Comparison of Cardiorespiratory and Metabolic Responses in Kettlebell High-Intensity Interval Training Versus Sprint Interval Cycling

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Abstract

Williams, BM and Kraemer, RR. Comparison of cardiorespiratory and metabolic responses in kettlebell high-intensity interval training versus sprint interval cycling. *J Strength Cond Res* 29(12): 3317–3325, 2015—The purpose of this study was to determine the effectiveness of a novel exercise protocol we developed for kettlebell high-intensity interval training (KB-HIIT) by comparing the cardiorespiratory and metabolic responses to a standard sprint interval cycling (SIC) exercise protocol. Eight men volunteered for the study and completed 2 preliminary sessions, followed by two 12-minute sessions of KB-HIIT and SIC in a counterbalanced fashion. In the KB-HITT session, 3 circuits of 4 exercises were performed using a Tabata regimen. In the SIC session, three 30-second sprints were performed, with 4 minutes of recovery in between the first 2 sprints and 2.5 minutes of recovery after the last sprint. A within-subjects' design over multiple time points was used to compare oxygen consumption ($\dot{V}O_2$), respiratory exchange ratio (RER), tidal volume (TV), breathing frequency (f), minute ventilation (V_E), caloric expenditure rate ($kcal \cdot min^{-1}$), and heart rate (HR) between the exercise protocols. Additionally, total caloric expenditure was compared. A significant group effect, time effect, and group × time interaction were found for $\dot{V}O_2$, RER, and TV, with $\dot{V}O_2$ being higher and TV and RER being lower in the KB-HIIT compared with the SIC. Only a significant time effect and group × time interaction were found for f, V_E, $kcal \cdot min^{-1}$, and HR. Additionally, total caloric expenditure was found to be significantly higher during the KB-HIIT. The results of this study suggest that KB-HIIT may be more attractive and sustainable than SIC and can be effective in stimulating cardiorespiratory and metabolic responses that could improve health and aerobic performance.

Key Words oxygen consumption, caloric expenditure, respiratory exchange ratio, heart rate, ventilatory response, Tabata

Introduction

In recent years, high-intensity interval training (HIIT) has become a popular modality for exercise training. According to the American College of Sports Medicine (ACSM), HIIT was reported to be the top fitness trend worldwide for 2014 (27) and the second top fitness trend for 2015 (28). Importantly, HIIT has been shown to be effective in producing musculoskeletal (19), metabolic (1–3,16), and cardiorespiratory adaptations (4,5,8,9,17,18,29,30). High-intensity interval training has generated much interest because of the tissue adaptations it can produce that are similar to traditional aerobic training and the time efficiency it provides (4,17,18). The most common reason for nonadherence to an exercise program is due to lack of time commitment for exercise training (20). Because HIIT is a form of training that can be used in a time-efficient manner (e.g., 3 plus bouts of high-intensity exercise across 20 minutes) and has a high impact on health benefits, it follows that HIIT should be an important option for improvement of aerobic fitness. Even for the "veteran" exerciser, changing regimen (such as incorporating HIIT more often) could be an effective strategy to help maintain exercise adherence (20).

A modality often used by HIIT exercisers is sprint interval cycling (SIC). In a study by Freese et al. (2013), cardiorespiratory responsiveness was examined during SIC with participants performing 4 succeeding 30 second sprints, each followed by a 4 minute active recovery. Oxygen consumption ($\dot{V}O_2$) increased from the first sprint to the second, but was similar in the succeeding sprints and was above 80% of the estimated maximal value. Respiratory exchange ratio (RER) also was observed to decline from the first to the last sprint. The findings of this previous study demonstrate the extent to which aerobic metabolism is used during this type

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TABLE 1. Baseline anthropometric and cardiorespiratory fitness level data of subjects (men = 8).

	Mean ± *SD*
Age (y)	21.5 ± 0.86
Height (cm)	176 ± 5.29
Weight (kg)	82.95 ± 11.62
Body fat (%)	18.52 ± 3.04
Fat-free mass (kg)	67.44 ± 8.55
HR_{max} (b·min^{-1})	189.75 ± 7.98
$\dot{V}O_2max$ (ml·kg^{-1}·min^{-1})	52.16 ± 6.55

HR = heart rate.

of HIIT and suggests that metabolic and cardiorespiratory adaptations can occur through SIC (8).

Modes of resistance training are often integrated with interval-based exercise training. One popular mode is the use of kettlebells (KBs). Kettlebells not only have been shown to be effective in improving muscular strength (12,15,21,31), but also have been seen to elicit strong cardiorespiratory responses and can be adjusted to be performed continuously (5,6,26). In a study by Farrar et al. (2010), continuous KB swings for a total of 12 minutes were observed to elicit an average of 65.3% of maximal oxygen consumption ($\dot{V}O_2max$) and an average of 86.8% of maximal heart rate (HR_{max}) responses, which meet ACSM recommendations for optimal intensity for improving cardiorespiratory fitness (6). In a recent study by Falatic et al. (2015), 20 minutes of KB snatching (with a 15:15 work-to-rest ratio) performed 3 days per week for 4 weeks was found to significantly increase aerobic capacity more (+2.3 ml·kg^{-1}·min^{-1} or ~6%) than circuit-weight training of the same training duration and frequency (5). Therefore, existing research suggests that KB training may influence a greater response by the cardiorespiratory system than traditional resistance exercise. Thus, this form of training may be used as an effective mode of training for maintaining or improving aerobic conditioning (5).

The cadence of the movements with the added resistance of the KB makes it possible for specific KB exercises to elicit greater responsiveness of the cardiorespiratory system. It is even possible for KB training to be adjusted to be performed continuously, with rest periods and alternation of exercises integrated within the protocol to reduce fatigue. In a study

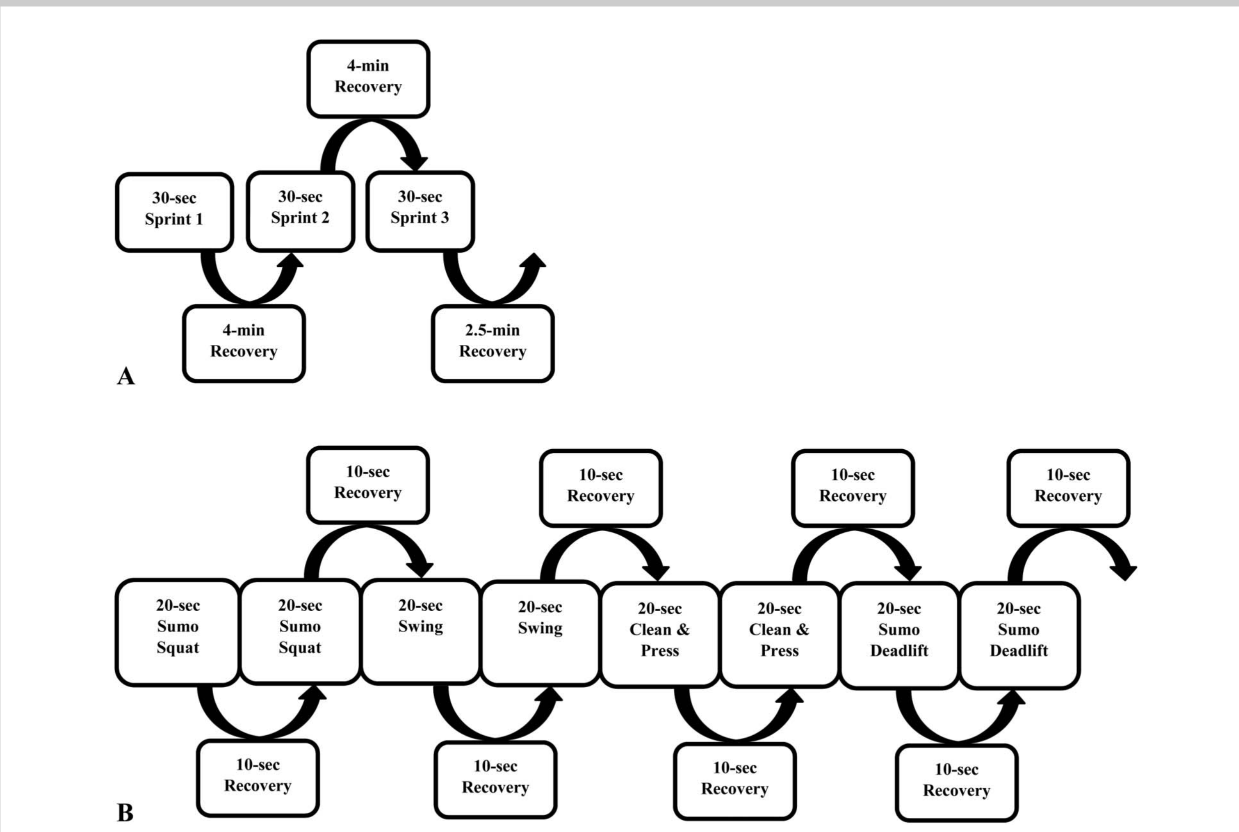

Figure 1. A) Sprint interval cycling (SIC) protocol, no repeat. B) Kettlebell high-intensity interval training (KB-HIIT) protocol, performed 3 times.

Table 2. Intraclass correlation coefficients.

	$\dot{V}O_2$	RER	TV	f	V_E	kcals·min^{-1}	HR
KB-HIIT	0.963	0.941	0.963	0.972	0.972	0.955	0.991
SIC	0.731	0.765	0.97	0.858	0.972	0.934	0.767

RER = respiratory exchange ratio; TV = tidal volume; f = breathing frequency; V_E = minute ventilation; HR = heart rate; KB-HIIT = kettlebell high-intensity interval training; SIC = sprint interval cycling.

by Thomas et al. (2014), a KB protocol at an intensity level of ~60% of $\dot{V}O_2$max was compared with graded-treadmill walking at roughly the same intensity. The protocol involved completing 10 repetitions of KB swings followed by 10 repetitions of KB sumo deadlifts at a set metronome cadence. This was performed continuously for 3 circuits of 10-minute duration with 3 minutes of rest in between. It was found that not only was the KB protocol comparable in intensity level to graded-treadmill walking, but also the KB protocol elicited a higher average HR and rate of perceived exertion (RPE) (26). These higher responses of HR and RPE likely were due to the upper body working harder in comparison to the lower extremities. Collectively, the studies by Falatic et al. (2015), Farrar et al. (2010), and Thomas et al. (2014) support the contention that KB training may be modified to elicit the same benefits as more traditional aerobic exercise training (i.e., treadmill walking). However, to date, there are no studies that have investigated the cardiorespiratory and metabolic responses of a specific KB protocol appropriate for HIIT.

A Tabata regimen is commonly used in HIIT and is a regimen that could be modified for use with KBs. This routine involves performing exercise intervals of 20 second durations with 10 seconds of recovery in between and is based on research by Tabata et al., who examined the acute cardiorespiratory and metabolic responses of high-intensity intermittent cycling and its training adaptations (24,25). These studies revealed that a Tabata routine in comparison to moderate-intensity aerobic exercise elicited a greater percentage of $\dot{V}O_2$max (170% vs. 70%) and produced a 28% increase in anaerobic performance (25). Thus, the purpose of this study was to determine whether a kettlebell high-intensity interval training (KB-HIIT) protocol that we designed using Tabata training principles would be as effective as a standard SIC protocol used for HIIT. We did this by comparing the cardiorespiratory and metabolic responses of the respective protocols. It was hypothesized that the KB-HIIT protocol and SIC protocol would elicit similar cardiorespiratory and metabolic responses. If verified, the study could lead to the use of a new form of HIIT using KBs by athletes and recreational exercisers that would provide an inexpensive and time-saving form of training to improve health status and aerobic performance.

Methods

Experimental Approach to the Problem

Subjects first completed 2 preliminary sessions: an informational and familiarization session and a session to perform assessment of cardiorespiratory fitness and anthropometric measures. This was followed by completion of 2 experimental sessions in a counterbalanced, randomized fashion: a KB-HITT session and a SIC session. There were 5–7 days between these sessions. $\dot{V}O_2$, RER, tidal volume (TV), breathing frequency (f), minute ventilation (V_E), caloric expenditure rate (kcal·min^{-1}), HR, and total caloric expenditure were compared between the KB-HIIT and SIC protocols. A within-subjects' design over multiple time points within the exercise protocols was used with most of the statistical analyses to reduce the variance of the cardiorespiratory and metabolic measures. The outcomes of this study should provide insight into the acute responses of the novel KB-HIIT protocol and allow its effectiveness for training to be determined.

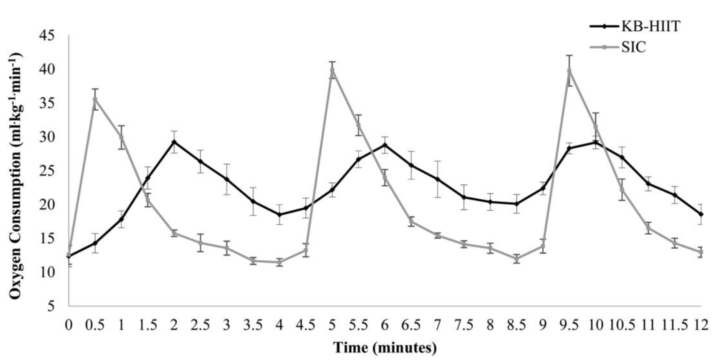

Figure 2. Oxygen consumption across the 12 minutes of exercise between the protocols. Values are expressed as mean ± *SE*. KB-HIIT = kettlebell high-intensity interval training; SIC = sprint interval cycling.

Subjects

Eight men between 20 and 23 years in age completed the study. Descriptive characteristics

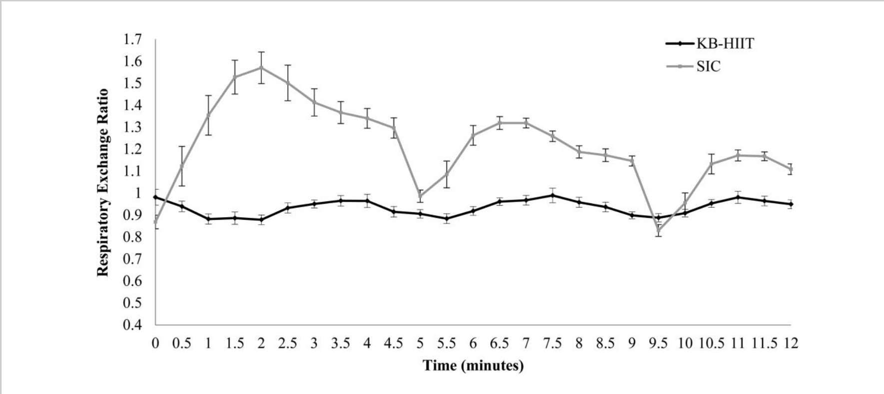

Figure 3. Respiratory exchange ratio across the 12 minutes of exercise between the protocols. Values are expressed as mean ± *SE*. KB-HIIT = kettlebell high-intensity interval training; SIC = sprint interval cycling.

of the subjects' baseline anthropometric and cardiorespiratory fitness data are shown in Table 1. All subjects were volunteers, and before their participation, they provided informed written consent after they were given a description of the study procedures and associated risks. The subjects had current or previous experience in some sports (e.g., football, pole vault, shot put, cross country, cross-fit, olympic lifting, and power lifting) and were considered "very active" (based on the average $\dot{V}O_2$max of 52.16 ± 6.55 $ml \cdot kg^{-1} \cdot min^{-1}$; range = 41.2–60.5 $ml \cdot kg^{-1} \cdot min^{-1}$). Most of the subjects had some previous experience with KB exercise and cycling; however, they were not considered trained KB athletes or cyclists.

Each perspective subject completed a medical history questionnaire and excluded if they had a current upper body or lower body musculoskeletal injury, musculoskeletal impairment, or had cardiovascular, pulmonary, or metabolic disease. The subjects were asked to (a) refrain from vigorous physical activity within 24 hours before each session, (b) maintain their normal dietary habits, (c) stay hydrated the night before and the day of each session, and (d) sleep an adequate amount of time (~8 hours) the night before each session. The study was approved by the Institutional Review Board of Southeastern Louisiana University.

Procedures

This study was conducted in the spring time of the year. All sessions were performed in the afternoon and each session lasted approximately 1 hour. A certified exercise physiologist and a certified athletic trainer were present during each session to ensure safety and procedural effectiveness.

In the first preliminary session, a certified KB instructor familiarized the subjects with proper form and lifting techniques of the KB exercises that they would perform. The 4 KB exercises used and the order of the exercises in the KB-HIIT protocol were (a) sumo squat (single-handed or 2-handed), (b) 2-handed swings, (c) clean and press (using the dominant arm), and (d) sumo deadlift (single-handed or 2-handed). Subjects practiced each KB exercise in a group setting for ~1 hour while the certified KB instructor evaluated their individual performance. During this session, the appropriate weight for each subject was determined for each KB exercise that would allow them to maintain a lifting rate without reaching volitional exhaustion quickly. The subjects informed the researchers of the weight that felt most appropriate for each KB exercise. Weight ranges for the KBs used in each exercise were sumo squat = 18–22 kg, 2-handed swing = 16–22 kg, clean and press = 10–22 kg, and sumo deadlift = 16–22 kg. Additionally, before or after the KB exercise familiarization, the subjects were familiarized with the specialized leg cycle ergometer used for the SIC protocol. Each subject performed 1 SIC interval to become accustomed to the intensity of the SIC protocol.

In the second preliminary session, body fat percentage was calculated by the 7-site skinfold measurement procedure and corresponding equation

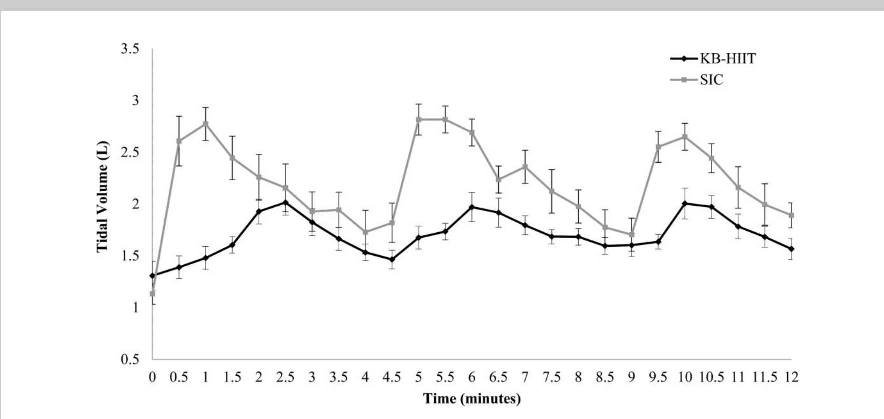

Figure 4. Tidal volume across the 12 minutes of exercise between the protocols. Values are expressed as mean ± *SE*. KB-HIIT = kettlebell high-intensity interval training; SIC = sprint interval cycling.

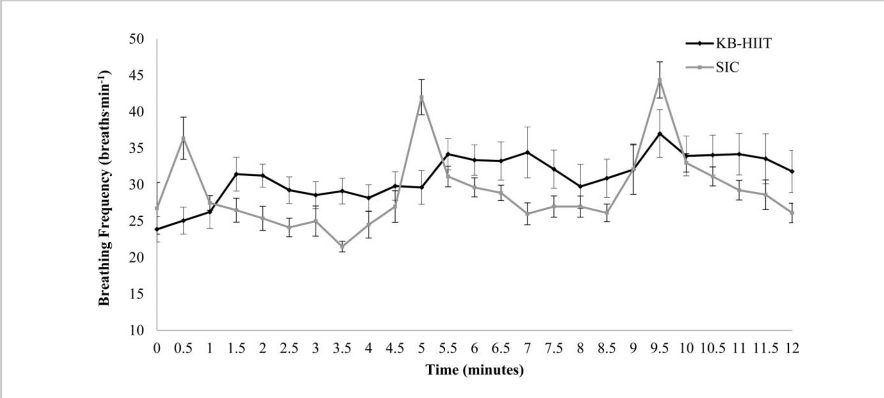

Figure 5. Breaths per minute across the 12 minutes of exercise between the protocols. Values are expressed as mean ± *SE*. KB-HIIT = kettlebell high-intensity interval training; SIC = sprint interval cycling.

(11). Height (cm) and weight (kg) were measured using a stadiometer scale. $\dot{V}O_2max$ and HR_{max} were determined from a graded-exercise test to exhaustion on a treadmill (Cardiac Science Quinton Q-Stress TM65 treadmill; Mortara Instrument, Inc., Milwaukee, WI, USA) using the Kraemer protocol (14). The participants first warmed up for 5 minutes on the treadmill at a speed of 1.5 mph and no grade. The protocol then was initiated and initially started at 2.5 mph and 4% grade. The speed was increased 1 mph every 2 minutes until the participant reached volitional exhaustion. Ventilatory and metabolic analyses were performed concurrently throughout the test using a metabolic analyzer (Parvo Medics' TrueOne 2400; Parvo Medics, Sandy, UT, USA). Heart rate was recorded every minute of the test by a HR monitor (Polar WearLink and FT7 watch; Polar Electro, Inc., Lake Success, NY, USA). All baseline anthropometric measures and graded-exercise testing were conducted by a certified exercise physiologist.

During the SIC experimental session, the subjects completed the protocol on a specialized leg cycle ergometer for sprint cycling (Monark Ergomedic 894E Peak Bike; Monark Exercise AB, Vansbro, Sweden). Resistance (by a plate-loaded weight basket) was applied to the flywheel of the leg cycle ergometer during each sprint interval. This resistance was calculated using 8.8% of the participants' fat-free body mass, a method used by Freese et al. (2013) to determine appropriate flywheel resistance during SIC (8). After a 5-minute passive rest, the participants completed a 10-minute warm-up on the bike at a speed of 50 revolutions per minute (rpm) with no resistance. During the last 15 seconds of the warm-up, the participants were instructed to cycle as fast as possible ("sprint") until they reached their peak rpm. At this point, the weight basket on the cycle ergometer was dropped, activating the load on the flywheel and the participants continued to sprint for 30 seconds against the resistance. Resistance was removed immediately after the 30-second sprint. After each sprint, the participants continued to pedal at 50 rpm with no resistance applied during the recovery period. The durations of the recovery periods were 4 minutes for the first and second recoveries and 2.5 minutes for the third. The second and third sprints began during the last 15-seconds of the first and second recovery periods. See Figure 1A for the specifics of the SIC protocol.

Before the KB-HIIT experimental session, the subjects were again familiarized with the KB exercises being used. For the protocol, participants passively rested for 5 minutes to record resting HR. After the resting period, the participants walked on the treadmill for 3 minutes at a speed of 1.5 mph and no grade, and then practiced the 4 exercises with the KBs for 7 minutes. Heart rate was measured during the last minute of the treadmill walk and after practicing the KB exercises. After warming up, the participants began the KB-HIIT 12-minute session. The pattern of 20-seconds of exercise followed by 10-seconds of rest was repeated for each exercise (Figure 1B). A metronome was used to standardize the cadence of the lifting and lowering of the

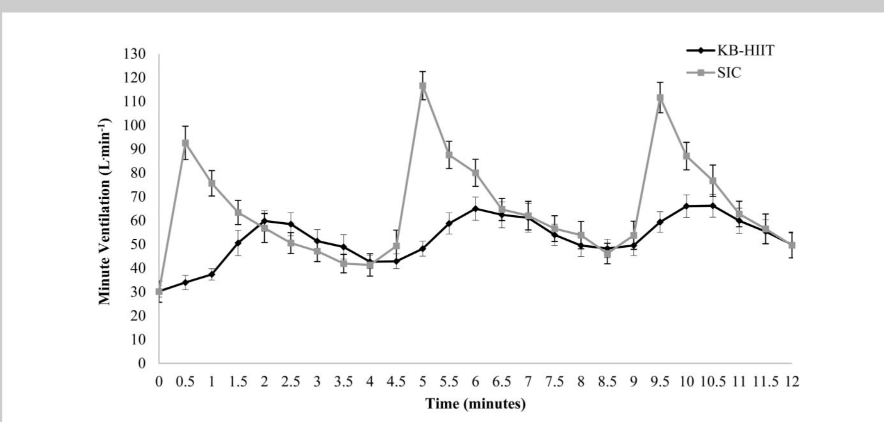

Figure 6. Minute ventilation across the 12 minutes of exercise between the protocols bouts. Values are expressed as mean ± *SE*. KB-HIIT = kettlebell high-intensity interval training; SIC = sprint interval cycling.

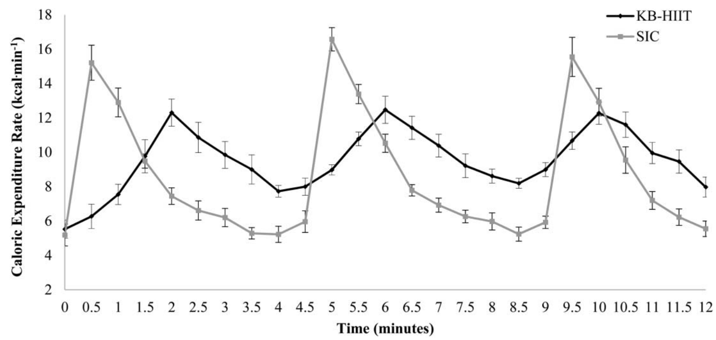

Figure 7. Caloric expenditure per minute across the 12 minutes of exercise between the protocols. Values are expressed as mean ± *SE*. KB-HIIT = kettlebell high-intensity interval training; SIC = sprint interval cycling.

KBs. The metronome was set at 40–44 $b \cdot min^{-1}$. For each of the exercises, except for the KB swings, the participants were instructed to move 2 beats for the lift phase and then 2 beats for the lowering phase of each exercise. For the KB swings, the cadence was 1 beat for the lift phase and 1 beat for the lowering phase of the exercise. Once the participant completed all 4 KB exercises, the whole process was repeated 2 more times for a total of 3 circuits of the 4 KB exercises.

During each experimental session, $\dot{V}O_2$, RER, TV, f, V_E, and $kcal \cdot min^{-1}$ were measured continuously by the metabolic analyzer. During the KB-HIIT session, HR was recorded immediately after the 20 second exercise and then at the end of the 10 second recovery period. During the SIC session, HR was recorded at the beginning and immediately after each sprint and also every minute of recovery.

Statistical Analyses

Intraclass correlation coefficients were calculated to assess the reliability of the $\dot{V}O_2$, RER, TV, f, V_E, $kcal \cdot min^{-1}$, and HR measures in each exercise protocol (Table 2). To examine the main effects of $\dot{V}O_2$, RER, TV, f, V_E, $kcal \cdot min^{-1}$, and HR across 12 minutes of exercise between the protocols, a 2 (Group) × 12 (Time point) repeated-measures analysis of variance was used. To examine the total caloric expenditure difference between the exercise protocols, an independent *t*-test was used. All statistical analyses were performed using the SPSS for Windows, version 20.0 (IBM Corp., Somers, NY, USA), statistical software program using an alpha level of $p \leq 0.05$.

Results

A significant ($p \leq 0.05$) group effect, time effect, and group × time interaction were found for $\dot{V}O_2$, RER, and TV (Figures 2–4). However, only a significant ($p \leq 0.05$) time effect and group × time interaction were found for f, V_E, $kcal \cdot min^{-1}$, and HR (Figures 5–8). The group main effects for $\dot{V}O_2$ [$F(1,14) = 4.886$, $p = 0.044$, partial eta-squared = 0.259, $\eta^2 = 0.539$], RER [$F(1,14) = 133.151$, $p < 0.001$, partial eta-squared = 0.905, $\eta^2 = 1.00$], and TV [($F(1,14) = 10.416$, $p = 0.006$, partial eta-squared = 0.427, $\eta^2 = 0.851$] revealed that there were significant differences between the KB-HIIT and SIC exercise protocols.

In the KB-HIIT protocol across time, there was a higher (mean ± *SE*) $\dot{V}O_2$ (22.6 ± 1.48 vs. 19.9 ± 1.01 $ml \cdot kg^{-1} \cdot min^{-1}$) and lower RER (0.93 ± 0.02 vs. 1.22 ± 0.04) and TV (1.7 ± 0.07 vs. 2.2 ± 0.15 L) than for the SIC protocol. $\dot{V}O_2$ was highest at the peak of each SIC interval in comparison to the KB-HIIT, but it was the lowest during the recovery periods (Figure 2). During the SIC, the average of the 3 highest $\dot{V}O_2$ values (38.4 ± 0.87 $ml \cdot kg^{-1} \cdot min^{-1}$) equated to 73.6% of $\dot{V}O_2max$, in comparison to the KB-HIIT (29.1 ± 0.09 $ml \cdot kg^{-1} \cdot min^{-1}$) which was 55.7% of $\dot{V}O_2max$. With the KB-HIIT, $\dot{V}O_2$ fluctuated in a specific pattern throughout the 3 circuits of this bout, but remained higher in comparison to the SIC throughout most of

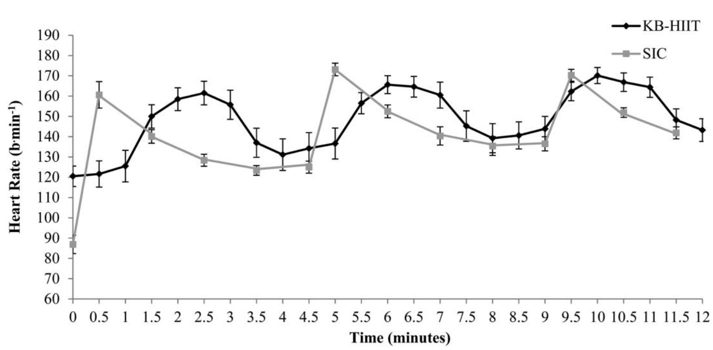

Figure 8. Heart rate across the 12 minutes of exercise between the protocols. Values are expressed as mean ± *SE*. KB-HIIT = kettlebell high-intensity interval training; SIC = sprint interval cycling.

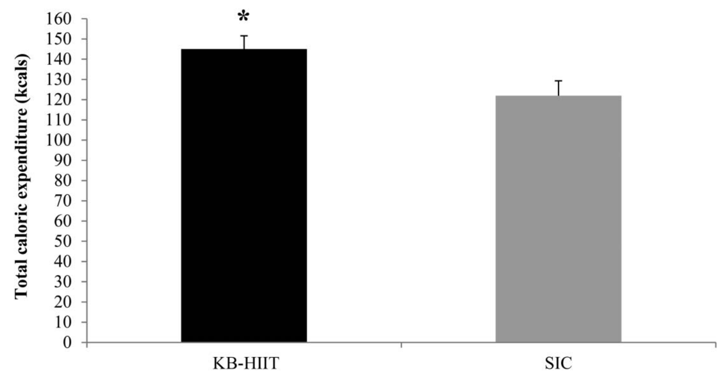

Figure 9. Total caloric expenditure between the protocols. Values are expressed as mean ± *SE*. *Denotes significant difference between the protocols, $p \leq 0.05$. KB-HIIT = kettlebell high-intensity interval training; SIC = sprint interval cycling.

the 12 minutes of exercise. Throughout a majority of the 12 minutes of exercise, RER was higher during the SIC than during the KB-HIIT, especially during the initial minutes (Figure 3). As time progressed during the SIC, RER gradually declined. During the KB-HIIT, RER remained fairly constant and fluctuated little. With TV, this measure also was highest during the SIC and declined during the recovery periods of this exercise protocol; however, even during the recovery periods, it remained higher in comparison to the KB-HIIT (Figure 4). During the KB-HIIT, TV was lower and it fluctuated less throughout the duration of the protocol in comparison with the SIC.

Average HR (±*SE*) was higher during the KB-HIIT protocol than the SIC protocol (149.16 ± 7.4 vs. 139.69 ± 7.85 $b \cdot min^{-1}$). Peak HR however was higher at the end of each SIC interval (Figure 8). During the SIC, the average of the 3 highest HR values (168 ± 2.21 $b \cdot min^{-1}$) equated to 88.5% of HR_{max}, in comparison to the KB-HIIT (166 ± 1.41 $b \cdot min^{-1}$) which was 87.5% of HR_{max}.

Analysis of the resulting total caloric expenditure during each exercise protocol using an independent *t*-test revealed a significant difference between the protocols [$t(14) = 2.323$, $p = 0.036$]. There was a greater average in total caloric expenditure during the KB-HIIT (144.87 ± 6.56 kcals) in comparison to the SIC (122 ± 7.34 kcals) (Figure 9).

Discussion

Findings from this study revealed that the hypothesis was partially supported. This is the first study to demonstrate that a KB-HIIT protocol can produce similar $kcal \cdot min^{-1}$, V_E, f, and HR responses over time as a standard SIC protocol, which is a well-known form of HIIT. Different from what was hypothesized, the KB-HIIT produced higher $\dot{V}O_2$ across time compared with the SIC, and the SIC was shown to elicit greater RER and TV across time. A comparison of each of the cardiorespiratory and metabolic responses to the KB-HIIT and SIC protocols relative to findings from previous studies suggests that KB-HIIT is an effective form of HIIT.

Although the SIC produced peak values for $\dot{V}O_2$ at 3 time points that were higher than those produced in the KB-HIIT, the KB-HIIT still elicited greater $\dot{V}O_2$ across time. This further suggests that KB-HIIT can be used effectively to promote cardiorespiratory and metabolic adaptations. The average $\dot{V}O_2$ (22.6 ± 1.48 $ml \cdot kg^{-1} \cdot min^{-1}$) for the KB-HIIT across time in this study only averaged 43.3% of $\dot{V}O_2max$, but this measure was affected by 10 seconds of passive recovery in between each exercise interval and including exercises that may not have been as metabolically demanding compared with the other exercises (i.e., sumo squat vs. swing). Thomas et al. (2014) reported an average value of ~60% of $\dot{V}O_2max$ throughout 3 circuits of continuous 10 minute KB swinging and sumo lifting (26). In this study, the 3 highest $\dot{V}O_2$ values averaged 55.7% of $\dot{V}O_2max$. This was a lower peak average %$\dot{V}O_2max$ than reported by Thomas et al. (2014), which is likely due to greater contribution of the phosphagen system and anaerobic glycolysis from the greater intensity of the protocol (i.e., more repetitions per minute) used in this study. This was indicated by higher and sustained RER values across time in this study than in the study by Thomas et al. (2014). RER, and also f, TV, and V_E, are important as well to note from this study because these ventilatory measures provide perspective of the greater sustainability of the KB-HIIT protocol compared with the SIC.

Respiratory exchange ratio was significantly different between the KB-HIIT and SIC protocols. This was likely due to the difference in degree of glycolytic activity and buffering of hydrogen ions (23) across time. Sprint interval cycling was associated with an erroneous RER (averaging at ~1.22 across the bout and peaking at 1.57), which presumably was due to excessive bicarbonate buffering (23) and greater TV from the elevated glycolytic activity during this particular exercise protocol. Respiratory exchange ratio peaked at the beginning of each SIC interval and declined after each SIC interval. Erroneous RER values and a trend for RER decline across the SIC bout were similar to what was observed by Freese et al. (8), whose study design used the same SIC protocol as in this study. The trend in decline of RER across the SIC bout may have been due to increased lipolysis over time from change in circulating catecholamine and insulin concentrations (13). Conversely, for the KB-HIIT protocol, there was less variability in RER with an average of ~0.9. This is similar to RER responses in previous KB studies. Hulsey et al. (2012) observed an average RER of ~0.95 (along with an average $\dot{V}O_2$ of ~34.1 $ml \cdot kg^{-1} \cdot min^{-1}$) during a 10 minute KB swinging bout, which included 35 second intervals of KB swings and 25 seconds of rest in between the intervals (10). V_E remained relatively stable during the KB-HIIT compared with the SIC (Figure 6). This was probably due to greater stability of TV and less fluctuation in f (Figures 4 and 5). Stable but elevated expired carbon dioxide (CO_2) associated with elevated RER would contribute to increased but stable V_E because of the relationship of arterial partial pressure of CO_2 with V_E (22). As a result, KB-HIIT may be easier to complete because of less hyperpnea and tachypnea than SIC.

In addition to the ventilatory responses being more sustained during the KB-HIIT than the SIC, so was HR (Figure 8). There are few studies that have examined HR responses across time with KB exercise. Hulsey et al. (2010) reported that HR across 10 minutes of KB swinging averaged at 89.1% of age-predicted HR_{max} (10). Farrar et al. (2012) examined HR responses across 12 minutes of KB swinging and observed an average HR of 86.8% HR_{max} (HR_{max} value was determined through grade-exercise testing) (6). The findings of these previous studies are similar to what was observed in this study. The average of the 3 highest values of HR during the KB-HIIT in this study was observed at 87.5% of HR_{max}, and KB swings were performed during the time points of these higher HR values. The percentage of HR_{max} during the KB-HIIT was similar to what was observed for the average of the 3 highest values of HR during the SIC (88.5% of HR_{max}). The average HR for SIC in this study was comparable with previously reported HR responses to SIC. Freese et al. (2013) found the peak value for HR at each SIC interval to average around 83–89% of age-predicted HR_{max} (8). A comparison of the average highest HR values to HR_{max} in this study is important to note because unlike previous studies examining KB or SIC effects on cardiorespiratory response (i.e., Hulsey et al. [2012] and Freese et al. [2013]), in this study, HR_{max} was measured during preliminary graded-exercise testing and used as a basis for comparison. $\%HR_{max}$ provides a more accurate measure of the degree of aerobic exercise stress. Elevated HR, as expected, was concomitant with increased metabolic rate and caloric expenditure.

The $kcal \cdot min^{-1}$ elicited by the KB protocol from the study by Thomas et al. (2014) was found to be similar to graded-treadmill walking set at the same intensity level (26). In this study, the work rate of the SIC and KB-HIIT protocols were different; however, there was no significant group effect for $kcal \cdot min^{-1}$. The average values across time were 9.51 $kcal \cdot min^{-1}$ during the KB-HIIT protocol and 8.6 $kcal \cdot min^{-1}$ during the SIC protocol. The average of the peak $kcal \cdot min^{-1}$ of the SIC intervals was 15.78 $kcal \cdot min^{-1}$. During the 3 highest peaks in the KB-HIIT (when KB swings were occurring), there was a 12.35 $kcal \cdot min^{-1}$ average. This is similar to the ~12.5 $kcal \cdot min^{-1}$ average in the 10 minutes of KB swings observed by Hulsey et al. (10). Furthermore, although the average $kcal \cdot min^{-1}$ of the KB-HIIT and SIC protocols were not significantly different (although the work rates were different), the total expenditure elicited by the KB-HIIT was significantly greater than the SIC (144.87 ± 6.56 vs. 122 ± 7.34 kcals, $p = 0.036$). The reason for the difference in total caloric expenditure, but no group difference in $kcal \cdot min^{-1}$, seems to be due to the 3 extended periods in which the KB-HIIT responses were ~5–6 $kcal \cdot min^{-1}$ higher than the SIC (specifically during the SIC recovery periods), whereas there were only brief time periods in which the SIC responses were ~7–8 $kcal \cdot min^{-1}$ greater than the KB-HIIT.

In conclusion, all of these physiological comparisons indicate that KB-HIIT can be an effective protocol for HIIT and may even be more attractive and sustainable than SIC. This study is 1 of 2 studies to date that has examined the use of a Tabata regimen with KB exercise. In a study by Fortner et al. (2014), a Tabata regimen with KB swinging was compared with a traditional regimen of KB swinging (included fewer sets and 90 seconds of rest between sets). It was found that not only could individuals complete the Tabata regimen significantly quicker (240.0 ± 0.0 vs. 521.5 ± 3.3 seconds), but also the routine elicited significantly higher average $\dot{V}O_2$ (33.1 ± 1.5 vs. 27.2 ± 1.6 $ml \cdot kg^{-1} min^{-1}$), percentage of $\dot{V}O_2$peak (71.0 ± 0.3 vs. 58.4 ± 0.3%), and HR response (162.4 ± 4.6 vs. 145.6 ± 4.8 $b \cdot min^{-1}$) than the traditional KB swing routine (7). In addition to this previous study, this study took into consideration of muscular fatigue that could occur during this type of HIIT. An onset of muscular fatigue, especially in large muscles and joints, can reduce a KB exerciser's performance and increase their risk of injury. When performing intermittent bouts of KB exercise, not only should the KB exerciser be familiarized with proper technique to reduce injury risk, but also localize fatigue needs to be considered with protocol programming so that it can be reduced (6,7,26). To help reduce fatigue, an alternation of more stressful and less stressful KB exercises, such as what was used in this study, should be considered. Accordingly, the effectiveness of the KB-HIIT protocol from this study offers additional exercise programming benefit, in addition to the time efficiency it can provide and influence on acute responses that can effectively augment cardiorespiratory and metabolic adaptations. In future studies, a comparison of the metabolic demand of different KB exercises would be beneficial, mostly to offer further insight into refining appropriate HIIT protocols such as the one used in this study. Additionally, the broader impact of this KB-HIIT protocol should be studied. Recent evidence by Madsen et al. (2015) indicates that HIIT can be used for effective glycemic control and improve pancreatic beta-cell function in type 2 diabetic patients (16).

Practical Applications

We developed a new KB-HIIT protocol that used Tabata training principles and was designed to elicit cardiorespiratory and metabolic responses similar to those induced by SIC. Our data revealed that KB-HIIT can be used as a form of high-intensity interval training and also provided further insight into the sustainability of the KB-HIIT protocol compared with SIC. This is a new and time-efficient exercise protocol that can be used safely with less physical strain than SIC and can produce physiological responses that could improve cardiorespiratory fitness and metabolic function. This is a protocol that should be considered by exercise practitioners (i.e., personal trainers, strength and conditioning specialists) to incorporate into their training programs for athletes or fitness clients.

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