BRIEF INTENSE STAIR CLIMBING AND CARDIORESPIRATORY FITNESS

EFFECT OF BRIEF INTENSE STAIR CLIMBING ON CARDIOMETABOLIC HEALTH

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LAY ABSTRACT

Sprint interval training (SIT), involving brief bouts of very intense exercise separated by short periods of recovery, is a time-efficient alternative to traditional endurance training for improving fitness. This has largely been established in laboratory settings using specialized equipment, which is impractical for many individuals. This project examined whether brief intense stair climbing was a practical model of SIT to elicit adaptations previously shown with cycling protocols. Subjects performed either three 20-s ascents interspersed with 2 min recovery periods, or three 60-s bouts of ascending and descending one or two flights of stairs, with 60-s recovery periods. Both protocols were 10 min in duration including warm-up and cool-down, and subjects trained three days per week for six weeks. The main finding was that stair climbing is a practical, time-efficient model to improve fitness in previously sedentary individuals.

ABSTRACT

Sprint interval training (SIT) is a time-efficient strategy to improve cardiorespiratory fitness; however, most protocols have been studied in a laboratory setting and require specialized equipment. We investigated the efficacy of brief intense stair climbing as a practical model of SIT to improve cardiometabolic health, with a key measure being cardiorespiratory fitness as indicated by peak oxygen uptake (VO_{2peak}). Two separate studies, each consisting of an acute and chronic phase, were conducted in a total of 31 sedentary women (age=24±10 y; BMI=23±4 $kg \bullet m^{-2}$). The acute phase of Study 1 established that the heart rate (HR), blood lactate concentration (BLa), and rating of perceived exertion (RPE) responses were similar when participants (n=8) performed a SIT protocol that involved 3x20-s "all-out" efforts of either continuous stair climbing or cycling, interspersed with 2 min of recovery. The chronic phase demonstrated that when participants (n=12) performed the 3x20-s stair climbing protocol 3 $d \bullet wk^{-1}$ for 6 wk, absolute and relative VO_{2peak} increased by 12%, or ~1 metabolic equivalent (1.80±0.25 to 2.02±0.27 $L \bullet min^{-1}$, $p<0.001$), as there were no changes in body mass (p=0.35), fat free mass (FFM; p=0.09) or % body fat (p=0.42). There were also no changes in resting systolic and diastolic blood pressure (BP; p=0.82 and p=0.97, respectively), resting HR (p=0.62), and fasting insulin sensitivity (p=0.52). The acute phase of Study 2 established that the HR and RPE responses were similar when participants (n=11) performed three different stair climbing protocols. The protocols investigated include the 3x20-s continuous ascent model used in Study 1 (protocol 1), as well as 3x60-s bouts of ascending and descending either one or two flights of stairs, with 60-s of recovery (protocol 2 and 3, respectively). The

chronic phase demonstrated that when the same group of subjects performed the 3x60-s 1-flight protocol 3 d•wk^{-1} for 6 wk, absolute and relative VO_{2peak} increased by 8 and 7%, respectively (1.79±0.36 to 1.93±0.39 L•min^{-1}, p=0.001; 31.2±4.6 to 33.3±5.3 mL•kg^{-1}•min^{-1}; p=0.01). Despite no changes in % body fat (p=0.10), there was an increase 3% increase in FFM (p<0.001). There was no change in systolic (p=0.50) and diastolic BP (p=1.00), but resting HR improved by 8% after training (p=0.03). The change in insulin sensitivity derived from an OGTT was 7.1±11 mg I^2•mmol^{-1}•mIU^{-1}•min^{-1} (p=0.056). These findings demonstrate that brief intense stair climbing is a practical, time-efficient strategy to improve cardiorespiratory fitness in previously untrained women.

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LIST OF ABBREVIATIONS

AMPK	5’ AMP-activated protein kinase
ATP	adenosine triphosphate
AUC	area under the curve
BMI	body mass index
BP	blood pressure
DBP	diastolic blood pressure
FG	fasting glucose
FI	fasting insulin
GLUT4	glucose transporter 4
HIIT	high-intensity interval training
HOMA	homeostatic model assessment
ISI	insulin sensitivity index
MAP	mean arterial blood pressure
MET	metabolic equivalent
MICT	moderate-intensity continuous training
MPO	mean power output
OGTT	oral glucose tolerance test
PPO	peak power output
RPE	rating of perceived exertion
SBP	systolic blood pressure
SIT	sprint interval training
VO_{2peak}	peak volume of oxygen consumption

PREFACE
DECLARATION OF ACADEMIC ACHIEVEMENT

FORMAT AND ORGANIZATION OF THESIS

This thesis is prepared in the standard format as outlined in the School of Graduate Studies' Guide for the Preparation of Theses. It includes a literature review (general introduction) chapter with well-defined sections, followed by a second chapter which contains the research results (two separate studies, each with an acute and chronic phase) and discussion, along with a summary statement of the results of the investigation.

CONTRIBUTIONS TO CONTENT OF THESIS

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Contribution:

M.K. Allison, B.J. Gurd and M.J. Gibala designed the study. J. Miranda, C. Murphy, N. Preobrazenski, S. Graves, and C. Leblanc were involved in data collection for the acute phase of Study 1. M.K. Allison, J.H. Baglole, B.J. Martin, and M.J. MacInnis were involved in data collection for the chronic phase of Study 1 and the acute and chronic phase of Study 2. M.K. Allison, J.H. Baglole, and B.J. Martin completed data analyses. M.K. Allison, B.J. Gurd and M.J. Gibala interpreted the results of experiments. M.K. Allison drafted the manuscript, with input from M.J. Gibala and all other authors.

CHAPTER 1:

Review of Literature

1.1 Introduction

Regular exercise is an effective therapeutic intervention for the prevention and treatment of many cardiometabolic diseases (1,2). Traditional endurance training improves many health indices including cardiorespiratory fitness (3), blood pressure (4), glucose homeostasis (2) and body composition (5). Cardiorespiratory fitness in particular is a strong and independent risk factor for cardiovascular disease and all-cause mortality (6), with unfit individuals having twice the risk of death as their fit counterparts, regardless of body composition (7,8). Current physical activity guidelines typically recommend at least 150 minutes of weekly moderately-intense exercise or 75 minutes of vigorous activity to improve health (5,9).

The health benefits of regular aerobic exercise are widely recognized, yet less than 15% of North American adults meet the physical activity guidelines (10,11). One of the largest perceived barriers in this regard is "lack of time" (12,13). Owing in part to the general lack of adherence to current physical activity guidelines, there has been a renewed interest in the potential for time-efficient interval training to elicit physiological adaptations that promote health (14–20). Traditional aerobic or endurance exercise typically involves 30-60 minutes of moderate-intensity continuous training (MICT) with target intensities of 64-76% of heart rate (HR) (5). In contrast, interval exercise involves alternating periods of relatively intense efforts with periods of lower intensity or complete rest for recovery (19). High-intensity interval training (HIIT) typically refers to protocols that include bouts of 'near-maximal' effort, with target intensities of 80-100 % of maximal heart rate (19,20), whereas sprint interval training (SIT) refers to 'supramaximal' efforts in which the

workload exceeds that what is required to elicit 100% of maximum oxygen uptake or which are performed in an 'all-out' manner (19,20). Examples of MICT, HIIT and SIT protocols are shown in Figure 1.

SIT is the most time-efficient alternative to endurance training that improves cardiometabolic health (18,20,21); however, most protocols have been studied in a laboratory setting and require specialized equipment, which is impractical for many individuals. Research is needed to determine whether more accessible modes of SIT are also effective and well-tolerated. Stair climbing offers the potential for SIT to be taken out of the lab and applied to a practical real-world setting. Stair climbing is likely to be an effective mode of SIT because it can elicit a strong cardiorespiratory response (22,23), and accumulating 30-70 minutes of weekly stair climbing in short bouts has been shown to improve indices of cardiovascular health (24–26). Furthermore, total stairs climbed each week independently predicts longevity (27), and public health physical activity initiatives are effective when they are lifestyle based (28). The purpose of this literature review is threefold: (1) to explore the physiological adaptations responsible for cardiorespiratory and glycemic improvements with SIT; (2) to examine these cardiorespiratory and glycemic adaptations in low-volume SIT; and (3) to consider stair climbing as a practical alternative to cycling-based SIT.

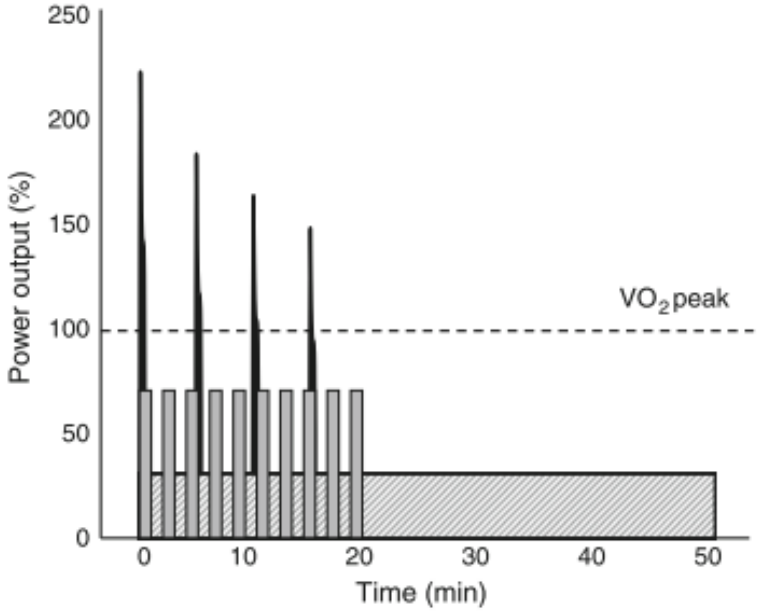

Figure 1. Example of MICT, HIIT and SIT. Protocols are 50 min at 70% maximum heart rate (MICT, hashed box); 4x30 s "all-out" efforts (SIT, black bars); and 10x60 s efforts at ~90% of maximum heart rate (SIT, grey bars). From Gibala et al. (19).

1.2 Effect of SIT on cardiorespiratory fitness and glycemic control

1.2.1 Cardiorespiratory fitness

Cardiorespiratory fitness refers to the capacity of the circulatory and respiratory systems to supply oxygen to metabolically active tissues, as well as the ability of the tissue to extract and use the oxygen for cellular respiration. The gold standard measure for assessing cardiorespiratory fitness is a peak oxygen uptake test (VO_{2peak}). Low cardiorespiratory fitness has greater consequences than hypertension, smoking, obesity and hyperlipidemia in terms of risk for adverse health outcomes (29), and those with preexisting disease can reduce risk of clinical events by improving their fitness (5,30). The physical activity guidelines recommend either moderate- or vigorous-intensity exercise for improving health, provided that approximately 1000 kcal are expended each week (5).

These recommendations suggest that the total amount of exergy expended is more important than exercise intensity; however, when exercise is matched for total work, higher intensity exercises confer larger improvements in cardiorespiratory fitness (31–33). This is evidenced by recent findings by Ross et al. (34), who found that expending approximately 1200 kcal/week at a moderate-intensity (*i.e.*, 50% of VO_{2peak}) may not be sufficient to improve cardiorespiratory fitness for a substantial portion of sedentary adults. Furthermore, for the same energy expenditure, higher intensity exercise (*i.e.*, 75% of VO_{2peak}) had a greater effect for improving VO_{2peak} than moderate-intensity exercise (34).

1.2.1.1 Efficacy of SIT for improving cardiorespiratory fitness

SIT interventions have been shown to rapidly improve cardiorespiratory fitness with significant increases occurring within 6-9 sessions over 2-3 weeks (35–39); although, not all studies show such rapid improvement (40,41). A recent meta-analysis by Sloth et al. (18) concluded that despite the reduced volume of work, there is strong evidence to support the efficacy of SIT for improving VO_{2peak}. Weston et al. (20) further analyzed the various SIT protocols and subject characteristics and found that the adaptive effect of interval training favours those who are less fit, and a mean protocol of 13 sessions with a work to rest ratio of 0.16 can elicit moderate improvements in both sedentary and recreationally active individuals. In another meta-analysis, Gist et al. (42) compared the improvements of SIT and MICT and found that they are equally effective for improving VO_{2peak}, citing a collective improvement of 3.6 mL/kg/min or 8% within 2-6 weeks of training. A collection of SIT interventions involving bouts of 30 s or less are shown in Table 1 of Appendix 1. These results may be important from a clinical perspective given

that a higher VO_{2peak} of 1 metabolic equivalent (1 MET = 3.5 mL $O_2 \bullet kg^{-1} \bullet min^{-1}$) has been associated with a 13% and 15% risk reduction of all-cause mortality and cardiovascular disease, respectively (6). Furthermore, these decrements in risk of all-cause mortality and cardiovascular disease are comparable to a 7-cm, 5-mmHg, and 1 mM decrease in waist circumference (43), systolic blood pressure (44), and fasting plasma glucose (45), respectively (6).

1.2.1.2 Central adaptations to SIT

Current knowledge of the cardiovascular adaptations to aerobic exercise have mostly been based on classic endurance training; nevertheless, there is likely a combination of central (*i.e.*, oxygen delivery) and peripheral (*i.e.*, oxygen extraction) adaptations leading to the improvements in cardiorespiratory fitness with SIT (46). During aerobic exercise, whole-body oxygen consumption (*i.e.*, VO_2) increases proportionately to exercise intensity in order to meet the energy demand of metabolically active tissues, primarily skeletal muscle. Acutely, the cardiovascular system substantially increases cardiac output (more than fivefold) through heart rate and stroke volume to increase delivery of oxygen to skeletal muscle so that it may be used by mitochondria, the cell's energy powerhouse.

It is generally thought that increases in VO_{2peak} following MICT are primarily a result of central adaptations (47,48). Aerobic training increases peak cardiac output largely through alterations in cardiac structure and hypervolemia (49–51). The repeated forceful contractions and "volume load" (*i.e.*, venous return and cardiac output) placed on the heart during endurance training leads to left ventricular hypertrophy and an increased end-diastolic volume (52). These adaptations are responsible for the larger stroke volume and

lower resting heart rate seen in endurance trained athletes, as resting cardiac output remains unchanged (49). A higher stroke volume following training is also the result of hypervolemia (51,53) which increases the venous return and thus the pre-load of diastolic ventricular filling (54). Within the first 2-4 weeks of training, hypervolemia is primarily a result of plasma volume expansion, which can increase within 4 days of beginning an endurance training program (51). After this time, further blood expansion is distributed more equally between plasma and red blood cell volumes (51).

The cardiovascular adaptations strictly associated with HIIT and especially SIT have not been as thoroughly investigated as compared to MICT. Warburton et al. (54) demonstrated that relatively high volumes of HIIT elicit a similar increase in blood and stroke volume as MICT when controlled for total work, with blood volume accounting for approximately 30% of the improvement in VO_{2peak}. Although plasma volume increased within 1 week of training, red blood cell volume did not increase until week 6 for SIT and MICT, suggesting interval and continuous training lead to similar hemodynamic adaptations (54). These results align with Esfandiari *et al.* (55), who found that 2 weeks of HIIT and MICT led to similar improvements in end diastolic volume, stroke volume, and cardiac output. Conversely, several studies have failed to observe an increase in peak cardiac output following SIT and HIIT (56,57). It has been suggested that SIT-induced improvements in VO_{2peak} may be mediated by peripheral factors that enhance oxygen extraction (18).

1.2.1.3 Peripheral adaptations to SIT

One of the best characterized adaptations within skeletal muscle following SIT is increased mitochondrial content. As little as six sessions of SIT can increase mitochondrial content as evidenced by increases in the maximal activity and protein content of mitochondrial enzymes including citrate synthase and complex IV (14,40,57–60). The increase in mitochondrial content was also associated with an increase in mitochondrial respiratory capacity using permeabilized fibres (57). SIT also increases the capillary-to-muscle fibre ratio which may improve oxygen extraction (61,62). A recent study has demonstrated that SIT acutely increases vascular endothelial growth factor mRNA, a regulator of angiogenesis, similar to MICT (63). Cocks et al. (64,65) have provided evidence demonstrating capillary density is increased after 4 and 6 weeks of SIT, respectively. Furthermore, Macpherson *et al.* (56) reported an increased arterial-venous oxygen difference following 6 weeks of SIT, but not MICT, in recreationally active men and women. Although these data suggest oxygen extraction can be increased with SIT, previous work suggests improved oxygen utilization only accounts for a small fraction of the difference in VO_{2peak} between athletes and sedentary individuals (3).

1.2.2 Glycemic Control

Exercise influences glycemic control (66,67), as skeletal muscle comprises 30-40% of body mass (68), and is the primary disposal site for ingested glucose (69). Several studies have shown that a single session of either endurance or interval exercise can improve glycemic control for about 24 h in those with type 2 diabetes, as measured with continuous

glucose monitoring (70–72). Muscle contraction acutely attenuates hyperglycemia by signaling glucose uptake in skeletal muscle, with improved insulin action typically lasting up to 48 h (66). It is less clear, however, as to whether improved glycemic control with exercise is chiefly a result of the acute exercise responses or chronic training adaptations. For these reasons, physical activity guidelines highlight the value of exercising on most days of the week (5). The time commitment required to exercise daily substantially increases when undertaking MICT, hence the appeal of low-volume SIT protocols.

1.2.2.1 Efficacy of SIT for improving glycemic control

Six weeks of SIT can improve glycemic control, based on oral glucose tolerance tests, in healthy (65,73–75) and overweight/obese men (64,76). Furthermore, Richards et al. (77) demonstrated that just 6 sessions of SIT across 2 weeks can improve chronic insulin sensitivity (*i.e.*, 72 h following the last training session). Insulin sensitivity was assessed with a hyperinsulinaemic euglycaemic clamp (77), which is the gold standard measures as it eliminates altered intestinal glucose absorption and insulin secretion as confounding variables (78). Although there is likely a coordinated response between multiple tissues, these results suggest SIT improves glycemic control primarily by altering skeletal muscle glucose uptake (78).

1.2.2.2 Skeletal muscle adaptations in glycemic control with SIT

Similar to other physiological adaptations with aerobic exercise, the skeletal muscle adaptations responsible for improved glycemic control have primarily been characterized with MICT (66). To meet the energy demands of aerobic exercise, skeletal muscle increases glucose uptake by translocating glucose transporter protein 4 (GLUT-4) to the sarcolemma

(66,79). The acute translocation of GLUT-4 in skeletal muscle during exercise is induced by a contraction-mediated and insulin-independent pathway (79), making exercise a potent therapeutic strategy for insulin-resistant individuals. The chronic improvements in insulin sensitivity with training are thought to be mediated by an increase in GLUT-4 content, and thus translocation of more GLUT-4 to the sarcolemma in response to a given insulin stimulus (66). Evidence demonstrates GLUT-4 protein content is increased following 6 weeks of HIIT (80). The adaptations specific to SIT are consisted with these findings as Burgomaster et al. (81) reported increased GLUT-4 content after only 1 week of SIT, with levels remaining elevated after an additional 5 weeks of training.

The signaling mechanisms regulating the contraction-mediated increase in GLUT-4 content and its translocation are believed to involve activation of 5' adenosine monophosphate-activated protein kinase (AMPK), the muscle's 'fuel sensor' (79). AMPK detects increases in adenosine monophosphate and adenosine diphosphate, the by-products of adenosine triphosphate (ATP) breakdown (82). The high degree of ATP breakdown (83), glycogen utilization (37,83), and fibre-recruitment during SIT (84), likely all contribute to the reported improvements of insulin sensitivity (66). Activation of AMPK with SIT can also stimulate mitochondrial biogenesis (85). Increasing mitochondrial density may play a role in mediating the improvement in insulin sensitivity (86,87), given that individuals with insulin resistance and type II diabetes have markedly lower levels of mitochondria (88,89), with reduced capacity compared to healthy individuals (90,91). Reduced mitochondrial density and oxidative capacity can lead to an accumulation of diacyl glycerol and ceramides, which can in turn impair insulin signaling and GLUT 4 translocation. Therefore,

the increase in mitochondrial density with SIT (14,40,57–60), could improve insulin sensitivity by improving lipid oxidation to remove the adverse lipid intermediates. Further research is necessary to determine the precise mechanisms of SIT that lead to improved glycemic control.

1.3 Low-volume SIT: A time-efficient model to elicit adaptations

SIT is commonly touted as a time-efficient method for improving cardiorespiratory fitness and glycemic control; however, Hardcastle et al. (92) has recently challenged this concept by citing that the total time commitment aligns with current physical activity guidelines. The most commonly studied SIT protocol is a repeated Wingate Test that typically includes four to six 30-s 'all-out' cycling efforts, interspersed by 4 minutes of recovery. When warm-up and cool-down are included, the total time commitment is about 25-30 min per session, and the current guidelines recommend 75 minutes of vigorous activity each week (5); therefore, "lack of time" remains to be a perceived barrier (12). Conversely, recent investigations have further reduced the time commitment and have challenged the minimal time necessary to elicit cardiometabolic adaptations (35,76,93–96), with some studies (97–99) revisiting the original Tabata protocol (*i.e.*, eight 20-s efforts interspersed with 10 s of recovery) (100). Considering the low-volume SIT protocols mentioned here, Ma et al. (97) reported the largest improvement in cardiorespiratory fitness, with a 19% improvement in VO_{2peak} in young men following a 4-week SIT intervention involving eight 20-s cycling bouts at 170% peak power, interspersed with 10 s of recovery. Given that the other low-volume SIT protocols mentioned here, all involving

40 – 160 s of supramaximal efforts within ≤15 min per session performed three times per week, also found significant improvements in VO_{2peak} (35,76,93,95,96,98,99), low-volume SIT can be considered an efficacious mode of training for improving cardiorespiratory fitness.

Considering total work and time commitment, the minimalist protocol that has been found to improve indices of cardiometabolic health involves only 2-3 minutes of hard exercise per week (93,95). Each session includes a 2 minute warm-up, two or three 20-s "all-out" efforts, and a 3-minute cool-down for a total of 10 minutes per session (93,95). In addition to reducing the duration of each sprint from 30 s to 20 s, the typical workload of the Wingate sprints was also reduced from 7.5% to 5.0% of body weight. Despite this reduced workload and volume, Metcalfe et al. (93) and Gillen et al. (95) reported VO_{2peak} improved by 12-15% after training 3 days per week for 6 weeks. Interestingly, both studies found significant improvements in insulin sensitivity with men, but not women, which could be a result of the small sample sizes, or it could lend to possible sex-based differences in physiological adaptations to SIT (93,95). Nevertheless, these studies demonstrate low-volume SIT is a potent stimulus. But perhaps the most convincing data is that reported in a more recent study by Gillen et al. (96). In a direct comparison between low-volume SIT (3x20-s "all-out" effort) and MICT (50 min at 70% maximum HR), a 5-fold difference in total-time commitment, 12 weeks of training 3 days per week elicited similar improvements in VO_{2peak}, insulin sensitivity via the intravenous glucose tolerance test, and mitochondrial content. These results suggest that training intensity is more critical than volume for improving cardiometabolic health. Although the optimal exercise stimulus for individual

measures of cardiovascular and metabolic health remains to be determined, low-volume SIT is currently the most time-efficient.

1.4 Stair climbing as a practical model of low-volume SIT

Low-volume SIT is an effective form of exercise for improving cardiometabolic health; however, the majority of SIT research has been completed in a laboratory setting using specialized equipment. Access to fitness facilities and even basic exercise equipment poses a barrier for many individuals, and inclement weather can prevent participation in many equipment-free activities. Stair climbing offers the potential for SIT to be taken out of the lab and applied to a real-world setting because it is (1) readily accessible and therefore easily implemented into daily routine, (2) a functional activity of daily living, and (3) an easily achievable form of exercise that can be appropriately challenging for many fitness levels. Athletes have used stair climbing as a potent training stimulus for many years, but it is also considered a vigorous activity for the general population when climbing at a self-selected pace (101,102). Data from the Harvard Alumni Health Study demonstrate that climbing 25-35 stories per week is associated with a reduced risk of cardiovascular disease, and lower rates of death from all causes (27). Several studies have assessed the acute exercise responses (22,23,103–105), and the improvements in cardiometabolic health associated with various stair climbing training interventions (24–26,106–110); however, the adaptations to interval stair climbing have yet to be assessed. Given the time-efficiency of SIT and the practicality of stair climbing, stair climbing-based SIT may be an effective way to improve the cardiometabolic health for the general population.

1.4.1 Practicality of stair climbing

1.4.1.1 Accessibility

Stairs are readily accessible regardless of socioeconomic status. They are located in most houses and in a variety of indoor and outdoor public settings (e.g., shopping malls, hotels, business buildings, etc.) with no associated costs. Unlike other forms of exercise, stair climbing can be completed at home, at work, or when travelling without the need to access special facilities or equipment. Access to facilities has proven to be an important factor as it is independently associated with a higher levels of physical activity, except for those with an annual family income greater than $80 000 (111). Furthermore, physical activity facilities are typically not as accessible in rural and remote communities. Socioeconomic status is another important aspect to address given that higher income Canadians participate in more active leisure (112), and are more likely to acquire sufficient physical activity each week (111). People with higher income levels usually have better access to physical activity facilities (111). Implementing stair climbing as an exercise routine allows individuals to avoid financial and environmental barriers.

1.4.1.2 Functionality

Stair climbing is also an important, but neglected skill that is necessary for maintaining mobility and independence throughout the lifespan (113). The ability to independently climb stairs can affect quality of life (114), with approximately one third of elderly people living sedentary lives due to difficulties related to climbing stairs (113). Furthermore, the ability to climb stairs is independently correlated with postoperative cardiopulmonary complications (115), demonstrating the importance of including stair

climbing in rehabilitation programs. Although most people have the ability to climb stairs, it should be included regular exercise programs to prevent decline with aging.

1.4.1.3 Achievability

Climbing stairs is an achievable form of exercise for the general population because it can be adapted to suit all fitness levels, and it does not require a high-degree of coordination or any sport-specific skills. It is a relatively familiar movement compared to other forms exercise such as cycling, which may improve an individual's self-efficacy for exercising at high-intensities. Self-efficacy, defined as the confidence in personal ability to carry out a behavior, plays a central role in behavior change and influences intensity and persistence of the behavior (116). Self-efficacy is consistently associated with higher levels of physical activity regardless of age, education and family income (111). Most forms of exercise that effectively improve cardiorespiratory fitness involve equipment and movements that are less familiar to sedentary populations, whereas stair climbing is a simple task that can elicit a strong stimulus even when climbing at a relatively slow-to-moderate pace.

1.4.2 Acute stair climbing responses

1.4.2.1 Cardiorespiratory response

Stair climbing is a form of heavy unsteady-state exercise (22), engaging the body's largest muscle groups to repeatedly lift one's body weight up each step. Due to the relatively high intensity, stair climbing provides an inconspicuous method for increasing heart rate. Aziz and Teh (23,103) have repeatedly demonstrated that the physiological

demand required for stair climbing (ascending and descending) at a moderate pace, is well above the minimum exercise intensity values of 50% of VO_{2max}, or 65% of HR maximum for improving cardiorespiratory fitness (117). In a large controlled trial, Teh et al. (23) found that when healthy women climbed 11 stories consisting of 22 flights (180 steps or 27 m) at 90 steps/min (13.5 m/min), the last 30-s of the ascent elicited a heart rate of 92%, and a VO_2 of 88% of maximum, which is equivalent to 9.2 METs. Bassett et al. (1997) and Ainsworth et al. (2000) reported slightly lower MET values of 8.6 and 8.0 for stair climbing, respectively; however, this is likely due to using a step mill and climbing at a slower frequency. Climbing a step mill should not be directly compared to a climbing a physical stair case because the steps drop electronically, and therefore an individual is not be required to lift their body weight the entire height of each step. Teh et al. (23) also determined that descending a public stair case (independent of a previous climb) at 110 steps/min (16.5 m/min), elicits a HR of 58% and a VO_2 of 39% of maximum (4.9 METs), and it therefore considered to be a moderately-intense activity (5).

According to ACSM and the data from Teh et al. (23), climbing up and down stairs is a vigorous activity; that is, 6-10 METs, 77-95% of HR maximum, and 64-90% of VO_2 maximum (5). To meet physical activity guidelines, an individual needs to climb up and down 11 stories 6-8 times, or spend 20-30 min ascending and descending 3-5 days each week (5,9). Interestingly, climbing stairs twice is as difficult as walking briskly (3.8 METs), and is roughly equivalent to jogging at a pace of ~7 min/km (9.0 METs), whereas running upstairs is equivalent to running ~4 min/km (15.0 METs). Given the high effort

necessary, stair climbing is an efficient form of exercise for eliciting the high physiological stress necessary to improve respiratory fitness.

Another concept of stair climbing that should be considered it the difference between single- and double-step climbing. Single-step climbing (1 step/stride) elicits a slower rate of energy expenditure than double-step climbing (2 steps/stride); however, single-step climbing requires a greater total energy cost for a given height than double-step climbing (*i.e.*, 2 steps per stride), likely due to the duration of the ascent being longer (104). In a study that controlled climbing duration, the ventilation, VO_2 and HR responses were still greater for single-step climbing, but the slight differences in these cardiorespiratory responses were not considered to be practically significant (103).

1.4.2.2 Metabolic response

Stair climbing also elicits a potent metabolic response in terms of glycemic control. In an acute cross-over study, short bouts of moderate stair climbing-descending exercise 90 min after a meal augmented the decrease in blood glucose in men with impaired glucose tolerance compared to walking at a brisk pace (105). These results demonstrate that climbing stairs at a moderate pace can efficiently improve postprandial glucose levels; however, more research is needed as no other studies have assessed the acute or chronic glycemic adaptations with stair climbing exercise.

1.4.2.3 Stair climbing versus cycling

The intense nature of stair climbing suggests that it would be a suitable alternative for cycling-based SIT. Oldenburg et al. (22) found that when power output was matched, stair climbing and cycling elicited a similar HR and total VO_2 response; however, blood

lactate accumulation was higher following cycling. Cycling relies on less muscle mass to generate the same power output, likely leading to a larger recruitment of type II fibres and anaerobic stores, contributing to greater CO_2 production and blood lactate accumulation. Interestingly, stair climbing also led to a significantly greater fall in blood oxygen saturation and a lower ventilation rate (22). Overall, the similar HR and VO_2 responses to stair climbing and cycling suggest that cycling-based SIT could be adapted to stair climbing and elicit similar improvements in cardiometabolic health.

1.4.3 Chronic stair climbing interventions

A limited number of studies have examined the cardiometabolic adaptations to stair climbing (Table 2, Appendix 2). The first studies that evaluated the feasibility and efficacy of stairclimbing for improving cardiorespiratory fitness were completed by Fardy and Ilmarinen (106–108). These investigations examined the impact using the stairs in the work environment by having participants climb stairs as a part of their daily working routine, instead of taking the elevator. It was reported that 12 weeks of climbing 125 floors (~340 m) per day improved predicted VO_{2peak} by 10% (106). In a follow up study (107), participants were able to increase their predicted VO_{2peak} by 15% following 10 weeks of climbing only ~30 floors (105 m) per work day. Importantly, participants would climb an average of 7 floors per ascent, and elevate their HR to 130-159 bpm for ~8 min and to 160-180 bpm for ~1 min each day. These interventions demonstrated that stair climbing can be an effective daily activity for improving cardiorespiratory fitness.

Research on the health adaptions associated with regular stair climbing transitioned into randomized and controlled interventions of relatively high volume training programs. Interventions either met or exceeded the physical activity recommendations using step mills (109,110). Twelve weeks of high-volume stair climbing improved lower limb power output (110) and strength (109) in moderately active and sedentary females, respectively. Both interventions involved 30-40 minutes of stair climbing at 70-90% of maximum HR; however, the moderately active group only improved their cardiorespiratory fitness by 5% (110) compared to the 11% improvement seen in the sedentary group.

More recent stair climbing investigations have shown that accumulating short bouts of stair climbing (24–26) and bench stepping (118) throughout the day can improve important cardiovascular risk factors. Climbing 8 flights of 18-25 stairs (24-33 m or ~2 min ascents) at a comfortable but brisk rate (75-90 steps/min or 12-15 m/min) 3-6 times on a daily basis, for a total of 30-60 min of stair climbing each week, improves cardiorespiratory fitness by 9.5-17% (25,26) and blood lipid concentrations (24,25) within 8 weeks. Bench stepping for 27 min per week accumulated in 3x3 min sessions, 3 days per week at a vigorous intensity of ~75% HR reserve was also found to improved submaximal cardiorespiratory response within 4 weeks (118). The majority of these stair climbing studies have only estimated cardiorespiratory fitness, and therefore more research directly measuring VO_2peak is needed. Nonetheless, these studies suggest that a relatively low amount of stair climbing bouts accumulated throughout each day can elicit improvements in VO_{2peak} similar to SIT and MICT.

1.5. Purpose and Hypothesis

The purpose of this thesis was to explore the efficacy of brief intense stair climbing as a practical form of low-volume SIT to improve cardiometabolic health. While a number of studies have established stair climbing as an effective form of exercise to enhance CRF, the minimum effective "dose" of stair climbing remains unknown. The project consisted of two separate studies, each with an acute and chronic phase. The goal of Study 1 was to determine whether 'all-out' stair climbing elicits responses similar to a cycling mode of SIT, previously shown to improve cardiorespiratory fitness and insulin sensitivity. Building on the results of Study 1, the goal of Study 2 was to assess the efficacy of two other stair climbing protocols that involved ascending and descending either one or two flights of stairs as opposed to continuously climbing five to six flights. We hypothesized that (1) single sessions of intermittent, 'all-out' stair climbing and cycling would elicit similar physiological responses, and (2) 6 weeks of training using the various stair climbing protocols would improve cardiorespiratory fitness, as determined by a VO_{2peak} test.

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CHAPTER 2:

Brief intense stair climbing enhances cardiorespiratory fitness.

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Brief intense stair climbing enhances cardiorespiratory fitness.

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ABSTRACT

Purpose: Sprint interval training (SIT) is a time-efficient strategy to improve cardiorespiratory fitness (CRF); however, most protocols have been studied in laboratory settings and require specialized equipment. We investigated the efficacy of brief intense stair climbing as a practical model of SIT to improve CRF. **Methods:** Two separate studies, each consisting of an acute and chronic phase, were conducted in a total of 31 sedentary women (age=24±10 y; BMI=23±4 $kg \bullet m^{-2}$). **Results:** The acute phase of Study 1 established that the mean heart rate (HR), blood [lactate], and ratings of perceived exertion (RPE) were similar when participants (n=8) performed a SIT protocol that involved 3x20-s "all-out" efforts of either continuously ascending stairs or cycling. The chronic phase demonstrated that CRF, as determined by peak oxygen uptake (VO_{2peak}), increased by 12%, or ~1 metabolic equivalent (1.80±0.25 to 2.02±0.27 $L \bullet min^{-1}$; $p<0.001$) when participants (n=12) performed the 3x20-s stair climbing protocol 3 $d \bullet wk^{-1}$ for 6 wk. The acute phase of Study 2 established that HR and RPE were similar when participants (n=11) performed three different stair climbing protocols: the 3x20-s continuous ascent model used in Study 1, and two 3x60-s models of ascending and descending either one or two flights of stairs ($p>0.05$). The chronic phase demonstrated that VO_{2peak} increased by 8% (1.79±0.36 to 1.93±0.39 $L \bullet min^{-1}$; $p=0.001$) when the same group of participants performed the one-flight 3x60-s protocol 3 $d \bullet wk^{-1}$ for 6 wk. The Cederholm index determined from an oral glucose tolerance test was 57±17 and 64±21 $mgI^2 \bullet mM^{-1} \bullet mIU^{-1} \bullet min^{-1}$ before and after training, respectively ($p=0.056$). **Conclusion:** Brief, intense stair climbing is a practical, time-efficient strategy to improve CRF in previously untrained women.

Keywords: SPRINT INTERVAL TRAINING, CARDIOMETABOLIC HEALTH, VO_2 PEAK, GLUCOSE HOMEOSTASIS, EXERCISE

INTRODUCTION

Low cardiorespiratory fitness (CRF) is a strong predictor of cardiovascular disease and all-cause mortality (22). Unfit individuals have twice the risk of death as their fit counterparts, regardless of body mass index (BMI) or body composition (2, 23). Epidemiological evidence has also established that a one metabolic equivalent (MET) higher CRF is associated with 15% and 13% reductions in risk of cardiovascular disease and all-cause mortality, respectively (22). Public health guidelines generally prescribe 150 minutes of weekly moderate-intensity physical activity to achieve health benefits (12). While this prescription is undoubtedly beneficial, it may be insufficient to enhance CRF in a substantial portion of the population (34). Some agencies advocate 75 min of vigorous activity as an alternative to 150 minutes of moderate activity (12). This recommendation is based mainly on the similar energy expenditure for the two prescriptions, as opposed to a specific effect of exercise intensity *per se* (12). Nonetheless, mounting evidence suggest that high-intensity exercise confers larger improvements in CRF than moderate-intensity exercise when matched for total work (6, 18).

Sprint interval training (SIT), which involves brief intermittent bursts of very intense exercise separated by recovery periods, is also efficacious for improving CRF (16, 35, 39, 40). As little as two or three 20-s "all-out" sprints, within a 10-min time commitment, can improve cardiorespiratory fitness by ~1 MET when performed three times per week for 6 weeks (14, 15, 29). It was also recently shown that 12 weeks of training in this manner improved CRF and insulin sensitivity to the same extent as a moderate-intensity continuous exercise protocol that involved a 5-fold greater exercise

volume and time commitment (14). These findings are noteworthy given that accelerometer data suggest ≤15% of North American adults meet current physical activity guidelines (9, 37), with perceived "lack of time" commonly cited as a barrier that negatively correlates with physical activity participation (36).

Access to physical activity facilities is another strong correlate of physical activity participation (36). The majority of research demonstrating the efficacy of SIT has been conducted in a laboratory setting using specialized equipment, such as cycle ergometers, which are inaccessible to many individuals. In contrast, stair climbing is a readily accessible form of exercise that offers the potential for SIT to be performed outside of the laboratory. While it has been established that vigorous stair climbing for 30-160 min per week for 8-12 weeks can improve CRF (3, 4, 21, 25), whether smaller doses of stair climbing performed according to a SIT protocol improves CRF remains unknown.

The present work explored the potential for brief, intense stair climbing to improve CRF and other indices of cardiometabolic health. Two separate but related studies were conducted, each involving an acute and chronic phase. The acute phases assessed physiological and perceptual responses to various SIT protocols using randomized crossover designs. The chronic phases examined the effect of two distinct 6-week training interventions: the first study involved repeated 20-s bouts of continuously ascending stairs, and the second study involved repeated 60-s bouts of ascending and descending stairs. We tested two main hypotheses: (1) an acute bout of stair climbing would elicit similar physiological and perceptual responses similar to a Wingate-based cycling protocol, and

(2) 6 weeks of stair climbing would improve cardiorespiratory fitness, similar to what has been demonstrated for cycling-based SIT.

METHODS

Subjects

A total of 31 sedentary, but otherwise healthy women were recruited. The acute and chronic phases of Study 1 had separate groups of women, while a third group participated in the acute and chronic phases of Study 2 (Table 1). Participants were considered sedentary but healthy based on a self-report of ≤ 1 h of structured physical activity per week and the Physical Activity Readiness Questionnaire (PAR-Q). Physical activity levels were confirmed for the chronic phases by a peak oxygen uptake (VO_{2peak}) < 70^{th} percentile (1). The experimental procedures and associated risks were explained to all subjects prior to their participation, and all subjects provided written informed consent. The acute phase of Study 1 was conducted at Queen's University and approved by Queen's University Health Sciences Research Ethics Board. The remaining phases were completed at McMaster University and approved by the Hamilton Integrated Research Ethics Board.

Experimental Design

Overview. Two separate studies were conducted, both of which involved an acute exercise comparison and a subsequent 6-week training intervention. In Study 1, we initially compared the acute physiological and perceptual responses to a SIT protocol using two different exercise modes. The protocol involved 3x20-s "all-out" efforts of either cycling or stair climbing, given that the cycling model was previously shown to enhance CRF when

participants trained 3 $d \bullet wk^{-1}$ for 6 weeks (15). After confirming that the acute physiological and perceptual responses were similar, we subsequently assessed indices of cardiometabolic health before and after 6 weeks of training with the 3x20-s stair climbing protocol. In Study 2, we initially compared the acute physiological and perceptual responses to three different stair-climbing protocols: the 3x20-s protocol employed in Study 1, and two other protocols that involved 3x60-s of vigorously climbing up and down either one flight (3x60-s 1F protocol) or two flights (3x60-s 2F protocol) of stairs. The rationale was that the latter two protocols might be easily adapted to a typical home or dwelling with one or two stories, whereas the 3x20-s protocol necessitated a building with 3-4 stories and an "all-out" pace. Upon determining that the acute physiological and perceptual responses to the three protocols were similar, and that participants preferred the 3x60-s 1F protocol, we assessed indices of cardiometabolic health before and after 6 weeks of training with the 3x60-s 1F protocol.

Study 1: Acute Phase. A randomized cross-over design was implemented to compare acute responses to the stair climbing and cycling protocols. Each involved a 2-min warm up, 3x20-s "all-out" efforts interspersed with 2 min of recovery, and a 3-min cool down. The two trials were separated by ≥ 24 h. The 20-s stair climbing efforts were performed as a continuous ascent in a local stairwell (120 stairs, stair height = 0.135 m). Participants were instructed to, "Climb the stairs as quickly and safely as possible, taking one step at a time." The warm-up included walking on flat ground at a brisk pace, while the recovery periods and cool-down included walking down the stairs and on flat ground at a self-selected pace. The 20-s cycling efforts were performed on a stationary cycle

ergometer (Monark 874 Ergometer, AB, Sweden) as previously described (15), and constituted a modified Wingate test using a resistance equivalent to 5% of body weight. The warm-up, recovery periods and cool down involved light cycling against no load (15). HR was monitored continuously throughout each session while finger-prick blood lactate concentration and RPE were measured prior to the first, and immediately following each subsequent 20-s bout.

Study 1: Chronic Phase. Participants reported to the lab on three separate occasions over ~14 d for baseline testing and familiarization. During the initial visit, participants completed a continuous incremental VO_{2peak} test after refraining from food and beverages for ~2 h. At least 4 d later, participants reported to the laboratory following a standardized dinner and 10-h overnight fast for body composition analysis and to provide a resting blood sample for assessment of fasting insulin sensitivity. Body composition was analyzed using air displacement plethysmography (BOD POD; Life Measurement, Inc, Concord, CA). Following 1-2 days, participants returned for seated resting heart rate (RHR) and blood pressure (BP) measures, and to complete the modified Canadian Aerobic Fitness Test (mCAFT). On the same day, participants practiced the 3x20-s stair climbing protocol and were given the same instructions as those from the acute phase. Participants then trained 3 $d \bullet wk^{-1}$ for 6 wk in a local stairwell (99 stairs; stair height = 0.195 m). Warm-up was modified to include a moderately paced climb up and down 2 flights (*i.e.,* 1 story or 18 stairs) at a self-selected pace prior to the brisk walk to ensure an adequate warm-up. During each session, HR was monitored continuously, RPE was recorded prior to warm-up and following each 20-s bout, and the number of stairs climbed and vertical work output

were recorded for each 20-s bout. All training sessions were supervised. Approximately 72 h following the final training session, body composition and fasting insulin sensitivity were assessed. A VO_{2peak} test and the mCAFT were administered at least 4 and 6 d after the final training session, respectively. BP and RHR were measured prior to the mCAFT test. All procedures were identical to those employed during baseline testing.

Study 2: Acute Phase. The acute phase of Study 2 was completed following baseline testing but prior to training. The immediate exercise responses of two different modified-protocols were compared with the 3x20-s protocol from Study 1 using a William's square (*i.e.*, complete counter-balanced) design. All participants reported to the laboratory on four separate occasions over the course of ~10 d. The first visit included an exercise familiarization session, during which participants were introduced to the RPE scale and each of the three stair-climbing protocols using standardized instructions. Participants practiced climbing at an "all-out" and vigorous pace. During each of the following three visits, participants completed either the 3x20-s "all-out" protocol from Study 1 or one of the two modified 3x60-s vigorous protocols in a local stairwell (stair height = 0.205 m). The 3x60-s 1F and 2F protocols involved ascending and descending 1 flight of 10 stairs and 2 flights with a total of 18 stairs, respectively. The bouts were extended to 60 s in order to ensure participants spent at least 20 s ascending stairs, aligning with the 3x20-s protocol. Instructions for the 3x20-s protocol were the same as those used in Study 1, but for the 3x60-s protocols, participants were instructed to "Climb up and down the stairs one step at a time for 1 min, ascending vigorously and descending as desired. Vigorous means relatively intense, but not all-out." The warm-up, recovery, and

cool-down periods were the same as the 3x20-s protocol in the chronic phase of Study 1; however, the recovery periods were shortened to 1 min instead of 2 min. Finger prick samples for blood lactate determination were obtained prior to warm-up following a seated 5-min rest and immediately after the final 20-s or 60-s bout (no difference in timing between protocols; p=0.12). Continuous HR, RPE, stairs climbed and vertical work output were measured for each protocol (as reported in the chronic phase of Study 1). Each session was separated by 48-72 h and completed at roughly the same time of day. After completing the acute phase of Study 2, participants were asked to rank all protocols in their order of preference, and the most preferred modified protocol was used for the chronic phase.

Study 2: Chronic Phase. Participants completed at least two separate pre-training VO_{2peak} tests to account for possible learning effects and to ensure accurate baseline measures. The first VO_{2peak} test was completed as a screening measure 6-8 wk prior to the baseline measures, during which the second VO_{2peak} test was completed. All baseline measures were completed ~1 wk prior to the acute phase to avoid possible exercise or training effects. Following a standardized dinner and 10-h overnight fast, participants reported to the laboratory for body composition analysis (as reported in Study 1) and an oral glucose tolerance test (OGTT). Participants returned 1-2 d later following another overnight fast for seated RHR and BP measures, along with the second VO_{2peak} test. Participants trained 3 $d \bullet wk^{-1}$ for 6 wk using the 3x60-s 1F protocol in the same stairwell as the acute phase, with continuous HR, RPE, number of stairs climbed and vertical work output recorded for each session (as reported in the chronic phase of Study 1). Approximately 72 h following the last training session, participants returned to the

laboratory for body composition analysis and an OGTT. Participants returned ~24 h later for RHR and BP measurements, as well as a final VO_{2peak} test. All procedures were identical and completed at the same time of day (± 0-3 h) as the baseline measures.

Measurements

VO_{2peak} Test. Participants performed an incremental test to exhaustion on an electronically braked cycle ergometer (Lode Excalibur Sport V 2.0, The Netherlands) to directly measure VO_{2peak} and peak power output (PPO). Following a 1-min warm-up at 50 W, power output increased by 1 W every 2 s until the pedal cadence fell below 50 rpm. Oxygen consumption and carbon dioxide production were analyzed with a metabolic cart (Moxus, AEI technologies, Pittsburgh, PA), and the greatest 30-s average was recorded as VO_{2peak}. Tests were considered valid if two or more of the following criteria were met: a plateau in VO_2 despite increasing intensity, RER > 1.1, HR within 10 beats of age-predicted maximum, and/or volitional exhaustion.

Modified Canadian Aerobic Fitness Test (mCAFT). The mCAFT was used as a practical method to estimate VO_{2peak}, as might be encountered in a clinical or training setting. According to standardized procedures (7), participants completed one or more 3-min stages of stepping using a set of two steps (0.203 m). The frequency of stepping was predetermined (based on age and gender) and increased as the test progressed. The test ended when participants achieved or exceeded 85% of their age-predicted maximum heart rate at the end of a 3-min stage.

Resting Blood Pressure and Heart Rate. BP was measured in triplicate while seated using an automatic oscillometric device in Study 1 and Study 2 (Contec 08A, Qinhaungdo, China and Omeron BP765CAN, Kyoto, Japan, respectively), according to the standardized technique recommended by the Canadian Hypertension Education Program (10). Briefly, participants sat quietly in a room free from any distractions or interruptions for 10 min prior to three measurements that were separated by ~1 min. BP was determined from an average of the latter two measurements. HR was monitored continuously throughout, and RHR is reported as the average of the latter 5 min of the 10-min rest.

Blood Sampling. Participants consumed a standardized meal the evening prior to an overnight fast. In Study 1, a fasting sample was obtained from an antecubital vein via venipuncture. For Study 2, a standard seven-sample OGTT was performed (8). An indwelling catheter was inserted into an antecubital vein and a fasting blood sample was obtained before ingestion of a 75 g glucose drink (NERL^{TM} Trutol^{TM}, Thermo Fisher Scientific Inc., Waltham, MA), followed by blood samples collected at 10, 20, 30, 60, 90, and 120 min post-ingestion. Plasma and serum were separated by centrifugation (10 min at 1500 *g*) and stored at -80 °C for subsequent analysis. Plasma samples were sent to the Core Laboratory (Hamilton Research Laboratory Medicine Program) for glucose analysis in Study 1, and plasma glucose was determined using the glucose oxidase method with a glucose analyzer (YSI Stat 2300, Yellow Springs, OH) in Study 2. Insulin was measured by ELISA (ALPCO Immunoassays, Salem NH, USA). The area under the curve (AUC) for glucose and insulin were calculated using the trapezoidal rule, and insulin sensitivity

was calculated using the homeostatic (ISI-HOMA) (27), and Cederholm models (ISI-Cederholm) (8).

Exercise and Training Measures. HR was monitored continuously throughout every session (Polar Team System, Polar Electro OY, Kemple, Finland). Participants reported their RPE using the Borg Category-Ratio Scale (0-10) in the acute phase of Study 1, and the 6-20 scale (5) for all subsequent phases. The RPE scale was altered from the 1-10 scale to the 6-20 scale following analysis of the first phase in attempt to align RPE and HR responses more accurately (5). Blood lactate concentration was measured using regular finger-prick methods with portable lactate analyzers (Lactate Plus, Nova Biomedical Corporation, Cheshire, UK). For stair climbing, the number of stairs climbed and vertical work output (Work [kJ] = body mass [kg] • 9.81 m/s^2 • height [m]/1000) was calculated for each session. For cycling, the mechanical work output was calculated according to the manufacturer.

Statistical Analysis

Results are expressed as means ± SD. For the acute phase of Study 1, n=8 for all measures except for HR (n=6) due to technical difficulties. For the chronic phase of Study 1, n=12 for all measures. For the acute phase of Study 2, n=11 for all measures except peak HR (n=9) and work output (n=10), due to technical difficulties. For the chronic phase of Study 2, n=11 for all measures except for RHR and BP (n=10), owing to participant unavailability at the requisite testing time. A two-way, repeated measures analysis of variance (ANOVA) was used to test for differences in work output, peak HR, blood lactate

concentration and RPE in the acute phases of Study 1 (3x2 Time by Mode for work output and peak HR; 4x2 Time by Mode for blood lactate and RPE) and Study 2 (3x3 Time by Protocol for work output and peak HR; 2x3 Time by Protocol for blood lactate; 4x3 Time by Protocol for RPE). A one-way, repeated measures ANOVA was used to test for differences in mean HR between protocols in the acute phase of Study 2, as well as mean HR, RPE and total stairs climbed across weeks in the chronic phase of Study 1 and 2. Greenhouse-Geisser correction was used when data did not meet the assumption of sphericity, and post hoc analyses were completed using Bonferroni correction. A paired t-test was used to compare the mean HR in the acute phase of Study 1, as well as all pre- and post-training measurements in the chronic phases. Spearman's rho was used to test for associations between direct and estimated (*i.e.*, mCAFT) VO_{2peak} values, given that the data were not normally distributed. The exercise training measures reported for the chronic phases (*i.e.,* stairs climbed, RPE, and HR) are presented as averages from all training sessions, unless otherwise stated. The level of significance for all analyses was set at $p \leq 0.05$.

RESULTS

Study 1

Acute Phase. Mean HR was similar between the stair climbing and cycling protocols ($p=0.40$; Figure 1 A). Peak HR, blood lactate and RPE values increased with each subsequent bout ($p<0.01$; Table 2). There was an interaction between mode and time for RPE ($p=0.002$) and peak HR ($p=0.04$), such that stair climbing elicited a lower RPE

prior to bout 1 ($p<0.01$) and a higher peak HR was following bouts 1 and 2 ($p<0.05$). The increase in lactate with each bout was not different between mode ($p=0.40$). Vertical work output was greater during stair climbing compared to cycling (main effect for mode, $p=0.01$; Table 2).

Chronic Phase. Participants completed 99% of all training sessions without incident. Participants climbed 58 ± 4 stairs (11.4 ± 0.8 m) during each 20-s bout. There was a main effect of time across weeks for total stairs climbed each session ($p<0.001$), such that participants improved by 7% from week 1 to 6 (168 ± 14 to 180 ± 11 stairs/session, $p=0.001$). There was also a main effect of time for average RPE ($p=0.02$), which significantly increased from 13.6 ± 1.4 in week 1 to 14.4 ± 1.6 in week 3 (*i.e.*, "somewhat hard – hard" for both; $p=0.005$). Participants fatigued by 14 ± 4% from the first to the last 10 s within bouts, and by 7 ± 4% from bout 1 to bout 3. When averaged across the 20-s bouts, HR was 82 ± 4, 88 ± 3 and 90 ± 3% of maximum for bouts 1-3, respectively. The mean HR for the entire 10 min session was 81 ± 4% of max HR, with no effect of time across weeks ($p=0.65$).

VO_{2peak} measured directly increased by 12% after training (1.80 ± 0.25 to 2.02 ± 0.27 L • min^{-1}, $p<0.001$; Fig. 2 A) and this was associated with an 8% increase in PPO ($p<0.001$, Table 3). VO_{2peak} estimated from the mCAFT increased by 4% ($p=0.007$; Table 3), and there was a 5% attenuation in the HR response to the first stage of the mCAFT following training (152 ± 17 to 147 ± 21 bpm, $p=0.01$). There were no correlations between direct and estimated VO_{2peak} (calculated from the mCAFT) for pre-training ($r=0.51$, $p=0.09$), post-training ($r=0.13$, $p=0.68$), and change in VO_{2peak} ($r=0.35$, $p=0.26$); There

were also no training-induced changes in resting systolic BP (p=0.82), diastolic BP (p=0.97), RHR (p=0.55), BMI (p=0.39), body mass (p=0.35), fat free mass (p=0.09), fat mass (p=0.70), % body fat (p=0.42), fasting glucose concentration (p=0.15), fasting insulin concentration (p=0.31), or HOMA-IS (p=0.52; Table 3).

Study 2

Acute Phase. Mean HR was similar between all three stair climbing protocols (p=0.20; Figure 1 B). Peak HR, lactate and RPE values increased with each subsequent bout (p<0.01; Table 2). There was a significant interaction between protocol and time for lactate (p=0.001), such that the 3x20-s protocol elicited a higher concentration after the third bout compared to the 3x60-s 1F and 2F protocols (p<0.01; Table 2). Vertical work output was lower during the 3x20-s protocol compared to the 3x60-s 1F and 2F protocols (main effect for protocol, p<0.001; Table 2), which correspond to an average of 53 ± 6, 74 ± 8 and 71 ± 6 stairs climbed per bout, respectively.

Chronic Phase. Participants completed 100% of all training sessions without incident. Participants spent 27 ± 3 s ascending 8 ± 1 flights of 10 stairs (16.7 ± 2.1 m) and 33 ± 3 s descending each 60-s bout (times based on third and final sessions). There was a main effect of time (p<0.001) for total stairs climbed each session, such that participants improved by 11% from week 1 to week 6 (232 ± 26 to 257 ±30 stairs, p<0.001). The average RPE elicited for each session was 14.3 ± 1.2 (*i.e.*, "somewhat hard – hard"), with no main effect of time across weeks (p=0.54). Participants fatigued by 10 ± 4% from the first to the last ascent within bouts, and by 4 ± 3% from bout 1 to bout 3. When averaged

across the 60-s bouts, HR was 81 ± 6, 89 ± 4, and 93 ± 3% of maximum for bouts 1-3, respectively. The mean HR for the entire 10 min session was 80 ± 4% of max HR, with no effect of time across weeks (p=0.44).

After training, VO_{2peak} measured directly increased by 8% from baseline (1.79 ± 0.37 to 1.93 ± 0.39 L • min^{-1}, p=0.001; Fig. 2 B), and this was associated with a 9% increase in PPO (p<0.001; Table 3). There were no differences between screening and baseline VO_{2peak} (1.76 ± 0.34 L • min^{-1}, p=0.37) and PPO (170 ± 33, p=0.44). There was a significant increase in BMI (p=0.02), body mass (p=0.05) and fat free mass (p<0.001), but no change in fat mass (p=0.36) or % body fat following training (p=0.10; Table 4). Systolic and diastolic BP were unchanged (p=0.50 and p=1.00, respectively), but RHR was reduced by 8% after training (p=0.03; Table 3). There were no training-induced changes in OGTT-derived parameters including mean glucose (p=0.20) and insulin (p=0.07) concentrations, AUC for glucose (p=0.35) and insulin (p=0.20), fasting glucose (p=0.52) and insulin (p=0.35) concentrations, HOMA-IS (p=0.59) or the ISI-Cederholm (p=0.056; Table 3).

DISCUSSION

The major novel finding of the present work is that brief, intense stair climbing is a time-efficient strategy to increase CRF. VO_{2peak} increased by ~1 MET after 6 weeks of training using the protocol employed in Study 1, which involved 3x20-s bouts of continuously ascending stairs interspersed with 2 min of recovery. The 12% improvement in VO_{2peak} over 6 weeks was strikingly similar to the improvement reported by Gillen et al. (15), who employed the same protocol, but used a cycle ergometer to train participants.

The protocol employed in Study 2, which involved 3x60-s bouts of ascending and descending one flight of stairs, interspersed with 60 s of recovery, improved VO_{2peak} by 8%. These data demonstrate that stair climbing is an efficacious model of SIT for improving CRF, making it a practical alternative to cycling-based SIT.

Previous studies have reported that ascending stairs for 30-70 min each week for 8 weeks can improve CRF (3, 4, 21, 25). The total time spent ascending and descending stairs in the present study was much lower, and amounted to ≤ 9 min within a weekly time commitment of 30 min. Due to the influence of perceived "lack of time" and lack of access to specialized facilities on physical activity participation (36), it is important to identify time-efficient exercise protocols that do not require special equipment. Prior to the present work, few studies have assessed the efficacy of SIT outside of a laboratory setting (26) and without the use of specialized exercise equipment (26, 28). Given that SIT has been established as a time-efficient strategy for improving CRF (16, 35, 39, 40), the intent of the present work was to assess the efficacy of SIT when adapted to stair climbing since it is an accessible form of exercise that could be easily adopted into daily routine.

Acute responses to stair climbing and Wingate-based SIT are similar

The acute exercise data from Study 1 of the present investigation suggests that stair climbing and Wingate-based SIT elicit a similar metabolic stress. In contrast, Oldenburg et al. (31) reported that the accumulation of blood lactate during stair climbing was less than that during cycling; however, they matched power output for the two modes of exercise. Given that the HR and VO_2 were similar between stair climbing and cycling (31),

the higher blood lactate concentration during cycling was likely a result of recruiting a greater proportion of the leg musculature (*i.e.*, more type II fibres and a greater reliance on anaerobic metabolism) as cycling relies on less total muscle mass to generate the same power as stair climbing. The similar lactate concentrations reported in Study 1 of the present investigation align with Oldenburg et al. (31) since participants generated more power output during stair climbing as compared to cycling. The higher power output generated during stair climbing was associated with a generally higher peak HR; however, there were no differences in perceived exertion across modes. Together these data suggest that when Wingate-based SIT protocols are transferred to stair climbing, they still elicit similar, if not greater, acute physiological responses.

Cardiorespiratory fitness improves by 1 MET

Low cardiorespiratory fitness has greater consequences than hypertension, smoking, obesity and hyperlipidemia in terms of risk for adverse health outcomes (20). Although athletes have long used interval training to improve fitness (19), there has been a renewed interest in SIT due, in part, to the health benefits that can be achieved with low volumes of exercise. Gist et al. (16) concluded that despite the reduced volume of work, SIT and traditional endurance training are equally effective for improving VO_{2peak}, citing a collective improvement of 8% (~3.6 mL • kg^{-1} • $min^{-}1$) within 2-6 weeks of training. We found that 6 weeks of brief and intermittent bouts of "all-out" stair climbing increased relative VO_{2peak} by 12% or ~1 MET (*i.e.*, 3.5 mL • kg^{-1} • min^{-1}). These findings are important given that the decrements in risk of all-cause mortality and cardiovascular

disease that are associated with a 1-MET higher VO_{2peak} are comparable to having a 7-cm, 5-mmHg, or 1 mM lower waist circumference, systolic blood pressure, and fasting plasma glucose, respectively (22).

The improvement in CRF in the present work is similar to previous stair climbing studies using higher-volume and lower intensity protocols (3, 21, 25); however, to our knowledge, only two studies have directly measured aerobic capacity (3, 25), the gold standard in fitness assessment. Of these two studies, Boreham et al. (3) evaluated a lower-volume protocol and reported that sedentary women improved their relative VO_{2peak} by 17% (4.5 mL • kg^{-1} • $min^{-}1$) after 8 weeks of training; however, in addition to a longer training period, peak training volume was ~825 m•wk^{-1} at a rate of ~15 m•min^{-1}, versus 100-150 m•wk^{-1} at a rate of 34-37 m•min^{-1} in the present investigation. This ~7-fold difference in total work per week and only ~2-fold difference in climbing speed supports the idea that intensity has a greater impact than total work (*i.e.*, training volume) for improving aerobic capacity (13, 14).

Given the applied nature and goals of this investigation, the mCAFT was used as a more practical and realistic assessment of CRF that may be encountered in the field. We found that the mCAFT overestimated VO_{2peak}, the improvements detected by the mCAFT were much smaller compared to the direct VO_{2peak} test, and correlations between mCAFT and direct VO_{2peak} values were poor. Although a previous study concluded that the mCAFT was valid for the general population, it demonstrated low specificity for participants with poor fitness (38), which agrees with the overestimated values in our study (~20%).

Modifying the mCAFT might improve its accuracy for individuals with poor fitness; however, further research with a larger sample size is necessary.

Protocol Modification

The aim of Study 2 was to improve the practicality of the 3x20-s "all-out" protocol so that it could be completed at a sub-maximal pace in a house or small building, while still eliciting a similar improvement in CRF. The 20-s bouts of continuously ascending as fast as safely possible (~60 stairs or ~3 stories) were adjusted to 60 s of vigorously climbing up and down 1 or 2 flights (10-18 stairs or ~1 story). The 3x20-s and 3x60-s protocols elicited a similar RPE, peak HR following each bout, and mean HR for the entire 10-min sessions, potentially owing to the decreased climbing pace but increased exercise duration. Interestingly, most participants preferred the 3x20-s protocol over the 3x60-s protocols, and the majority of the participants chose the 3x60-s 1F protocol over the 2F, with many participants reporting that turning corners during the 2F protocol led to feelings of instability or dizziness.

The individual improvements in absolute VO_{2peak} were quite similar with the 3x20-s (Study 1) and 3x60-s (Study 2) protocols; however, the mean improvement was higher for the 3x20-s "all-out" protocol. The participants training with the 3x20-s protocol may have achieved a greater improvement in CRF as a result of starting at a lower relative fitness level, or the improvement in relative VO_{2peak} elicited by the 3x60-s was masked by the increase in body mass. It is possible that the slightly greater improvements in VO_{2peak} with the 3x20-s protocol are a result of "peripheral" responses given that blood lactate concentration was higher compared to the 3x60-s protocols. Nevertheless, both protocols

elicited improvements in CRF well within the range of SIT inventions cited by Gist et al. (17). These results suggest that when a high-intensity is sustained, it is not necessary to climb at an "all-out" pace to benefit from brief bouts of stair climbing.

Insulin Sensitivity

Both stair climbing protocols did not improve measures of fasting insulin sensitivity, and despite using an OGTT in Study 2, glucose and insulin values did not improve following training. The lack of improvements in insulin sensitivity contradict findings from Gillen et al. (15), but align with Metcalfe et al. (29). These discrepancies could be due to the fact that the women were older and overweight in Gillen et al. (15) compared with the women in Metcalfe et al. (29) and the present study. Furthermore, it is possible that menstrual phase influences insulin sensitivity. When plasma estradiol levels were increased by ~200%, insulin action was increased by 20% in post-menopausal women when compared to a control trial (33); however, this may not apply to pre-menopausal women. Although we attempted to control for menstrual cycle in Study 2, the variability of menstrual cycles and logistical issues of time-sensitive measures prevented such control for most of the women.

Stair climbing is a practical model of low-volume SIT

Stair climbing is likely to be an effective form of exercise given that public health physical activity initiatives are effective when they are lifestyle based (11) and the total stairs climbed each week independently predicts risk of cardiovascular disease and all-

cause mortality (24). Stair climbing is also likely to be more practical than cycling and running-based SIT protocols for the general population because it can be completed outdoors and indoors in private and public settings with no associated costs. Opdenacker et al. (32) demonstrated that lifestyle-based physical activity interventions (*i.e.*, integrated into daily routine and home-based programs supported by telephone calls) are just as efficacious, but more effective than structured physical activity interventions (*i.e.*, supervised in a fitness facility) such that maintenance of CRF was better 2 years following intervention. Stair climbing-based SIT is also practical because climbing stairs is an important, but neglected skill that is necessary for maintaining mobility and independence throughout the lifespan (30). Furthermore, the stair climbing protocols used in this investigation are based on individuals' perceived exertion and therefore can elicit an appropriate stimulus for many different fitness levels. Subjects in the present study completed all training sessions without incident, suggesting that brief and intermittent bouts of stair climbing are a tolerable and appropriate form of exercise for sedentary adults.

Conclusion

In summary, we report that a 10 min exercise protocol involving a total of 1-3 min of intermittent stair climbing improved CRF when performed 3 $d \bullet wk^{-1}$ for 6 wk. The investigation demonstrates that stair climbing represents a model of low-volume SIT that is efficacious when performed outside of a laboratory setting. We recognize that training was not completed in free-living conditions, and therefore future studies should assess the retention and effectiveness of home or work-based SIT using stair climbing with larger

sample sizes. The conclusions that can be made from our data are (1) the acute physiological and perceptual responses to “all-out” stair climbing and cycling SIT are similar; (2) brief and intermittent bursts of stair climbing can markedly improve cardiorespiratory fitness in 6 weeks, similarly to cycling-based protocols; and (3) despite the low volume of exercise, an all-out pace was not necessary to improve CRF. With a minimal weekly time-commitment of 30 min, brief and intermittent bouts of intense stair climbing are a plausible alternative to cycling-based SIT.

TABLES

TABLE 1. Participant characteristics.

	Study 1		Study 2
	Acute	*Chronic*	
Variable	***n = 8***	***n = 12***	***n = 11***
Age (y)	19 ± 2	26 ± 11	26 ± 11
Height (cm)	161 ± 8	162 ± 5	160 ± 6
Body Mass (kg)	56 ± 5	62 ± 9	58 ± 15
BMI ($kg \bullet m^{-2}$)	22 ± 4	24 ± 3	23 ± 5

Values are means ± SD. BMI, body mass index.

TABLE 2. Acute exercise responses.

		Study 1		Study 2		
Variable	bout	*3x20-s SC*	*3x20-s CL*	*3x20-s*	*3x60-s 1F*	*3x60-s 2F*
work output (kJ)	*1*	6.9 ± 1.2 *	5.5 ± 1.5	6.5 ± 1.5 *	8.8 ± 2.0	8.6 ± 2.4
	2	6.5 ± 1.4 *	5.2 ± 0.8	6.4 ± 1.4 *	8.8 ± 2.2	8.5 ± 2.2
	3	6.3 ± 1.3 *	5.1 ± 0.6	6.3 ± 1.4 *	8.6 ± 2.5	8.2 ± 2.1
peak HR (bpm) †	*1*	173 ± 13 *	166 ± 8	165 ± 15	166 ± 11	164 ± 13
	2	178 ± 10 *	173 ± 6	173 ± 12	175 ± 10	174 ± 13
	3	179 ± 9	178 ± 6	176 ± 11	180 ± 11	179 ± 13
blood lactate (mM) †	*pre*	1.7 ± 0.5	1.8 ± 0.5	1.4 ± 0.5	1.2 ± 0.4	1.3 ± 0.6
	1	2.3 ± 1.2	2.5 ± 1.0	--	--	--
	2	7.2 ± 2.0	6.2 ± 1.5	--	--	--
	3	9.8 ± 2.8	8.7 ± 1.0	11.7 ± 4 *	8.8 ± 1.9	8.8 ± 1.7
RPE † Study 1: 0-10 Study 2: 6-20	*pre*	1 ± 1 *	2 ± 1	7 ± 1	6 ± 0	7 ± 1
	1	5 ± 2	4 ± 1	13 ± 2	13 ± 2	12 ± 1
	2	7 ± 2	6 ± 1	15 ± 2	15 ± 1	14 ± 1
	3	9 ± 2	8 ± 1	16 ± 1	16 ± 2	16 ± 2

Values are means ± SD. In Study 1, n=8 except for peak HR (n=6). In Study 2, n=11 except for work output (n=10) and peak HR (n=9). † Main effect for time, with each time point higher than the previous ($p<0.05$), except for the blood lactate following bout 1. * Significantly different than corresponding bout(s) within study ($p<0.05$), as determined by post-hoc analyses following a significant Time x Group interaction. **HR**, heart rate; **pre**, immediately prior to bout 1 for Study 1 and prior to warm-up for Study 2; **RPE**, rating of perceived exertion.

TABLE 3. Cardiometabolic measures pre- and post-training.

	Study 1		Study 2	
Variable	*PRE*	*POST*	*PRE*	*POST*
Peak Exercise Capacity				
$\dot{V}O_{2peak}$ (mL•kg^{-1}•min^{-1})	28.9 ± 3.4	32.4 ± 3.6 *	31.2 ± 4.6	33.3 ± 5.3 *
mCAFT (mL•kg^{-1}•min^{-1})	35.9 ± 2.7	37.4 ± 3.2 *	--	--
PPO (W)	172 ± 21	186 ± 23 *	168 ± 29	183 ± 32 *
Resting Cardiovascular Measures				
SBP (mmHg)	104 ± 8	104 ± 7	97 ± 12	98 ± 11
DBP (mmHg)	67 ± 6	66 ± 6	67 ± 9	67 ± 7
HR (bpm)	77 ± 7	75 ± 10	86 ± 12	78 ± 8 *
Body Composition				
BMI (kg•m^{-2})	23.6 ± 3.0	23.7 ± 3.0	22.5 ± 4.7	22.9 ± 4.7 *
Body Mass (kg)	62.2 ± 9.5	62.6 ± 9.7	58.1 ± 15.0	58.9 ± 14.8 *
Fat Free Mass (kg)	41.7 ± 4.6	42.2 ± 4.4	40.1 ± 4.8	41.3 ± 5.0 *
Fat Free Mass (kg)	41.7 ± 4.6	42.2 ± 4.4	40.1 ± 4.8	41.3 ± 5.0 *
Body Fat (%)	32.5 ± 5.7	32.0 ± 5.4	28.8 ± 9.7	28.0 ± 9.4
Glycemic Measures				
FG (mM)	5.2 ± 0.6	5.4 ± 0.4	4.8 ± 0.4	4.9 ± 0.5
FI (µIU•mL^{-1})	15.1 ± 21.7	12.3 ± 13.5	7.6 ± 4.9	6.5 ± 2.6
HOMA-IS	11.1 ± 7.9	10.2 ± 5.6	17.9 ± 14.1	15.6 ± 8.1
ISI – Cederholm	--	--	57.3 ± 16.7	64.42 ± 21.4 #
Insulin AUC (µIU•mL^{-1} • 2h)	--	--	6365 ± 3028	5635 ± 2908
Glucose AUC (mM • 2h)	--	--	801 ± 145	768 ± 144

Values are means ± SD. In Study 1, n=12. In Study 2, n=11 except for resting cardiovascular measures (n=10) due to participant complications. * $p<0.05$ vs. pre-training within study. # $p=0.056$ vs. pre-training in Study 2. **PRE**, pre-training; **POST**, post-training; $\dot{V}O_{2peak}$, direct peak oxygen uptake; **mCAFT**, estimated peak oxygen uptake via modified Canadian Aerobic Fitness Test; **PPO**, peak power output; **SBP**, systolic blood pressure; **DBP**, diastolic blood pressure; **HR**, heart rate; **BMI**, body mass index; **FG**, fasting glucose; **FI**, fasting insulin; **ISI**; insulin sensitivity index; **AUC**, area under the curve.

FIGURES

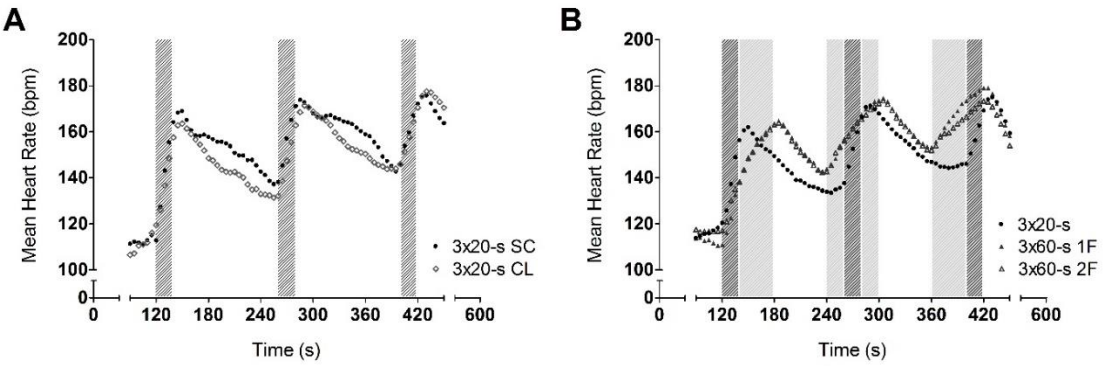

Figure 1. Similar heart rate responses during the acute 3x20-s and 3x60-s exercise sessions. Mean heart rate response for the acute exercise sessions in Study 1 (Panel A) and Study 2 (Panel B) including the last 30 s of warm-up, the bouts and recoveries and the first 30 s of cool-down. Values are means ± S.D. SC, stair climbing; CL, cycling; F, flight; black hashed lines represent the 20-s bouts; gray hashed lines represent the 60-s bouts.

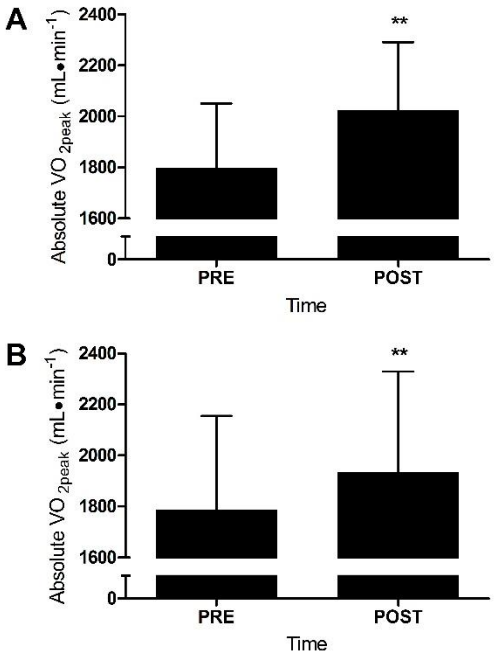

Figure 2. Similar improvements in $\dot{V}O_{2peak}$ after 6 weeks of 3x20-s and 3x60-s 1F. Measured at baseline (PRE) and after 6 weeks of training (POST) with the 3x20-s (Panel A) and 3x60-s 1-flight (Panel B) protocols. Values are means ± S.D. ** p≤0.001 vs. PRE.

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APPENDICES

APPENDIX A: Characteristics of SIT and stair climbing intervention studies.

Table 1. Characteristics of sprint interval training interventions involving ≤30-s bouts.

References	Study Design	Sample Size	Subjects	Intervention	Protocol	No. Reps Start	No. Reps End	Cardiovascular measures and results	Metabolic measures and results
Sharp *et al*. 1986	NC	8 M	Untrained 22-29 y	4 d/wk x 8 wk	30-s all-out, 7.5% BW; 2 min rec.	8	8	VO_{2peak} ↑ 8.3%	muscle buffer capacity ↑ 29 %
Allemeier *et al*. 1994	C	11 M	Untrained 23±5 y	2-3 d/wk x 6 wk	30-s all-out, 7.5% BW; 20 min rec.	3	3	VO_{2peak} ↑ 12.5%	n.d.
Stathis *et al*. 1994	NC	6 M, 2 W	Untrained 22±1 y	2 d/wk x 5 wk	30-s all-out; 3-4 min rec.	3	10	VO_{2peak} ↑ 4.2%	ATP depletion ↓ 52%
MacDougall *et al*. 1998	NC	12 M	Untrained 23±2 y	3 d/wk x 7 wk	30-s all-out, 7.5% BW; 2-4 min rec.	4	10	VO_{2peak} ↑ 6.9%	HK, PFK, CS, SDH, and MDH ↑ activity
Barnett *et al*. 2004	C	8 M	Untrained 21±1 y	3 d/wk x 8 wk	30-s all-out, 9 rev per pedal crank; 3 min rec.	3	6	VO_{2peak} ↑ 8.2%	CS activity ↑ 42% Resting glycogen ↑ 17% PFK, fibre type ↔
Burgomaster *et al*. 2005	C	6 M, 2 W	Sed-healthy 22±1 y	3d/wk x 2 wk	30-s all-out, 7.5% BW; 4 min rec.	4	7	VO_{2peak} ↔	CS activity ↑ 38% Resting glycogen ↑ 26%
Harmer *et al*. 2005	C	3 W, 5 M	T1D	3d/wk x 7 wk	30-s all-out, 7.5% BW; 3-4 min rec.	4	10	VO_{2peak} ↑ 6% Hct ↔ [Hb] ↔	Resting PG ↔
Burgomaster *et al*. 2006	C	8 M	Untrained 22±1 y	3d/wk x 2 wk	30-s all-out, 7.5% BW; 4 min rec.	4	7	n.d.	CS activity ↑ 11% HAD ↔ Resting glycogen ↑ 50%
Gibala *et al*. 2006	C	8 M	Untrained 22±1 y	3d/wk x 2 wk	30-s all-out, 7.5% BW; 4 min rec.	4	6	n.d.	COX II/IVactivity ↑ Resting glycogen↑ 28% muscle buffer capacity ↑ 8%
Burgomaster *et al*. 2007	C	8 M	Untrained 22±1 y	3d/wk x 6 wk	30-s all-out, 7.5% BW; 4 min rec.	4	6	n.d.	GLUT4 ↑ @ 1wk of TR COX IV ↑ @ 1wk of TR FAT/CD36 ↔ FABPpm ↔
Burgomaster *et al*. 2008	NC	5 M, 5 W	Untrained 24±1 y	3d/wk x 6 wk	30-s all-out, 7.5% BW; 4.5 min rec.	4	6	VO_{2peak} ↑ 7.3% submax VO_2 ↓ 4% submax HR ↓ 6%	CS activity ↑ β-HAD ↑ PGC-1α ↑

References	Study Design	Sample Size	Subjects	Intervention	Protocol	No. Reps Start	No. Reps End	Cardiovascular measures and results	Metabolic measures and results
Trapp *et al*. 2008	C	11 W	Sed-healthy 20±2 y	3 d/wk x 15 wk	8-s all-out, ≥0.5 kg; 12 s rec.	15	60	VO_{2peak} ↑ 24%	FI ↓ 31% FG ↔ HOMA-IR ↔ fat mass ↓
Babraj *et al*. 2009	NC	16 M	Untrained + Sed-healthy 21±1 y	3 d/wk x 2 wk	30-s all-out, 7.5% BW; 4 min rec.	4	7	n.d.	FI, FG ↔ Cederholm-IS ↑ 23% OGTT gluc. AUC ↓ 12% OGTT ins. AUC ↓ 37%
Hazell *et al*. 2010	C	8 M, 4W	Untrained 24±3 y	3 d/wk x 2 wk	30-s all-out, 10% BW; 4 min rec.	4	6	VO_{2peak} ↑ 9.3%	n.d.
		8 M, 4W			10-s all-out, 10% BW; 4 min rec.			VO_{2peak} ↑ 9.2%	n.d.
		8 M, 4W			10-s all-out, 10% BW; 2 min rec.			VO_{2peak} ↔	n.d.
Richards *et al*. 2010	C	5 M, 7 W	Untrained + Sed-healthy 29±3 y	3 d/wk x 2 wk	30-s all-out, 7.5% BW; 4 min rec.	4	7	n.d.	FG ↔ Eug. Ins. clamp GIR ↑ 23% (72 h)
Whyte *et al*. 2010	NC	10 M	Sed-healthy overweight/obese 32±9 y	3 d/wk x 2 wk	30-s all-out, 6.5% FFM; 4.5 m rest	4	6	VO_{2peak} ↑ 9.5%	FI ↓25% (24 h), ↔ (72 h) FG ↔ (24, 72 h) OGTT ins. AUC ↓15% (24 h), ↔ (72 h) OGTT gluc. AUC ↔ (24, 72 h) IS ↑ 23% (24 h), ↔ (72 h)
Bayati *et al*. 2011	C	8	Untrained 25±1 y	3 d/wk x 4 wk	30-s all-out 7.5% BW; 4 min rec.	3	5	VO_{2peak} ↑ 9.6%	n.d.
	C	8			30-s, 125% PPO; 2 min rec.	6	10	VO_{2peak} ↑ 9.7%	n.d.
Macpherson *et al*. 2011	NC	6 M, 4 W	Untrained 24±3 y	3d/wk x 6 wk	30-s all-out running; 4 min rec.	4	6	VO_{2peak} ↑ 11.5% CO_{max} ↔ SV_{max} ↔ $(a\text{-}v)O_{2max}$ ↑ 7.1%	% body fat ↓ 1.8% Fat mass ↓ 12 % FFM↑ 1% RMR ↔
Tong *et al*. 2011	NC	8	Sed-healthy obese 23±2 y	3d/wk x 6 wk	30-s all-out, 120 % PPO; 1 min rec.	20	20	VO_{2peak} ↑ 6.6%	n.d.

References	Study Design	Sample Size	Subjects	Intervention	Protocol	No. Reps		Cardiovascular measures and results	Metabolic measures and results
						Start	End		
Trilk *et al.* 2011	C	14 W	Sed-healthy overweight/obese 30±7 y	3d/wk x 4 wk	30-s all-out, 5% BW; 4 min rec.	4	7	$CO_{50\% VO2peak}$ ↔ $HR_{50\% VO2peak}$ ↓ 8.1% $SV_{50\% VO2peak}$ ↑ 11.4% $(a\text{-}v)O_{2\ 50\%VO2peak}$ ↔	% body fat ↔
Astorino *et al.* 2012	C	11 M, 9 W	Untrained 25±5 y	3d/wk x 2 wk	30-s all-out, 7.5% BW; 5 min rec.	4	6	VO_{2peak} ↑ 5.5% O2 pulse ↑ 5.9% Resting HR ↔ Resting BP ↔	% body fat ↔ waist:hip ratio ↔
Metcalfe *et al.* 2012	C	7 M, 8 W	Sed-healthy overweight/obese 25±3 y	3d/wk x 6 wk	10-20 s all-out, 7.5% BW; ~3.5 min rec.	1	2	VO_{2peak} ↑ 15% (M); 12% (W)	Cederholm-IS ↑ 28% (M); ↔ (W) OGTT gluc. AUC ↔ (M); ↑ 6% (W) OGTT ins. AUC ↔
Rowan *et al.* 2012	NC	7 W	Soccer Ath. 20	2d/wk x 5 wk	30-s all-out; 4.5 min rec.	5	5	VO_{2peak} ↑ 4.7%	n.d.
Sandvei *et al.* 2012	NC	4 M, 7 W	Untrained 25±1 y	3d/wk x 8 wk	30-s near-max running 5-8% incl.; 3 min rec.	5	10	VO_{2peak} ↑ 5.3%	FG ↓ 3.8% (60 h) FI ↔ HOMA-IR ↔ HOMA β-cell ↑ 8.2 OGTT gluc. AUC ↓ 5.8% OGTT ins. AUC ↔ LDL ↓ 9.4% Total chol. ↓ 6.7% Body fat % ↔ FFM ↔
Cocks *et al.* 2013	NC	8 M	Sed-healthy 22±1 y	3d/wk x 6 wk	30-s all-out, 7.5% BW; 4.5 min rec.	4	6	VO_{2peak} ↑ 7.6% RHR ↓ 6.2% MAP ↓ 4.9% SBP ↔ DBP ↓ 4.8 % eNOS ↑36% cap.-fibre ratio ↑24% cap. density ↑32% cPWV ↓ 7% pPWV ↔	Matsuda-IS ↑ 27% (48 h) OGTT gluc. AUC ↓ 17% OGTT ins. AUC ↓ 35%

References	Study Design	Sample Size	Subjects	Intervention	Protocol	No. Reps Start	No. Reps End	Cardiovascular measures and results	Metabolic measures and results
Shepherd *et al.* 2013	NC	8 M	Sed-healthy 21±1 y	3d/wk x 6 wk	30-s all-out, 7.5% BW; 4.5 min rec.	4	6	VO_{2peak} ↑ 8.0%	FPI, FPG ↔ (48 h) Matsuda-IS ↑ 56 % OGTT gluc. AUC ↓ 17% OGTT ins. AUC ↓ 35% Resting IMTG ↑ 70% FFM ↑ 2.1%
Skleryk *et al.* 2013	NC	8 M	Sed-healthy overweight/obese 39±6 y	3d/wk x 2 wk	10-s all-out, 5.0% BW; 80 s rec.	8	12	VO_{2peak} ↔	FI, FG ↔ HOMA-IS ↔ NEFA ↔ GLUT4, AS160(p), SIRT1, COX II, IV ↔ body fat % ↔
Adamson *et al.* 2014	C	2 M, 6 W	Untrained overweight 43±8 y	2d/wk x 8 wk	6-s all-out, 7.5% (M) 6.5% (W) BW; 1 min rec.	10	10	VO_{2peak} ↑ 8.0% SBP, DBP ↔	FPG ↓ 6.5% (5 d) OGTT 2h gluc. ↓ 11% OGTT gluc. AUC ↓ 6%
Harris *et al.* 2014	NC	6 W	Sed-healthy 22±2 y	3d/wk x 4 wk	30-s all-out, 7.5% BW; 4.5 min rec.	4	4	VO_{2peak} ↑ 10% RHR ↔ SBP ↔ DBP ↔ CD34+ cells ↑ 43% FMD ↔ cPWV, pPWV↔ CAC function ↔	n.d.
Gillen *et al.*. 2014	NC	7 M, 7W	Sed-healthy overweight/obese 29±9 y	3d/wk x 6 wk	20-s all-out, 5.0% BW; 2 min rec.	3	3	VO_{2peak} ↑ 12% MAP ↓ 5.6% (M); 7.5% (W) SBP ↓ 6.4% (M); 8.3% (W)	mean CGM (48-72h post TR) ↓ 10% (M); ↔ (W) FG ↔ FI ↓ 21% (M); 26% (W) HOMA-IR ↓ 19%; 29%(W) GLUT4 ↑ 128% (M), ↑ 23% (W) CS activity ↑ 40% COX IV ↑ βHAD activity ↑ (M); ↔ (W)
Lunt *et al.* 2014	C	6 M, 3 F	Sedentary overweight/obese 54±6 y	3d/wk x 12 wk	30-45 s volitional max intensity walking or jogging; 4 min rec.	3	6	VO_{2peak} ↔ SBP ↔ DBP ↔	body fat % ↔ HOMA-IS ↔ total chol ↔ TG ↔ HDL chol ↔

References	Study Design	Sample Size	Subjects	Intervention	Protocol	No. Reps		Cardiovascular measures and results	Metabolic measures and results
						Start	End		
Scribbans *et al.* 2014a	C	8 M, 2 W	Untrained 21±4 y	4 d/wk x 6 wk	20-s, 170% VO2 peak; 20 s rec.	8	8	VO_{2peak} ↑ 14% cap. density ↑ O_2 pulse ↑	Est. oxidative capacity ↑ Est. glycolytic capacity ↑ Resting glycogen (type 1) ↑ IMTG ↑
Scribbans *et al.* 2014b	C	8 M	Untrained 22±1 y	4 d/wk x 6 wk	20-s, 170% VO2 peak; 20 s rec.	8	8	VO_{2peak} ↑ 6.2%	Resting RER ↔ SDH activity ↑ Resting glycogen ↑ IMTG content ↔
Shaban *et al.* 2014	NC	9 M/W	T2D 40±10 y	3 d/wk x 2 wk	30-s 100% est. workload; 4 min rec.	4	4	n.d.	FG, FI ↔ HOMA-IR ↔
Macpherson and Weston 2014	C	14 M	Soccer Ath. 25±4 y	3 d/wk x 2 wk	30-s all-out, 7.5% BW; 4 min rec.	4	7	VO_{2peak} ↑ 3%	n.d.
Zelt et al. 2014	C	11 M	Untrained 23±5 y	3d/wk x 4 wk	30-s all-out, 7.5% BW; 4.5 min rec.	4	6	VO_{2peak} ↑ 4% O_2 pulse $_{peak}$ ↔	Lactate threshold ↑ 19%
		12 M	Untrained 22±2 y		15-s all-out, 7.5% BW; 4.75 min rec.			VO_{2peak} ↑ 4% O2 pulse peak ↔	Lactate threshold ↑ 8.9%
Willoughby et al. 2015	NC	7 M, 7 W	Sed-healthy 23±3 y	3d/wk x 4 wk	30-s all-out, running; 4 min rec.	4	6	VO_{2peak} ↑ 3.9%	n.d.
		5 M, 9 W	Sed-healthy 45±3 y					VO_{2peak} ↑ 5.2%	n.d.
Gillen et al. 2016	C	9 M	Sed-healthy overweight/obese 27±8 y	3d/wk x 12 wk	20-s all-out, 5.0% BW; 2 min rec.	3	3	VO_{2peak} ↑ 19% MAP ↓ 5.6% (M); 7.5% (W) SBP ↓ 6.4% (M); 8.3% (W)	FG, FI ↔ (72 h post TR) HOMA-IR ↔ IVGTT-IS ↑ IVGTT gluc. AUC ↓ 26% IVGTT ins. AUC ↔ GLUT4 ↑ 50% CS activity ↑ 40% βHAD activity ↑ 28% Complex II, III, IV, ATP synthase-α, COX IV ↑

References	Study Design	Sample Size	Subjects	Intervention	Protocol	No. Reps		Cardiovascular measures and results	Metabolic measures and results
						Start	End		
Songsorn et al. 2016	C	5 M, 10 W	Untrained and Sed-healthy 24±6 y	3d/wk x 4 wk	20-s all-out, 7.5% BW	1	1	VO_{2peak} ↔	n.d.

Sample size of intervention group reported. C, controlled study; NC, no control group; M, men; W, women, Sed, sedentary; untrained, recreationally active but not trained; BW, body weight; rec., recovery periods; VO_{2peak}, peak oxygen uptake; HK, hexokinase; PFK, phosphofructokinase; CS, citrate synthase; SDH, succinate dehydrogenase; MDH, malate dehydrogenase; Hct., hematocrit; [Hb], hemoglobin concentration; PG, plasma glucose; βHAD, β-hydroxyacyl CoA dehydrogenase; COXII and IV cytochrome oxidase 2 and 4, respectively; GLUT4, glucose transporter 4; FAT/CD36, fatty acid transporter; FABPpm, plasma membrane fatty acid binding protein; PGC-1α peroxisome proliferator-activated receptor gamma coactivator 1-α; FI, fasting insulin; FG, fasting glucose; HOMA, homeostatic model of assessment; IR, insulin resistance; IS, insulin sensitivity; OGTT, oral glucose tolerance test; gluc., glucose; ins., insulin; AUC, area under the curve; eug. Ins., hyperinsulinaemic euglycaemic insulin clamp; GIR, glucose infusion rate; PPO, peak power output; CO, cardiac output; SV, stroke volume; (a-v)O2, arterial-venous oxygen extraction; FFM, fat free mass; RMR, resting metabolic rate; HR, heart rate; O_2 pulse, mL oxygen per beat; LDL, low-density lipoprotein; chol., cholesterol; HDL, high-density lipoprotein; RHR, resting heart rate; MAP, mean arterial blood pressure; SBP, systolic blood pressure; DBP, diastolic blood pressure; eNOS, endothelial nitric oxide synthase; cap., capillary; cPWV, central pulse wave velocity; pPWV, peripheral pulse wave velocity; IMTG, intra-muscular triglycerides; NEFA, non-esterified fatty acids; AS160, Akt substrate; SIRT1, sirtuin 1; FMD, flow mediated dilation; CAC, circulating angiogenic cells; CGM, continuous glucose monitoring; IVGTT, intra-venous glucose tolerance test.

Table 2. Characteristics of stair climbing intervention studies.

References	Study Design	Sample Size	Subjects	Intervention	Protocol	Intensity	Climbs/day Start	Climbs/day End	Cardiovascular measures and results	Metabolic measures and results
Fardy et al. 1975	C	30 M	Untrained 17-64 y	12 wk unsupervised at work	SC instead of elevator; upper 50th: 125 fl/d lower 50th: 55 fl/d; Str Ht = 0.180 m	~100 steps/min	n.d.	n.d.	Est. VO_{2peak} ↑ 10% (upper 50th) RHR ↔	% body fat ↔ calf skin fold ↓
Ilmarinen et al. 1978	C	19 M	Sed-healthy, untrained	10 wk unsupervised at work	SC instead of lift; ~30 fl/d; ~4 climbs/d; Str Ht= 0.173 m	~7 fl/climb; ~8 min at 130-159 bpm; ~1 min at 160-180 bpm	n.d.	n.d.	Est. VO_{2peak} ↑ 15%	n.d.
Ilmarinen et al. 1979	C	59 W	Sed-healthy, untrained 30-38 y	12 wk unsupervised at work	SC instead of elevator; ~ 64 floors/wk; 2-4 sessions/d; ~1 min/session;	peaks at ~70% VO_{2max}	n.d.	n.d.	Est. VO_{2peak} ↔	BW ↑
		26 W		24 wk unsupervised at work					Est. VO_{2peak} ↑ 4.8% in older ↑ 6.3 % in less fit	BW ↓
Loy et al. 1994	C	17 W	Sed-healthy 50-65 y	4 d/wk x 12 wk; stepmill	40 min/session	LOAD: 4-8% BW STAIR: BW 40-45 stairs/min; 70-85% MHR	n.a.	n.a.	VO_{2peak} ↑ 9.6% LOAD ↑ 11.1% STAIR	n.d.
Boreham et al. 2000	C	12 W	Sed-healthy 20±1 y	5 d/wk x 7 wk; local stairwell	~2 min/climb; ≥ 1 h b/w climbs; 1 climb = 199 stairs or 8 flights; Str Ht = 0.165 m	88 stairs/min HR peaks of 90% MHR	1	6	submax VO_2 ↓ 8.5% submax HR ↓ 4.2%	HDL ↑ 19% TC ↓ 8.1% TC:HDL ↑ 22%
Egana and Donner 2003	C	7 W	Untrained 31±3 y	3 d/wk x 12 wk; stepmill	30-40 min/session	70-90% MHR	n.a.	n.a.	VO_{2peak} ↑ 5.4%	% body fat ↓ 0.5%
Boreham et al. 2005	C	18 W	Sed-healthy 19±1 y	5 d/wk x 8 wk; local stairwell	~2 min/climb; ≥ 1 h b/w climbs; 1 climb = 199 stairs or 8 flights; Str Ht = 0.165 m	90 stairs/min; 'comfortable but brisk'	2	5	VO_{2peak} ↑ 17%	LDL ↓ 7.9% TC, HDL, TC/HDL, TG ↔

References	Study Design	Sample Size	Subjects	Intervention	Protocol	Intensity	Climbs/day Start	Climbs/day End	Cardiovascular measures and results	Metabolic measures and results
Kennedy et al. 2007	C	14 M, 15 W	Sed-healthy 44±7 y	5 d/wk x 8 wk; local stairwell	~2 min/climb; ≥ 1 h b/w climbs; 1 climb = 145 stairs or 8 flights; Str Ht = 0.165 m	75 steps/min; 'comfortable but brisk'	1	3	Est. VO_{2peak} ↑ 9.4% SBP, DBP ↔	% body fat ↔ TC, LDL, HDL, TC/HDL, TG ↔
Mair et al. 2014	C	12 M, 19 W	Sed-healthy 55-64 y	3 d/wk x 4 wk bench stepping; N=11 at home N=20 at work	2-3 min/session; Str Ht = 0.15, 0.20, 0.25 or 0.30 m	75±5% HRR 80-120 stairs/min	2	3	submax VO_2 ↓ 5.2% submax HR ↓ 6.8%	% body fat ↔
Donath et al. 2014	C		Untrained healthy 70±5 y	3 d/wk x 8 wk; local stairwell	INT_1=every step INT_2=every 2nd ; 1 climb = 128 stairs or 8 floors; elevator to descend	INT_1: 121±9 bpm INT_2: 128±7 bpm	2	5	submax VO2 ↓ INT_2, ↔ INT_1 RHR ↓ INT_2, ↔ INT_1	n.d.

Sample size of intervention group reported. C, controlled study; M, men; W, women, Sed, sedentary; SC, stair climbing; Str Ht, stair height; VO_{2peak}, peak oxygen consumption (direct measures unless stated); Est, estimated; RHR, resting heart rate; MHR, max heart rate; BW, body weight; TC, total cholesterol; HDL, high-density lipoprotein; LDL, low-density lipoprotein; TG, triglycerides; HRR; heart rate reserve; n.d., no data; n.a., not applicable.

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APPENDIX B: Training characteristics of Study 1

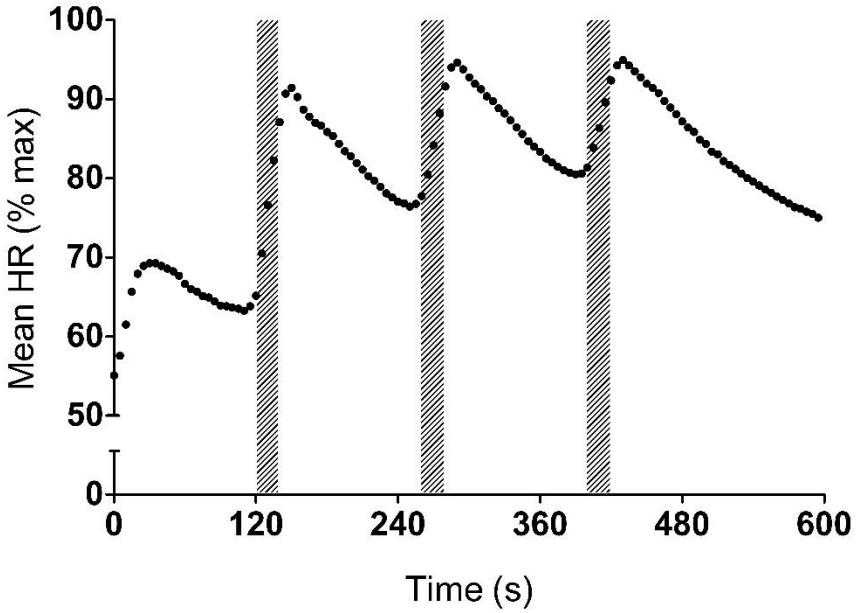

Figure 1. Relative mean heart rate response to the 3x20-s stair climbing SIT protocol. Values are mean percentages of maximum heart rate from all of the training sessions in the chronic phase of Study 1. Black hashed lines represent the timing of each 20-s bout (n=12).

Table 1: Relative heart rate responses to the 3x20-s SIT protocol.

Subject	**Bout 1**	**Bout 2**	**Bout 3**	**Peak 1**	**Peak 2**	**Peak 3**	**$Bout_{mean}$**	**$Peak_{mean}$**	**Total 10 min**
1	83	90	92	95	96	97	89	96	84
2	86	91	90	95	96	96	89	95	83
3	78	83	86	89	93	95	82	92	77
4	80	86	87	88	92	92	84	90	79
5	86	91	91	96	98	98	89	97	82
6	80	88	91	90	93	94	86	93	82
7	74	81	83	85	89	91	79	88	72
8	84	88	91	94	95	96	88	95	85
9	85	91	92	95	98	98	89	97	83
10	83	90	90	95	97	97	88	96	81
11	82	89	89	93	96	96	87	95	79
12	80	87	90	92	95	97	86	95	82
Mean	**82**	**88**	**89**	**92**	**95**	**96**	**85**	**94**	**81**
SD	4	3	4	4	3	2	4	3	4

Values are mean percentages of maximum heart rate from all training sessions.

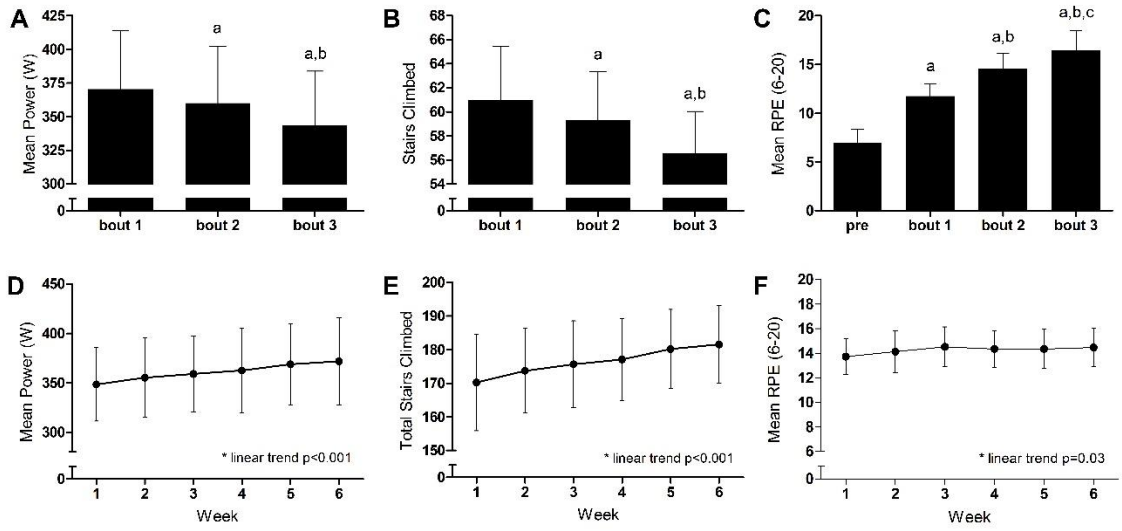

Figure 2. Acute and weekly training characteristics of the 3x20-s stair climbing SIT protocol. Mean values across bouts and weeks for power output (Panel A and D), stairs climbed (Panel B and E), and mean rating of percieved exertion (RPE; Panel C and F) from all trianing sessions. Means with different letters are signficantly different ($p<0.05$); * and ** $p<0.05$ vs. week 1 and 3, respectively; n=12. Error bars represent one SD.

Table 2: Weekly stair climbing characteristics for the 3x20-s protocol.

Variable	Week 1	Week2	Week 3	Week 4	Week 5	Week 6
Stairs climbed (stairs/bout)	56 ± 5	57 ± 5	58 ± 4	59 ± 4	60 ± 4	60 ± 4
Height climbed (m/bout)	10.9 ± 0.9	11.2 ± 0.8	11.3 ± 0.8	11.4 ± 0.8	11.6 ± 0.7	11.7 ± 0.7
Climbing rate (m/s)	0.55 ± 0.04	0.56 ± 0.04	0.57 ± 0.04	0.57 ± 0.04	0.58 ± 0.04	0.59 ± 0.03
Mean power (W)	343 ± 34	348 ± 35	353 ± 34	356 ± 39	362 ± 37	365 ± 39
Relative power (W/kg)	5.2 ± 0.4	5.3 ± 0.3	5.3 ± 0.4	5.4 ± 0.3	5.5 ± 0.3	5.5 ± 0.3
Fatigue index per bout (%)	14.5 ± 5.3	14.5 ± 3.6	14.1 ± 5.1	13.9 ± 4.9	13.0 ± 7.5	11.2 ± 8.3

Values are means ± SD, n=11. Stair height = 0.195 m. ~20 stairs per floor. Climbing rate and power calculations do not account for time spent on landings between flights (≥1 s per landing, ~5 landings). Power = body mass (kg) • 9.81 m/s^2 • height climbed (m) / 20 s.

APPENDIX C: Trianing characteristics of Study 2.

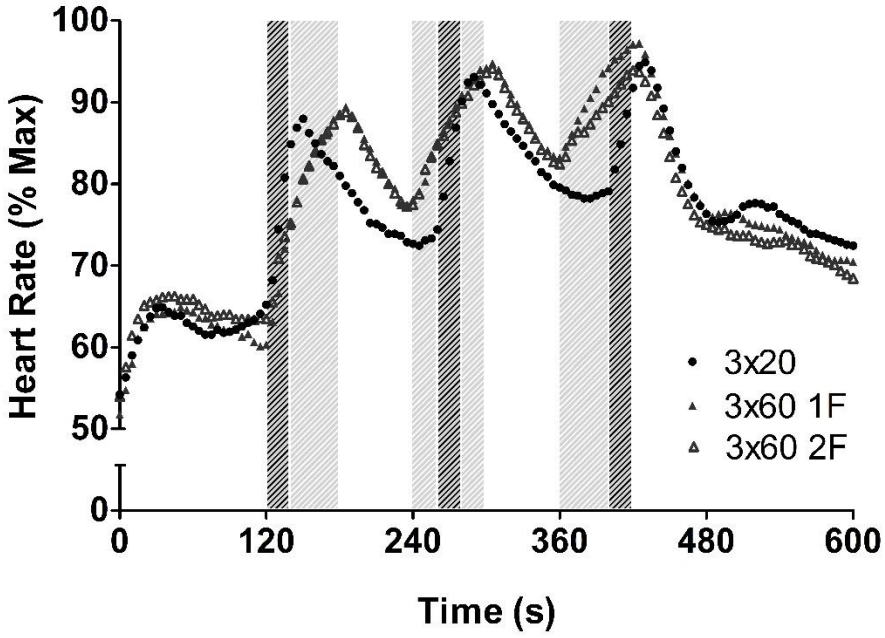

Figure 1. Relative mean heart rate response to single sessions of the 3x20-s and 3x60-s stair climbing protocols. Values are mean percentages of maximum heart rate from one session of the 3x20-s 'all-out', and the 3x60-s one-flight (1F) and two-flight (2F) protocols in the acute phase of Study 2 (n=9). Black and grey hashed lines represent the 20-s bouts and the 60-s bouts, respectively.

Table 1: Relative heart rate responses single sessions of the 3x20-s, 3x60-s 1 and 2 flight protocols.

Protocol	Bout 1	Bout 2	Bout 3	Peak 1	Peak 2	Peak 3	$Bout_{mean}$	$Peak_{mean}$	Total 10 min
3x20-s	77 ± 6	84 ± 4	87 ± 3	88 ± 3	93 ± 2	95 ± 2	82 ± 6	92 ± 4	76 ± 3
3x60-s 1F	78 ± 4	87 ± 3	91 ± 2	89 ± 2	94 ± 2	96 ± 2	87 ± 6	93 ± 4	78 ± 3
3x60-s 2F	78 ± 5	87± 3	91 ± 2	88 ± 3	94 ± 2	96 ± 2	85 ± 6	93 ± 4	77 ± 3

Values are percentages of maximum heart rate (means ± SD; n=9).

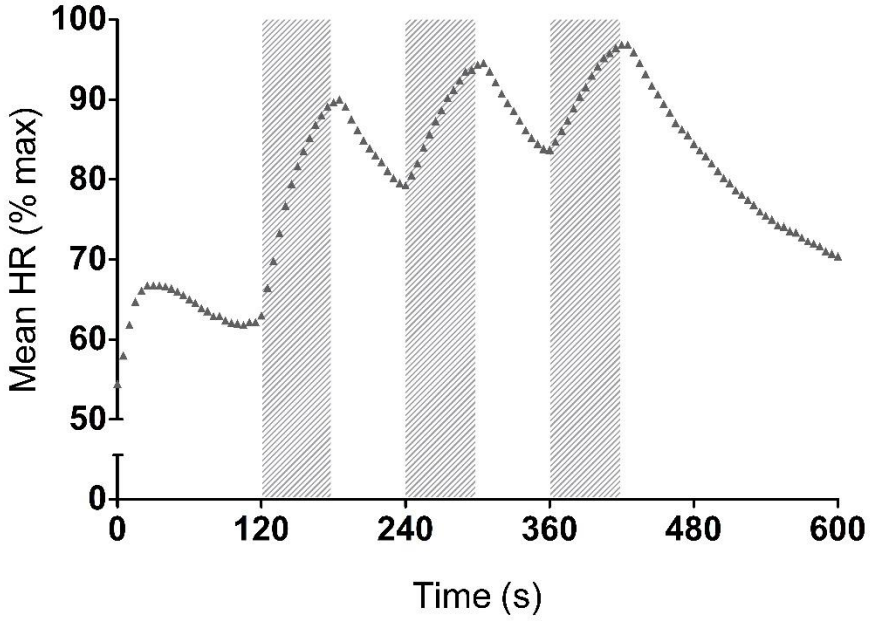

Figure 2. Relative mean heart rate response to the 3x60-s 1-flight stair climbing protocol. Values are mean percentages of maximum heart rate from week 1, 3 and 6 in the chronic phase of Study 2 (n=11). Grey hashed lines represent the timing of each 60-s bout.

Table 2: Relative heart rate responses to the 3x60-s 1 flight protocol.

Subject	**Bout 1**	**Bout 2**	**Bout 3**	**Peak 1**	**Peak 2**	**Peak 3**	**$Bout_{mean}$**	**$Peak_{mean}$**	**Total 10 min**
1	80	88	91	90	94	97	86	94	80
2	79	87	90	89	93	96	85	92	79
3	82	89	92	89	93	96	87	92	78
4	83	89	92	92	94	96	88	94	82
5	79	89	92	90	93	95	86	93	77
6	84	92	95	94	96	98	90	96	80
7	82	89	91	92	95	96	87	94	80
8	75	86	92	88	95	98	84	93	79
9	87	93	94	94	96	98	91	96	83
10	82	88	92	90	93	97	88	93	82
11	84	91	94	92	96	98	90	95	83
Mean	**82**	**89**	**92**	**91**	**95**	**97**	**88**	**94**	**80**
SD	3	2	2	2	1	1	2	1	2

Values are mean percentages of maximum heart rate from week 1, 3 and 6 in the chronic phase of Study 2.

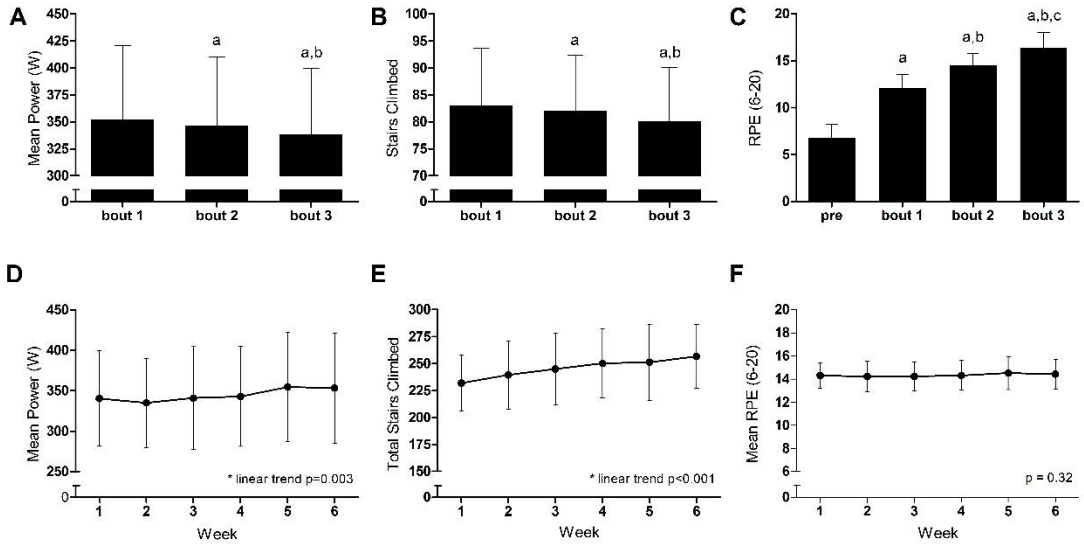

Figure 3. Acute and weekly training characteristics of the 3x60-s stair climbing protocol. Mean values across bouts and weeks for power output (Panel A and D), stairs climbed (Panel B and E), and mean rating of percieved exertion (RPE; Panel C and F) from all trianing sessions. Means with different letters are signficantly different ($p<0.05$); n=11. Error bars represent one SD.

Table 3: Weekly stair climbing characteristics for the 3x60-s 1-flight protocol.

Variable	Week 1	Week2	Week 3	Week 4	Week 5	Week 6
Stairs climbed (stairs/bout)	77 ± 9	80 ± 11	82 ± 11	83 ± 11	84 ± 12	86 ± 10
Height climbed (m/bout)	15.9 ± 5.3	16.4 ± 6.5	16.7 ± 6.9	17.1 ± 6.5	17.2 ± 7.2	17.5 ± 6.0
Climbing rate (m/s)	0.59 ± 0.07	0.61 ± 0.08	0.62 ± 0.08	0.63 ± 0.08	0.64 ± 0.09	0.65 ± 0.07
Mean power (W)	340 ± 59	335 ± 55	341 ± 63	343 ± 62	355 ± 68	353 ± 68
Relative power (W/kg)	6.0 ± 0.6	5.9 ± 0.6	6.0 ± 0.7	6.0 ± 0.7	6.2 ± 0.6	6.2 ± 0.6
Fatigue index per bout (%)	7.5 ± 6.0	9.1 ± 5.2	9.3 ± 5.4	8.9 ± 4.5	10.4 ± 5.2	14.8 ± 5.7

Values are means ± SD, n=11. Stair height = 0.205 m; 10 stairs per flight. Mean power is an average of the first and last ascent. Power = body mass (kg) • 9.81 m/s^2 • 2.05 m / time of ascent (s).

APPENDIX D: Individual improvements in cardiorespiratory fitness.

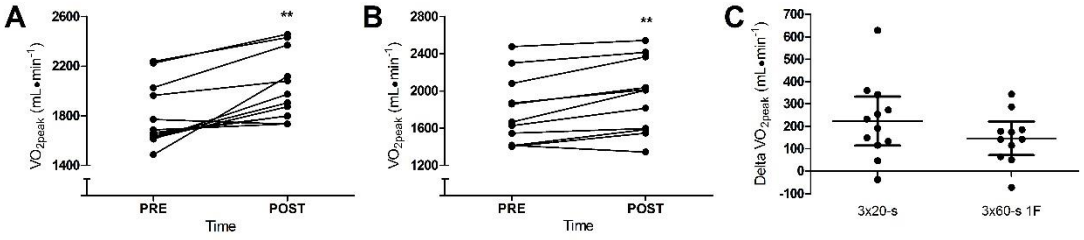

Figure 1. Six weeks of 3x20-s and 3x60-s 1-flight protocols elicit similar improvements in cardiorespiratory fitness. Individuals' absolute VO_{2peak} in Study 1 (Panel A) and Study 2 (Panel B), and the respective changes (Panel C) before and after training with the 3x20-s and 3x60-s 1-flight, respectively. Each solid circle respresents an individual, ** $p \leq 0.001$.

APPENDIX E: Oral gluocse tolerance test results.

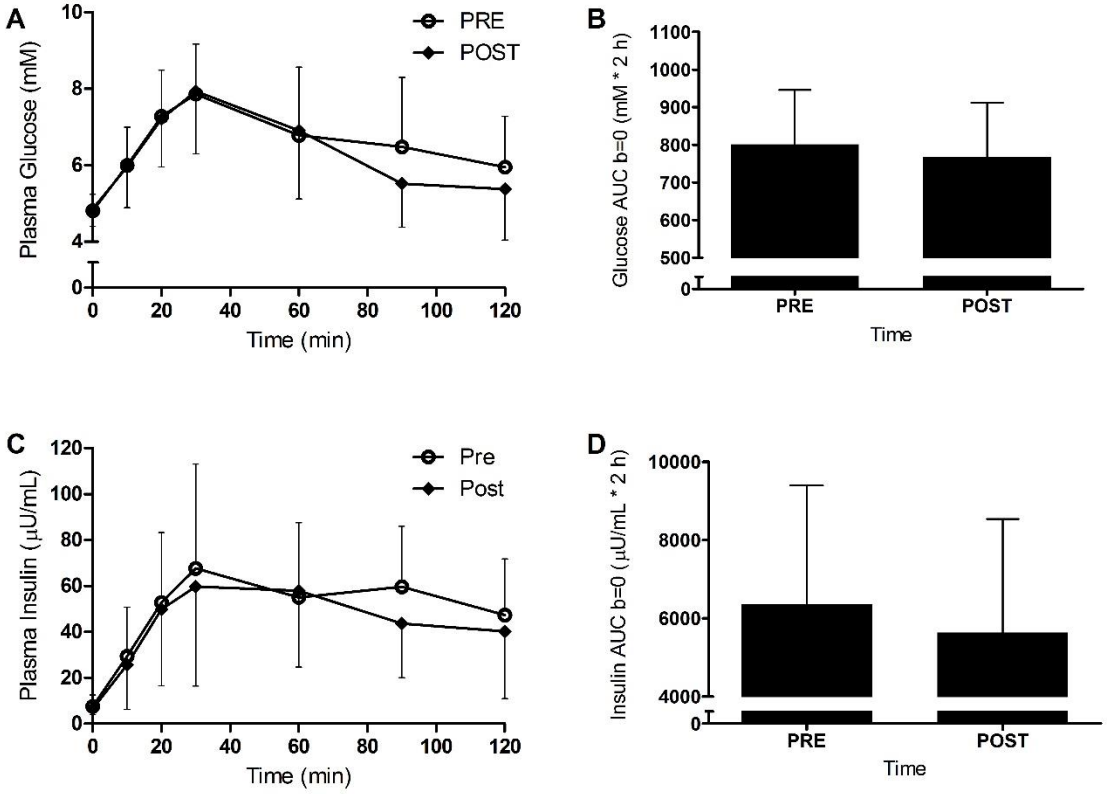

Figure 1. Glycemic control does not improve following 6 weeks of training. Time-course of plasma glucose and insulin concentrations (Panel A and C, respectively) and area under the curve (Panel B and D, respectively) during an oral gluocse tolerance test before and after training. PRE, pre-trianing; POST, post-training. Error bars represent one SD (n=11).