. MICT) has dependably shown facilitations in the reductions of total body weight and FM (30, 75). However, both training volume (product of frequency, intensity, and time (13)) and dietary consumption are constituents to inducing significant improvements for both variables (75). Consequently, it is difficult to predict whether reductions in FM would be as consistent within HIIT and SIT protocols, as training volumes are inconsistent.

Previous exercise programs, such as MICT, that have *not* controlled dietary consumption, but have seen significant changes in total body weight and FM, have greatly exceeded the public health recommendations for levels of physical activity (30, 75). When considering the physical activity recommendations, the minimum guideline of 150 minutes per week equates to about 500 MET-minutes per week in regard to energy expenditure (22). Current exercise recommendations suggest exceeding 1000 MET-minutes per week to promote significant loss of total body weight or FM (22). Therefore, regardless of the vast HIIT and SIT training volumes, it is possible to determine the effectiveness of these interventions on changes in FM, by considering such terms of energy expenditure.

A recent meta-analysis of 47 studies involving 634 men and 749 women, suggests that HIIT protocols did not provide significant reductions in total body mass or FM, or increases in

FFM when compared to a non-exercising control or MICT group (22). However, all HIIT protocols within the study were considered “low-volume”, defined as energy expenditure ≤500 MET-minutes per week. Therefore, it is not unexpected that weight loss was not achieved, as energy expenditure did not exceed the minimum requirements. These results are supportive of current exercise recommendations that suggest exceeding 1000 MET-minutes per week to promote significant loss of total body mass or FM (22).

Within the current review, 12 studies determined significant reductions in FM (5, 16, 19, 26, 31, 43, 51, 52, 58, 59, 61, 66) irrespective of caloric restrictions. Several of these studies substantiate that energy expenditure exceeding 500 MET-minutes per week, without alterations in caloric intake, can induce significant decreases in FM. For example, Zhang et al. (16) implemented a 12-week HIIT intervention that resulted in significant reductions in FM. The intervention included four training sessions per week, which included cycling at 90% VO_2max for four minutes, followed by three minutes of passive recovery; this interval was repeated until reaching 200-300 kJ. The average energy expenditure was 49.8±4.2 MET-hours per week or ~3000 MET-minutes per week. Zhang et al. (5) and Tong et al. (66) also reported average energy expenditures which greatly exceeded the recommended 500 MET-minutes per week (or ~8.3 MET-hours per week) necessary to induce fat loss (HIIT: 84.4±14.6 MET-hours per week and HIIT: 79.7±15.7 MET-hours per week; SIT: 51.1±5.4 MET-hours per week, respectively). Expectedly, both studies revealed significant decreases in FM. Although reported in disparate units, Trapp et al. (51) assessed energy expenditure with an average of 834.5±11.3 kJ per *session*. This value was converted into MET-minutes per week in order to equate for energy expenditure in comparable units. Although an estimate, it was determined that subjects surpassed the minimum criterion to induce reductions in FM. Numerous studies did not report data pertaining to energy expenditure; however, with similar interventions and subject samples (comparable age and BMI), one could postulate that similar energy expenditure was achieved. It is critical for future researchers to identify total energy expenditure during HIIT sessions to further equate for this notion.

When assessing subject characteristics within this review, all 12 studies that accounted for reductions in FM identified subjects as either sedentary or only participating in two structured physical education courses twice per week. Because data only pertains to mostly sedentary individuals, generalizability of the data is limited. Additionally, the losses in FM may be attributable to greater FM levels at baseline. In conclusion, while exceeding 500 MET-minutes per week may equate to losses in FM, there is no guarantee that this reason alone could account for all reductions in FM across all populations.

Another possible explanation for a decrease in FM with HIIT is an increase in excess post-exercise oxygen consumption (EPOC) (59). During exercise, there is an increased demand for oxygen uptake (VO_2) in order to support an increase in energy expenditure (76, 77). However, after exercise, VO_2 does not immediately return to resting (pre-exercise) levels and may remain elevated for a period of time (76, 77). Once exercise ceases, the body must restore (or recover) itself to a pre-exercise state, which continues to require a higher level of energy expenditure and therefore, an increased consumption of VO_2; this continued need for increased oxygen consumption is referred to as EPOC (77). Prolonged elevated VO_2 levels and extended energy demands contribute to the body burning additional calories while at rest (43). While the increase in calories burned could account for either carbohydrates or fats, previous research has found that lipids (fats) are the main energy substance of EPOC after exercise (43).

Furthermore, after high intensity or exhaustive exercise, there is a greater shift from carbohydrates to fat as a fuel or substrate (43). This means an increase in post-exercise fat-oxidation following HIIT could explain decreases in FM (43). A recent study determined that both HIIT and SIT protocols produced greater post-exercise fat loss per unit of energy expenditure when compared to MICT (78). Additionally, research has determined a positive, linear correlation between exercise intensity and EPOC; exercising at a higher intensity promotes a more substantial and extended EPOC (43). Therefore, after HIIT protocols, it is expected to see a more pronounced effect on EPOC, with higher intensities requiring more energy to restore the body to pre-exercise levels. Thus, FM losses could partially be attributable to the increased oxygen consumption and energy expenditure after the termination of exercise.

Lastly, untrained individuals, in comparison to their trained counterparts, have a slower return of VO_2 to resting levels after exercise when working at the same relative rates (77). Slower rates of recovery prolong the duration of EPOC (77). As previously mentioned, all 12 studies (5, 16, 19, 26, 31, 43, 51, 52, 58, 59, 61, 66) that reported reductions in FM included untrained subjects. Therefore, it is plausible that EPOC was extended within these subjects and could have produced greater losses in FM.

Energy Intake and Fat Mass

While it is beneficial to account for energy expenditure, it is equally important to consider energy (caloric) intake. It has been suggested that when looking to reduce FM, dietary restrictions alone prove to be more effective than exercise interventions (79). Moreover, adjustments to diet are more influential towards weight loss (79), and exercise interventions facilitate weight maintenance and improvements in muscular strength and endurance (13, 80). In the several studies that failed to report significant reductions in FM (10, 11, 17, 23, 54, 55, 60), it is possible that an increase in caloric intake following exercise could account for the failure to significantly reduce FM. Previous research has indicated that given a progressive increase in exercise in *sedentary* populations, there is generally an enhanced appetite, and therefore an increase in caloric intake (47, 53). One common variable across all studies that did not report reductions in FM were physical activity characteristics is that all subjects were sedentary. Thus, without controlling for diet within this population, it is reasonable to assume reductions in FM will be limited.

Fat Free Mass

Despite the fact that caloric restriction has been shown to be an effective weight loss strategy that can combat excessive fat accumulation and lead to obesity (51, 62), the main focus of adjusting caloric intake is to decrease total body weight and FM. While focusing on a reduction in total body weight is, at times, beneficial, it can also be problematic (5, 81), as losses in total body weight can also lead to substantial reductions in FFM. It is well documented that detriments in skeletal muscle mass, one constituent of FFM, can lead to decreased functional performance, mobility and independence over time (13). Therefore, researchers have suggested that supplementing dietary restrictions with exercise interventions is essential, as exercise contributes to not only decrease in FM, but improvements in FFM. Additionally, exercise interventions often focus on changing body *composition* (decreasing FM and increasing FFM), rather than merely reducing total body weight, which is more effective for managing obesity and reducing associated risk factors such as CVD, glucose intolerance, and type-II diabetes (22, 81).

Of the 13 studies (10, 11, 19, 23, 26, 31, 43, 52, 54, 55, 59, 60, 65) that examined changes in FFM, less than 50% (26, 31, 43, 52, 59, 65) reported significant increases in FFM after HIIT interventions. Zeng et al. (43) expressed that rate of change in FFM was significantly greater within the first six weeks, compared to the final six weeks of a 12 week intervention. This suggests that HIIT interventions exceeding six weeks may be unable to progressively provide improvements in FFM and will show a gradual reduction in the rate of change over time. The aforementioned studies that reported significant changes in FFM (26, 31, 52, 59, 65) were only six weeks in duration, so it is plausible that including additional weeks within each intervention may pose the same results. Therefore, with continued use of HIIT, it would be beneficial to complement these interventions with resistance training (RT), as it is well-document that RT is attributable to considerable improvements in skeletal muscle mass (13), particularly in comparison to aerobic-based exercise.

Body Fat Percentage

Of the 12 studies that revealed reductions in FM (5, 16, 19, 26, 31, 43, 51, 52, 58, 59, 61, 66), all but two (51, 52) also assessed BF%. Studies that assessed both found reductions in FM, accompanied by decreases in BF%, with the exception of one (66). While it may seem evident that losses in FM may account for fluctuations in BF%, total body weight is also a constituent of BF% and therefore, must be considered (82). Total body weight is effected by not only FM, but FFM (82). Accordingly, decreases in FFM may offset reductions in BF% (82). Subject’s in Tong et al. (66) had reductions in FM, but BF% was unchanged. This could be attributable to losses in FFM, but data surrounding FFM was not presented in the study. It is well-recognized that reductions in total body weight can occur from participation in aerobic-based exercise training; inevitably a proportion of weight loss can be from reduction in FFM (82), again, emphasizing the importance of performing RT together with aerobic exercise (13).

CHAPTER V: CONCLUSION

Although the number of publications surrounding HIIT has increased, studies generally focus much on supporting this protocol as effective for augmenting CRF and body composition and less frequently concentrate on identifying the moderating variables that could further improvements, or conversely, limit them. Because manipulation of these moderating variables has not been sufficiently studied yet, if is difficult to determine whether all HIIT protocols would benefit everyone equally. To our knowledge, this is the first review of literature examining the effects of HIIT on CRF and body composition in women, specifically. Moreover, this is the first review that took into consideration how manipulation of numerous variables could influence the effect of HIIT on the aforementioned components of physical fitness.

The current review suggests that HIIT can significantly improve CRF in women, irrespective of age, training status, BMI, and training frequency. However, the duration of the exercise intervention, in conjunction with the appropriate intensity of exercise may influence the effect. Moreover, HIIT interventions that are shorter in duration (≤7 week) should utilize supramaximal intensities to elicit improvements in CRF, while using intensities ranging from 85-95% VO_2max are sufficient to augment CRF in interventions exceeding 7 weeks. Because lack of time is a common barrier to exercise for women, this type of exercise protocol appears to be a suitable alternative to traditional MICT when aspiring to enhance CRF and overall health.

The effect of HIIT on body composition in women is still equivocal. EPOC and/or energy expenditure greatly exceeding 500 MET-minutes per week may account for reductions in FM. However, there is no guarantee that these reasons alone account for all reductions. It has been proposed that HIIT alone, without dietary restrictions, may not elicit significant reductions in FM

(31, 83). Nevertheless, while most studies instructed participants to maintain daily dieting habits, the possibility that some individuals altered there nutritional intake cannot be ignored.

There were improvements in FFM across very few (*n* = 6) studies. It is well-documented that the change in FFM following RT are significantly greater than after aerobic exercise (51). As an aerobic based training protocols, HIIT is structured more so to alter CRF and assist with reductions in total body weight. Inevitably, a proportion of weight lost during aerobic exercise (e.g. HIIT), can be attributable to not only reductions in FM, but also FFM, especially if performed exclusive of exercise focusing on muscular maintenance gains (e.g. RT) (5, 81). Therefore, individuals are recommended to complement HIIT interventions with RT to further increase musculature (51). Additionally, future studies may want to consider controlling for diet more thoroughly, as previous research has identified that the combination of diet and exercise are supportive of not only weight loss, but preserving muscle mass and therefore, improving body composition (e.g. BF%) (17).

While studies may support HIIT as an effective intervention, it can be challenging to introduce such a vigorous exercise protocol to inactive individuals (17). Several theories (e.g. self-determination theory, achievement motivation theory) contend that high levels of motivation are necessary for regular participation in exercise (84). Non-athletes and sedentary populations generally feel less competent and insecure in regard to exercise, and are therefore less likely to invest effort into exercise programs (84). Nevertheless, if these subgroups are initially willing to participate, research still notes that adherence to HIIT within non-athlete and sedentary populations is quite low (17). This could be explained by the vigorous intensity; typically, with the increased exercise intensity, there is a decrease in adherence to exercise (22). Therefore, regardless of its time-efficient methods, HIIT may not be a feasible protocol for all subgroups of women.

Furthermore, outcomes beyond the supervised visits within the laboratory are unknown (22). Within the laboratory, subjects are held accountable with supervised training sessions and are more likely to adhere to the target intensity and frequency, as researchers assure these criteria are being met. This could mean that there is low ecological validity in reference to HIIT. Future studies should consider examining home-based or unsupervised protocols to establish whether or not similar improvements can be observed outside of a laboratory setting.

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