COMPARISON OF RESPONSES TO TWO HIGH-INTENSITY INTERMITTENT EXERCISE PROTOCOLS

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ABSTRACT

Gist, NH, Freese, EC, and Cureton, KJ. Comparison of responses to two high-intensity intermittent exercise protocols. *J Strength Cond Res* 28(11): 3033–3040, 2014—The purpose of this study was 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." Eleven (8 men and 3 women) moderately trained, college-aged participants (age = 21.9 ± 2.1, body mass index = 24.8 ± 1.9, $\dot{V}O_2$peak = 54.1 ± 5.4 $ml\cdot kg^{-1}\cdot min^{-1}$) completed 4 testing sessions across 9 days with each session separated by 48–72 hours. Using a protocol of 4 repeated bouts of 30-second "all-out" efforts interspersed with 4-minute active recovery periods, responses to SIC and HIC were classified relative to peak values. Mean values for %$\dot{V}O_2$peak 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: %$\dot{V}O_2$peak Cohen's $d = 0.51$ (0.48–0.53) and %HR_{peak} Cohen's $d = 0.57$ (0.55–0.59). A low-volume, high-intensity bout of repeated whole-body calisthenic exercise induced cardiovascular responses that were not significantly different but were ~1/2*SD* lower than "all-out" SIC. 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. The potential efficacy of this alternative interval training method provides support for its application by athletes, coaches, and strength and conditioning professionals.

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" (14). Dudley et al. (13) 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 (8,16,20,31). 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 (7,19).

Using a specific training protocol of low-volume (30-second sprints, 4-minute recovery intervals, and 4–7 repetitions), Burgomaster et al. (7) and Gibala et al. (19) showed that the effects of repeated bouts of SIT were similar when compared with moderate-intensity continuous endurance training despite a significantly reduced time commitment. Training involving only 6 sessions of repeated 30-second "all-out" cycle ergometer sprinting doubled endurance time to exhaustion (at ~80% $\dot{V}O_2$peak) in recreationally active subjects, with a total exercise training time of only 15 minutes (cumulative time of sprints) (8). When portions of an endurance running training program were replaced by 30-second sprints in 2 separate studies, moderately trained subjects significantly improved $\dot{V}O_2$max and time-trial performance (15) and maintained muscle oxidative capacity, capillarization, and endurance performance (24) despite the reduction in training volume. The HIT literature includes many different work-rest intervals and exercise intensities; however, the recent interest in extremely low-volume sprints highlights the need for examination of alternatives to running or cycling.

The results of several studies indicate that repeated maximal-effort sprinting bouts elicit near-maximal cardiovascular strain

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(17) and improve muscle oxidative capacity (2,8,19,25,26), maximal oxygen uptake (4,11,12,26), and endurance performance (4,6,19,27). A systematic review and meta-analysis of SIT impact on aerobic capacity also highlighted its effectiveness as a potent training method (21). However, in the research cited above, sprinting required specialized and expensive ergometers, and sprint interval running requires a treadmill or a minimal amount of terrain on which to run. McRae et al. (28) 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. Such an alternative method that supplements sport-specific training while inducing vigorous physiological responses would seem beneficial to enhancing fitness through a functional movement pattern while also mitigating boredom through greater variety of training options.

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 2 high-intensity intermittent exercise protocols: repeated bouts of sprint interval cycling (SIC) and repeated bouts of high-intensity intermittent calisthenics (HIC). Knowledge of acute responses helps to inform the development and practical application of new training methods to realize desired physiological adaptations, physical performance goals, and health outcomes. 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 the exercise mode, and the primary dependent variables were %$\dot{V}O_2$peak and %HR_{peak}. In addition, peak blood lactate ($[La^-]_b$) and ratings of perceived exertion (RPE) were recorded to further compare responses of the 2 exercise protocols. Each study participant completed all 4 testing sessions at the same time of the day and across 9 days with each session separated by 48–72 hours. The experimental design supports the aim to compare the acute responses to a protocol with numerous known benefits to a novel protocol. The direct comparison of cardiorespiratory, metabolic, and perceptual responses is the first step in determining the potential effectiveness of HIC as an alternative for athletes, coaches, and strength and conditioning professionals to enhance performance. Knowledge of these acute responses will inform the development of interventions and sport-preparation programming to include beneficial HIC.

TABLE 1. Participant characteristics (mean ± *SD*).*

	Men (*n* = 8)	Women (*n* = 3)	Combined (*n* = 11)
Age (y)	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
$\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	56.5 ± 3.2	47.8 ± 5.5	54.1 ± 5.4
HR_{peak} ($b \cdot min^{-1}$)	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; $\dot{V}O_2$peak = peak oxygen uptake; HR = heart rate; MAOD = 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.

Subjects

Eleven (8 men and 3 women) college-age (range, 19–27 years) moderately trained members of a university U.S. Army Reserve Officers' Training Corps organization volunteered for the study. Physical characteristics are provided in Table 1. For at least 1 year before the start of the study, all subjects participated in preplanned supervised activity a minimum of 3 days per week for a duration of approximately 1 hour. For all participants, programmed and supervised group physical activity consisted of calisthenics, moderate-intensity running, and varied team sport activities. The study was approved by the Human Subjects Office of the University Institutional Review Board. Following a comprehensive explanation of procedures, benefits and risks, volunteers provided written informed consent.

Procedures

During the first visit to the laboratory, eligibility was confirmed through health screening questionnaire, test instructions for each exercise protocol were explained by research staff, and familiarization to testing included participant practice. 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). Pretest instructions directed subjects to arrive euhydrated and to avoid caffeinated beverages, alcohol, tobacco, stimulants, and exercise at least 6 hours before arrival at the laboratory. Before the start of each of the 4 testing sessions, participants completed a 24-hour history document to confirm adherence to pretest 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, USA) 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 (model 145900; Polar Electro, Inc., Woodbury, NY, USA) 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 RPE during the last 15 seconds of each stage and at the completion of exercise bouts (5). 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. Sessions 1 (peak oxygen uptake) and 2 (maximal accumulated oxygen deficit [MAOD]) were completed to determine individual peak cardiorespiratory, metabolic, and perceptual responses. Before testing sessions 3 (SIC) and 4 (HIC), investigators again 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. (29), a discontinuous uphill running graded exercise test was administered on a treadmill (Trackmaster; JAS Fitness System, Newton, KS, USA) to determine physiological responses to incremental increases in velocity. After a 5-minute walking warm-up, participants completed 5-minute treadmill running bouts (with a 5-minute 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 $km \cdot h^{-1}$, respectively, and was increased by 0.64 $km \cdot h^{-1}$ at each stage until subjects could no longer complete a 5-minute stage. Expiratory gases were continuously measured and averaged over 30-second intervals. Peak oxygen uptake ($\dot{V}O_2peak$) was defined as the highest 30-second $\dot{V}O_2$ during the test with maximal effort classified as attainment of least 2 of the following: peak heart rate within 10 $b \cdot min^{-1}$ of age-estimated maximum (220-age); respiratory exchange ratio (RER) $\geq$1.10; blood lactate concentration ($[La^-]_b$)

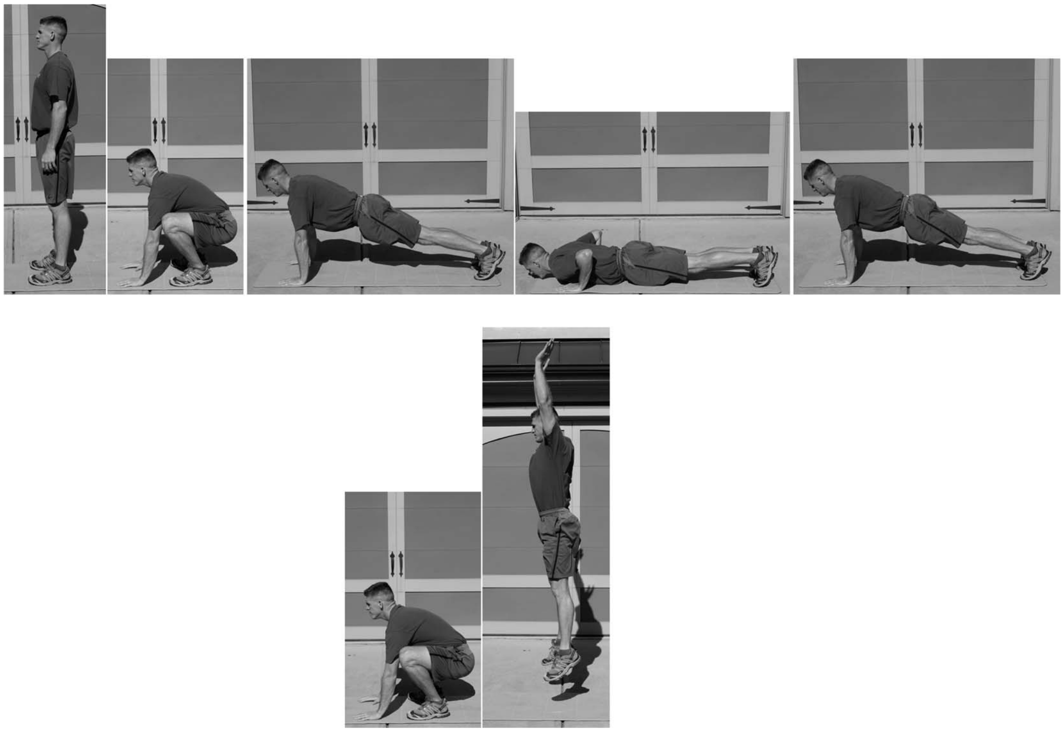

Figure 1. The burpee exercise begins in a standing position (arms at sides). Lower into a squat position by flexing the knees and hips and place the hands on the ground in front of the feet. Kick the feet back and lower with a push-up. Straighten the arms with a push-up and return the feet to the squat position. Extend the knees/hips and leap up as high as possible from the squat position with the arms extended overhead.

TABLE 2. $\dot{V}O_2$peak and related measures observed during maximal effort graded exercise test.*

Subject No.	Sex (M/F)	$\dot{V}O_2$peak ($L \cdot min^{-1}$)	$\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	HR_{peak} ($b \cdot min^{-1}$)	$\dot{V}_{E\ peak}$ ($L \cdot min^{-1}$)	RER_{peak}	RPE_{peak} (6–20 Borg)	$[La^-]_b$ ($mmol \cdot L^{-1}$)
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

*$\dot{V}O_2$peak = peak oxygen uptake; HR_{peak} = peak heart rate; $\dot{V}_{Epeak}$ = peak ventilation; RER_{peak} = peak respiratory exchange ratio; RPE_{peak} = peak rating of perceived exertion; $[La^-]_b$ = peak blood lactate concentration.

≥8.0 $mmol \cdot L^{-1}$; RPE (Borg 20-point scale) ≥18. Peak values for heart rate (HR_{peak}), RER (RER_{peak}), and RPE (RPE_{peak}) were the highest recorded 30-second values. Three minutes postexercise, a finger stick blood sample (~5 μl) was obtained to determine peak $[La^-]_b$ (Lactate Pro Test Meter, model LT-1710; KDK Corp., Kyoto, Japan).

Maximal Accumulated Oxygen Deficit

Using the protocol described by Medbo et al. (29), individual data from the discontinuous running protocol involving at least five to seven 5-minute stages at submaximal intensities were used to establish a linear regression between running velocity and oxygen uptake. On a different day, after a 5-minute warm-up at approximately 50% $\dot{V}O_2$peak, participants completed a supramaximal treadmill running bout at a velocity estimated to elicit 115% of $\dot{V}O_2$peak, which was extrapolated from the linear relation described above. Participants exercised to exhaustion. Maximal accumulated oxygen deficit 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 (30).

TABLE 3. Peak cardiorespiratory responses (mean ± *SD*).*

Variable	SIC	HIC	*p*
%$\dot{V}O_2$peak			
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

*SIC = sprint interval cycling; HIICE = high-intensity intermittent calisthenic exercise; %$\dot{V}O_2$peak = percent of peak oxygen uptake; % HR_{peak} = percent of peak heart rate.

†$p \leq 0.05$.

Sprint Interval Cycling

Participants completed a 5-minute warm-up on a mechanically braked, stationary cycle ergometer (model 874E; Monark Exercise AB, Vansbro, Sweden). During this session, participants were instructed to pedal as fast as possible for 5 seconds until the resistance (7.5 ± 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-minute active recovery period after each sprint, participants cycled against no resistance. The work-rest cycle was repeated 3 times for a total of 4 sets. Finger stick was used to determine $[La^-]_b$ at 3 minutes after each 30-second bout.

High-Intensity Intermittent Calisthenics

Warm-up consisted of 5 minutes 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 seconds followed by 4 minutes of active recovery (stepping in place at self-selected pace). This work-rest cycle was repeated

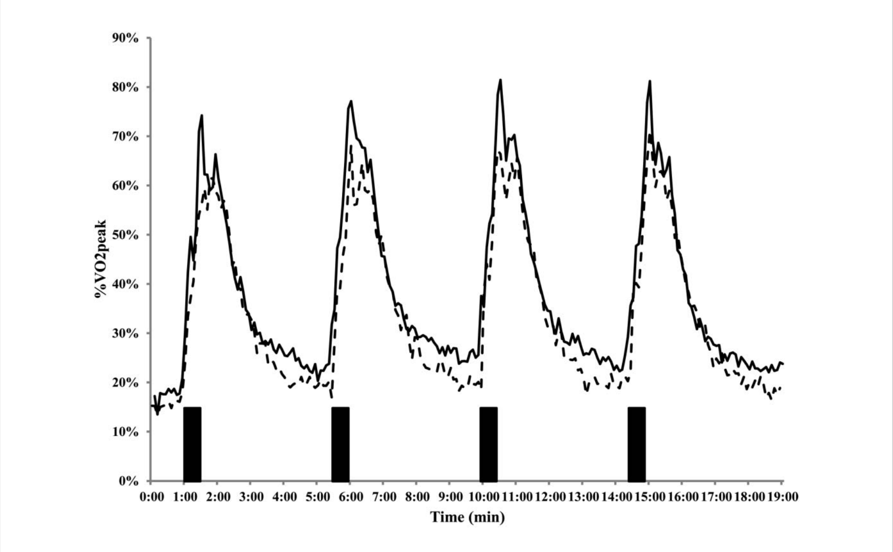

Figure 2. Oxygen uptake (%$\dot{V}O_2$peak) during 4 × 30-second bouts of "all-out" cycling (solid line) and calisthenics (dotted line) separated by 4-minute active recovery periods. The solid bars represent the 30-second work period.

3 times for a total of 4 sets. Blood lactate concentration was measured 3 minutes after each 30-second 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 Burpee (9) (Figure 1).

Statistical Analyses

All analyses were performed using SPSS for Windows software (version 19.0; SPSS, Inc., Chicago, IL, USA). Using %$\dot{V}O_2$peak as the primary outcome variable, a priori power analysis revealed the need for a sample size of 9 participants to detect a moderate effect of 0.5*SD* 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 1-way analysis of variance 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 *SD*. Using a 1-way random single measures intraclass correlation coefficient (1,1), reliability of oxygen uptake and heart rate responses was 0.36 and 0.52, respectively. Statistical significance for all comparisons was set at $p \leq 0.05$.

RESULTS

Individual $\dot{V}O_2$peak and related measures are provided in Table 2. The peak cardiorespiratory responses for the 2 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) for $\dot{V}O_2$peak and 86.8 ± 3.9% (SIC) and 84.6 ± 5.3% (HIC) for HR_{peak} across the 4 sets. Subjective RPE reported immediately on completion of each set of exercise was 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 3. Peak $[La^-]_b$ 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 group responses for each protocol are depicted in Figures 2 and 3.

Effect sizes and corresponding 95% confidence intervals for differences in peak cardiorespiratory and perceptual responses to the 2 protocols were: %$\dot{V}O_2$peak 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).

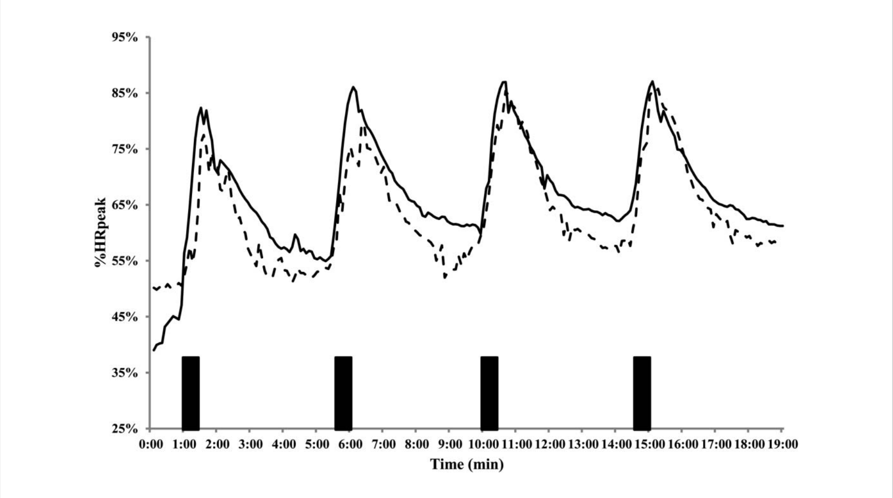

Figure 3. Heart rate (%HR_{peak}) during 4 × 30-second bouts of "all-out" cycling (solid line) and calisthenics (dotted line) separated by 4-minute active recovery periods. The solid bars represent the 30-second work period.

Discussion

This study measured physiological and perceptual responses to a unique calisthenics protocol and compared the data to a frequently studied SIC protocol. Protocols were administered using equivalent instructions for participant effort, work duration, and active rest interval. Contrary to our hypothesis, the primary findings indicated 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 $\sim 1/2SD$ lower, whereas perception of exertion was more than $1SD$ 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* (18), the peak $\dot{V}O_2$, 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 range 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 the protocol of low-volume, HIC 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 HIC exercise. The current findings are of specific interest to strength and conditioning professionals who want to provide athletes and other clients with a vigorous whole-body aerobic conditioning alternative to traditionally programmed running, cycling, or swimming.

In addition to the acute cardiorespiratory responses, peak $[La^-]_b$ provides an additional marker with which to classify the HIC protocol and compare with SIC responses. With the exception of Bout 1 for the HIC protocol, lactate values exceeded those commonly associated with lactate threshold ($4.0\ mmol \cdot L^{-1}$) and reflect a work rate commensurate with assessments performed to volitional exhaustion, as well as values associated with "all-out" maximal exercise (22,32). In both protocols, the apparent increase in $[La^-]_b$ from bout 1 to bout 2 reflects metabolic acidosis that typically occurs during repeated bouts of supramaximal exercise. The combination of apparent increase and concentrations that exceed lactate threshold is an indicator of the high work rate attained by participants whose aerobic capacity is well above the population mean.

An unanticipated finding was that participant perceptions of exertion were significantly different ($p \leq 0.05$). Although the self reports ranged from "hard" (HIC) to "very hard" (SIC), relative to "all-out" SIC, the subjects perceived the calisthenics to be easier. Despite the difference, reported RPE during both sessions characterizes the exercise intensity as vigorous. Although whole-body skeletal muscle activation data are not available, we assume that the motor unit recruitment patterns in SIC primarily involved the leg flexor and extensor muscles during 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 throughout a weight-bearing functional movement pattern. The difference in perception of effort can partially be attributed to the observed difference in cardiovascular strain. Further elucidation of perceptual difference may have been possible through the use of a pain rating scale with a specific focus on the thighs (10). Although we cannot draw any conclusions supported by data, it is also possible that the workload borne by the legs during cycling induced a localized muscle strain and fatigue that was observed in the higher RPE values.

The published findings of others that describe the chronic effects of SIT provide evidence for the potential benefits of our calisthenic protocol. In an exercise intervention study using the repeated Wingate test (bouts of 30-second "all-out" work alternated with 4-minute active recovery periods), MacDougall et al. (26) reported that a 7-week training program increased $\dot{V}O_2max$, maximum short-term power output, glycolytic enzyme activity (phosphofructokinase and hexokinase), and oxidative enzyme activity (malate dehydrogenase, succinate dehydrogenase, and citrate synthase). The results of Bailey et al. (1) indicate that 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 also reported significant increases in aerobic capacity (2,4,15,23,33). Despite reduced exercise duration, SIT has been proven to confer physiological adaptations favorable to improvements in skeletal muscle oxidative metabolism, metabolic capacities, and performance. The responses elicited by the HIC protocol suggest that its use may confer similar beneficial adaptations.

In addition to the low time commitment when compared with traditional low-moderate-intensity endurance-type activity, 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. (3) 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.

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 during an "all-out" 30-second effort, 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 or jump portion of the sequence, respectively. Further examination of participant expectations and enjoyment is necessary; however, the potential of HIC as a beneficial modality is evident. 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 this 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 after training programs using traditional aerobic training modalities. The programming of HIT by strength and conditioning professionals is becoming more frequent as clients seek alternative methods that enhance fitness with relatively little time commitment. Inclusion of high-intensity whole-body calisthenics performed in the manner described in this study provides a vigorous exercise stimulus in a very short time. Such a program may be well suited to both recreational and competitive athletes seeking rapid improvements in fitness with minimal time commitment.

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REFERENCES

1. Bailey, SJ, Wilkerson, DP, Dimenna, FJ, and Jones, AM. Influence of repeated sprint training on pulmonary O2 uptake and muscle deoxygenation kinetics in humans. *J Appl Physiol (1985)* 106: 1875–1887, 2009.
2. Barnett, C, Carey, M, Proietto, J, Cerin, E, Febbraio, MA, and Jenkins, D. Muscle metabolism during sprint exercise in man: Influence of sprint training. *J Sci Med Sport* 7: 314–322, 2004.
3. Bartlett, JD, Close, GL, MacLaren, DPM, Gregson, W, Drust, B, and Morton, JP. High-intensity interval running is perceived to be more enjoyable than moderate-intensity continuous exercise: Implications for exercise adherence. *J Sport Sci* 29: 547–553, 2011.
4. Bayati, M, Farzad, B, Gharakhanlou, R, and Agha-Alinejad, H. A practical model of low-volume high-intensity interval training induces performance and metabolic adaptations that resemble 'all-out' sprint interval training. *J SportS Sci Med* 10: 571–576, 2011.
5. Borg, G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med* 2: 92–98, 1970.
6. Burgomaster, KA, Heigenhauser, GJF, and Gibala, MJ. Effect of short-term sprint interval training on human skeletal muscle carbohydrate metabolism during exercise and time-trial performance. *J Appl Physiol (1985)* 100: 2041–2047, 2006.
7. Burgomaster, KA, Howarth, KR, Phillips, SM, Rakobowchuk, M, MacDonald, MJ, Mcgee, SL, and Gibala, MJ. Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. *J Physiol* 586: 151–160, 2008.
8. Burgomaster, KA, Hughes, SC, Heigenhauser, GJF, Bradwell, SN, and Gibala, MJ. Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in humans. *J Appl Physiol* 98: 1985–1990, 2005.
9. Burpee, RH. *Seven Quickly Administered Tests of Physical Capacity, in Teachers College.* New York, NY: Columbia University, 1940. pp. 151.
10. Cook, DB, O'Connor, PJ, Eubanks, SA, Smith, JC, and Lee, M. Naturally occurring muscle pain during exercise: Assessment and experimental evidence. *Med Sci Sports Exerc* 29: 999–1012, 1997.
11. Creer, AR, Ricard, MD, Conlee, RK, Hoyt, GL, and Parcell, AC. Neural, metabolic, and performance adaptations to four weeks of high intensity sprint-interval training in trained cyclists. *Int J Sports Med* 25: 92–98, 2004.
12. Daussin, FN, Zoll, J, Dufour, SP, Ponsot, E, Lonsdorfer-Wolf, E, Doutreleau, S, Mettauer, B, Piquard, F, Geny, B, and Richard, R. Effect of interval versus continuous training on cardiorespiratory and mitochondrial functions: Relationship to aerobic performance improvements in sedentary subjects. *Am J Physiol Regul Integr Comp Physiol* 295: R264–R272, 2008.
13. Dudley, GA, Abraham, WM, and Terjung, RL. Influence of exercise intensity and duration on biochemical adaptations in skeletal muscle. *J Appl Physiol Respir Exerc Physiol* 53: 844–850, 1982.
14. Edwards, RHT, Ekelund, LG, Harris, RC, Hesser, CM, Hultman, E, Melcher, A, and Wigertz, O. Cardiorespiratory and metabolic costs of continuous and intermittent exercise in man. *J Physiol* 234: 481–497, 1973.
15. Esfarjani, F and Laursen, PB. Manipulating high-intensity interval training: Effects on VO2max, the lactate threshold and 3000 m running performance in moderately trained males. *J Sci Med Sport* 10: 27–35, 2007.
16. Farzad, B, Gharakhanlou, R, Agha-Alinejad, H, Curby, DG, Bayati, M, Bahraminejad, M, and Maestu, J. Physiological and performance changes from the addition of a sprint interval program to wrestling training. *J Strength Cond Res* 25: 2392–2399, 2011.
17. Freese, EC, Gist, NH, and Cureton, KJ. Physiological responses to an acute bout of sprint interval cycling. *J Strength Cond Res* 27: 2768–2773, 2013.
18. Garber, CE, Blissmer, B, Deschenes, MR, Franklin, BA, Lamonte, MJ, Lee, IM, Nieman, DC, Swain, DP, and Med, ACS. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Med Sci Sport Exer* 43: 1334–1359, 2011.
19. Gibala, MJ, Little, JP, van Essen, M, Wilkin, GP, Burgomaster, KA, Safdar, A, Raha, S, and Tarnopolsky, MA. Short-term sprint interval versus traditional endurance training: Similar initial adaptations in human skeletal muscle and exercise performance. *J Physiol* 575: 901–911, 2006.
20. Gibala, MJ and McGee, SL. Metabolic adaptations to short-term high-intensity interval training: A little pain for a lot of gain? *Exerc Sport Sci Rev* 36: 58–63, 2008.
21. Gist, NH, Fedewa, MV, Dishman, RK, and Cureton, KJ. Sprint interval training effects on aerobic capacity: A systematic review and meta-analysis. *Sports Med* 44: 269–279, 2013.

22. Goodwin, ML, Harris, JE, Hernandez, A, and Gladden, LB. Blood lactate measurements and analysis during exercise: A guide for clinicians. *J Diabetes Sci Technol* 1: 558–569, 2007.
23. Hazell, TJ, MacPherson, REK, Gravelle, BMR, and Lemon, PWR. 10 or 30-s sprint interval training bouts enhance both aerobic and anaerobic performance. *Eur J Appl Physiol* 110: 153–160, 2010.
24. Iaia, FM, Hellsten, Y, Nielsen, JJ, Fernstrom, M, Sahlin, K, and Bangsbo, J. Four weeks of speed endurance training reduces energy expenditure during exercise and maintains muscle oxidative capacity despite a reduction in training volume. *J Appl Physiol (1985)* 106: 73–80, 2009.
25. Little, JP, Safdar, A, Wilkin, GP, Tarnopolsky, MA, and Gibala, MJ. A practical model of low-volume high-intensity interval training induces mitochondrial biogenesis in human skeletal muscle: Potential mechanisms. *J Physiol* 588: 1011–1022, 2010.
26. MacDougall, JD, Hicks, AL, MacDonald, JR, McKelvie, RS, Green, HJ, and Smith, KM. Muscle performance and enzymatic adaptations to sprint interval training. *J Appl Physiol (1985)* 84: 2138–2142, 1998.
27. Macpherson, RE, Hazell, TJ, Olver, TD, Paterson, DH, and Lemon, PW. Run sprint interval training improves aerobic performance but not maximal cardiac output. *Med Sci Sports Exerc* 43: 115–122, 2011.
28. McRae, G, Payne, A, Zelt, JGE, Scribbans, TD, Jung, ME, Little, JP, and Gurd, BJ. Extremely low volume, whole-body aerobic-resistance training improves aerobic fitness and muscular endurance in females. *Appl Physiol Nutr Metab* 37: 1124–1131, 2012.
29. Medbo, JI, Mohn, AC, Tabata, I, Bahr, R, Vaage, O, and Sejersted, OM. Anaerobic capacity determined by maximal accumulated O-2 deficit. *J Appl Physiol (1985)* 64: 50–60, 1988.
30. Saltin, B. Anaerobiosis in exercise: Limitations and implications for performance. Presented at Proceedings of the first IOC Work Congress on Sport Science. Colorado Springs, CO, 1989.
31. Tabata, I, Nishimura, K, Kouzaki, M, Hirai, Y, Ogita, F, Miyachi, M, and Yamamoto, K. Effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and VO2max. *Med Sci Sports Exerc* 28: 1327–1330, 1996.
32. Thomas, C, Sirvent, P, Perrey, S, Raynaud, E, and Mercier, J. Relationships between maximal muscle oxidative capacity and blood lactate removal after supramaximal exercise and fatigue indexes in humans. *J Appl Physiol (1985)* 97: 2132–2138, 2004.
33. Trilk, JL, Singhal, A, Bigelman, KA, and Cureton, KJ. Effect of sprint interval training on circulatory function during exercise in sedentary, overweight/obese women. *Eur J Appl Physiol* 111: 1591–1597, 2011.