RESPONSES AND ADAPTATIONS TO ACUTE AND CHRONIC

HIGH-INTENSITY INTERVAL TRAINING

by

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(Under the Direction of Kirk J. Cureton)

ABSTRACT

Sprint interval training (SIT) involving repeated 30-s "all out" efforts appears to be an effective and time-efficient stimulus for fitness improvement. Three studies were completed for this dissertation. The purposes were: 1) to perform a meta-analysis to assess the population effect of SIT on aerobic capacity; 2) to compare physiological responses of two SIT protocols of different modality; and 3) to determine the effects of a SIT intervention on fitness and performance. The meta-analysis revealed SIT has a small-to-moderate effect (Cohen's d = 0.32, 95% CI: 0.10, 0.55; z = 2.79, p < 0.01) on aerobic capacity. The effect is large in comparison to no-exercise control groups (Cohen's d = 0.69, 95% CI: 0.46, 0.93; z = 5.84; p < 0.01) and not different when compared to endurance training control groups (Cohen's d = 0.04, 95% CI: -0.17, 0.24; z = 0.36, p = 0.72). In the second study, mean values for $\%VO_{2peak}$ and $\%HR_{peak}$ for cycling (80.4 ± 5.3% and 86.8 ± 3.9%) and calisthenics (77.6 ± 6.9% and 84.6 ± 5.3%) were similar (p > 0.05), but calculated effect sizes revealed a meaningful difference in $\%VO_{2peak}$ (Cohen's d = 0.51) and $\%HR_{peak}$ (Cohen's d = 0.57). In the third study, moderately-trained members of the Army Reserve Officers' Training Corps (ROTC) completed 4 weeks of exercise training 3 days·wk^{-1} consisting of either ~60 min of typical cadet physical training (TCT) or whole-body calisthenics (HIT) involving 4-7 sets of 30-s "all out" burpees separated by 4 min of active recovery. Following training, there were no changes in VO_{2peak}, anaerobic capacity or Army Physical Fitness Test (APFT) performance ($p > 0.05$). For the TCT group, mitochondrial function (T_c: time constant of recovery) was improved (2.4 ± 4.6 s decrease in T_c; $p = 0.081$; $d = -0.51$ (-2.37, 1.35)); whereas, mitochondrial function decreased in HIT (2.4 ± 4.6 s increase in T_c; $p = 0.087$; $d = 0.50$ (-1.36, 2.36)). In conclusion, studies in the literature indicate that SIT has a large effect on aerobic capacity relative to no exercise and an effect similar to prolonged, moderate-intensity continuous exercise. SIT involving whole-body calisthenic exercise elicits vigorous cardiovascular responses with peak values less than cycling SIT. SIT involving low-volume whole-body calisthenics sustains fitness in Army ROTC cadets. A program that includes SIT as part of a larger program may be well suited to moderately-trained armed forces personnel seeking to maintain fitness with minimal time commitment and without access to equipment.

INDEX WORDS: High-intensity interval training, Sprint interval training, Meta-analysis, Calisthenics, Aerobic capacity, Military physical training

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DEDICATION

I dedicate this work to my best friend and wife, Dea, and my two wonderful children, Maddie and Graham. We are a great team!

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CHAPTER 1

INTRODUCTION

High-intensity interval training (HIT) has been a frequently used method of training among elite endurance athletes as a means to improve aerobic and anaerobic capacity, as well as performance in events of various durations and distances. Although there is no single definition of ideal frequency, mode, intensity and duration, HIT has been described as “brief periods of intense muscular activity alternating with periods of recovery” (1) with training sessions often characterized by “an intensity greater than the anaerobic threshold” (2). Interval training was first described by Reindell and Roskamm and was a noted part of the training of 1948 and 1952 Olympic champion, Emil Zatopek (3). First studied in the 1960s by Per Olaf Astrand, the science of interval training has included numerous reports of the immediate physiological responses to and the long term effects of programs with varied characteristics. In a relatively recent review, Billat (3) provided a summary classification of the different types of HIT and highlighted the effectiveness of many variations of interval training. In 1982, Dudley et al (4) reported that the duration of exercise necessary to bring about beneficial skeletal muscle adaptations decreases as intensity increases, providing support for the idea that *less* exercise may be equally effective if intensity is sufficiently *high*.

The efficacy of HIT with respect to cardiorespiratory and metabolic adaptations has led to greater recent research interest in the effects of time-efficient sprint interval training (SIT) (5). In studies utilizing repeated Wingate Anaerobic Tests, the exercise bout involves 30 seconds of supramaximal-intensity cycling against a braking force on a specialized cycle ergometer; exercise participants typically completed 4-7 sprints separated by four minutes of recovery (6-13). SIT interventions with as little as 15 minutes (cumulative time of sprints) of "all out" effort during six sessions across two weeks resulted in significantly improved skeletal muscle oxidative capacity, aerobic capacity (VO_{2max}) and endurance performance (6, 14-16). Others have added to the body of research by using the same cycling protocol or by applying the 30-s:4-min interval to other modalities such as running and rowing (17-22). The findings of these studies have highlighted the potential impact of SIT on several health and fitness variables.

Whether performed in a traditional programmed exercise setting, during athletic competition or in association with occupational requirements, high-intensity intermittent exercise training has proven to be an effective technique for improving several physiological markers of fitness, as well as performance in sport. Athletes competing in sports not traditionally identified as endurance-type events have also employed HIT as part of their competition preparation. For example, the intermittent nature of soccer demands that its athletes sprint frequently during a match in which the periods of intense activity alternate with periods of low-to-moderate intensity action. Scientific and empirical evidence highlighting the benefits of various interval training methods makes its inclusion in preparation for sport competition a common practice.

Similarly, the physical demands placed on armed warfare combatants often involve long periods of lower intensity work interspersed with short periods of high-intensity activity. Therefore, warfighter training should match the expected physical demands of designated mission requirements. There is a need for a physical training stimulus that confers physiological adaptations across energy provision systems, is time efficient, and requires no equipment. Within military organizations, preparation for deployment to areas of operation is often completed on short notice, requires travel, and involves numerous competing requirements that leave little time for programmed exercise.

The effects of SIT using running, cycling, and rowing ergometry have been studied (17-26), but these forms of training require either specialized equipment or considerable space, which may not be available in military deployment and operational settings. High-intensity interval calisthenic exercise, which can be done in limited space without equipment, might convey similar adaptations, but its effects have not been studied in military personnel nor compared to a typical military fitness regimen.

Objectives

The first objective of this research was to perform a systematic review of the literature that examined the effect of repeated 30-s sprint activity (all reported modalities) on aerobic capacity and to synthesize the results using meta-analysis.

The second objective was to document and compare the acute physiological and perceptual responses to two high-intensity intermittent exercise protocols: repeated 30-s bouts (4-min interval of active recovery) of sprint interval cycling and repeated 30-s bouts of a whole-body calisthenic exercise.

The third objective was to determine the physiological and performance effects of a 4-week low-volume, high-intensity interval calisthenic exercise training intervention. The final objective was to compare participant ratings of energy, fatigue and enjoyment in response to the training intervention.

Hypotheses

Study 1. No hypothesis was stated for the systematic review and meta-analysis.

Study 2. It was hypothesized that the acute cardiorespiratory responses to the two high-intensity interval protocols would be similar, and peak physiological and perceptual responses would classify the activities as "vigorous" according to the American College of Sports Medicine (27).

Study 3. It was hypothesized that replacing 4-weeks (3 sessions$\cdot$wk^{-1}) of Army ROTC physical training with low-volume, high-intensity interval training (4-7 sets$\cdot$session^{-1} of whole-body calisthenic exercise) would sustain aerobic and anaerobic capacity, as well as overall performance on the Army Physical Fitness Test (APFT).

Significance of the Study

In Study 1, the quantitative synthesis of studies employing SIT summarizes the typical and variable effects of a program of 30-s "all out" efforts on aerobic capacity. This evaluation of effects and analysis of moderating variables enhances the findings of several small-sample studies and contributes to the practical application of SIT to improve fitness.

The findings of Studies 2 and 3 provide new information regarding the acute responses to and chronic effects of repeated sprint-type training and provide scientific basis for implementation of a novel no-cost, time efficient, and convenient (accessible to all populations in all environments) physical activity modality directed at improving or sustaining aerobic and anaerobic fitness. In addition to the reduced time commitment, evidence of sustained fitness may appeal to military organizations with significant time commitments to combat missions, operational training and equipment maintenance.

CHAPTER 2

REVIEW OF THE RELATED LITERATURE

High-Intensity Interval Training (HIT)

Research examining the physiological adaptations of submaximal endurance training in sedentary and recreationally active individuals has provided a large body of knowledge that informs exercise prescription. The well-known central adaptations that contribute to changes in aerobic capacity include increases in plasma volume, red blood cell mass, left ventricular wall thickness, and left ventricular chamber size; changes in skeletal muscle, or peripheral adaptations, include increases in mitochondrial density, oxidative enzyme activity, and capillary density (28).

A large body of knowledge also exists on the impact of high-intensity interval training (HIT). A synthesis of studies examining effects of exercise intensity on further improvements in performance in already highly-trained athletes highlights its importance (29). While HIT is a frequently used methodology among elite endurance athletes, its use by the general population as a means to improve health, fitness and performance is considerably less. The prescription of aerobic-type exercise for recreational athletes, sedentary populations, and diseased populations has traditionally been limited to moderate-intensity endurance activities with recommended durations of 30-60 min/day (30). Contemporary research findings have increasingly included examination of the effects of high-intensity training on not only performance but also on numerous health-related outcomes. The following review highlights the acute responses to and the chronic adaptations and performance effects of HIT with primary emphasis on repeated supramaximal sprint training, or sprint interval training (SIT).

Acute Responses to HIT

Understanding the acute cardiorespiratory and metabolic responses to a bout of exercise provides the foundation for the development of exercise programs intended to elicit a specific physiological adaptation and accompanying sport or occupational performance improvement. According to the American College of Sports Medicine (ACSM), vigorous intensity for low-resistance rhythmic exercise is classified as 77-95% of maximum heart rate (HR_{max}), 64-90% of maximal oxygen uptake (VO_{2max}) or a rating of perceived exertion (RPE) of somewhat hard to very hard (RPE 14-17), and higher values are classified as maximal or supramaximal (27). In one of the earliest studies involving HIT, Astrand et al (31) reported that 2-min intervals run at the velocity associated with VO_{2max} (vVO_{2max}) alternated with an equal duration of passive rest elicited a VO_2 of 95% VO_{2max}. Employing shorter intervals of 30 seconds at vVO_{2max} with 30 seconds of active recovery, the results of Billat et al (32) revealed that runners sustained VO_{2max} not only during sprints but also during recovery periods from the fifth to the 18^{th} repetition. Rozenek et al. (33) also studied running intervals at vVO_{2max}. With varied work-rest ratios of 15:15 seconds up to 60:15 seconds, ranges for response variables were: $\%VO_{2max}$ ~71-89%, $\%HR_{max}$ ~85-90%, and RPE ~13-18. In a study of the acute aerobic and anaerobic responses to high-intensity intermittent cycling, Tabata et al (34) found that oxygen uptake and oxygen deficit were very near maximum when short (10-s) rest periods were used; however, when the rest period was extended to two minutes, oxygen uptake and oxygen deficit were significantly less than maximal values.

While these studies highlight the vigorous nature of HIT, they also hint at the high importance of the work-rest ratio.

During the last decade, a very specific SIT protocol of repeated Wingate Anaerobic Tests (35) has been applied in experimental designs examining the acute responses to a single exercise session. Consisting of 30-s "all out" efforts against pre-determined resistance on a cycle ergometer, the most frequently used designs have administered 4-7 bouts alternating with 4-min active recovery periods of no-resistance pedaling. While the chronic effects of this training methodology will be reviewed in the subsequent section, acute response data may at least in part explain the stimuli that signal physiological adaptation. Freese et al (36) reported that this model of SIT elicited peak oxygen uptake, heart rate, and ventilation responses that were at least 80% of estimated maximal values. Despite the extremely short duration of supramaximal effort, the cardiovascular demand was high. In a modification of the 30-s:4-min work-rest protocol, Buchheit et al (37) assessed responses to 30-s bouts with a 2-min rest interval for a total of six sprints. The sprints elicited peak VO_2 of ~90% of maximum, HR_{max} of ~96% of maximum, blood [La] of ~15 $mmol \cdot L^{-1}$, RPE of ~19, and a high degree of muscle deoxygenation. While mean O_2 consumption was only 48% VO_{2max} during the sprint session, the peak values provide evidence for the cardiovascular strain and tissue deoxygenation that may provide the stimulus for skeletal muscle adaptation. The findings reported by Hazell et al (38) provide support for the protracted effect of high-intensity exercise on post-exercise metabolism. During exercise, O_2 consumption was ~150% greater for 30-min of continuous cycling at ~70% VO_{2max} when compared to an 18-min (4 x 30-s:4-min work-rest interval) sprint cycling protocol. However, the accumulation of exercise O_2 consumption and the 24-hr excess post-exercise O_2 consumption (EPOC) revealed no difference between groups, highlighting the impact of exercise intensity on acute metabolic response. Despite the intermittent nature of these protocols, the activities elicited repeated near maximal cardiorespiratory, metabolic and perceptual responses.

Chronic Effects of HIT

While knowledge of the acute responses to a bout of exercise directs the development of exercise programs intended to elicit a specific physiological adaptation and accompanying sport or occupational performance improvement, empirical evidence of training adaptations is gained through examination of the chronic effects of an exercise intervention. Adaptations and performance effects of SIT on skeletal muscle, metabolic capacities and physical performance are reviewed in this section.

The growing body of research into SIT has shown that as little as 15 minutes (cumulative time of sprints) of effort during six sessions across two weeks can significantly improve skeletal muscle oxidative capacity, maximal oxygen uptake and endurance performance (6, 14-16). In the first study to formalize the use of repeated Wingate Anaerobic Test model of SIT, MacDougall et al (39) reported that a 7-week training program increased VO_{2max}, maximum short term power output, glycolytic enzyme (phosphofructokinase and hexokinase) activity, and oxidative enzyme (malate dehydrogenase, succinate dehydrogenase, citrate synthase) activity. The 7% increase in VO_{2max} and upregulation of enzymes occurred even though the duration and volume of training stimulus were extremely small and more traditionally defined as anaerobic. In a modification of the sprint interval protocol, Hazell et al (10) administered 10-sec sprints with recovery periods of 2- and 4-min that produced similar results in terms of improvements in peak power output and 5-km time trial performance. Burgomaster et al. (40) reported that six sessions (scheduled over two weeks) of 30-sec "all out" cycle ergometer sprinting with a 4-min active recovery doubled endurance time to exhaustion (at ~80% VO_{2peak}) in recreationally active subjects. A study examining the effects of repeat sprint training on the performance and VO_{2peak} in moderately-trained high school rowers provided further support for the efficacy of maximal sprint training using an alternative modality (24). More recent results with the same training stimulus indicated that administration of a 4-week SIT intervention to obese (48 ± 5.7% body fat) women (30.1 ± 6.8 years) was well tolerated and resulted in a 12% increase in VO_{2max} (11). Additional support for the equally effective benefits of high-intensity, low-volume exercise when compared to moderate-intensity, high-volume activity has been provided in randomized controlled trials (RCT) performed by Burgomaster et al (23) and Gibala et al (41) in which effects of SIT were similar when compared to moderate-intensity continuous endurance training. When portions of an endurance running training program were replaced by 30-s sprints in two separate studies, moderately trained participants significantly improved VO_{2max} and time trial performance (42) and maintained muscle oxidative capacity, capillarization and endurance performance (20) despite the reduction in training volume, providing further evidence that low-volume HIT can improve fitness in already trained athletes. Despite a significantly reduced training volume and time commitment, SIT has proven to confer physiological adaptations favorable to improvements in metabolic capacities and performance.

The results of this type of low-volume, high-intensity exercise intervention are intriguing, but a comparison to traditional aerobic-type endurance training using randomized controlled trials provides the best evidence. Using moderate-intensity continuous cycling of 40-60 minutes duration as an endurance training stimulus, further support for the importance of exercise intensity has been shown in separate studies by Burgomaster et al (23) and Gibala et al (41), who showed that the effects of SIT were similar following six weeks of training despite the reduced time commitment and lower training volume. Workout time (including recovery intervals) in the SIT groups was only 20-33% of the endurance training group requirement, and training volume (total work) was 10-15% of that completed by the endurance training participants. Using a similar experimental design, MacPherson et al (22) assessed changes in VO_{2max} and performance, as well as body composition, cardiac output, stroke volume, and arterial-venous O_2 (a-vO_2) difference. The findings in this running study indicated that SIT and endurance training improvements in VO_{2max}, time trial performance, and body composition were similar; however, the adaptations in the SIT group were peripheral (a-vO_2 difference) whereas the adaptations in the endurance training group appear to be central (stroke volume). The results suggest that longer duration intervals and/or a mix of SIT and endurance training would be appropriate to elicit both central and peripheral physiological adaptations. Again, the significantly reduced time commitment of SIT produced performance improvements of the same magnitude when compared to longer duration continuous training.

The majority of SIT research has used untrained and recreationally active subjects; hence, findings are not generalizable to already-trained populations. In their review article, Laursen and Jenkins (2) suggest that improvements in performance among highly-trained endurance athletes may only be attained through HIT. Iaia et al (20) examined the effects of drastically reduced training volume in trained distance runners by replacing typically programmed continuous moderate-intensity endurance training with 8-12 30-s bouts (93% of “all out” running speed) interspersed with 3-min rest periods. Despite the 65% reduction in volume, muscle oxidative capacity, capillarization, and performance were unchanged. In other words, the HIT sustained physiological markers of fitness when compared to traditional endurance training. Similar findings were reported by Esfarjani et al (42) though groups performing longer intervals at vVO_{2max} had the greatest relative improvements in VO_{2max} and lactate threshold. In the already trained athlete, manipulation of training intensity can lead to significant improvements in performance.

In a study designed to assess the effects of supplementing the competition preparation of elite Iranian wrestlers with SIT, researchers asked the experimental group to perform two sessions$\cdot$wk^{-1} of six maximal effort 35-m sprints alternated with a short recovery of ten seconds (19). Highlighting the effects of such a low-volume supplemental conditioning program were a 5.4% increase in VO_{2max}, a 32% increase in time to exhaustion, and increases in peak and mean power output during Wingate tests. In summary, four minutes of sprinting during eight sessions across a 4-week time period elicited significant improvements with potential to positively impact competition performance. The low-volume, high-intensity additional training played an important role in improving fitness in a short time.

While aerobic metabolism primarily fuels periods of relatively low intensity, intermittent periods of high-intensity are fueled by aerobic and anaerobic pathways. In order to determine the aerobic, anaerobic and performance effects of a very short training program, Rodas et al (43) used daily SIT for two weeks. Training sessions included 15-sec and 30-sec "all out" sprints followed by 45-sec and 12-min rest periods, respectively, progressing from two bouts in the first session to seven bouts in the final session. In addition to an 11% increase in VO_{2max}, pre- and post-training muscle biopsies revealed significant increases in enzymatic activity: creatine kinase (+44%), lactate dehydrogenase (+45%), phosphofructokinase (+100%), citrate synthase (+38%), and 3-hydroxyacyl-CoA dehydrogenase (+60%). The increased VO_{2max} as well as aerobic and anaerobic enzyme activities provides further support for the benefits of low-volume SIT. The work-rest ratios in this study are different from most other studies of SIT; however, the results of such a program are of interest in designing an optimal training stimulus for rapid adaptations.

Acknowledging time as a limiting factor, researchers studied the effects of three 30-min programs (continuous, intermittent and supramaximal) on the aerobic and anaerobic fitness of U.S. Navy sea-air-land personnel (SEALs) (44). All training was completed on cycle ergometers at an average intensity of 70% VO_2max; the intermittent group performed 1-minute bouts at 110% VO_{2max} with 2-min active recovery periods while the supramaximal group completed maximal 30-s efforts interspersed throughout the 30 minutes of training. Following three weeks of training (mean of nine sessions), aerobic capacity was unchanged in all groups, but the intermittent and supramaximal groups significantly increased maximal oxygen deficit. These results suggest intermittent activity of maximal-to-supramaximal intensity sustains aerobic fitness while improving anaerobic fitness.

As expected, the studies of SIT have almost exclusively involved cycling, running or rowing, as those modalities are traditionally associated with aerobic endurance training and performance. There is only one known investigation of the effects of low-volume, high-intensity calisthenic exercise programs on aerobic power and skeletal muscle (45). Using a protocol originally developed by Tabata et al (34) in which participants complete 8 consecutive sets of 20-s:10-s work-rest intervals, researchers administered a 4-week intervention of whole-body aerobic-resistance training (mountain climbers, jumping jacks, squat and thrusts, burpees). When compared to 30 $min \cdot day^{-1}$ of continuous high-intensity treadmill running, the Tabata protocol elicited similar improvement in VO_{2peak} (~7-8%). Additionally, the low-volume whole-body calisthenics consisting of only 4 $min \cdot day^{-1}$ (4 $days \cdot wk^{-1}$) was effective in inducing improvements in measures of skeletal muscle endurance (leg extension, chest press, push-up, sit-up, and back extension) on observed in the endurance training group. This study by McRae et al (45) provides evidence for the effectiveness of short duration, whole-body interval training in improving aerobic fitness and assessments of muscular endurance.

In its evidence-based recommendations, ACSM defines aerobic-type exercise as “regular, purposeful exercise that involves major muscle groups and is continuous and rhythmic in nature” (30). Prescription of running, cycling, rowing and even circuit training to improve aerobic fitness is common; however, less is known about the effects of whole-body calisthenic interval training on VO_{2peak}, anaerobic capacity and physical function. This gap in the literature necessitates further examination of alternative modes of whole-body HIT.

Energy and Fatigue

The impact of physical activity on self-report measures of mood has significant implications for overall health, exercise behavior and physical performance. The degree to which mood is altered following an acute bout or chronic period of exercise has been a frequent topic of research as investigators attempt to elucidate the relationship between exercise stimulus and specific subcomponents of mood. Although the consensus of research highlights the benefits of exercise on mood subcomponents of energy and fatigue, the inter-relationships are more complex when examining the various aspects of experimental design, such as exercise mode, frequency, intensity and duration. In his review, Yeung (46) concluded that a single exercise session positively impacts mood, but he also acknowledged the parameters of exercise were not systematically examined. Following a systematic review and meta-analysis, Puetz et al (47) found a significant effect (Cohen's *d* of 0.37) of chronic exercise interventions on increased feelings of energy and lessened feelings of fatigue. In another selective review, Berger and Motl (48) indicated that exercise frequency, mode, intensity and duration moderated mood as measured by the Profile of Mood States (POMS). Though the beneficial effects of exercise on mood are not disputed, no single exercise stimulus has been found to maximize mood.

Based on predominant findings, Berger (49) suggests a taxonomy of training guidelines for maximizing the psychological benefits of exercise. Although the impact of exercise intensity on mood appears to be equivocal, moderate intensity is commonly reported as most beneficial (50-52). In a study of acute effects, Steptoe and Bolton (53) found that highly fit subjects reported greater vigor following high-intensity exercise than moderately fit subjects. Motl et al (54) examined the effects of an acute bout of cycling exercise on highly trained cyclists and reported that moderate intensity cycling induced increased feelings of vigor and reduced fatigue while high- and maximal-intensity cycling resulted in no mood changes and negative responses, respectively. Examination of chronic exercise effects on energy and fatigue across a swimming season indicated a dose-response relationship in relation to training volume and intensity; as volume and intensity increase, feelings of vigor decreased and fatigue increased whereas subsequent increases in vigor and decreases in fatigue followed periods of low volume and intensity (55). Varying exercise duration seems to impact mood as reported in another chronic exercise study involving swimmers; with intensity held constant, swimming duration (distance) was increased with athletes reporting increases in fatigue and total mood disturbance scores (56). In a study that permitted participants to self-select exercise intensity, both POMS subscale scores and Physical Activity Enjoyment Scale (PACES) scores were highest despite this group having the highest mean heart rate among groups exercising at various intensities (57). While cited taxonomies for maximizing mood provide guidelines, the research involving healthy moderately-to-highly trained athletes has focused on responses to an acute bout of exercise or chronic endurance training. Less is known about the effects of low-volume, high-intensity exercise programs on energy and fatigue.

Enjoyment

Among sport and exercise psychologists, enjoyment has been defined as a positive affective response to a sport experience (58), a positive emotion associated with meeting environmental challenges (59), and an optimal psychological state (60). In an effort to conceptualize enjoyment, Kimiecik and Harris (60) hypothesized that the more intrinsically motivated individual is more likely to continue to perform the activity perceived to have caused the enjoyment. Using exercise as an example and according to their definition of enjoyment, the activity experience then becomes self-motivating. Thus, the quantification of subjective feelings of enjoyment of a specific exercise experience may have significant implications relating to continued participation in and motivation toward the activity.

To determine an individual's enjoyment of physical activity, researchers have used several self-report assessments with varying degrees of reliability and validity evidence. Many experimental designs were cross-sectional and reported correlational data for physical activity level and enjoyment as a means to highlight the determinants of regular physical activity or exercise (61-63). A more frequently used measure has been the 18-item bipolar PACES. As part of the development of the enjoyment scale in 1991, Kendzierski and DeCarlo provided preliminary reliability and validity evidence for its use as a self-report metric designed to assess whether college-aged students enjoyed (or did not enjoy) a specific exercise program (64).

Nearly all research that has included the PACES focused on enjoyment as a determinant of physical activity; however, two studies have assessed the relationship between exercise and enjoyment. Using a quasi-experimental design, Raedeke (65) sought to examine the relationship between enjoyment and affective response following exercise. Prior to and following a 30-minute group aerobic exercise protocol, participants completed the POMS-B; participants completed the PACES post-exercise. The results indicated that increased vigor and enjoyment were positively correlated, whereas negative feelings were not, revealing that enjoyment may impact exercise-related increases in positive affect (65). These findings seem to support the conceptual framework of enjoyment.

In a study manipulating exercise intensity as the independent variable, Bartlett et al (66) aimed to determine whether high-intensity interval running was more enjoyable than moderate-intensity continuous running. Eight recreationally active male participants completed two exercise sessions: the high-intensity protocol required the subjects to run for three minutes at a speed estimated to elicit 90% VO_{2max} followed by an active recovery period of running at 50% VO_{2max} for three minutes (the work-rest interval was repeated five times for a total of six sets); the moderate-intensity protocol involved running for 50 minutes at 70% VO_{2max}. Including warm-up, the total exercise duration for each session was 50 minutes at an average intensity of 70% VO_{2max}. Despite higher ratings of perceived exertion, participant ratings of enjoyment were significantly higher following completion of the high-intensity running protocol. Because the experimental design was able to match most aspects of the exercise stimulus (duration, distance run, average VO_2, and energy expenditure), the varied aspect of the interval running and the intensity seem to be the divergent factors. Whether either factor led participants to differ in their ratings of perceived enjoyment is unknown but the results have implications for future research including exercise intervention strategies of varying intensities.

Determination of level of enjoyment associated with exercise intensity can inform the development of interventions designed to improve fitness.

Summary

High-intensity interval training in the form of 30-s “all out” repeated sprint intervals appears to be a potent stimulus for fitness improvement. Examination of acute physiological responses indicates that SIT elicited repeated near maximal cardiorespiratory, metabolic and perceptual responses. When compared to traditionally programmed continuous, moderate-intensity endurance training, the positive chronic effects of SIT on aerobic capacity and selected markers of skeletal muscle metabolism were not different between groups despite the significantly reduced time commitment and training volume. In the already trained athlete, manipulation of training intensity can lead to significant improvements in performance.

Few studies have examined the effects of near-maximal or maximal exercise on feelings of energy and fatigue, and only one study we are aware of has studied the impact of HIT-type whole-body calisthenics on enjoyment. This dearth of evidence necessitates the inclusion of mood and attitude assessments in our research to further elucidate the complex inter-relationships between exercise intensity, mode, duration and frequency.

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CHAPTER 3

SPRINT INTERVAL TRAINING EFFECTS ON AEROBIC CAPACITY: A SYSTEMATIC REVIEW AND META-ANALYSIS[1]

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ABSTRACT

Background: Sprint interval training (SIT) involving repeated 30-s “all out” efforts have resulted in significantly improved skeletal muscle oxidative capacity, maximal oxygen uptake and endurance performance. The positive impact of SIT on aerobic capacity has far reaching health implications. **Purpose:** The study’s purpose was to perform a systematic review of the literature and meta-analysis to determine the effects of SIT on aerobic capacity. **Methods:** A search of the literature was conducted using the key words *sprint interval training*, *high intensity intermittent training/exercise, aerobic capacity*, and *maximal oxygen uptake*. Seventeen effects were analyzed from 16 randomized controlled trials of 318 participants. The mean ± SD number of participants was 18.7 ± 5.1. Participant age was 23.5 ± 4.3 years. **Results:** The effect size calculated for all studies indicates that supramaximal-intensity SIT has a small-to-moderate effect (Cohen’s d = 0.32, 95% CI: 0.10, 0.55; z = 2.79, P < 0.01) on aerobic capacity. The effect is large in comparison to no-exercise control groups (Cohen’s d = 0.69, 95% CI: 0.46, 0.93; z = 5.84; P < 0.01) and not different when compared to endurance training control groups (Cohen’s d = 0.04, 95% CI: -0.17, 0.24; z = 0.36, P = 0.72). **Conclusion:** SIT improves aerobic capacity in healthy, young people. Relative to continuous endurance training of moderate intensity, SIT presents an equally-effective alternative with a reduced volume of activity. This evaluation of effects and analysis of moderating variables consolidates the findings of small-sample studies and contributes to the practical application of SIT to improve fitness and health.

Key Words: high-intensity intermittent exercise; VO_{2max}

1 Introduction

High-intensity interval training is frequently used by endurance athletes. A synthesis of studies examining effects of exercise intensity on further improvements in performance in already-highly-trained athletes highlights its importance (1). However, the prescription of aerobic-type exercise for recreational athletes, sedentary populations, and diseased populations has traditionally been limited to moderate-intensity endurance activities with recommended durations of 30-60 min per day (2).

In 1982, Dudley et al (3) reported that the duration of exercise necessary to bring about beneficial skeletal muscle oxidative metabolism adaptations decreases as intensity increases, providing some support for the idea that "less" exercise may be equally effective if intensity is relatively high. In studies utilizing repeated Wingate Anaerobic Tests, in which the exercise bout involves 30 seconds of "all out" cycling against a braking force on a specialized cycle ergometer; exercise participants completed 4-6 sprints separated by four minutes of recovery (4-11). SIT interventions with as little as 15 minutes (cumulative time of sprints) of "all out" effort during six sessions across two weeks resulted in significantly improved skeletal muscle oxidative capacity, aerobic capacity (VO_{2max}) and endurance performance (4, 12-14). Others have added to the body of research by using the same protocol of cycling or by applying the 30-s:4-min interval to other modalities such as running and rowing (15-20). The findings of these studies have highlighted the potential impact of SIT on several health and fitness variables.

Additional support for the equally-effective benefits of high-intensity, low-volume exercise when compared to moderate-intensity, high-volume activity has been provided in randomized controlled trials (RCT) performed by Burgomaster et al (21) and

Gibala et al (22) in which effects of SIT were similar when compared to moderate-intensity continuous endurance training. Specifically, the positive effects on aerobic capacity and selected markers of skeletal muscle metabolism (carbohydrate and lipid metabolism, cytochrome oxidase activity, muscle buffering capacity, muscle glycogen content) were not different between groups despite the significantly reduced time commitment and training volume of SIT (21, 22). As lack of time is a commonly cited reason for physical inactivity (23), the time-efficient aspect of SIT has significant implications for exercise adherence. Additionally, the findings of Bartlett et al (24) indicated that participants enjoyed high-intensity intermittent running more than longer duration, continuous running.

The development of new exercise interventions aimed at reducing health problems associated with physical inactivity is a far-reaching research effort that holds great value. Epidemiological studies have shown that low cardiorespiratory fitness is associated with higher rates of cardiovascular disease, type-2 diabetes, cancer, and all-cause mortality (25-30). Cardiorespiratory fitness, typically assessed via a measure of aerobic capacity or maximal oxygen uptake (VO_{2max}), has a negatively linear relationship with increasing age up to 45 with reported declines of ~8% per decade with accelerated reduction of up to 20% per decade at age 70 (31, 32). In a meta-analysis including only studies of women, decreases in aerobic capacity negatively impacted function, often resulting in loss of independence (33). The importance of improvement or attenuation of age-related decline in aerobic capacity extends beyond athletic performance.

Based on what is known regarding the potential effects of low-volume, high-intensity intermittent exercise on aerobic capacity, a quantitative synthesis of studies employing SIT can inform about the typical and variable effects of SIT. Although several studies have reported the positive impact of such training on various health- and performance-related dependent variables, many failed to include a control group (5, 34-39) or lacked a measure of aerobic capacity (13, 22, 40, 41). The objectives of this review and meta-analysis were to estimate the population effect of SIT of maximal or greater intensity on aerobic capacity defined as maximal oxygen uptake (VO_{2max}) and to assess whether those effects vary by participant type or study characteristics. The scope of this review has been limited to the inclusion of studies using the repeated Wingate protocol based on its recent frequent use and apparent impact despite the very low training volume. Protocols involving a different intensity, work duration or recovery duration may have different effects. This evaluation of effects and analysis of moderating variables may enhance the findings of several small-sample studies and contribute to the practical application of SIT to improve physiological and health outcomes in the adult population.

2 Methods

2.1 Literature Search

The review and analysis was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) Statement guidelines (42). A systematic search of the research literature was conducted for randomized controlled trials studying the effects of SIT interventions on aerobic capacity. The search included articles published prior to January 1, 2013, as well as theses/dissertations completed and available by the same date. PubMed, MEDLINE and Web of Science databases were searched using the terms *sprint interval training, high intensity intermittent* *training/exercise, aerobic capacity,* and *maximal oxygen uptake*. Reference lists from retrieved studies were also reviewed.

2.2 Inclusion and Exclusion Criteria

Participants of any age were included. Studies meeting the following inclusion criteria were considered for review: 1) available in English, 2) participants were randomly assigned to a SIT group or Control group, 3) training intensity classified as *all out*, *supramaximal*, *maximal*, or $\geq 100\%\ VO_{2max}$, 4) SIT work:rest ratio of 30-s:4-min (rest interval of 3-5 minutes) and 5) laboratory assessment of VO_{2max} or VO_{2peak}. Studies were excluded for the following: 1) assessment included only an endurance performance measure, 2) animal subjects, or 3) training intensity did not meet the *supramaximal* or *maximal* threshold.

2.3 Study Selection

A search of electronic databases and a scan of article reference lists revealed 303 relevant studies (Figure 3.1). Two-hundred sixty four articles were dismissed based on a review of the title or abstract or lack of control group in the experimental design. Thirty-nine RCTs were evaluated, and 16 were included for the meta-analysis. Each study was read and coded for descriptive variables: country, age, sex, BMI, training status (sedentary, recreational, and trained), type of control group (no exercise, endurance training), control group exercise mode and intensity, experimental group exercise mode and intensity, work:rest ratio, and length of intervention.

2.4 Data Collection

Aerobic capacity data were extracted in the forms of pre- and post-training intervention means, standard deviations, and sample sizes for SIT and control conditions.

Dependent variables included maximal or peak oxygen uptake reported in $mL \cdot kg^{-1} \cdot min^{-1}$ or $L \cdot min^{-1}$ (if relative values were not reported). In studies that reported intermediate and post-intervention values, only final values for aerobic capacity were compared to baseline.

2.5 Study Characteristics

Seventeen effects were collected from 16 RCTs (6-9, 18, 20, 21, 43-51) of 318 participants. Two effects were calculated and included from a study by Bailey et al (6) because the experimental design included a sprint training group, an endurance training group, and a no-exercise control group; thus, permitting a comparison of SIT to the endurance training as well as the no-exercise controls. The mean ± SD number of participants was 18.7 ± 5.1. Participant age was 23.5 ± 4.3 years. Six effects involved studies of men only; four included exclusively women; seven enrolled both men and women. Aerobic capacity (VO_{2max} or VO_{2peak}) was a primary outcome for nine of the studies. The mode of sprint exercise for interventions primarily involved cycling (9 studies); six studies administered a sprint interval running protocol, and one study used rowing. Training intervention length was 4.8 ± 2.3 weeks with 2.9 ± 0.4 sessions per week. There were 4 studies conducted in Canada, 4 in the United States, 2 in the United Kingdom, 2 in Australia, 2 in Iran, 1 in Denmark, and 1 in Norway.

2.6 Meta-analysis

Effect sizes (ES) were calculated by subtracting the mean change in the control group from the mean change in the experimental group and dividing by the pooled standard deviation of baseline values (52). A random effects model with each effect weighted by its degrees of freedom was applied because of variability in several experimental factors (e.g., length of intervention, type of control group, mode of training, participant characteristics) across studies. Consistency (i.e., homogeneity) of effects was assessed using Q and I^2 (53, 54).

2.7 Data Synthesis and Analysis

Using SPSS macros (MeanES, MetaReg; IBM SPSS 20.0, Inc), an aggregated mean ES, Cohen's *d*, associated 95% confidence intervals and moderator effects of control group type, participant fitness level, intervention length, additional training, and mode of training were calculated (55). Distribution of ES was determined to be heterogeneous if Q reached a significance level of $P < 0.05$ and the sampling error accounted for less than 75% of the observed variance (53). An I^2 statistic was also calculated to assess heterogeneity of effects (54). In order to determine the number of unpublished studies of null findings necessary to negate the significant ES of included studies, a fail-safe number was calculated to address publication bias (56). As an explorative tool, a funnel plot of standard error versus ES was developed to address the potential of publication bias relating to study sample size. A two-way (effects x raters) intraclass correlation coefficient (ICC) for absolute agreement was calculated to assess inter-rater reliability in the determination of effect sizes (57). An ICC (2, 2) of 0.98 was calculated for all effects, and differences in ES calculation were resolved prior to final analysis.

2.8 Moderator Variables

Five potential moderators were selected a priori based on their theoretical or empirical relation to changes in aerobic capacity: type of control group, baseline fitness level, length of training intervention, inclusion of additional training, and mode of training. Planned contrast weights were assigned to each level of moderating variable. For type of control group, levels were: no exercise and endurance exercise; participant baseline activity level: sedentary, recreational or trained; length of intervention, levels were: < 6 weeks and ≥ 6 weeks; inclusion of training in addition to SIT; and mode of training: cycling, running or rowing. Multiple linear regression analysis was used to determine the independent effects of moderator variables on variation in effect size. Macros for a random model using maximum likelihood parameter estimates were used to determine significance levels and compute effects sizes and confidence intervals (55).

3 Results

3.1 Description of Included Studies

Sixteen studies with a total of 318 participants were included in the meta-analysis. Study characteristics are summarized in Table 3.1.

3.2 Meta-analysis

Twelve effects (~71%) were greater than zero and the Cohen's *d* range of effects for all studies was -0.39 to 1.22. A forest plot depicting the individual ES, random effects mean Cohen's *d* and associated 95% confidence intervals is shown in Figure 3.2. Mean ES Cohen's *d* was 0.32 (95% CI: 0.10, 0.55; $z = 2.79$, $P < 0.01$). The significant improvement in aerobic capacity following SIT was heterogeneous ($Q_{16} = 59.87$; $P < 0.01$) (58) with moderate inconsistency of effects ($I^2 = 74.95$, 95% CI: 68.02, 80.37) (54). The fail-safe number of effects was 28, and although sample size range was only 11-29 participants, visual examination of the funnel plot (Figure 3.3) indicates lack of publication bias.

3.3 Moderator Analysis

Planned contrasts were applied to examine the individual impact of moderators: type of control group, length of the SIT intervention, and physical activity level of the study participants. The overall meta-regression model was significant ($Q_5 = 22.09$; $P < 0.01$; $R^2 = 0.55$; $Q_{11} = 18.01$; $P = 0.08$). Only the type of control group accounted for significant variation in the overall effect of SIT on aerobic capacity ($\beta = -0.33$; $z = -3.57$; $P < 0.01$). Effects were not significant when the type of control included moderate-intensity continuous endurance exercise (Cohen's $d = 0.04$; 95% CI: -0.17, 0.24; $z = 0.36$, $P = 0.72$); effects of SIT were moderate and statistically significant when compared to no-exercise control groups (Cohen's $d = 0.69$; 95% CI: 0.46, 0.93; $z = 5.84$; $P < 0.01$). Effects were not significantly different when moderating by fitness level, length of intervention, inclusion of additional training, or mode of training.

4 Discussion

The aggregated findings indicate SIT is moderately effective (mean ES Cohen's $d = 0.32$) in improving aerobic capacity (VO_{2max}). The effect is large in comparison to no-exercise control groups (Cohen's $d = 0.69$) and not different when compared to endurance training control groups (Cohen's $d = 0.04$). The improvement equates to an approximately 3.6 $mL \cdot kg^{-1} \cdot min^{-1}$ or 8% increase in maximal oxygen uptake relative to no-exercise controls and results in similar improvements compared to traditional endurance-type exercise of moderate intensity. This evidence supports the prescription of supramaximal SIT to improve aerobic fitness and enhance physiological function.

During a 2-week study comparing low- and high-volume training interventions, Gibala and colleagues reported that participants in the low-volume SIT group spent only 15 minutes (135 minutes including recovery) exercising while those in the high-volume endurance training group spent 630 minutes exercising (59). Despite completing a training volume of only 10% that of the endurance training group, the SIT group had similar improvements in oxidative capacity and exercise performance. Given the commonly reported reason of "lack of time" for exercise, the time-efficient aspect of low-volume SIT has significant implications for participation in and adherence to this type of activity.

A limitation of included studies was the young age (23.2 ± 4.3 years) and normal health of participants. Jackson et al (31) highlighted the accelerated decline in cardiorespiratory fitness after age 45 in men and women. Further study of the impact of SIT on older populations is needed to not only support its efficacy across age but also to determine its feasibility relative to musculoskeletal limitations, exercise tolerance and protocol adherence. In a study to determine the effectiveness of high-intensity interval training (85-95% heart rate reserve) in 56 ± 7 year old Coronary Artery Disease patients, Warburton and colleagues (60) reported improvements in aerobic fitness similar to controls completing moderate-intensity endurance training. Although excluded from the current analysis due to insufficient intensity (90-95% peak heart rate), interval training improved aerobic capacity 46% in 76.5 ± 9 year old Congestive Heart Failure patients with an ES of 3.14 relative to no-exercise controls and 2.84 when compared to moderate-intensity continuous exercise controls. These significant improvements occurred after training periods of 4-12 weeks with only three sessions per week. In separate studies by Trilk et al (9) and Whyte et al (59), SIT using the repeated Wingate protocol with 4-4.5 minutes active recovery was well-tolerated in 30-32 year old sedentary overweight/obese participants and resulted in significant improvement in VO_{2max}, circulatory function, mean power output, insulin sensitivity, resting fat oxidation, and systolic blood pressure. Tjonna and colleagues (61) reported greater reduction of metabolic syndrome risk factors in a group completing near maximal interval training when compared to continuous moderate exercise. The results of these studies provide further support for the use of low-volume, high-intensity aerobic training interventions designed to improve fitness.

The majority of included RCTs required participants to perform sprints on a cycle, while six studies used running, and only one study used a rowing ergometer. The non-weight bearing nature of stationary cycling, coupled with minimal eccentric contraction of leg muscles, seems to mitigate risk of injury and discomfort; however, well-designed RCTs using various modes of SIT are needed to increase the knowledge of effects across exercise type. Additionally, longer studies of all age ranges are necessary to determine the impact of SIT in older populations and to further assess exercise adherence and enjoyment.

5 Conclusion

In conclusion, this systematic review and meta-analysis indicates SIT is a beneficial training methodology to improve aerobic capacity among healthy and young people. Relative to continuous endurance training of moderate intensity, SIT presents an equally effective alternative with a much lower volume of activity and reduced time commitment. This evaluation of effects and analysis of moderating variables consolidates the findings of small-sample studies and contributes to the practical application of SIT to improve fitness and health.

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Table 3.1: Characteristics of studies examining the effect of sprint interval training on aerobic capacity.

Study	No. of Participants	Age (mean ± SD)	Sex	Fitness Level	Type of Control Group	Intervention Length (weeks)	Training Mode	Cohen's *d* Effect Size (95% CI)
Cocks et al, 2012	16	21 ± 7	M	Sedentary	ET	6	Cycling	-0.39 (-1.38, 0.60)
Carr, 2011	20	16 ± 1	F	Trained	ET	4	Rowing	-0.34 (-1.22, 0.55)
Iaia et al, 2009	17	34 ± 2	M	Trained	ET	4	Running	-0.31 (-1.27, 0.65)
Burgomaster et al, 2008	20	23 ± 1	MF	Recreational	ET	6	Cycling	-0.17 (-1.04, 0.71)
MacPherson et al, 2011	20	24 ± 3	MF	Recreational	ET	6	Running	-0.02 (-0.90, 0.86)
Rowan et al, 2012	11	19 ± 1	F	Trained	ET	5	Running	0.10 (-1.09, 1.29)
Sandvei et al, 2012	23	25 ± 1	MF	Recreational	ET	8	Running	0.14 (-0.68, 0.96)
Laursen et al, 2002	21	25 ± 6	M	Trained	ET	4	Cycling	0.28 (-0.58, 1.14)
Barnett et al, 2004	16	21 ± 1	M	Recreational	No exercise	8	Cycling	0.31 (-0.67, 1.30)
Astorino et al, 2012	29	25 ± 5	MF	Recreational	No exercise	2	Cycling	0.31 (-0.48, 1.10)
Bailey et al, 2009	12	21 ± 4	MF	Recreational	ET	2	Cycling	0.58 (-0.42, 1.58)
Bailey et al, 2009	12	21 ± 4	MF	Recreational	No exercise	2	Cycling	0.60 (-0.40, 1.61)
Reid, 2012	16	24 ± 4	F	Recreational	No exercise	6	Running	0.67 (-0.49, 1.82)
Esfarjani et al, 2007	11	19 ± 2	M	Trained	ET	10	Running	0.74 (-0.49, 1.96)
Trilk et al, 2011	28	31 ± 6	F	Sedentary	No exercise	4	Cycling	0.82 (0.06, 1.60)
Hazell et al, 2010	22	24 ± 3	MF	Recreational	No exercise	2	Cycling	0.96 (0.06, 1.85)
Bayati et al, 2011	16	25 ± 1	M	Recreational	No exercise	4	Cycling	1.22 (0.16, 2.29)

Sex: M (all male participants), F (all female participants), MF (male and female participants); ET: endurance training;
Cohen's $d = (\text{mean}_{\text{experimental}}) - (\text{mean}_{\text{control}})/\text{SD}_{\text{pooled}}$.

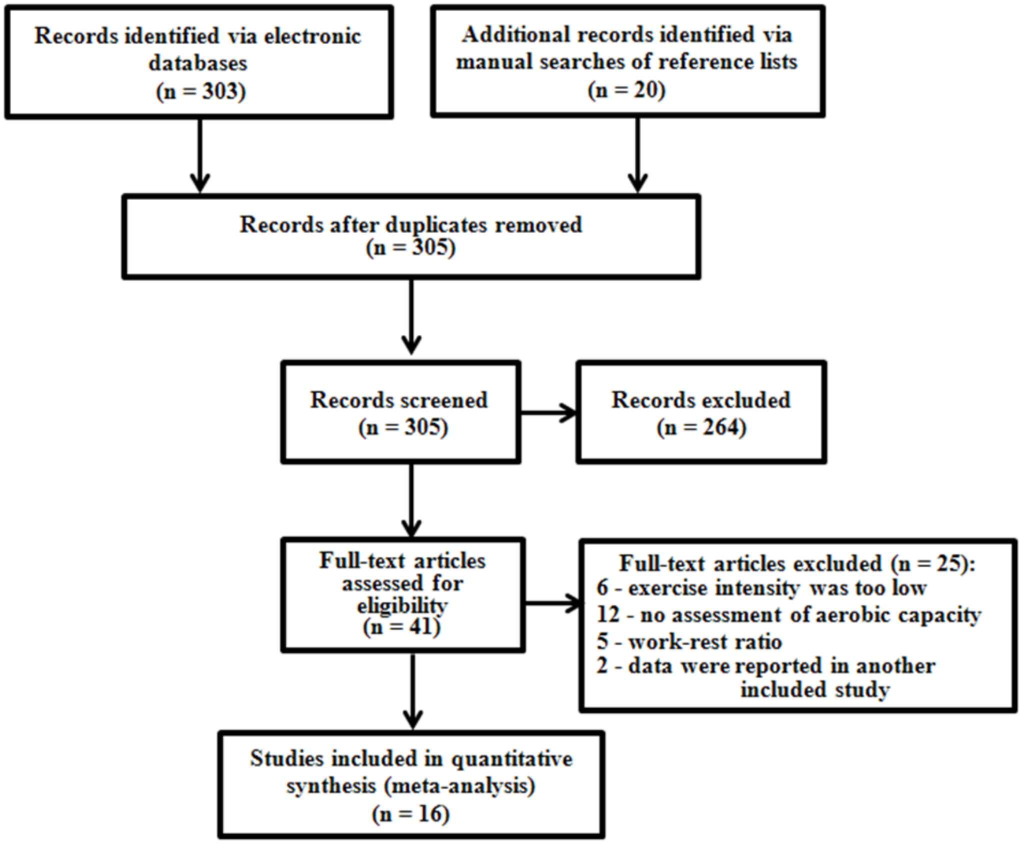

Figure 3.1: Flow chart of study selection.

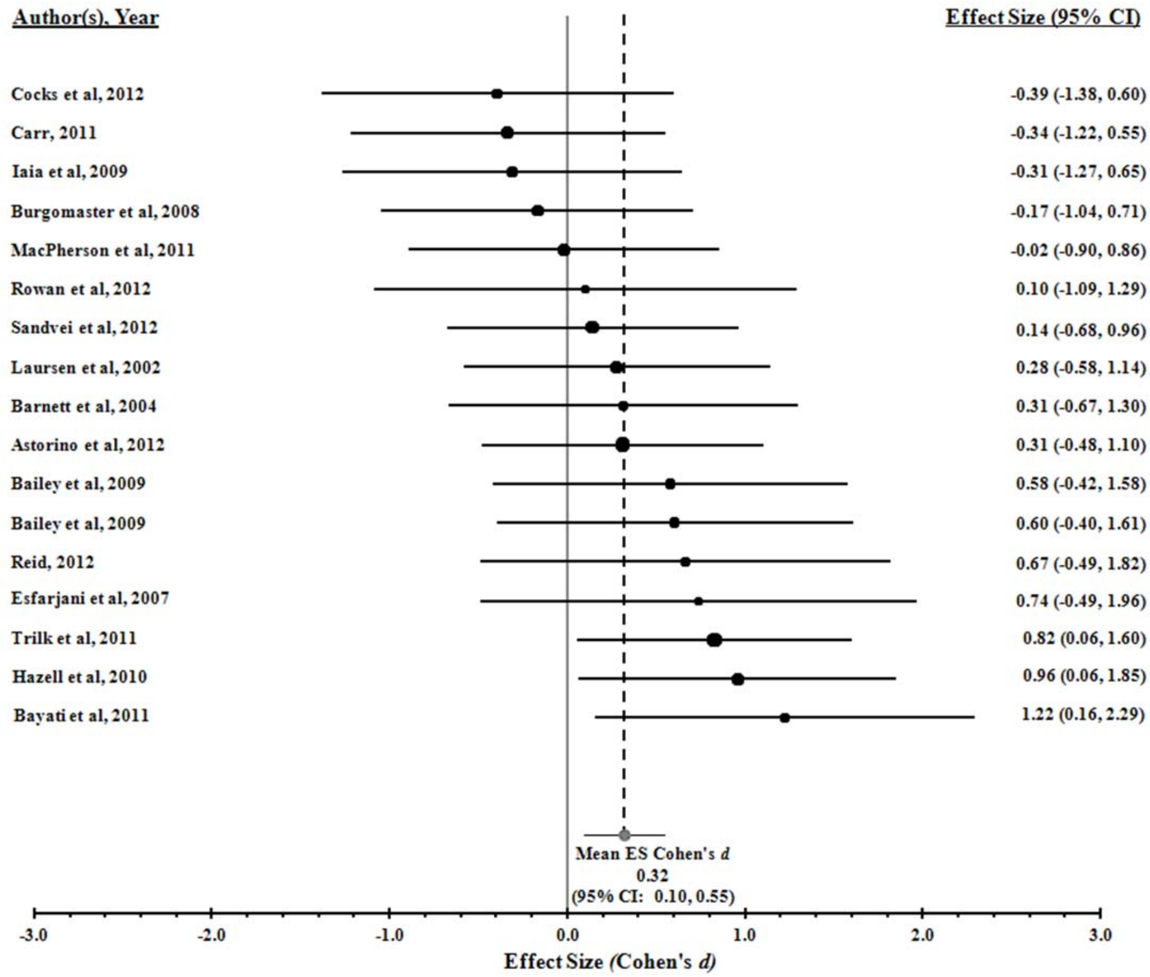

Figure 3.2: Forest plot of *Cohen's d* effect sizes. The aggregated Cohen's *d* is the random effects mean effect size weighted by degrees of freedom. CI: confidence interval.

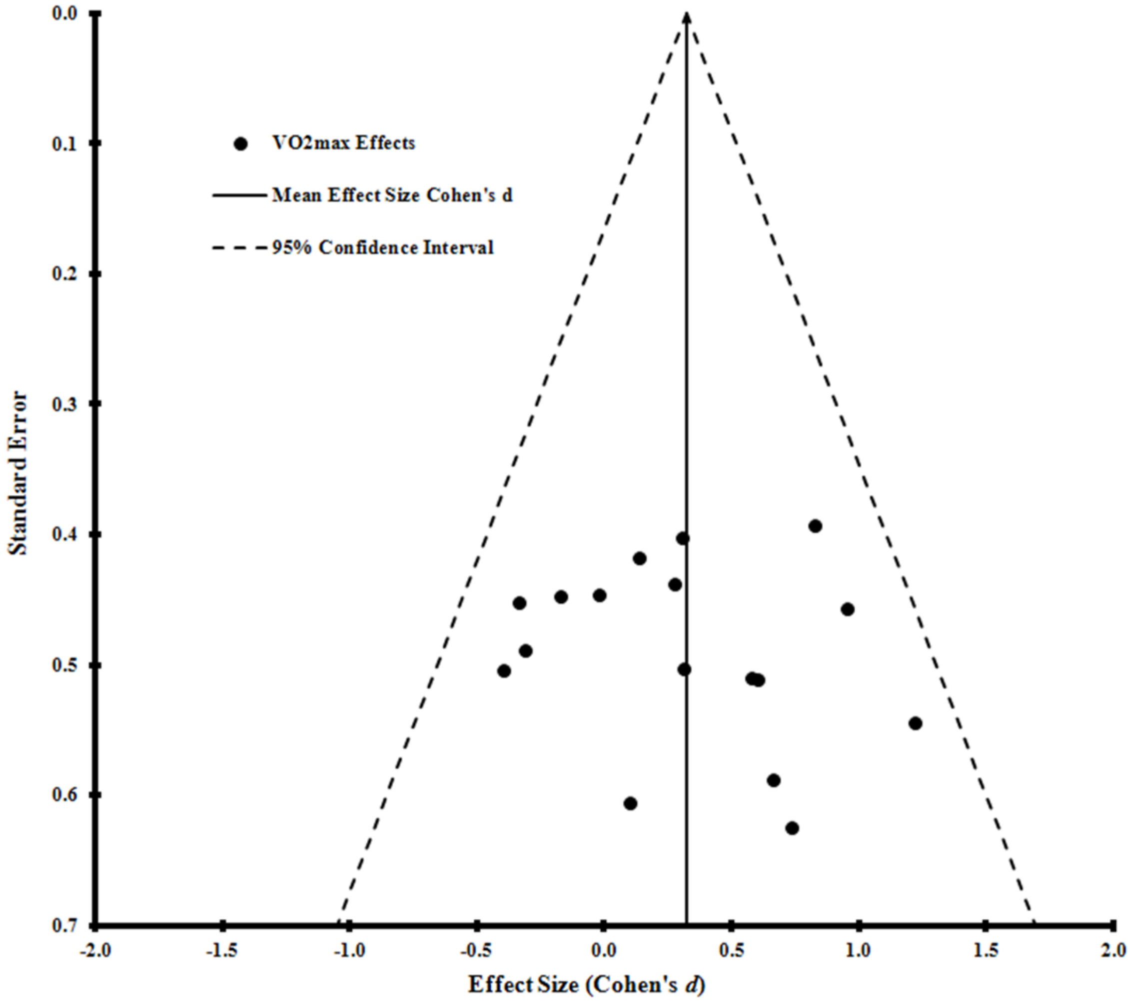

Figure 3.3: Funnel plot of *Cohen's d* effect size versus standard error of the effect (a measure of study sample size). The aggregated Cohen's *d* is the random effects mean effect size weighted by degrees of freedom. VO_{2max}: maximal oxygen uptake.

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CHAPTER 4

COMPARISON OF RESPONSES TO TWO HIGH-INTENSITY INTERMITTENT EXERCISE PROTOCOLS[2]

[2] Gist, Nicholas H., Eric C. Freese, and Kirk J. Cureton. Submitted to *Journal of Strength and Conditioning Research*, 5/22/2013.

ABSTRACT

Repeated bouts of supramaximal interval cycling, or sprint interval training (SIT), confer cardiorespiratory and aerobic metabolic adaptations similar to longer-duration traditional endurance training. Whether or not high-intensity interval calisthenic exercise elicits similar acute responses is unknown. **Purpose:** To compare peak cardiorespiratory, metabolic and perceptual responses to acute bouts of Sprint Interval Cycling (SIC) and a High-intensity Intermittent Calisthenics (HIC) protocol consisting of modified "burpees". **Methods:** Eleven (8 men and 3 women) moderately-trained, college-aged participants (age = 21.9 ± 2.1, BMI = 24.8 ± 1.9, VO_{2peak} = 54.1 ± 5.4 mL·kg^{-1}·min^{-1}) completed four testing sessions across nine days with each session separated by 48-72 hours. Using a protocol of four repeated bouts of 30-sec "all out" efforts interspersed with 4-min active recovery periods, responses to SIC and HIC were measured and classified relative to individual peak values. **Results:** Mean values for %VO_{2peak} and %HR_{peak} for SIC (80.4 ± 5.3% and 86.8 ± 3.9%) and HIC (77.6 ± 6.9% and 84.6 ± 5.3%) were not significantly different (p > 0.05). Effect sizes (95% confidence interval) calculated for mean differences were: %VO_{2peak} Cohen's d = 0.51 (0.48, 0.53); %HR_{peak} Cohen's d = 0.57 (0.55, 0.59). **Conclusions:** A low-volume, high-intensity bout of repeated whole-body calisthenic exercise induced cardiovascular responses that were ~1/2 standard deviation lower than "all-out" SIC; however, the peak HIC responses were classified as vigorous. **Practical Applications:** These results suggest that in addition to the benefit of reduced time commitment, a high-intensity interval protocol of calisthenics elicits vigorous cardiorespiratory and perceptual responses and may confer physiological adaptations and performance improvements similar to those reported for SIC.

Key Words: sprint interval training; calisthenics; burpees

INTRODUCTION

High-intensity interval training (HIT) has been a frequently used training methodology among elite runners, cyclists, swimmers, cross-country skiers and other endurance athletes as an effective means to improve performance. Although there is no agreement on optimal frequency, mode, intensity and duration, HIT has been described as "brief periods of intense muscular activity alternating with periods of recovery" (1). Dudley et al (2) reported that the duration of exercise necessary to bring about beneficial skeletal muscle adaptations decreases as intensity increases, providing some support for the idea that "less" exercise may be equally effective if intensity is relatively high. The results of several recent studies support the idea that low-volume, supramaximal-intensity interval training is a potent methodology for fitness and performance improvement with a minimal time commitment (3-6). Repeated bouts of supramaximal intervals, or sprint interval training (SIT), have been shown to confer cardiorespiratory and metabolic adaptations similar to longer duration traditional endurance training (7, 8).

Burgomaster et al (7) and Gibala et al (8) showed that the effects of repeated bouts of sprint interval cycling (SIC) were similar when compared to moderate-intensity continuous endurance training despite a significantly reduced time commitment. Training involving only six sessions of repeated 30-sec "all out" cycle ergometer sprinting doubled endurance time to exhaustion (at ~80% VO_{2peak}) in recreationally active subjects, with a total exercise training time of only 15 minutes (cumulative time of sprints) (3). A study examining the effects of SIT on the performance and VO_{2peak} in moderately-trained high school rowers provided further support for the benefits of maximal sprint training (9). During a 4-week training intervention and using an exercise stimulus of six maximal 30-sec efforts on a rowing ergometer performed three times per week, participants randomly assigned to the HIT group improved 2-km time trial rowing performance equivalent to improvement observed in the endurance training group. When portions of an endurance running training program were replaced by 30-sec sprints in two separate studies, moderately-trained subjects significantly improved VO_{2max} and time trial performance (10) and maintained muscle oxidative capacity, capillarization and endurance performance (11) despite the reduction in training volume.

The results of several studies indicate that repeated maximal-effort sprinting bouts elicit near-maximal cardiovascular strain (12) and improve muscle oxidative capacity (3, 8, 13-15), maximal oxygen uptake (14, 16-18) and endurance performance (8, 16, 19, 20). However, in the research cited above, SIC and rowing each required specialized and expensive ergometers; and sprint interval running requires a treadmill or a minimal amount of terrain on which to run. McRae and colleagues (21) reported that extremely low volume, whole-body aerobic-resistance training improved aerobic fitness and muscular endurance. In comparison to traditional moderate-intensity, continuous endurance treadmill training, the program of intermittent calisthenic exercises was as beneficial in enhancing cardiovascular fitness. Calisthenics may provide an exercise mode and stimulus that elicits similar benefits but with minimal equipment and space requirements. To our knowledge, no research has been conducted to determine the cardiorespiratory, metabolic and perceptual responses to a low-volume, high-intensity protocol of calisthenic exercise. The purpose of this study was to document and compare the physiological responses to two high-intensity intermittent exercise protocols: repeated bouts of sprint interval cycling (SIC) and repeated bouts of a high-intensity intermittent calisthenics (HIC). We hypothesized that HIC would elicit physiological responses similar to SIC and of sufficient cardiovascular strain to classify its peak responses as vigorous.

METHODS

Experimental Approach to the Problem. A repeated-measures experimental design was used in which the independent variable was exercise mode, and the primary dependent variables were $\%VO_{2peak}$ and $\%HR_{peak}$. Each study participant completed all four testing sessions across nine days with each session separated by 48-72 hours.

Subjects. Eleven (8 men, 3 women) moderately-trained members of the University of Georgia's Army Reserve Officers' Training Corps (ROTC) volunteered for the study. Physical characteristics are provided in Table 4.1. For at least one year prior to the start of the study, all subjects participated in pre-planned supervised activity a minimum of three days per week for duration of approximately one hour. Programmed activity consisted of calisthenics, moderate intensity running, and varied team sport activities. The study was approved by the Institutional Review Board. Following a comprehensive explanation of procedures, benefits and risks, volunteers provided written, informed consent.

Procedures. During the first visit to the lab, eligibility was confirmed via health screening questionnaire. Anthropometric data were recorded: height was measured to the nearest 0.1 cm using a wall stadiometer and body mass was measured to the nearest 0.1 kg using an electronic scale (model FW-150KA1, A&D Co., Ltd., Tokyo). Prior to the start of each of the four testing sessions, participants completed a 24-hour history document to confirm adherence to pre-test instructions and readiness for testing.

Throughout all exercise, expired air was collected and analyzed by a Parvo Medics TrueOne 2400 Metabolic Measurement System (Parvo Medics, Inc., Sandy, UT) to determine rates of oxygen uptake and associated cardiorespiratory and metabolic variables. Equipment was calibrated in accordance with manufacturer instructions. Subjects wore a Polar Vantage XL heart rate transmitter (Polar Electro, Inc., Woodbury, NY, model 145900) to permit continuous monitoring; heart rate was recorded at the end of each stage and at the completion of the test. Borg's 15-point Scale was used to measure ratings of perceived exertion (RPE) during the last 15-s of each stage and at the completion of exercise bouts (22). Participants were instructed to provide ratings based on *how heavy and strenuous the exercise feels* with exertion *mainly felt as strain and fatigue in their muscles and as breathlessness or aches in the chest*. Tests were separated by 48-72 hours and performed at the same time of day for individual participants. Sessions 1 (Peak Oxygen Uptake) and 2 (Maximal Accumulated Oxygen Deficit) were completed to determine individual peak cardiorespiratory, metabolic and perceptual responses. Prior to Testing Sessions 3 (SIC) and 4 (HIC), investigators administered orientation bouts to familiarize participants with the protocols. The order of SIC and HIC sessions was randomized.

Peak Oxygen Uptake. Using a modified protocol from Medbo et al (23), a discontinuous uphill running graded exercise test was administered on a treadmill (Trackmaster, JAS Fitness System, Newton, KS) to determine physiological responses to incremental increases in velocity. Following a 5-min walking warm-up, participants completed 5-min treadmill running bouts (with a 5-min rest between bouts) at 10% grade with incremental increases in velocity. The running velocity for men and women during the initial stage was 5.63 and 4.83 km·h^{-1}, respectively, and was increased 0.64 km·h^{-1} each stage until subjects could no longer complete a 5-min stage. Expiratory gases were continuously measured and averaged over 30-s intervals. Peak oxygen uptake (VO_{2peak}) was defined as the highest 30-s VO_2 during the test with maximal effort classified as attainment of least two of the following: peak heart rate within 10 bt·min^{-1} of age-estimated maximum (220-age); respiratory exchange ratio (RER) ≥ 1.10; blood lactate concentration ([La]) ≥ 8.0 mmol·L^{-1}; RPE (Borg 20-point scale) ≥ 18. Peak heart rate (HR_{peak}), RER (RER_{peak}) and RPE (RPE_{peak}) were the highest 30-s values. Three minutes post-exercise, a finger stick blood sample (~5 μL) was obtained to determine peak blood lactate concentration (Lactate Pro Test Meter, model LT-1710, KDK Corp., Kyoto, Japan).

Maximal Accumulated Oxygen Deficit. Using the protocol described by Medbo et al (23), individual data from the discontinuous running protocol involving at least 5-7 5-min stages at submaximal intensities were used to establish a linear regression between running velocity and oxygen uptake. On a different day, following a 5-min warm-up at approximately 50% VO_{2peak}, participants completed a supramaximal treadmill running bout at a velocity estimated to elicit 115% of VO_{2peak}, which was extrapolated from the linear relation described above. Participants exercised to exhaustion. Maximal accumulated oxygen deficit (MAOD) was calculated as the difference between estimated oxygen demand and oxygen uptake measured during running; values were multiplied by 0.9 to correct for the portion of the deficit estimated to account for oxygen stores in venous blood and bound to myoglobin (24).

Sprint Interval Cycling (SIC). Participants completed a 5-min warm-up on a mechanically-braked, stationary cycle ergometer (Model 874E, Monark Exercise AB, Sweden). During this session, participants were instructed to pedal as fast as possible for 5 seconds until the resistance ($7.5 \pm 0.1\%$ body mass) was applied to the flywheel. The participants continued to pedal "all-out" against the resistance for 30 seconds (Wingate Anaerobic Power Test). During the 4-min active recovery period following each sprint, participants cycled against no resistance. The work-rest cycle was repeated three times for a total of four sets. Finger stick was used to determine lactate concentration at three minutes following each 30-s bout.

High-intensity Intermittent Calisthenics (HIC). Warm-up consisted of 5-min of cycling at self-selected pace followed by 10 squats, 10 push-ups and 5 burpees. Investigators administered a protocol of HIC, in which as many burpees as possible were performed for 30-s followed by 4-min of active recovery (stepping in place at self-selected pace). This work-rest cycle was repeated three times for a total of four sets. Blood lactate concentration was measured three minutes following each 30-s bout. A burpee is a physical exercise consisting of a squat thrust made from and ending in a standing position as modified from a test of physical capacity developed by R.H. Burpee (25):

1. Begin in a standing position (arms at sides).
2. Lower into a squat position by flexing knees and hips and place hands on the ground in front of feet.
3. Kick feet back and lower with a pushup.
4. Straighten arms with a pushup and return feet to the squat position.
5. Extend knees/hips and leap up as high as possible from the squat position with arms extended overhead.

Statistical Analyses. All analyses were performed using SPSS for Windows software (SPSS 19.0, Chicago, IL). Using $\%VO_{2peak}$ as the primary outcome variable, *a priori* power analysis revealed the need for a sample size of nine participants to detect a moderate effect of 0.5 standard deviation at a power of 82% with a correlation of 0.9 between repeated measures. Descriptive statistics (mean ± SD) were determined to characterize group responses. A repeated-measures one-way ANOVA was applied to compare peak responses to the SIC and HIC protocols. Effect sizes (Cohen's *d* with 95% confidence interval) were calculated as the change in mean scores divided by a pooled standard deviation. Statistical significance for all comparisons was set at $p \leq 0.05$.

RESULTS

Individual VO_{2peak} and related measures are provided in Table 4.2. The peak cardiorespiratory responses for the two high-intensity intermittent exercise sessions are reported relative to observed peak values and were 80.4 ± 5.3% (SIC) and 77.6 ± 6.9% (HIC) of VO_{2peak} and 86.8 ± 3.9% (SIC) and 84.6 ± 5.3% (HIC) of HR_{peak} across the four sets. Subjective ratings of perceived exertion reported immediately upon completion of each set of exercise were 17.0 ± 1.7 ("very hard") for SIC and 14.5 ± 2.2 ("hard") for HIC. Descriptive data for each bout are shown in Table 4.3. Peak blood lactate concentrations were 9.1 ± 2.0, 12.8 ± 1.3, 11.8 ± 4.0, and 11.9 ± 3.0 $mmol \cdot L^{-1}$ (SIC) and 3.7 ± 2.6, 7.7 ± 2.9, 8.3 ± 2.4, and 8.2 ± 3.3 $mmol \cdot L^{-1}$ (HIC). The continuous oxygen uptake and heart rate mean responses for each protocol are depicted in Figures 4.1 and 4.2.

Effect sizes and corresponding 95% confidence intervals for differences in peak cardiorespiratory and perceptual responses to the two protocols were: $\%VO_{2peak}$ Cohen's *d* = 0.51 (0.48, 0.53), $\%HR_{peak}$ Cohen's *d* = 0.57 (0.55, 0.59), and RPE_{peak} Cohen's *d* = 1.19 (0.24, 2.14).

DISCUSSION

The present study measured physiological and perceptual responses to a unique calisthenics protocol and compared the data to a SIC protocol, which was administered using equivalent instructions for participant effort, work duration and active rest interval. Contrary to our hypothesis, the primary findings indicate the HIC provided a cardiorespiratory stimulus that was lower than a frequently used SIC protocol consisting of repeated Wingate tests. Although not statistically significant, the cardiorespiratory responses were ~1/2 standard deviation lower while perception of exertion was more than one standard deviation lower. In accordance with the American College of Sports Medicine's *Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults: Guidance for Prescribing Exercise (26)*, the peak VO_2, HR and RPE responses for burpees classify the exercise intensity as vigorous (64-90% of maximal oxygen uptake, 77-95% of maximum heart rate, or a rating of perceived exertion of somewhat hard to very hard (RPE 14-17)). The oxygen uptake and heart rate responses were not statistically equivalent to those recorded for repeated "all-out" stationary cycling efforts, but the results suggest our protocol of low-volume, high-intensity intermittent calisthenics may confer cardiorespiratory and metabolic adaptations favorable to increasing physiological markers of fitness, such as aerobic capacity, anaerobic capacity, and skeletal muscle oxidative metabolism based on the vigorous classification of peak responses to whole-body calisthenics. To our knowledge, this is the first study to record the physiological responses to high-intensity intermittent calisthenic exercise. The value of the current findings is limited until further determination of training adaptations can be made; however, comparison to SIC warrants further discussion.

The published findings of others that describe the chronic effects of SIC provide evidence for the potential benefits of our calisthenic protocol. In an exercise intervention study employing the repeated Wingate protocol (bouts of 30-sec "all out" work alternated with 4-min active recovery periods), MacDougall et al (14) reported that a 7-week training program increased VO_{2max}, maximum short term power output, glycolytic enzyme activity (phosphofructokinase and hexokinase), and oxidative enzyme activity (malate dehydrogenase, succinate dehydrogenase, citrate synthase). The results of Bailey et al. (27) indicate the same repeated sprint training improved muscle oxygen extraction, resulting in improved oxygen uptake kinetics and exercise time to exhaustion. The randomized controlled trials of others using a similar training stimulus have reported significant increases in aerobic capacity (10, 13, 16, 28, 29). Despite reduced exercise duration, SIC has been proven to confer physiological adaptations favorable to improvements in skeletal muscle oxidative metabolism, metabolic capacities and performance.

In addition to the low time commitment, other desirable characteristics of our novel exercise intervention include its simplicity and lack of expense. Unlike the SIC that requires specialized equipment or a running protocol that requires access to at least a minimum amount of terrain or to a treadmill, the HIC is cost-free, accessible to all, and may be completed in small space. Although we did not assess enjoyment, the findings of Bartlett et al (30) indicated that participants enjoyed high-intensity intermittent running more than longer duration, continuous exercise. Whether individuals engaged in whole-body calisthenics would be more likely to enjoy or adhere to such an exercise protocol more than traditionally prescribed sessions of continuous moderate-intensity exercise is unknown.

Results from our study reveal significantly lower perceptions of effort (RPE) for the HIC compared to SIC. These findings provide some evidence that the calisthenics were “easier” than the cycling. Although whole-body skeletal muscle activation data are not available, we assume that the motor unit recruitment patterns in SIC primarily involve the leg flexor and extensor muscles during “all out” stationary cycling. During HIC, a greater amount of whole body musculature is active in performing burpees as the movement requires flexion and extension at multiple joints. The difference in perception of effort can likely partially be attributed to the observed difference in cardiovascular strain. While we cannot draw any conclusions, it is also possible that the workload borne by the legs during cycling induced a localized muscle strain and fatigue that we observed in the higher RPE values. Elucidation of this difference may have been possible through the use of a pain rating scale with a specific focus on the thighs (31).

We acknowledge the potential limited application of our protocol in deconditioned or sedentary populations that may not be able to execute multiple complete repetitions as described, thus reducing the intensity of the protocol. Despite these apparent limitations, modifications allow for decreased or increased difficulty relative to individual fitness level. The movement may be modified to increase or decrease difficulty, which may include additions of a plyometric box jump or elimination of the push-up and/or jump portion of the sequence. Further examination of participant expectations and enjoyment is necessary to draw conclusions regarding HIC; however, its potential as a beneficial modality is evident. Tolerance, adherence and enjoyment should also be assessed to determine feasibility. The mechanisms responsible for any adaptation also must be elucidated. The training effects of this type of protocol warrant further investigation as understanding the cardiorespiratory and metabolic responses to a bout of exercise provides the foundation for the development of exercise programs intended to elicit a specific physiological adaptation and accompanying sport or occupational performance improvement.

PRACTICAL APPLICATIONS

The results of the present study suggest that the cardiovascular strain elicited by a single session of low-volume, high-intensity intermittent burpees may be sufficient to confer cardiorespiratory and metabolic adaptations equivalent to those reported in studies using SIC. These vigorous, or near maximal, acute responses complement previously reported findings of increased skeletal muscle oxidative capacity, maximal oxygen uptake, and endurance performance following training programs using traditional aerobic training modalities. Such a program of high-intensity calisthenics may be well suited to moderately-trained groups seeking rapid improvements in fitness with minimal time commitment.

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DISCLOSURES

The authors have no financial disclosures or conflicts of interest.

Table 4.1: Participant characteristics (mean ± SD).

	Men (n=8)	Women (n=3)	Combined (n=11)
Age (yr)	22.1 ± 2.4	21.3 ± 1.2	21.9 ± 2.1
Height (cm)	177.7 ± 4.8	169.6 ± 3.4	175.5 ± 5.7
Weight (kg)	79.1 ± 5.5	68.9 ± 7.3	76.3 ± 7.4
BMI ($kg \cdot m^{-2}$)	25.1 ± 1.9	23.9 ± 1.8	24.8 ± 1.9
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	56.5 ± 3.2	47.8 ± 5.5	54.1 ± 5.4
HR_{peak} ($bt \cdot min^{-1}$)	194 ± 9	195 ± 7	194 ± 8
MAOD[†] ($mL \cdot kg^{-1}$)	68.0 ± 7.5	50.6 ± 19.5	63.2 ± 13.5

BMI: body mass index; VO_{2peak}: peak oxygen uptake; HR: heart rate;
[†] Maximal Accumulated Oxygen Deficit (MAOD) corrected for O_2 bound to hemoglobin and myoglobin, O_2 dissolved in body fluids, and O_2 present in the lungs.

Table 4.2: $\dot{V}O_{2peak}$ and related measures.

Participant No.	Sex (M/F)	$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	HR_{peak} ($bt \cdot min^{-1}$)	$\dot{V}_{E\ peak}$ ($L \cdot min^{-1}$)	RER_{peak}	RPE_{peak} (6-20 Borg)	[La] ($mmol \cdot L^{-1}$)
1	M	4.49	60.25	178	175.7	1.09	20	14.4
2	M	4.84	56.73	193	146.4	1.04	19	13.7
3	F	3.26	52.59	187	106.9	1.08	19	8.9
4	M	4.50	55.94	186	170.3	1.10	19	14.0
5	F	3.20	41.88	198	118.5	1.12	19	10.2
6	M	4.77	61.70	205	178.3	1.13	19	13.3
7	M	4.80	54.16	205	178.3	1.06	18	11.3
8	M	4.11	51.95	192	140.2	1.11	20	11.9
9	M	4.17	55.99	192	136.8	1.06	18	10.6
10	F	3.34	48.97	199	117.5	1.14	19	10.7
11	M	4.05	55.28	200	167.2	1.04	20	14.7
Group (mean ± SD)		4.14 ± 0.62	54.13 ± 5.42	194 ± 8	148.7 ± 26.7	1.09 ± 0.04	19.1 ± 0.7	12.2 ± 2.0

VO_{2peak}: peak oxygen uptake; HR: heart rate; V_E: ventilation; RER: respiratory exchange ratio; RPE: rating of perceived exertion; [La]: blood lactate concentration.

Table 4.3: Peak cardiorespiratory and perceptual responses (mean ± SD).

Variable	SIC	HIC	*p*-value
$\%\dot{V}O_{2peak}$			
Bout 1	79.6 ± 7.8	72.7 ± 4.5	0.008*
Bout 2	83.1 ± 10.3	76.8 ± 13.2	0.216
Bout 3	85.1 ± 8.3	77.7 ± 6.1	0.017*
Bout 4	82.6 ± 8.9	83.0 ± 8.4	0.930
All	80.4 ± 5.3	77.6 ± 6.9	0.211
$\%HR_{peak}$			
Bout 1	84.2 ± 5.1	80.4 ± 7.2	0.149
Bout 2	87.1 ± 4.5	83.8 ± 6.1	0.108
Bout 3	88.3 ± 3.9	86.7 ± 4.9	0.135
Bout 4	88.2 ± 3.0	87.5 ± 4.8	0.497
All	86.8 ± 3.9	84.6 ± 5.3	0.152
RPE_{peak}			
Bout 1	15.5 ± 1.8	13.1 ± 2.1	0.002*
Bout 2	16.6 ± 2.0	14.2 ± 2.3	0.002*
Bout 3	17.4 ± 1.9	15.0 ± 2.4	0.001*
Bout 4	18.6 ± 1.4	15.8 ± 2.3	0.000*
All	17.0 ± 1.7	14.5 ± 2.2	0.001*

VO_{2peak}: peak oxygen uptake; HR: heart rate; RPE: rating of perceived exertion; SIC: Sprint Interval Cycling; HIC: High-intensity Intermittent Calisthenics; *statistically significant ($p \leq 0.05$).

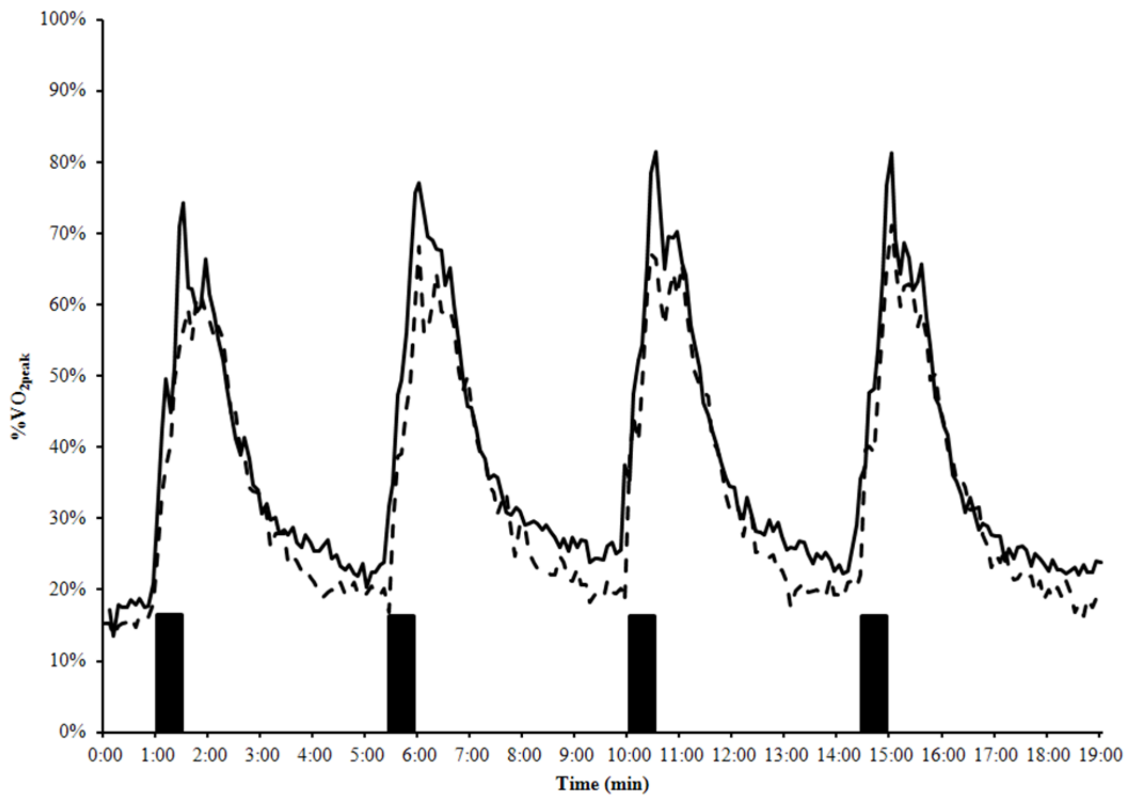

Figure 4.1: Oxygen uptake (%VO_{2peak}) during 4 x 30-s bouts of "all-out" sprint interval cycling (solid line) and high-intensity intermittent calisthenics (dotted line) separated by 4-min active recovery periods. Solid bars represent the 30-s work period.

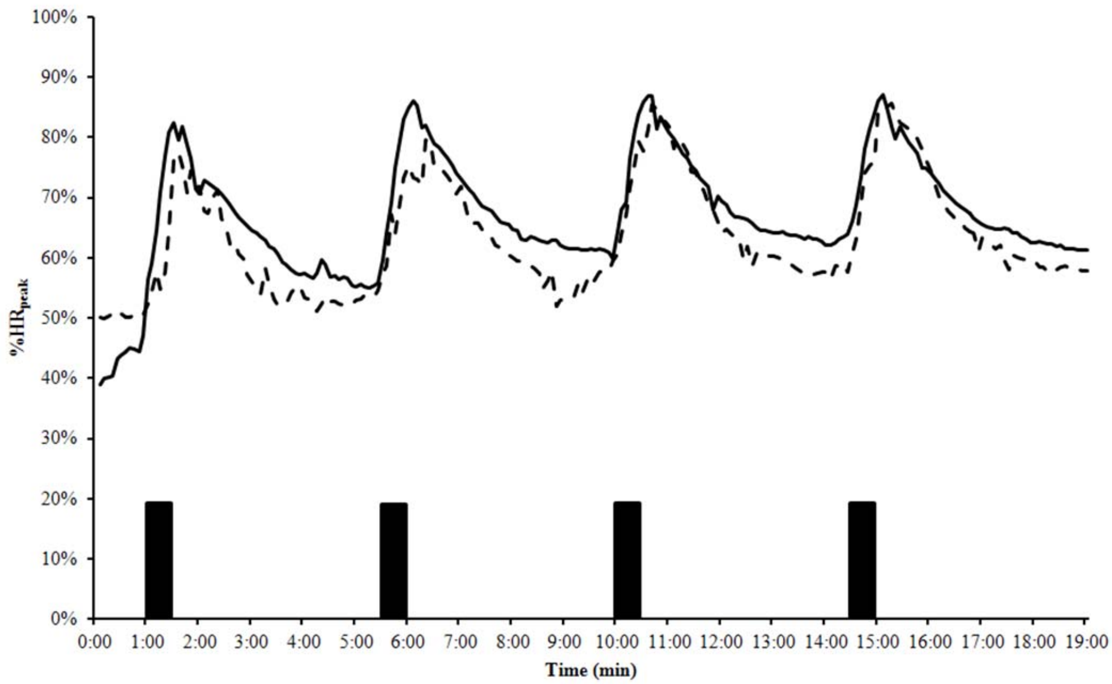

Figure 4.2: Heart rate (%HR_{peak}) during 4 x 30-s bouts of "all-out" sprint interval cycling (solid line) and high-intensity intermittent calisthenics (dotted line) separated by 4-min active recovery periods. Solid bars represent the 30-s work period.

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CHAPTER 5

PHYSIOLOGICAL AND PERFORMANCE EFFECTS OF LOW-VOLUME, HIGH-INTENSITY WHOLE-BODY CALISTHENICS ON ARMY ROTC CADETS[3]

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ABSTRACT

OBJECTIVE: To determine the effects of a 4-week low-volume, high-intensity interval training (HIT) intervention on fitness and performance in ROTC cadets and compare these effects with those induced by a typical military physical training (TCT) program. **METHODS:** Twenty six (17 men, 9 women) college-aged (20.5 ± 1.7 years) members of the University of Georgia's Army Reserve Officers' Training Corps (ROTC) completed 4 weeks of exercise training 3 days·wk^{-1} consisting of either ~60 min of TCT or HIT whole-body calisthenics involving 4-7 sets of 30-s "all out" burpees separated by 4 min of active recovery. Pre- and post-intervention assessments of VO_{2peak}, anaerobic capacity, mitochondrial function, and performance on the Army Physical Fitness Test (APFT) were compared. Participants' enjoyment and feelings of energy and fatigue were also examined prior to, weekly, and after training. **RESULTS:** Following training, there were no changes in VO_{2peak}, anaerobic capacity or APFT performance ($p > 0.05$). For the TCT group, mitochondrial function (T_c: time constant of recovery) improved as observed in the 2.4 ± 4.6 s decrease in T_c ($p = 0.081$; $d = -0.51$ (-2.37, 1.35)); whereas, mitochondrial function decreased in HIT as seen in the 2.4 ± 4.6 s increase in T_c ($p = 0.087$; $d = 0.50$ (-1.36, 2.36)). **CONCLUSION:** This HIT sustained fitness despite the short duration and reduced volume. A program that includes HIT as part of a larger program may be well suited to moderately-trained armed forces personnel seeking to maintain fitness with minimal time commitment without access to equipment.

INTRODUCTION

High-intensity interval training (HIT) is frequently used by endurance athletes as a method to improve competitive performance. A synthesis of studies examining the effects of exercise intensity on further improvements in the performance of highly-trained athletes highlights its efficacy (1). Although there is no agreement on optimal frequency, mode, intensity and duration, HIT has been described as short bouts of muscular activity alternating with periods of recovery with training sessions often characterized by an intensity greater than the anaerobic threshold (2). Noted as an integral part of the training and success of 1948 and 1952 Olympic champion, Emil Zatopek, and first researched in the 1960s by Per Olaf Astrand, HIT has a strong foundation of scientific and empirical evidence highlighting its benefits, which make its inclusion in preparation for sport competition a common practice (3); however, its inclusion in recreational and military physical training programs has only recently grown in popularity.

The physical demands placed on armed warfare combatants often involve long periods of lower intensity work interspersed with short periods of high-intensity activity. In a recent review, Kraemer and Svizak (4) referred to the modern-day combat environment as the “anaerobic battlefield” in which the diverse physical and environmental demands require more than aerobic fitness. While physical training is often focused on aerobic endurance-type training and preparation for assessments that include push-ups, sit-ups and/or pull-ups, the focus of warfighter training should instead match the expected physical demands of designated mission requirements.

The efficacy of HIT with respect to cardiorespiratory and metabolic adaptations has led to greater recent research interest in the effects of supramaximal HIT, or sprint interval training (SIT) (5). In studies utilizing the Wingate Anaerobic Test as a training stimulus, the exercise bout involves repeated 30-s bouts of supramaximal-intensity cycling against a braking force on a specialized cycle ergometer (6-13). This time-efficient model of SIT with as little as 15 minutes (cumulative time of sprints) of "all out" effort during only six sessions across two weeks has significantly improved skeletal muscle oxidative capacity, aerobic capacity (VO_{2max}) and endurance performance (6, 14-16). Others have added to the body of research by using the same protocol of cycling or by applying the 30-s:4-min interval to other modalities such as running and rowing (17-22). The findings of these studies have highlighted the potential impact of low-volume, high-intensity training on several fitness variables.

Additional support for the equally-effective benefits of this SIT model when compared to moderate-intensity, high-volume activity has been provided in randomized controlled trials (RCT) performed by Burgomaster et al (23) and Gibala et al (24) in which effects of repeated sprint cycling were similar when compared to moderate-intensity continuous endurance training. Specifically, the positive effects on aerobic capacity and selected markers of skeletal muscle metabolism (carbohydrate and lipid metabolism, cytochrome oxidase activity, muscle buffering capacity, muscle glycogen content) were not different between groups despite the significantly reduced time commitment and training volume (23, 24).

In another model of time-efficient HIT, Tabata and colleagues (25) administered low-volume repeated sprint cycling and reported simultaneous improvements in both anaerobic capacity and maximal aerobic power. Combining the Tabata interval timing protocol and whole-body aerobic-resistance exercise, McRae et al (26) trained recreationally active females using whole-body aerobic-resistance training intervals (burpees, mountain climbers, jumping jacks, and squat and thrusts). Improvements in aerobic fitness in the HIT group were similar to those in the endurance training group; the HIT group had additional improvements in muscular endurance (various lower- and upper-body exercises) not observed following endurance training. In a study of U.S. Navy Sea-Air-Land (SEALs) personnel, Jacobs et al (27) reported significant improvements in aerobic and anaerobic measures of fitness following a 3-week intervention of maximal effort sprints, providing further evidence for the efficacy of high-intensity training for inducing rapid cardiorespiratory and metabolic adaptations.

HIT in the form of whole-body calisthenic exercise, which can be done in limited space without equipment, might convey similar adaptations, but to our knowledge its effects on both aerobic and anaerobic capacities, as well as mitochondrial function, have not been studied. Anticipated findings will provide a basis for implementation of a novel no-cost, time efficient, and convenient (accessible to all populations in all environments) physical activity modality directed at improving or sustaining aerobic and anaerobic fitness. In addition to the reduced time commitment, evidence of physiological adaptations and performance improvements in a relatively short timeframe may appeal to military organizations with significant time commitments to combat missions, training and equipment maintenance.

The primary aim of this study was to determine the effects of a 4-week low-volume, HIT intervention on fitness and performance in ROTC cadets and compare these effects with those induced by a typical military physical training program. We hypothesized that a protocol of “all out” whole-body calisthenic HIT would sustain metabolic capacities, mitochondrial function and physical performance at least as well as typical cadet training (TCT).

Although the impact of exercise intensity on mood appears to be equivocal, moderate intensity is commonly reported as most beneficial (28-30), and chronic exercise appears to have a modest positive effect on feelings of energy and fatigue (31). To our knowledge, no studies have assessed the impact of HIT calisthenics on energy and fatigue. The observations of Raedecke et al (32) indicated that increased energy and enjoyment were positively correlated following an exercise session, whereas negative feelings were not, revealing that enjoyment may impact exercise-related increases in positive affect. Whether these acute mood and attitude relationships to exercise occur following chronic exercise is unknown. Others have shown evidence that HIT-type exercise may be perceived as more enjoyable (26, 33). To gain a better understanding of the psychological effects of HIT, our secondary aim was to compare participant ratings of energy, fatigue and enjoyment in response to the training intervention.

METHODS

Participants

Twenty six (17 men, 9 women) college-aged (20.5 ± 1.7 years) members of the University of Georgia's Army Reserve Officers' Training Corps (ROTC) volunteered for the study. Participants were moderately-trained and previously participated in planned and supervised activity a minimum of 3 days·wk^{-1} for duration of ~60 min. Collaboration with the Army ROTC Professor of Military Science included review of the study design, assistance with participant recruitment, scheduling of testing sessions, and assistance with management of the intervention. The study was approved by the Institutional Review

Board of the University of Georgia in accordance with policies regarding the execution of human subjects research. Following a comprehensive explanation of procedures and risks and confirmation of eligibility, participants provided written, informed consent.

Study Design

The experimental design was a repeated measures, randomized two-group design in which pre- and post-training outcome measures were compared following a 4-week exercise training intervention (Figure 5.1). Participants were randomly assigned to one of two groups: typical cadet training (TCT) or high-intensity interval training (HIT). To ensure equal baseline aerobic capacity (primary dependent variable) between groups, men and women were separately ranked by VO_{2peak} ($mL \cdot kg^{-1} min^{-1}$) and were divided into matched pairs. One individual from each group was randomly assigned to TCT or HIT using random.org.

Training Intervention

The 4-week training intervention began within 48-72 hours after completion of baseline assessments. Training for both groups required participants to complete at least ten of the twelve training sessions.

Participants assigned to TCT performed Army ROTC physical training as programmed prior to initiation of this study. Sessions were supervised by military science faculty and designated cadet leadership. Duration of each session was ~60 min and consisted of cardiorespiratory training (running), as well as mixed muscular strength and endurance exercises (calisthenics).

In lieu of Army ROTC Physical Training, participants assigned to HIT completed intermittent calisthenic exercise utilizing burpees. A burpee is a calisthenic exercise consisting of a squat thrust made from and ending in a standing position as modified from a test of physical capacity developed by R.H. Burpee (34):

1. Begin in a standing position (arms at sides).
2. Lower into a squat position by flexing knees and hips and place hands on the ground in front of feet.
3. Kick feet back and lower with a pushup.
4. Straighten arms with a pushup and return feet to the squat position.
5. Extend knees/hips and leap up as high as possible from the squat position with arms extended overhead.

Following standard warm-up activities, participants performed burpees at an "all out" intensity for 30-s followed by 4-min of active recovery (walking at self-selected pace). The work:rest interval was repeated for 4-7 sets; workload progression was implemented by administering four sets in Week 1, five in Week 2, six in Week 3, and seven in Week 4. At the completion of each training session, participants reported overall session ratings of perceived exertion using the 0-10 scale developed by Foster and colleagues as a means to subjectively estimate intensity for the entire exercise period (35).

Anthropometry

Prior to baseline testing, anthropometric data were recorded: standing height was measured to the nearest 0.1 cm using a wall stadiometer (model 242, seca, Hamburg, Germany) and body mass was measured in light clothing to the nearest 0.1 kg using an electronic scale (model WB-110A, Tanita Corporation, Tokyo, Japan). Dual-energy x-ray absorptiometry (DXA) was used to assess body fat percent via whole body scan (Lunar iDXA Bone Densitometer, GE Healthcare, Fairfield, CT).

Pre- and Post-Intervention Assessments

Prior to and following the 4-week training intervention, we assessed aerobic capacity, anaerobic capacity, mitochondrial function in the vastus lateralis, and physical performance to evaluate the effects of the protocols. Participants were asked to abstain from caffeine, alcohol, and nicotine 24 hours prior to testing. They were also asked to avoid strenuous physical activity during the same pre-test period. Post-intervention assessments were conducted in the same order and at the same time of day as baseline measures.

Mood was assessed at baseline and at the conclusion of each of the four weeks of training. Participants completed the 30-item Profile of Mood States Brief (POMS-B) to provide measures of energy (vigor) and fatigue (36). Attitude toward the intervention was measured weekly using the 18-item Physical Activity Enjoyment Scale (PACES) (37). A self-report 7-day Physical Activity Recall (7-d PAR) was used to estimate weekly energy expenditure during the intervention period (38). All self-report measures were completed in a quiet, classroom environment on the same day and time prior to the final training sessions of each week. In an evaluation of the psychometric properties of the POMS, O'Connor (39) summarized evidence for its reliability and validity as a suitable measure of energy and fatigue and further suggested limitations may be avoided by using the POMS Brief form (36).

Physical Assessments

Aerobic Capacity

Using a protocol modified from Medbo et al (40), investigators administered a discontinuous uphill treadmill (Trackmaster, JAS Fitness System, Newton, KS) running graded exercise test to determine cardiovascular and metabolic responses to submaximal and maximal exercise (41). Following a 5-minute walking/jogging warm-up, participants completed several (5-7) 5-minute treadmill running bouts (with a 5-minute rest between bouts) at 10% grade with incremental increases in velocity. Using indirect calorimetry, expired air was collected and analyzed by a TrueOne 2400 Metabolic Measurement System (Parvo Medics, Inc., Sandy, UT) to determine rates of oxygen uptake and associated cardiorespiratory and metabolic variables. The protocol was selected to simultaneously record individual participant relationships between exercise intensity and oxygen uptake at submaximal running velocities, as well as to assess VO_{2peak}. Standard gases of known composition were used to calibrate the oxygen and carbon dioxide analyzers, and a 3-L syringe was used to calibrate the pneumotachometer prior to each testing session. Heart rate (HR) was monitored continuously using a Polar Vantage XL heart rate monitor (model 145900, Polar Electro, Inc., Lake Success, NY) and recorded at the end of each stage and at the completion of the test. Borg's 15-point Scale (42) was used to measure ratings of perceived exertion (RPE) during the last 15-s of each stage. Participants ran to exhaustion (could not complete a 5-minute stage). Three minutes post-exercise, a finger stick blood sample (~5 µL) was obtained to determine peak blood lactate concentration (model LT-1710, Lactate Pro Test Meter, KDK Corp., Kyoto, Japan). Oxygen uptake and related measures were averaged over 30-s intervals. Classification of individual aerobic capacity (VO_{2peak}) was made with evidence of maximal effort in which a minimum of two of the following four criteria were met: HR (within 10 $bts \cdot min^{-1}$ of age-estimated HR_{max}); respiratory exchange ratio (RER) (≥ 1.10); RPE (≥ 18 on Borg 15-point scale); blood lactate concentration ([Lac]) (≥ 8.0 $mmol \cdot L^{-1}$).

Skeletal Muscle Mitochondrial Function

Investigators administered an exercise protocol of electrical stimulation to assess changes in skeletal muscle mitochondrial function using non-invasive near-infrared spectroscopy (NIRS)(43). Using a continuous-wave near infrared spectrophotometer (Oxymon MK III, Artinis Medical Systems, The Netherlands) affixed to the skin surface over the vastus lateralis of the participant's leg, the rate of recovery of muscle VO_2 was assessed using a series of repeated arterial occlusions following exercise. Foil electrodes attached to an electrical stimulator (Theratouch 4.7, Rich-mar, Inola, OK) were placed on the skin proximally and distally to the light source/detector. A pneumatic tourniquet (Hokanson E20, Bellevue, WA) was placed on the thigh proximal to the measurement site to provide a means for arterial occlusion. To stimulate mitochondrial oxygen consumption, 15 seconds of twitch electrical stimulation (4 Hz, pulse duration = 200 μs, pulse interval = 50 μs) was applied as previously described (44). Following the electrical stimulation, a series of arterial occlusions was performed as follows: cuffs 1-10: 3 seconds on/ 2 seconds off, cuffs 11-15: 7 seconds on/ 7 seconds off, cuffs 16-19: 10 seconds on/ 10 seconds off, and cuffs 20-23: 10 seconds on/ 20 seconds off. During each occlusion, muscle oxygen consumption was measured as the slope of the oxyhemoglobin (O_2Hb) and deoxyhemoglobin (HHb) signals. The repeated occlusion measurements of muscle oxygen consumption were fit to a monoexponential function and a time constant (T_c) was calculated, which is inversely proportional to mitochondrial function (43).

Anaerobic Capacity

We used data from the discontinuous treadmill running assessment to establish individual participant linear regression; at each submaximal intensity, VO_2 was plotted against treadmill velocity. The regression equation was used to estimate exercise intensity (running velocity) at a supramaximal oxygen demand of 125% VO_{2peak}. The calculated velocity was used in the following protocol for estimating anaerobic capacity. Following a 5-minute walking/jogging warm-up, participants completed a treadmill running bout at 10% grade and at the velocity estimated to elicit 125% VO_{2peak}. Participants were asked to run to exhaustion. Cardiorespiratory, metabolic and RPE data were collected as described previously. Using methods described by Medbo et al (40) as the most widely used approach for estimating anaerobic capacity, the maximal accumulated oxygen deficit (MAOD) was calculated as the difference between estimated oxygen demand and the measured oxygen uptake at 15-s intervals using breath-by-breath data.

Army Physical Fitness Test (APFT)

The APFT is a standard U.S. Army assessment consisting of two minutes of push-ups (PU), two minutes of sit-ups (SU), and a 2-mile run (2MR)—done in that order—on the same day. Participants were permitted ~10 minutes rest between events. The test was administered in accordance with Department of the Army Field Manual 7-22, Army Physical Readiness Training, with individual event and overall raw and scale scores reported on Department of the Army Form 705 (45).

Psychological Assessments

Mood

At baseline and at the conclusion of each training week, participants completed the POMS-B, a measure of mood states using a list of 30 words that describe how participants feel (36). We asked participants to rate "how you have been feeling during the past week, including today" using the 5-point Likert-type scale ranging from '0 – Not at all' to '4 – Extremely'. The POMS-B includes six factors; however, our analysis was limited to energy (vigor) and fatigue. The T-scores for energy and fatigue were derived from the raw scores per the form instructions.

Attitude

At the conclusion of each training week, participants completed the PACES. This assessment of participant attitude toward physical activity has 18 bipolar statements with a 7-point Likert-type scale (37). A summation of responses provided the unidimensional enjoyment score. Norm-referenced data were not available for the PACES; therefore, we used a scale midpoint to classify scores. Scores greater than 72 represent relative 'enjoyment' of the training while scores 72 or less represent relative 'lack of enjoyment'.

Statistical Analysis

All statistical analyses were performed using SPSS Statistics 20.0 (IBM, Somers, NY). Data are presented as means ± SD. Significance for all comparisons was set at $p \leq 0.05$. Differences in the mean changes in VO_{2peak}, T_c, MAOD, and the APFT were analyzed by independent samples *t*-tests. A two-factor (Group x Time) mixed design analysis of variance (ANOVA) was used to analyze Energy, Fatigue, Enjoyment, and Session RPE data. In the case of statistical significance for repeated measures, *post hoc* pairwise comparisons were made using Bonferroni corrections. Effect sizes (Cohen's *d* with 95% confidence interval) were calculated as the change in mean scores divided by a pooled standard deviation. Effects of 0.5 standard deviation or greater were considered to represent physiological and performance benefit (46). Using aerobic capacity as the primary outcome, *a priori* power analysis using G*Power 3.0.10 (Franz Faul, Universitat Kiel, Germany) revealed the need to recruit a total combined sample of 34 to detect a moderate effect of 0.5 standard deviation with a power of 0.80 (1-β), an α-level of 0.05, and a correlation of repeated measures of 0.90 for the primary dependent variable (VO_{2peak}).

RESULTS

Thirty-three cadets volunteered and met inclusion criteria for the study. Six were screened and completed some or all of baseline testing but did not begin the training intervention (1 – illness; 1 – travel for family emergency; 1 – less than maximal effort on baseline assessment; 3 – injuries incurred during another military training event). Of the 27 participants who began the training protocol, 26 completed all aspects of the study. One cadet was unable to complete post-training assessments due to a musculoskeletal injury unrelated to the training protocol. Physical characteristics prior to the training intervention are provided in Table 5.1.

Overall adherence was 95 ± 5% (11.4 ± 0.6 of the 12 training sessions completed) with no differences between groups ($p > 0.05$). There were no changes in anthropometric variables in either group from pre- to post-intervention ($p > 0.05$).

Physical Assessments

Aerobic capacity

No differences were observed between the groups at baseline (p = 0.594). Following the training intervention, there was no difference in changes in VO_{2peak} ($L \cdot min^{-1}$) in the TCT (p = 0.245) and HIT (p = 0.591) groups (Table 5.2 and Figure 5.2). With the exception of changes in peak blood lactate concentration ([LAC]) (p = 0.014), changes in all other related variables were similar for the two groups (p > 0.05).

Mitochondrial function

The recovery time constant (T_c) for TCT (27.9 ± 4.4 s) was similar to HIT (27.9 ± 5.4 s) at baseline. For the TCT group, mitochondrial function improved as observed in the 2.4 ± 4.6 s decrease in T_c (p = 0.081; d = -0.51 (-2.37, 1.35)). In the HIT group, mitochondrial function decreased as seen in the 2.4 ± 4.6 s increase in T_c (p = 0.087; d = 0.50 (-1.36, 2.36)). The significant interaction (p = 0.015) of observed changes is shown in Figure 5.3.

Anaerobic capacity

The MAOD was similar at baseline (TCT = 60.4 ± 16.8 $mL \cdot kg^{-1}$; HIT = 54.7 ± 14.9 $mL \cdot kg^{-1}$) (p = 0.370), and no change was observed in either group following the training intervention (p = 0.927).

Army Physical Fitness Test

Individual event scores (push-ups, sit-ups, two-mile run) were not different between groups at baseline, and no significant changes were observed between groups following training (Table 5.3).

Psychological Assessments

Mood

Prior to the start of the training intervention, energy (Figure 5.4A) and fatigue (Figure 5.4B) scores were similar for TCT and HIT ($p > 0.05$). A repeated measures ANOVA (Group x Time) of energy scores revealed no interaction ($F_{0.05}(4, 96) = 1.241$; $p = 0.299$). However, a main effect for Time was observed ($F_{0.05}(4, 96) = 6.337$; $p < 0.001$). Pairwise comparisons revealed the following differences: Pre-training to Week 2 ($p = 0.003$) and Pre-training to Week 4 ($p = 0.007$). There were no differences between Groups ($F_{0.05}(1, 24) = 1.220$; $p = 0.280$). From Pre-training to Week 3, Cohen's *d* (95% confidence interval) values were: -0.38 (-3.03, 2.28) for TCT and -1.01 (-3.67, 1.64) for HIT. From Pre-training to Week 4, Cohen's *d* values were: -0.84 (-3.49, 1.81) for TCT and -1.23 (-3.88, 1.42) for HIT.

An analysis of fatigue revealed a Group x Time interaction ($F_{0.05}(4, 96) = 2.769$; $p = 0.032$) in which participant ratings indicated reduced fatigue in the TCT group but increased fatigue in the HIT group. From Pre-training to Week 3, Cohen's *d* values were: -0.55 (-2.97, 1.87) for TCT and 0.64 (-1.78, 3.05) for HIT. From Pre-training to Week 4, Cohen's *d* values were: -0.59 (-3.00, 1.83) for TCT and 0.26 (-2.16, 2.68) for HIT. No main effect for Time was observed ($F_{0.05}(4, 96) = 1.564$; $p = 0.190$). There were no differences between Groups ($F_{0.05}(1, 24) = 1.801$; $p = 0.192$).

Attitude

Mean scores for both groups at all observed time points were above the scale midpoint (> 72) for enjoyment of the physical training (Figure 5.5). There was an observed interaction ($F_{0.05}(3, 72) = 3.630$; $p = 0.029$) but no main effect for Time ($F_{0.05}$(3,

72) = 2.445, $p = 0.090$). There were no differences between Groups ($F_{0.05}(1, 24) = 2.001$, $p = 0.170$).

Physical Activity Questionnaire

Weekly physical activity outside the study was similar between groups (TCT: 270.9 ± 22.6 $kcal \cdot kg^{-1} \cdot wk^{-1}$; HIT: 268.3 ± 26.8 $kcal \cdot kg^{-1} \cdot wk^{-1}$) and across the four weeks of the study ($p = 0.721$). Values observed from self-report 7-d PAR were typical for college-aged men and women (47).

Characteristics of the Training Intervention

Subjective participant ratings of exertion for training sessions (Figure 5.6) indicated that the HIT group perceived their workouts on average to be “very hard” (7.3 ± 1.3) with a duration of 23-36.5 minutes (includes 5-min warm-up); whereas, the TCT group rated their workouts on average as “hard” (5.0 ± 1.8) with typical duration of ~60 minutes. Session RPE values were significantly different between groups ($p < 0.001$).

DISCUSSION

In the current study, the primary objective was to compare changes in metabolic capacities and physical performance induced by a typical ROTC cadet physical training program and a novel low-volume, high-intensity whole-body calisthenics training protocol. The major findings indicate the HIT protocol consisting solely of burpees sustains fitness as measured by aerobic capacity, anaerobic capacity and performance on a functional fitness assessment despite the short duration and reduced volume of activity. During twelve training sessions across four weeks, HIT participants completed only 33 cumulative minutes of “all out” effort exercise. The HIT group required no additional equipment and only enough space normally required to perform a push-up. Participant session RPE data indicate the HIT was more difficult than TCT, providing support for the intended design difference. While initially it is possible the HIT group was unaccustomed to the modality of exercise and may have rated their workout higher, ratings remained elevated above TCT across the 12 sessions. Another explanation for the divergence in reported exertion may be the progression in the HIT group from four sets in Week 1 to seven sets in Week 4; whereas, training volume in the TCT group remained relatively constant. Although no objective measure of intensity was used while training, the RPE observations made immediately following each session indicate the HIT protocol was at least subjectively "harder" than TCT. The session RPE scale provides a reliable and valid means to assess the global intensity of a bout of non-steady state HIT (35).

Other studies have compared supramaximal HIT cycling to moderate-intensity endurance training. In two separate randomized controlled trials, healthy young men and women of average maximal aerobic power had similar improvements in VO_{2peak} and skeletal muscle oxidative capacity (23), as well as exercise performance and muscle buffering capacity (24), despite a ~80-90% difference in total exercise volume across the 2-wk training intervention. A possible explanation for the lack of improvement in our sample was the participant state of training upon selection. The cadets were of above average fitness (53.2 ± 5.6 $mL \cdot kg^{-1} \cdot min^{-1}$) and were accustomed to aerobic-type exercise. While it is known that additional submaximal endurance exercise in trained individuals is unlikely to improve performance or related physiological variables, HIT programs in various forms have proven beneficial as a supplement to or replacement of typical training (2). Within our HIT group, the limited amount of time at near maximal-to-maximal intensity and the relatively long rest interval may explain the lack of improvement in physiological and performance measures. Although it was not the aim of this study to determine the optimal intensity and duration of whole-body calisthenics necessary to induce change, the apparent effectiveness of the repeated 30-s "all out" effort and 4-min active recovery interval in other modalities (6, 11, 16, 22) was not observed in Army ROTC cadets performing burpees.

Although a single bout of whole-body calisthenic exercise performed in an "all out" manner for 30 seconds is expected to primarily involve anaerobic energy systems, multiple bouts of intermittent exercise place a high demand on aerobic processes (48). Whole-body burpee exercise appears to require recruitment of core-stabilizing muscle and upper body muscle during concentric and eccentric phases of the squat, push-up, thrust, and jump movements. As cardiovascular strain is generally proportional to the quantity of muscle mass recruited (49), the inclusion of primarily whole-body movements conducted with maximal effort over relatively short duration may induce physiological responses conducive to simultaneously improving aerobic and anaerobic capacities. Although data are not available, we speculate that the recruitment and activation of skeletal muscle includes not only the majority of the upper- and lower-body but also all fiber types. The vigorous nature of the activity provides support for its use as a stimulus for physiological adaptations.

Potentially, a greater volume of calisthenics, greater duration at or near VO_{2peak}, and/or reduced rest interval may have conferred physiological adaptations and performance improvement. The interaction of exercise frequency, intensity, duration and mode has been studied extensively (50). In a recent study by McRae et al (26), a protocol of 20-s:10-s HIT was applied based on the findings of previous research in which a HIT cycling protocol originally administered by Tabata et al (25) simultaneously improved VO_{2max} and anaerobic capacity after six weeks of training. In the McRae study (26), the same protocol applied to whole-body aerobic-resistance training (mountain climbers, jumping jacks, burpees, and squat thrusts) was successful in improving VO_{2peak} in addition to several measures of skeletal muscle endurance. In a sample of trained U.S. Navy SEAL personnel ($mL \cdot kg^{-1} \cdot min^{-1}$), supramaximal HIT cycling consisting of 3-5 30-s sprints during a 30-min session of low-intensity cycling did not elicit a change in maximal aerobic power but improved MAOD by ~38% following three weeks of training (27). It is generally accepted that the phosphogenic and glycolytic metabolic pathways are best trained through the increased intensity often applied in repeated sprint training (51). Our results do not show an increase in MAOD, which may be a function of the relatively long 4-min rest interval or the lower volume of training for this group of fit participants.

The increased mitochondrial function in TCT and decreased function in HIT was an interesting finding in our data. Although the changes within each group were not significant, the moderate effect sizes (d_{TCT} = 0.51 improvement; d_{HIT} = 0.50 decrement) are indicative of physiological adaptation in oxidative capacity. However, the apparent changes in skeletal muscle oxidative metabolism may not influence whole-body aerobic power and performance on assessments of fitness. Using another non-invasive assessment (^{31}P magnetic resonance spectroscopy) of mitochondrial function, Larson-Meyer et al (52) reported a significant correlation between whole-body aerobic power and citrate synthase activity (r = 0.69) but a non-significant correlation between aerobic power and cytochrome oxidase activity (*r* = 0.36), indicating that such peripheral changes within the mitochondria of skeletal muscle may not influence measurements of VO_{2peak}. It is not unusual that despite changes in mitochondrial function as measured by NIRS in our study, VO_{2peak} did not seem to be similarly influenced in either TCT or HIT. Although a direct measure of work performed was not made, the difference in mitochondrial function following training may be the result of the HIT group having greater relative "work" performed by the upper body musculature during burpees. In comparison, the TCT group primarily performed typical endurance running, which consisted of repeated contractions of the leg musculature at moderate intensity. Nonetheless, mitochondrial function assessed via NIRS indicated the HIT regimen was ineffective is improving skeletal muscle oxidative metabolism.

The APFT served as an indicator of upper- and lower-body muscular endurance (PU and SU), as well as another assessment of aerobic fitness (2MR) (53). Performance on the test (individual event and overall score) was not different in either group following training. While the TCT group frequently performed push-ups and sit-ups following endurance running during training sessions, the HIT group's protocol was not designed for specificity. Similar to the results observed for aerobic and anaerobic capacities, neither TCT nor HIT was effective in improving APFT performance; however, participants in the short-duration HIT group sustained individual event and overall scores.

A second objective of the study was to compare participant ratings of energy, fatigue and enjoyment in response to the physical training intervention. Assessment of mood provides possible insight into the psychological benefits of exercise training programs. Conceptualized as mood states, energy and fatigue represent subjective feelings of having the capacity to complete mental or physical activities and having a reduced capacity to complete mental or physical activities, respectively. Prior to and throughout the training intervention, participant transient feelings of energy and fatigue were greater than and less than, respectively, age normative scores (54). At baseline and through Week 2 of training, mood scores were similar in TCT and HIT; however, effect sizes (change from baseline to post-intervention) indicate a large decrease in feelings of energy (d = -1.23) and a smaller increase in feelings of fatigue (d = 0.26) in the HIT group. In the TCT group that performed moderate-intensity exercise, we also observed a large decrease in energy (d = -0.84); but fatigue was reduced in this group (d = -0.59). In a systematic review and meta-analysis of literature examining the effects of exercise on self-reported feelings of energy and fatigue, Puetz et al (31) reported that chronic exercise increased energy and reduced fatigue by a mean effect size of 0.37 when compared to control groups. We are not aware of any other studies to have examined the chronic effects of HIT on energy and fatigue, but in a study of collegiate swimmers (no control group), energy scores decreased ~1.4 SD and fatigue increased ~1.1 SD in response to progressively increasing training volume (55). It is generally accepted that moderate intensity exercise is most beneficial (28-30), but little is known about the effects of high-intensity exercise. The large decreases in energy observed in both groups are contrary to most data but are consistent with changes observed with harder training. The group interaction for fatigue is more difficult to interpret, but the effect is primarily due to the decreased feelings of fatigue in the TCT group. Although the change only approached statistical significance (p = 0.062), the effect size of ~0.60 indicating a decrease in fatigue is notable given the group's decrease in energy. Such a decrease in fatigue is consistent with meta-analytic findings; however, the increase in fatigue in HIT is again similar to results reported for hard training. Regardless of group assignment, the administered protocols had primarily negative effects on energy and fatigue.

Despite the higher perceived exertion reported by the HIT group, the participants enjoyed the activity and scores did not differ from the TCT group. The quantification of subjective feelings of enjoyment of a specific exercise experience may have implications relative to continued participation in and motivation toward the activity. Ratings of enjoyment remained stable throughout the intervention for the TCT group; however, the HIT group ratings reveal a non-significant decrease (d = -0.28 (-5.69, 5.12)) from baseline to post-intervention. Whether the downward trend in enjoyment would continue is unknown but should be noted for programming of HIT. The observations of Raedecke et al (32) indicated that increased energy and enjoyment were positively correlated following an exercise session, whereas negative feelings were not. Although cause is unknown, the strong relationship is notable. The findings of Bartlett et al (33) indicated participants enjoyed high-intensity intermittent running more than longer duration, continuous running, and McRae et al (26) reported that participants engaged in their whole-body aerobic-resistance interval training protocol had increased enjoyment from pre- to post-intervention. We recommend some caution in interpreting results from these studies as the 1- or 2-question scales used have little or no reliability and validity evidence. Inclusion of the PACES as a reliable and valid assessment of enjoyment should be considered in future studies (32, 37, 57, 58). Kimiecik and Harris (59) hypothesized that the more intrinsically motivated individual is more likely to continue to perform the activity perceived to have caused the enjoyment. Therefore, determination of level of enjoyment associated with exercise intensity can inform the development of interventions designed to improve fitness.

One of the acknowledged limitations of the study is the lack of statistical power (small sample size). While the *a priori* goal was to randomize at least 34 participants in order to detect a significant difference in VO_{2peak} of 0.5 SD, the primary findings revealed neither training protocol had an effect on metabolic capacities. Effect sizes were computed for mitochondrial function and provide additional information regarding the impact of TCT and HIT in this sample of Army ROTC cadets.

Another limitation was the lack of a non-exercise control group. However, the experimental design selected for this study contributes to the ecological validity evidence for an alternative HIT modality performed in lieu of or as part of typical military training. Furthermore, while the effects of physical activity on mood are known, the specific impact of the two training protocols in this study can only be compared to each other and not to a no-exercise control group of Army ROTC cadets taken from the same sample.

The APFT administered to cadets is "designed to ensure the maintenance of a base level of physical fitness essential for every Soldier, regardless of Army MOS [military occupational specialty] or duty assignment" (45). We acknowledge that other functional assessments could be applied, but the APFT is a standardized assessment with age- and sex-specific norms. A more diverse set of assessments specific to each MOS and organizational mission may be appropriate to gaining greater understanding of the impact of training programs on fitness variables such as muscular strength.

Future research should attempt to determine longer term consequences of HIT. Much of the supramaximal HIT literature indicates training periods as short as two weeks may be effective in conferring rapid physiological adaptations and performance benefits. Comparison of varied work:rest ratios and energy system contributions is also necessary to expand on our observations. Aerobic interval training at 90-100% VO2max with a 1:1 work:rest ratio is a commonly applied practice among trained endurance athletes (3). Knowledge of the effects on strength and body composition relative to performance of military occupational tasks would also be of benefit to leaders of physical training programs. Whether this modality of HIT would be effective as part of a more comprehensive fitness regimen is unknown and should be explored further.

CONCLUSION

In conclusion, these findings support our hypothesis that a protocol of low-volume, high-intensity whole-body calisthenics can sustain metabolic capacities and physical performance and add to the growing body of literature on HIT of various work:rest intervals and modalities. An intervention consisting solely of short duration whole-body calisthenics performed in an "all out" manner sustained metabolic capacities and performance, and these results were similar to the effects of typical cadet physical training.

Preparation for military deployment to training centers or contingency areas of operation is often conducted on short notice and involves numerous competing requirements that leave little time for programmed exercise while frequent travel and extended work periods in austere environments may limit availability of equipment and space for exercise. In a study examining the effects of varying intensity and duration on skeletal muscle adaptations in rats , Dudley et al (60) reported that the duration of exercise necessary to bring about beneficial skeletal muscle adaptations decreases as intensity increases, providing some support for the idea that "less" exercise may be equally effective if intensity is relatively high. The apparent popularity of high-intensity exercise and growing body of scientific evidence showing its effectiveness support its inclusion in military physical training. A program that includes high-intensity calisthenics as part of a larger program directed at enhancing physical preparedness for a variety of tasks may be well suited to moderately-trained armed forces personnel seeking to maintain fitness with minimal time commitment and in austere environments without access to equipment.

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DISCLOSURE

The authors have no financial disclosures or conflicts of interest.

Table 5.1: Participant characteristics before training (mean ± SD).

Variable	TCT (n=13) 8 men, 5 women	HIT (n=13) 9 men, 4 women	*t*-test *p*-value
Age (years)	20.5 ± 1.5	20.5 ± 1.9	0.909
Height (cm)			
Men	176.4 ± 8.2	180.5 ± 4.6	0.214
Women	162.0 ± 5.0	165.7 ± 3.6	0.258
Body mass (kg)			
Men	76.2 ± 11.7	79.8 ± 11.8	0.532
Women	55.2 ± 6.3	58.9 ± 2.6	0.317
BMI ($kg \cdot m^{-2}$)			
Men	24.5 ± 3.3	24.4 ± 2.9	0.980
Women	21.0 ± 2.2	21.4 ± 0.7	0.731
Body fat (%)			
Men	19.5 ± 4.4	21.2 ± 3.7	0.415
Women	25.6 ± 2.0	26.2 ± 2.2	0.680
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)			
Men	4.10 ± 0.50	4.21 ± 0.50	0.681
Women	2.78 ± 0.43	2.78 ± 0.39	0.995
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)			
Men	54.3 ± 5.7	53.1 ± 5.0	0.631
Women	50.4 ± 6.3	47.1 ± 5.1	0.429

TCT: typical cadet training; HIT: high-intensity training; BMI: body mass index; VO_{2peak}: peak oxygen uptake; *significantly different ($p \leq 0.05$) before training.

Table 5.2: $\dot{V}O_{2peak}$ and related measures (mean ± SD).

Variable	TCT Pre-training	TCT Post-training	HIT Pre-training	HIT Post-training	*t*-test *p*-value
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	3.59 ± 0.81	3.69 ± 0.83	3.77 ± 0.82	3.82 ± 0.81	0.697
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	52.8 ± 6.0	54.4 ± 3.9	51.2 ± 5.6	52.0 ± 6.9	0.658
HR_{peak} ($bt \cdot min^{-1}$)	193 ± 10	190 ± 9	198 ± 8	197 ± 9	0.078
$\dot{V}_{E\ peak}$ ($L \cdot min^{-1}$)	125.4 ± 31.9	121.4 ± 33.0	130.5 ± 31.2	130.6 ± 31.3	0.298
RER_{peak}	1.10 ± 0.04	1.09 ± 0.04	1.10 ± 0.04	1.09 ± 0.03	0.596
RPE_{peak} (6-20 Borg scale)	19.1 ± 1.0	19.2 ± 0.9	18.8 ± 1.0	18.9 ± 0.8	1.000
[La] ($mmol \cdot L^{-1}$)	12.3 ± 2.7	10.4 ± 2.0	10.8 ± 3.3	11.1 ± 2.9	0.014*

TCT: typical cadet training; HIT: high-intensity training; VO_{2peak}: peak oxygen uptake; HR: heart rate; V_E: ventilation; RER: respiratory exchange ratio; RPE: rating of perceived exertion; [La]: blood lactate concentration; *significantly different ($p \leq 0.05$) between groups.

Table 5.3: Physical performance measures (mean ± SD).

Variable	TCT		HIT		*t*-test
	Pre-training	Post-training	Pre-training	Post-training	*p*-value
APFT total score (points)	281.1 ± 20.0	278.5 ± 22.6	274.7 ± 18.4	268.0 ± 20.7	0.608
Push-ups (repetitions)	61.8 ± 13.4	63.4 ± 13.3	61.5 ± 7.5	61.5 ± 7.1	0.865
Sit-ups (repetitions)	74.8 ± 7.1	73.0 ± 8.4	74.5 ± 9.6	72.6 ± 9.8	0.823
2-mile run time (min:s)	14:03 ± 1:07	14:07 ± 1:00	14:25 ± 1:07	14:46 ± 1:08	0.456

TCT: typical cadet training; HIT: high-intensity training; APFT: Army Physical Fitness Test; APFT total scores are scaled points using sex and age norms; push-up, sit-up and 2-mile run data are raw scores; *significantly different ($p \leq 0.05$) between groups.

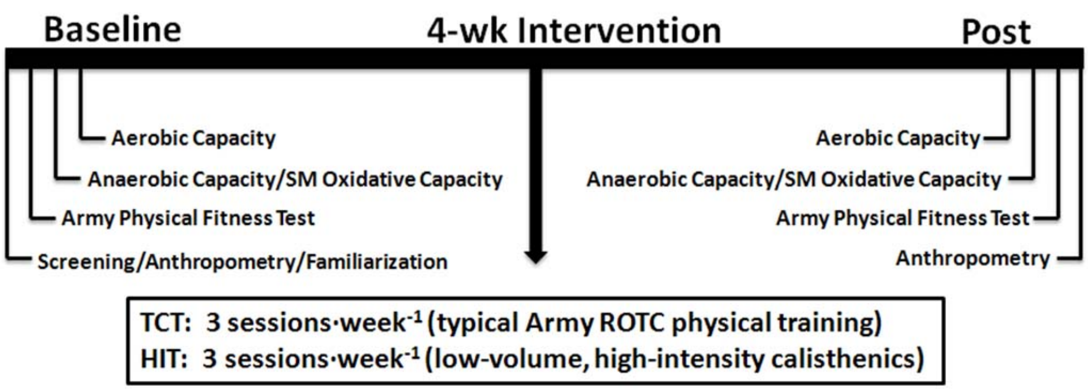

Figure 5.1: Schematic of the experimental protocol.

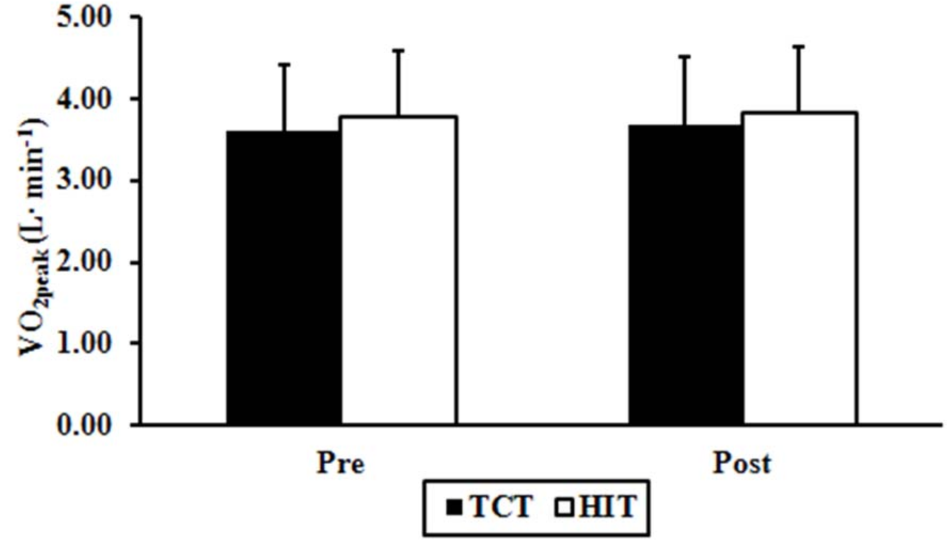

Figure 5.2: Peak oxygen uptake (absolute values); TCT: typical cadet training; HIT: high-intensity interval training; values are means ± SD; *significantly different ($p \leq 0.05$).

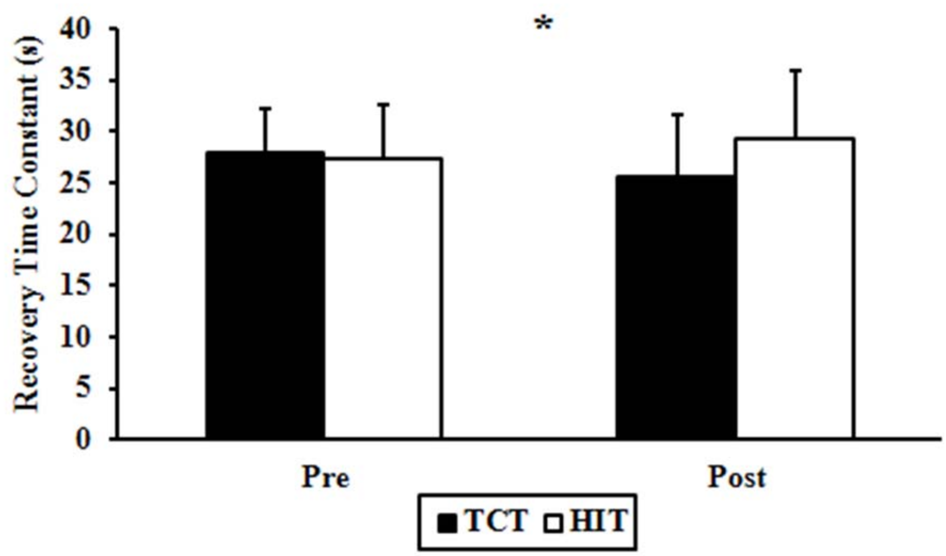

Figure 5.3: Mitochondrial function represented by a recovery time constant; TCT: typical cadet training; HIT: high-intensity interval training; values are means ± SD; *significantly different ($p \leq 0.05$).

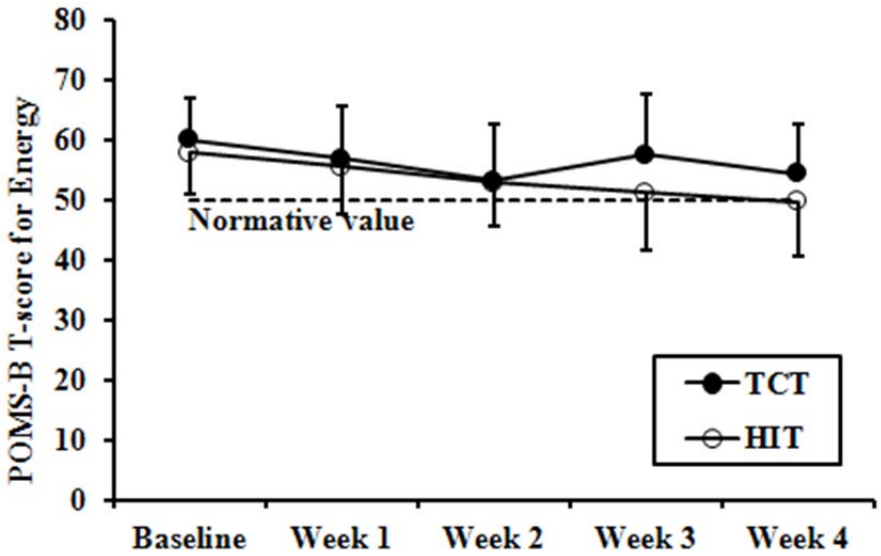

Figure 5.4a: Profile of Mood States-Brief (POMS-B) Vigor (Energy) scores; dotted line represents normative data for this instrument; TCT: typical cadet training; HIT: high-intensity interval training; values are means ± SD; *significantly different ($p \leq 0.05$).

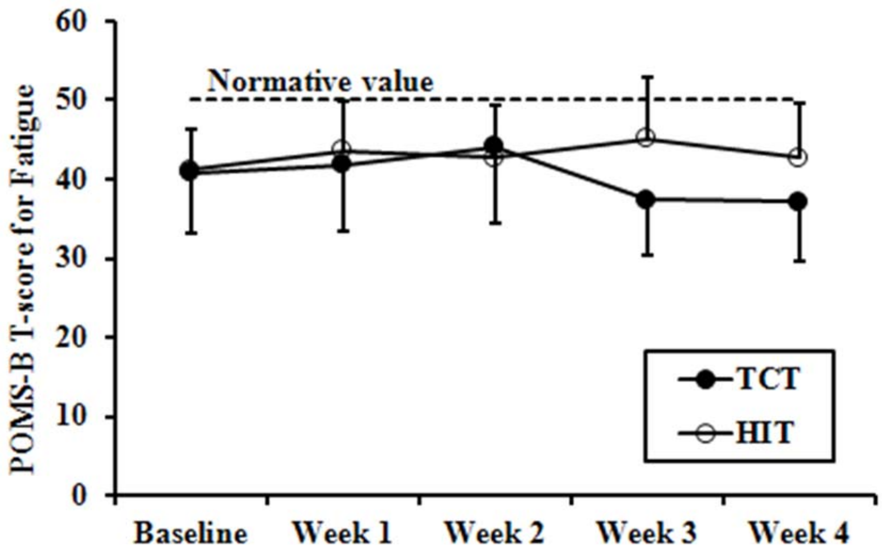

Figure 5.4b: Profile of Mood States-Brief (POMS-B) Fatigue scores; dotted line represents normative data for this instrument; TCT: typical cadet training; HIT: high-intensity interval training; values are means ± SD; *significantly different ($p \leq 0.05$).

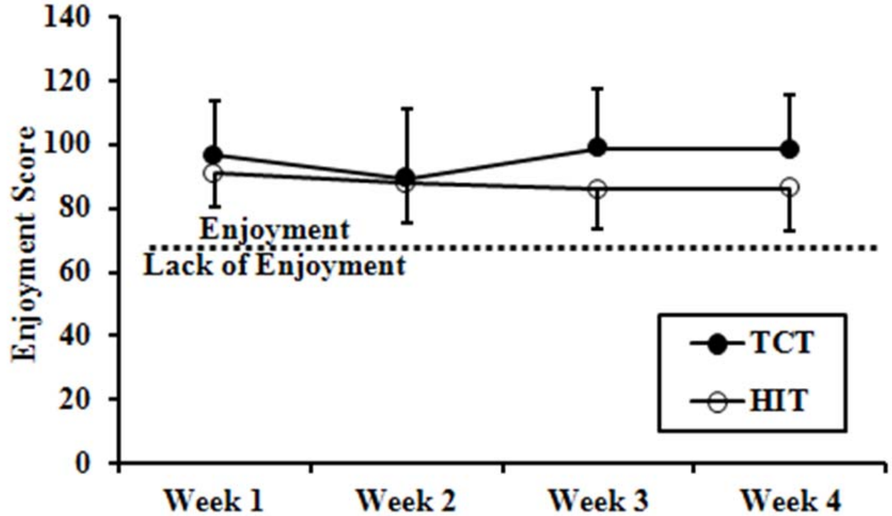

Figure 5.5: Physical Activity Enjoyment Scale (PACES) scores; dotted line represents scale mid-point; TCT: typical cadet training; HIT: high-intensity interval training; values are means ± SD; *significantly different ($p \leq 0.05$).

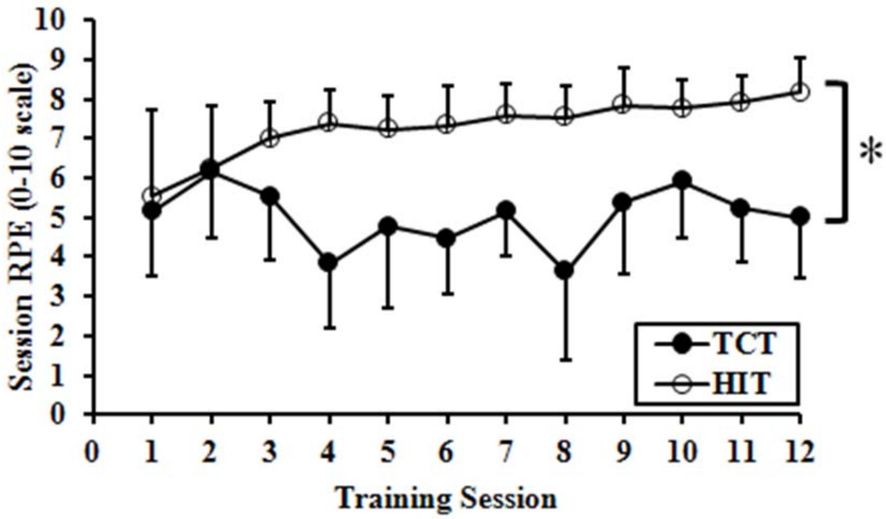

Figure 5.6: Session ratings of perceived exertion (RPE); TCT: typical cadet training; HIT: high-intensity interval training; values are means ± SD; *significantly different ($p \leq 0.05$).

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CHAPTER 6

SUMMARY AND CONCLUSIONS

High-intensity interval training (HIT) has been a frequently used method of training among elite endurance athletes as a means to improve both aerobic and anaerobic capacity, as well as performance in events of various durations and distances. The efficacy of HIT with respect to physiological adaptations and physical performance improvements has led to greater recent research interest in the effects of a time-efficient model of sprint interval training (SIT) in which repeated “all out” 30-s efforts are interspersed with 4-min active recovery periods. Whether this methodology can be effective when applied to whole-body calisthenics was unknown.

In the first study, a systematic review and quantitative analysis were conducted to estimate the population effect of SIT of maximal or greater intensity on aerobic capacity and to assess whether those effects vary by participant type or study characteristics. From 16 randomized controlled trials (RCT), including 17 effects and 318 participants, the effect size indicated that supramaximal-intensity SIT has a small-to-moderate effect (Cohen’s d = 0.32, 95% CI: 0.10, 0.55; z = 2.79, P < 0.01) on aerobic capacity. The effect was large in comparison to no-exercise control groups (Cohen’s d = 0.69, 95% CI: 0.46, 0.93; z = 5.84; P < 0.01) and not different when compared to endurance training control groups (Cohen’s d = 0.04, 95% CI: -0.17, 0.24; z = 0.36, P = 0.72). This synthesis of several small sample RCTs indicates SIT is a beneficial training methodology to improve aerobic capacity among healthy and young people.

Furthermore, relative to continuous endurance training of moderate intensity, SIT presents an equally effective alternative with a much lower volume of activity and reduced time commitment.

In the second study, the acute responses to two high-intensity intermittent exercise protocols (SIC: sprint interval cycling; HIC: high-intensity intermittent calisthenics) were compared. Mean values for %VO_{2peak} and %HR_{peak} for SIC (80.4 ± 5.3% and 86.8 ± 3.9%) and HIICE (77.6 ± 6.9% and 84.6 ± 5.3%) were not significantly different ($p >$ 0.05), but effect size calculations revealed a meaningful difference (%VO_{2peak} Cohen's d = 0.51; %HR_{peak} Cohen's d = 0.57), indicating that a low-volume, high-intensity bout of repeated whole-body calisthenic exercise induced lower cardiorespiratory responses. We speculate that the motor unit recruitment patterns in SIC primarily involve the leg flexor and extensor muscles during stationary cycling. During HIC, it is likely a greater amount of whole body musculature is active as the movement requires flexion and extension at multiple joints. In both protocols, the "all out" nature suggests recruitment and activation of all muscle fiber types. Based on our observations, peak responses are still be classified as vigorous, and these results suggest that in addition to the benefit of reduced time commitment, a high-intensity interval protocol of calisthenics may confer physiological adaptations and performance improvements similar to those reported for SIC.

In the third study, the chronic effects of a 4-week low-volume, HIT intervention on fitness and performance in ROTC cadets were assessed and compared to the effects induced by a typical military physical training program (TCT). There were no changes in metabolic capacities (VO_{2peak} and Maximal Accumulated O_2 Deficit), or physical performance (Army Physical Fitness Test); however, mitochondrial function improved in the TCT group and decreased in the HIT group. A program that includes high-intensity calisthenics may be well suited to moderately-trained groups seeking to maintain fitness with minimal time commitment and in austere environments without access to equipment.

The results of this research support the following conclusions:

1) SIT is a beneficial training methodology to improve aerobic capacity among healthy and young people. Relative to continuous endurance training of moderate intensity, SIT presents an equally effective alternative with a much lower volume of activity and reduced time commitment.

2) The cardiovascular strain elicited by a single session of low-volume, high-intensity intermittent whole-body calisthenics may be sufficient to confer cardiorespiratory and metabolic adaptations equivalent to those reported in studies using SIT.

3) A protocol of low-volume, high-intensity whole-body calisthenics can sustain metabolic capacities and physical performance.

4) Despite the higher perceived exertion reported by the HIT group, the Army ROTC participants enjoyed the activity as well as their typical training program.

5) Participant self-ratings of energy and fatigue are not different during and subsequent to training programs of differing volumes and intensities.