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Examining work-to-rest ratios to optimize upper body sprint interval training

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ABSTRACT

The objective was to compare the metabolic influence of varying work-to-rest ratios during upper body sprint interval training (SIT). Forty-two recreationally-trained men were randomized into a training group [10 s work - 2 min of rest (10:2) or 4 min of rest (10:4), or 30 s work - 4 min of rest (30:4)] or a control group (CON). Participants underwent six training sessions over two weeks. Assessments consisted of a graded exercise test [maximal oxygen consumption (VO_2peak) and peak power output (PPO)], four constant-work rate trials [critical power, anaerobic working capacity, and electromyographic fatigue threshold], and an upper body Wingate test (mean/peak power and total work). Post-training absolute and relative VO_2peak was greater than pre-training for 30:4 ($p = .005$ and $p = .009$, respectively), but lower for CON ($p = .001$ and $p = .006$, respectively). Post-training PPO was greater in 30:4 ($p < .001$). No differences were observed during the constant-work rate trials or Wingate test. Traditional SIT appears to have enhanced VO_2peak in the upper body over a short-term two-week intervention.

1. Introduction

Sprint interval training (SIT) is a popular method of exercise that traditionally incorporates 4–6 brief (i.e. 30-s), but intense, maximal effort bouts of exercise (Sloth et al., 2013; Vollaard et al., 2017). As a form of high intensity interval training (HIIT), SIT has led to increases in muscle oxidative capacity and VO_2peak (Burgomaster et al., 2005; Gillen et al., 2014; Jacobs et al., 2013; Sloth et al., 2013), along with enhanced glycolytic enzyme activity and maximum anaerobic power (Burgomaster et al., 2006; MacDougall et al., 1998). Modified protocols of SIT (< 30 s) have become increasingly more common and demonstrate comparable results to the traditional protocol with interventions ranging from 2 to 9 weeks in duration (Hazell et al., 2010; Olek et al., 2018; Yamagishi and Babraj, 2017; Zelt et al., 2014; Zinner et al., 2016). Many of these studies highlight the rapid production of peak power as the most likely cause for SIT adaptations during lower body cycling (Hazell et al., 2010; Iaia et al., 2015; Lloyd Jones et al., 2017; Zelt et al., 2014).

When training the lower body is not feasible, training the upper limbs can also improve aerobic capacity considerably within a short or moderate period of time (Schoenmakers et al., 2016; Zinner et al., 2016). Various sports such as judo, wrestling, kayaking, and cross-country skiing rely more on upper body musculature during training and competition (Garrett and Kirkendall, 2000). In addition, upper body training may be relevant to individuals undergoing rehabilitation and to a variety of special populations (those with limited mobility, spinal cord injuries, overweight/obesity, and aging). To the best of our knowledge, only a minimal number of training studies have been performed on the upper body musculature while specifically utilizing SIT (Vandbakk et al., 2017; Zinner et al., 2016). Since the upper body musculature, in comparison to the lower body, has a smaller diffusion area, larger diffusion distance, and a greater type II fiber distribution (Calbet et al., 2003; Sanchis-Moysi et al., 2010; Zinner et al., 2016), it has a higher predisposition to utilize anaerobic resources. Therefore, the upper body may be more sensitive for adaptation to high-intensity aerobic training. Zinner et al. (2016) noted that the anaerobic predominance in the arms does not appear to limit their ability to increase aerobic capacity in response to SIT. Thus, the evaluation of a modified (< 30 s work bouts) short duration SIT intervention in the upper body appears to be warranted.

Since the upper body has the potential for aerobic and anaerobic adaptations, parameters from the work-time relationship [i.e., critical

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power (CP) and anaerobic working capacity (W')] may provide insight into the unique adaptations involved with altering the work-to-rest ratio during upper body SIT. In particular, CP is associated with aerobic metabolism (Jones et al., 2010) while W' is associated with anaerobic metabolism and the VO_2 slow component (Monod and Scherrer, 1965; Vanhatalo et al., 2011). Since maximal aerobic changes are possible within two weeks (Hazell et al., 2010; Zinner et al., 2016) and the physiological factors that enhance CP and VO_2peak are similar (Laursen and Jenkins, 2002) in addition to the high correlation between CP and VO_2peak (Burnley and Jones, 2007), there is a potential for change in CP. Endurance training interventions have been shown to improve CP without any effect on W' (Jenkins and Quigley, 1992; Poole et al., 1990), while high-intensity exercise has been reported to improve W' without any change in CP (Jenkins and Quigley, 1993). While the assessment of work-time relationship in the upper body has been evaluated, and CP has been determined to be a valid assessment tool for upper body endurance (Belasco Junior et al., 2010), the potential impact of a SIT intervention has yet to be explored.

Similar to the concept of CP, the electromyographic fatigue threshold (EMG_{FT}) is considered the highest power output that can be achieved without an increase in EMG amplitude over time (Moritani et al., 1993). EMG_{FT} occurs when there is a progressive recruitment of additional motor units or an increase in firing frequency of previously fatigued motor units in order to compensate for the deficit in fatigued motor units (Moritani et al., 1993). In response to cycling exercise, HIIT has been shown to cause a delay in the onset of neuromuscular fatigue within a relatively short period (3 and 6 weeks) of training (Smith et al., 2009). In addition, increases in muscle fiber recruitment [i.e., elevated root mean square (RMS) values] and a decrease in mean frequency have been observed after four weeks of SIT in the lower body (Creer et al., 2004). Both of these findings imply greater synchronization and force potentiation that can improve efficiency and coordination, thereby delaying fatigue. However, acute SIT investigations (i.e. two weeks) have yet to explore changes in EMG_{FT}. While a considerable amount of research has focused on EMG_{FT} during lower body cycling, its application in the upper body is lacking and may provide insight into the unique adaptations resulting from altered work-to-rest ratios during SIT.

The primary objective of this study was to evaluate the effectiveness of upper body SIT protocols with varying work-to-rest ratios on both aerobic and anaerobic performance. The secondary purpose was to investigate the changes in metabolic and neuromuscular fatigue thresholds from two weeks of SIT in recreationally active men. We hypothesized that both traditional and modified SIT would improve aerobic and anaerobic performance, delay neuromuscular fatigue, and increase CP while having no effect on W'.

2. Methodology

2.1. Experimental design and methodology

A randomized, repeated measures design was employed to examine the effectiveness of traditional and modified SIT protocols on the upper body. Participants were randomized into one of 3 training groups or a control (CON). All participants were asked to complete pre- and post-testing consisting of a graded exercise test (GXT) on day 1, three constant work-rate tests on day 2, and a Wingate test on day 3. Following pre-testing, participants that were assigned to one of the three training protocols underwent a two-week training intervention while the control group was instructed not to significantly alter their current activity level and only perform pre- and post-testing. All participants were instructed to maintain their regular caloric intake habits throughout the course of the investigation.

2.2. Participants

Forty-two recreationally active men were recruited and completed all testing and training sessions, except for one participant that did not complete post-testing anthropometric and body composition measures. All participants provided written informed consent and the study was approved by the university's institutional review board. All participants were habitually active completing a minimum of two to three days per week of exercise for at least 30 min per day. In an attempt to eliminate residual fatigue, the participants were asked to refrain from any strenuous physical activity for 48 h prior to testing.

2.3. Body composition measures and familiarization trial

Body composition was estimated using a multi-frequency bioelectrical impedance device (Inbody 720, Biospace Co., Ltd.; Seoul, Korea). A familiarization of the GXT was provided to each subject with an upper body cycle ergometer (Brachumera sport, Lode, Groeningen, Netherlands) prior to all testing sessions. Each subject was seated with the crank arm lined up with the center of their glenohumeral joint and positioned so that their arms were extended, but not fully locked out during cranking. The researchers instructed participants to crank with minimal upper body rotation, feet planted flat on the floor, and a consistent handgrip position. Any participant that performed extraneous motions while cranking was given a warning and if the movements persisted the test terminated.

2.4. Graded exercise test

An incremental test to volitional exhaustion was performed on a cycle ergometer (Brachumera sport, Lode, Groeningen, Netherlands) to determine peak power output (PPO) and peak oxygen consumption (VO_2peak). Prior to testing, each participant was fitted with a heart rate monitor (Heart Rate Monitor, Garmin Ltd., Schaffhausen, Switzerland), to record the participants' heart rate, and a mask around their mouth and nose to collect respiratory gases. All gas exchange data was collected using a metabolic gas analyzer (Quark CPET, Cosmed, Rome, Italy). Prior to each use, the metabolic gas analyzer was calibrated with gases of known concentration (16% O_2, 5% CO_2, and N_2 bal) and calibrated for airflow with a 3 l syringe as per the manufacturer's instruction manual. Participants underwent an incremental ramp protocol that began at an initial workload of 30 W and was increased one W every six seconds (10 W every minute). Participants were required to maintain a cranking cadence of 50 rpm and continued until the participant was unable to maintain a cadence above 50 rpm for a duration of five seconds despite verbal encouragement, or volitional fatigue. The highest power output achieved was recorded as PPO and the highest 10-s average breath-by-breath oxygen consumption rate was recorded as VO_2peak.

2.5. Constant work rate test trials

Three high-intensity constant-work rate tests, at different power outputs (90%, 100%, and 120% PPO), were performed. All constant-work rate tests began with a 3–5 min warm-up at 50 W on the cycle ergometer (Brachumera sport, Lode, Groeningen, Netherlands). Exhaustion was determined to the nearest second at the moment of volitional fatigue or failure to maintain a cranking cadence above 50 RPM for a duration of five seconds. Time-to-exhaustion (TTE) and total work (TW) were calculated during each trial. Linear regression was used to determine the slope of the line from the relationship between TTE and TW. The calculated slope of the work-time relationship was considered CP while the y-intercept of the regression line was considered W' from the standard multi-trial CP test (Monod and Scherrer, 1965).

2.5.1. Electromyography (EMG)

To assess muscle activity during the constant-work rate trials, a bipolar (4.6 cm center-to-center) surface electrode (Quinton Quick-Prep silver-silver chloride) arrangement was placed over the biceps brachii on the right arm. The surface electrodes were placed over the muscle belly between the medial acromion and the fossa cubit at one-third the distance proximal to the fossa cubit, while the ground electrode was placed on the right wrist. Prior to the placement of the electrodes the skin was shaved, abraded, and cleaned with alcohol. The raw EMG signals were pre-amplified using a differential amplifier (MP150, BIOPAC Systems, Inc., Santa Barbara, CA), sampled at 1000 Hz, and stored on a personal computer (Dell Latitude E6530, Dell Inc., Round Rock, TX) for off-line analysis. Raw EMG data was processed through a band-pass Butterworth filter (from 10 to 500 Hz) on a computerized software program (AcqKnolwedge 4.2., BIPOAC Systems, Inc., Goleta, GA, USA). Root mean square values were taken in 10 s bins and plotted over time for each constant-work rate trial to obtain the slope of each trial. The power output for each constant-work rate trial was then plotted over each fatigue slope coefficient to determine the y-intercept, which was defined as the electromyographic fatigue threshold (EMG_{FT}) (Devries et al., 1982).

2.6. Wingate test

Each participant warmed up for 3–5 min prior to each testing session. A Wingate test was performed on an upper body cycle ergometer (891E, Monark Upper Body Ergometer, Vansbro, Sweden) using $0.05\ kg{\cdot}kg^{-1}$ of the participant's body mass. Each participant was told to accelerate as fast as possible from the command of "GO!" and to sprint maximally for the entire 30 s duration of the test. Power output was registered using the Monark software (Monark ATS software, Vansbro, Sweden). Peak power (PP) was recorded as the highest power output generated during the test and mean power (MP) was recorded as the average power output over the entire test. Total work completed was also recorded.

2.7. Exercise training protocol

A SIT program consisting of six training sessions (three sessions per week for two weeks) was employed, and each session was separated by at least 48 h. Each training session began with a five-minute warm-up at 50 W. Four 30-s or 10-s all-out sprints using $0.05\ kg{\cdot}kg^{-1}$ body mass loading (Franchini et al., 2016) interspersed by either two or four minutes of passive recovery resulting in three groups [30 s: 4 min (30:4), 10 s: 4 min (10:4), 10 s: 2 min (10:2)]. Training took place on a modified cycle ergometer (894E, Monark Cycle Ergometer, Vansbro, Sweden) that was affixed to adjustable scaffolding for arm cranking. Participants were instructed to perform all-out sprints trying to reach and maintain the highest power output for every sprint while strong verbal encouragement was given throughout. Training progression increased one repetition every two training sessions, thus four repetitions during the first two training sessions, five repetitions during the middle two training sessions, and six repetitions for the final two training sessions (Hazell et al., 2010). Peak power (PP), mean power (MP), and total work (TW) were recorded. In addition, participants were asked to provide a perceived readiness rating (PRR) within 15 s prior to each sprint. The PRR is a progressive scale from one to five with one stating "Not at all ready to begin" and five stating "Completely ready to begin." Exercise Density (in $J{\cdot}s^{-1}$) was also calculated for each participant by dividing the six session sum of TW over the sum of the inter-set recovery, in seconds, over the two-week intervention (Marston et al., 2017). Participant's maintenance of PP was calculated as the average PP over the course of their training relative to the participant's PP from their pre-Wingate and expressed as a percent. The intraclass correlation coefficient (ICC) and the standard error of the measurement (SEM) for the primary dependent variables were: [VO_2peak: 0.919 (SEM: .222 $L{\cdot}min^{-1}$); VO_2peak: 0.711 (SEM: 2.572 $mL{\cdot}kg^{-1}\ min^{-1}$); PPO: 0.979 (SEM: 4.67 W); PPO: 0.984 (SEM: 0.045 W·kg); CP: 0.579 (SEM: 13.181 W); W': 0.807 (SEM = 1.89 kJ); EMG_{FT}: 0.456 (SEM = 29.04 W); PP: 0.867 (SEM: 117.6 W); MP: 0.927 (SEM: 29.7 W); TW: 0.923 (SEM: 0.897 kJ)].

2.8. Statistical analysis

A two-way [time × group) repeated measures analysis of variance (ANOVA) was performed on all testing measurements, pre and post, to identify differences within and between groups for aerobic capacity, fatigue thresholds, and anaerobic performance. In the event of an interaction, dependent T-tests were used to examine within group differences while a one-way ANOVA was used to examine between group differences. An analysis of variance (ANOVA) was used to compare average TW, PP, MP, exercise density, and maintenance of PP over the training intervention between training groups, whereas a Kruskal-Wallis analysis of variance was used for PRR due its categorical scale and non-normality. When appropriate, post hoc Bonferroni pairwise comparisons were used to examine the differences among the groups. Outliers were removed if they fell outside three times the median absolute deviation (MAD) for VO_2peak, CP, and EMG_{FT} (Leys et al., 2013). With less than 6% of the training data missing (Tabachnick and Fidell, 2013), multivariate imputation using partial least squares method was performed via JMP Pro 12 (Cary, NC, USA). For effect size, the partial eta squared statistic was calculated on the main effects with an interpretation of 0.01, 0.06, and 0.14 as small, medium, and large effect sizes, respectively (Cohen, 1988). Concomitantly, Cohen's d effect size was calculated on all pre and posttest scores with the interpretation of small (.2), moderate (.5), and large (.8) (Cohen, 1988). Significance was established at an alpha of $p < 0.05$. All data were reported as mean ± SD. Statistical software (IBM SPSS Statistics for Windows, Version 23.0; Armonk, NY: IBM Corp) was used for all analyses.

Table 1
Anthropometric measures before (pre) and after (post) training.

	10:2 (n = 11)			10:4 (n = 11)			30:4 (n = 10)			CON (n = 9)		
	Pre	Post	*d*	Pre	Post	*d*	Pre	Post	*d*	Pre	Post	*d*
Body Mass (kg)	81.2 ± 9.5	82.2 ± 9.4	−0.11	83.6 ± 13.3	84.7 ± 13.7*	−0.08	73.9 ± 12.1	73.0 ± 11.8	0.08	77.0 ± 11.5	78.5 ± 12.2*	−0.13
%BF	15.7 ± 6.2	15.7 ± 6.3	0.00	17.8 ± 3.5	18.3 ± 4.7	−0.12	16.8 ± 5.9	16.7 ± 5.4	0.02	19.0 ± 7.3	18.6 ± 6.7	0.06
Total lean arm mass (kg)	8.1 ± 1.2	8.2 ± 1.1	−0.09	8.2 ± 1.7	8.2 ± 1.7	0.00	7.0 ± 1.1	7.0 ± 1.2	0.00	7.3 ± 1.2	7.5 ± 1.1	−0.17

Note. Data are mean ± standard deviation (SD) representing raw data measured before and after training in the 10 s 2 min group (10:2), 10 s 4 min group (10:4), 30 s 4 min group (30:4), and control group (CON). n = sample size. %BF = percent body fat; d = effect size.

* Significantly different from pre ($p < .05$).

Table 2
Graded exercise test, constant-work rate, and Wingate test variables before (pre) and after (post) training.

	10:2 (n = 11)			10:4 (n = 11)			30:4 (n = 10)			CON (n = 10)		
	Pre	Post	d	Pre	Post	d	Pre	Post	d	Pre	Post	d
VO_2peak (L·min^{-1})	2.53 ± 0.36	2.53 ± 0.38	0.00	2.60 ± 0.30	2.58 ± 0.29†	0.07	2.21 ± 0.30	2.36 ± 0.26*	−0.53	2.40 ± 0.38	2.17 ± 0.34*	0.64
PPO (W)	140 ± 22	143 ± 20	−0.13	130 ± 13	136 ± 12	−0.52	125 ± 14	136 ± 14	−0.81	128 ± 23	127 ± 22	0.06
CP (W)	97.6 ± 17.3	99.2 ± 17.9	−0.09	87.9 ± 14.2	95.4 ± 14.7	−0.52	84.9 ± 16.7	94.9 ± 16.2	−0.61	81.4 ± 15.8	85.5 ± 12.4	−0.29
W' (kJ)	6.38 ± 1.58	6.78 ± 1.90	−0.23	6.70 ± 1.68	6.34 ± 1.61	0.22	6.83 ± 2.43	6.95 ± 2.84	−0.05	7.29 ± 2.68	7.12 ± 3.37	0.06
PP (W)	753 ± 189	905 ± 295	0.61	666 ± 189	772 ± 195	0.55	630 ± 109	749 ± 159	0.87	682 ± 231	716 ± 224	0.15
MP (W)	427 ± 71	437 ± 75	0.14	396 ± 66	419 ± 65	0.35	372 ± 58	409 ± 69	0.58	379 ± 78	382 ± 78	0.04
TW (kJ)	12.2 ± 1.9	12.3 ± 2.2	0.05	11.3 ± 1.7	11.8 ± 1.7	0.29	10.8 ± 1.6	11.8 ± 1.8	0.59	10.8 ± 2.3	10.8 ± 2.3	0.00
	(n = 10)			(n = 10)			(n = 10)			(n = 8)		
EMG_{FT} (W)	100.7 ± 24.8	113.1 ± 20.8	0.54	103.7 ± 13.6	112.1 ± 17.7	0.53	96.9 ± 20.1	100.6 ± 16.9	0.20	93.4 ± 19.1	104.2 ± 33.4	0.40

Note. Data are mean ± standard deviation (SD) representing raw data measured before and after training in the 10 s 2 min group (10:2), 10 s 4 min group (10:4), 30 s 4 min group (30:4), and control group (CON). n = sample size. d = effect size. VO_2peak = peak oxygen consumption; PPO = peak power output; CP = critical power; W' = anaerobic working capacity; PP = peak power; MP = mean power; TW = total work; EMG_{FT} = electromyographic fatigue threshold. *Significantly different than pre (p < .05). †Significantly different than CON (p < .05).

3. Results

3.1. Anthropometric changes

Baseline participant characteristics of the groups were as follows: 10:2 (n = 11; 22.8 ± 3.2 yr; 176.4 ± 6.9 cm; 81.2 ± 9.5 kg), 10:4 (n = 11; 22.4 ± 3.2 yr; 176.2 ± 8.7 cm; 83.6 ± 13.3 kg), 30:4 (n = 10; 23.1 ± 3.2 yr; 172.9 ± 7.1 cm; 73.9 ± 12.1 kg), CON (n = 10; 24.3 ± 3.3 yr; 174.2 ± 4.7 cm; 77.6 ± 11.5 kg). A significant main effect for time was noted in body mass ($F_{1,37}$ = 11.888, p = .001, η^2 = .243) as well as an interaction ($F_{3,37}$ = 7.018, p = .001, η^2 = .363) (Table 1). 10:4 (p = .020) and CON (p = .001) were significantly heavier at post-testing compared to their pre-testing measurements. There was no main effect for time for %BF ($F_{1,37}$ = .015, p = .904, η^2 < .001. However, main effects of time existed for RA lean mass ($F_{1,37}$ = 4.409, p = .043, η^2 = .106; LA lean mass ($F_{1,37}$ = 7.380, p = .01, η^2 = .166, and total lean arm mass ($F_{1,37}$ = 6.134, p = .018, η^2 = .142 (Table 1).

3.2. Aerobic capacity and fatigue thresholds

There were interactions observed for absolute VO_2peak ($F_{3,38}$ = 4.966, p = .005, η^2 = .282) and PPO ($F_{3,37}$ = 4.520, p = .008, η^2 = .263). For absolute VO_2peak, the 30:4 group increased from pre- to post-testing (p = .005), while the CON group decreased from pre- to post-testing (p = .001). In addition, VO_2peak was significantly greater in 10:4 than CON at post-testing (p = .040). For PPO, the 30:4 group increased from pre- to post-testing (p < .001) (Table 2). Due to outliers (i.e. > 3MAD), four subjects were removed from EMG_{FT} analysis. A main effect for time was observed for CP ($F_{1,38}$ = 9.012, p = .005, η^2 = .192), and EMG_{FT} ($F_{3,33}$ = 5.554, p = .024, η^2 = .140), but not for W' ($F_{1,38}$ < .001, p = .997, η^2 < .001) (Table 2).

Relative to body weight, there were interactions for VO_2peak ($F_{3,38}$ = 5.782, p = .002, η^2 = .313) and PPO ($F_{3,37}$ = 7.310, p = .001, η^2 = .372). For both relative VO_2peak and PPO, the 30:4 group increased from pre- to post-testing (p = .009 and p < .001, respectively) while the CON group decreased from pre- to post-testing (p = .006 and p = .001, respectively). In addition, a main effect of time existed for CP ($F_{1,37}$ = 6.063, p = .019, η^2 = .141), but not for W' ($F_{1,37}$ = .051, p = .823, η^2 = .001;) or EMG_{FT} ($F_{1,33}$ = 3.062, p = .089, η^2 = .085) relative to body weight (Table 3).

3.3. Wingate performance

A main effect of time was noted for PP ($F_{1,38}$ = 17.209, p < .001, η^2 = .312), MP ($F_{1,38}$ = 8.553, p = .006, η^2 = .184), and TW ($F_{1,38}$ = 5.067, p = .030, η^2 = .118) (Table 2).

3.4. Training

All subjects within the training groups completed 100% of the training sessions. Average PP was significantly different between training groups ($F_{2,31}$ = 5.35, p = .011) with the 10:2 (p = .013) and 10:4 (p = .049) groups significantly greater than the 30:4 group. Average MP was significantly different between training groups ($F_{2,31}$ = 26.637, p < .001) with the 10:2 (p < .001) and 10:4 (p < .001) groups significantly greater than the 30:4 group. Average TW was significantly different between training groups ($F_{2,31}$ = 57.489, p < .001) with the 30:4 group greater than both the 10:2 (p < .001) and the 10:4 (p = .002) groups. There was a significant difference in the distribution of ranks between groups in PRR (X^2_3 = 7.178, p = .028) with 10:4 group (M = 4.77) having a greater median value than 30:4 (M = 4.14, p = .022), but no differences with 10:2 (M = 4.25). There was a significant difference between groups in ED ($F_{2,31}$ = 50.925, p < .001) with 10:2 having a greater density than 30:4 (p = .010) and both 10:2 (p < .001) and 30:4 (p < .001) having greater densities than 10:4 (Table 4). A significance difference existed between groups in the maintenance of PP ($F_{2,31}$ = 4.567, p = .019) with 10:4 maintaining a higher percent than 30:4 (94.8 ± 16.6% vs. 77.2 ± 9.6%, p = .016, respectively), however no differences were observed in comparison to 10:2 (86.4 ± 12.5%).

4. Discussion

The purpose of this study was to compare different work-to-rest ratios utilized during SIT on upper body aerobic capacity, fatigue thresholds, and anaerobic performance. The major finding of this study was that a two-week period of traditional SIT was effective in enhancing upper body aerobic capacity. It appears that completing a greater amount of total work with at least a moderate level of metabolic stress, quantified via ED, provides a more optimal stimulus for upper body aerobic adaptations. Alternatively, SIT did not bring about delays in fatigue thresholds or improvements in anaerobic performance.

In agreement with previous research examining similar work-to-rest ratio SIT protocols, aerobic capacity was improved (Gillen et al., 2014; Hazell et al., 2010; Zelt et al., 2014; Zinner et al., 2016). Although the current results of this study indicate that training with a reduced duration work bout (i.e. 10 s) does not diminish aerobic capacity, as observed by Zelt et al. (2014) and Hazell et al. (2010), the duration of the work bout appears to be influential. The 30:4 protocol elicited a positive response, in contrast to CON, in absolute and relative to body weight VO_2peak along with relative PPO values. Adaptations from shorter work-to-rest ratios could be due to a high metabolic demand and the overall greater total work within the 30:4 group (Combes et al., 2017). The greater metabolic demand may be supported by the lower

Table 3
Graded exercise test, constant-work rate, and Wingate test variables before (pre) and after (post) training relative to body weight.

	10:2 (n = 11)			10:4 (n = 11)			30:4 (n = 10)			CON (n = 9)		
	Pre	Post	d	Pre	Post	d	Pre	Post	d	Pre	Post	d
VO_2peak (mL·kg^{-1}·min^{-1})	29.0 ± 4.4	29.6 ± 4.6	−0.13	27.9 ± 3.7	28.9 ± 5.1	−0.21	28.6 ± 3.9	31.1 ± 4.9	−0.56	29.6 ± 3.6	26.8 ± 3.0*	0.85
PPO (W·kg)	1.73 ± 0.27	1.75 ± 0.27	−0.07	1.57 ± 0.17	1.63 ± 0.23	−0.30	1.71 ± 0.24	1.88 ± 0.27*	−0.67	1.68 ± 0.27	1.64 ± 0.26	0.15
CP (W·kg)	1.21 ± 0.19	1.22 ± 0.20	−0.05	1.07 ± 0.20	1.14 ± 0.18	−0.37	1.17 ± 0.26	1.32 ± 0.26	−0.58	1.10 ± 0.23	1.11 ± 0.20	−0.05
W' (kJ·kg)	0.08 ± 0.02 (n = 10)	0.08 ± 0.02	−0.17 (n = 10)	0.08 ± 0.02	0.08 ± 0.02	0.15 (n = 10)	0.09 ± 0.03	0.10 ± 0.04	−0.08 (n = 7)	0.09 ± 0.03	0.09 ± 0.04	−0.03
EMG_{FT} (W·kg)	1.25 ± 0.35	1.37 ± 0.23	−0.41	1.24 ± 0.13	1.32 ± 0.16	−0.55	1.32 ± 0.28	1.40 ± 0.25	−0.30	1.23 ± 0.29	1.33 ± 0.35	−0.31

Note. Data are mean ± standard deviation (SD) representing raw data measured before and after training in the 10 s 2 min group (10:2), 10 s 4 min group (10:4), 30 s 4 min group (30:4), and control group (CON). n = sample size. d = effect size. VO_2peak = peak oxygen consumption; PPO = peak power output; CP = critical power; W' = anaerobic working capacity; EMG_{FT} = electromyographic fatigue threshold.
* Significantly different than pre (p < .05).

Table 4
Performance variables during training.

	10:2 (n = 11)	10:4 (n = 11)	30:4 (n = 10)
PP (W)	638 ± 147*	611 ± 113*	482 ± 73
MP (W)	495 ± 85*	488 ± 73*	300 ± 38
TW (kJ)	149 ± 26*	147 ± 21*	248 ± 27
ED (J·s^{-1})	51.7 ± 8.9*,†	25.5 ± 3.7	43.1 ± 4.6
PP (%)	86.4 ± 12.5	94.8 ± 16.6*	77.2 ± 9.6

Note. Data are mean ± standard deviation from training in the 10 s 2 min group (10:2), 10 s 4 min group (10:4), 30 s 4 min group (30:4), and control group (CON). n = sample size. PP = average peak power; MP = average mean power; TW = average total work; PRR = perceived readiness rating; ED = exercise density.
* Significantly different than 30:4 (p < .05).
† Significantly different than 10:4 (p < .05).

average feeling of perceived readiness within participants from 30:4 as compared to 10:4. Similarly, Zinner et al. (2016) observed enhanced adaptations in the arms from two weeks of a combined upper and lower body traditional SIT protocol (i.e. 30 s sprints with four minutes of rest). Our findings are contrary to previous reports employing the same SIT protocols in the lower body by Hazell et al. (2010) which found 30:4 and 10:4 more beneficial for improvements in VO_2peak compared to CON. It is conceivable that 30:4 in the current investigation may have accumulated a greater amount of time at a higher relative VO_2max compared with the 10 s groups during training and achieved a greater training stimulus from the intervention (Buchheit et al., 2012).

The intermittent nature of SIT protocols provide VO_2 fluctuations inducing multiple exponentially accelerated bouts of VO_2 on-kinetics, which stimulate continual metabolic disturbances, and may lead to greater activation of signaling pathways in oxidative metabolism (Combes et al., 2017, 2015). Bailey et al. (2009) observed faster VO_2 on-kinetics and a reduced VO_2 slow component after 2 weeks of traditional lower body SIT. SIT has been shown to increase PGC-1α mRNA expression and protein content (Burgomaster et al., 2008; Gibala et al., 2009; Scalzo et al., 2014), which could induce a phenotypic expression characteristic of slow-twitch muscle fibers (Lin et al., 2002), and given the upper body's fast-twitch dominance (Sanchis-Moysi et al., 2010; Zinner et al., 2016) may result in a large potential for aerobic adaptation. In addition, it has been shown that SIT can induce a muscle fiber subtype transition from either type I or type IIb towards type IIa, thereby providing a transformation into a more hybrid fiber (Parcell et al., 2005; Ross and Leveritt, 2001). Given the differences between the upper and lower body musculature, the upper body may benefit from larger work-to-rest ratios that provide more work to be accomplished while maintaining a moderate to high ED. A greater ED may indirectly limit recovery of severely depleted PCr stores, which in turn, will rely heavily on aerobic metabolism to compensate (Bogdanis et al., 1995). This added metabolic cost along with a moderate exercise density may distinguish the adaptations observed in the 30:4 from the 10 s protocols. Further, improvements in VO_2peak due to SIT may be attributed to increased muscle oxygen extraction or capillarization in the active musculature as shown in the lower body (Vollaard et al., 2017) along with increased endothelial function and vascular distensibility (Rakobowchuk et al., 2008). Additionally, two weeks of lower body SIT and HIT has been shown to increase muscle oxidative capacity, resting muscle glycogen levels, muscle buffering capacity, and aerobic and anaerobic enzymatic activity (Gibala et al., 2006; Little et al., 2010; Rodas et al., 2000).

The current study appears to be the first to examine changes in the work-time relationship before and after a two-week SIT protocol in the upper body. Despite improvements in maximal aerobic capacity, two weeks of SIT did not stimulate increases in CP or W'. In agreement with the current findings, Zelt et al. (2014) observed a main effect for training over 4 weeks with two SIT protocols during lower body cycling. However, the authors did not recruit a control group and utilized 30 s work bouts with longer rest periods (i.e., 4.5 min and 4.75 min) than the current investigation. Likewise, Yamagishi and Babraj (2017) found significant improvements in CP over 9 weeks only in a modified protocol (i.e., 15 s with 2 min of rest), but not in the traditional SIT protocol. Despite the relationship between VO_2max and CP (Jenkins and Quigley, 1993; Moritani et al., 1981), reported increases in VO_2max can occur without changes in CP during lower body high-intensity interval training (Graef et al., 2009; Jenkins and Quigley, 1993; Kendall et al., 2009). Gaesser and Wilson (1988) suggested that changes in CP are not dependent on changes in VO_2peak, and despite both measures purportedly reflecting aerobic function, training-based improvements are not mutually exclusive. Since CP is a submaximal parameter of aerobic function (Moritani et al., 1981; Poole et al., 1990), the maximal nature of SIT may have a greater impact on maximal (i.e. VO_2peak) rather than submaximal measures. Due to the exploratory nature of the current investigation (i.e. two weeks), CP may require longer duration interventions to elicit changes.

Relatively few studies have examined the influence of high-intensity intermittent exercise on W’ derived from the work-time relationship (Jenkins and Quigley, 1993; Poole et al., 1990). Previous findings have demonstrated differing results on the relationship between anaerobic performance (TW, PP, and MP), from upper and lower body Wingate tests, and W’ (Bulbulian et al., 1996; Jenkins and Quigley, 1993; Zagatto et al., 2008). Hence, some researchers argue the validity of W’ as an estimation of anaerobic capacity (Dekerle et al., 2002; Poole et al., 2016). The current investigation did find significant correlations among W’ and anaerobic performance (PP, MP, and TW); however, no changes were noted following SIT. Future research is needed to clearly define the components within the work-time relationship for the upper body; however, the current findings support that W’ is a representation of anaerobic capabilities.

Sprint interval training and HIIT using the lower body has shown to increase motor unit recruitment and delay the onset of neuromuscular fatigue over 4 and 3 weeks, respectively (Creer et al., 2004; Smith et al., 2009). In the current study, SIT did not delay neuromuscular fatigue in the biceps brachii via EMG_{FT}, which coincides with a lack of improvements following SIT in the submaximal aerobic parameters measured. Previous studies have reported no training related increases in muscle activation after lower body sprint training (Sleivert et al., 1995). This may be due to the incorporation of many muscle groups, including antagonists, during upper body arm cranking and this load sharing may inhibit an adequate activation response from a single muscle (Hug et al., 2009; Lusina et al., 2008). Stimulation of the type II fibers are evident above EMG_{FT}, but SIT may not induce a greater expression of type I, IIa, or IIx in the upper body after 2 weeks (Zinner et al., 2016). This may partly explain the lack of change in the onset of neuromuscular fatigue in the current study. Furthermore, training at maximal speeds (i.e. all-out), such as those utilized in the SIT protocols, may not evoke greater motor unit activation at slow speeds (i.e. 50RPM) (Cormie et al., 2011), such as those utilized in the constant work-rate trials. Similarly, to CP, longer training interventions may be required to stimulate changes within EMG_{FT}. Lastly, this investigation observed a significant intra-individual variation of EMG response in certain subjects, which may also be related to the slow constant-load crank rate (Foss and Hallén, 2005; Takaishi et al., 1996).

In contrast to previous investigations on anaerobic performance following lower body SIT (Astorino et al., 2012; Bayati et al., 2011; Burgomaster et al., 2006; Hazell et al., 2010; Zinner et al., 2016), two-weeks of SIT did not elicit improvements in upper body PP, MP, or TW. SIT has been shown to enhance upper body anaerobic performance as Zinner et al. (2016) found greater PP and MP over two-weeks of traditional SIT despite no changes in oxidative enzyme activity, muscle glycogen content, proportion of muscle fiber types, or cross-sectional area of the triceps brachii. However, the authors did not implement a control group to account for a training effect, and all participants performed upper body SIT alongside lower body SIT (Zinner et al., 2016). Furthermore, Zelt et al. (2014) observed a training effect in PP and MP for two SIT protocols (30 s vs. 15 s work bouts), but were unable to differentiate between groups over a 4-week lower body SIT intervention. Alternatively, previous studies have reported increases in VO_2max and PPO with no increases in anaerobic performance following a 2-week lower body cycling intervention (Rodas et al., 2000) or minimal increases following a 4-week running-based SIT intervention (McKie et al., 2017). Many authors have attributed the initial production of power output to the observed SIT adaptations (Hazell et al., 2010; Iaia et al., 2015; Lloyd Jones et al., 2017; Zelt et al., 2014). However, our results indicated that total work completed during training was more crucial for the improvements seen in this investigation. In addition, our results show a balance between volume and intensity given by the moderate ED performed in 30:4 compared to both 10 s protocols. The ED in conjunction with the participants subjective PRR (a much lower rating in 10:2 and 30:4 compared with 10:4) suggest an alternative performance mechanism to initial power production. Interestingly, Hazell et al. (2010) implemented a load equivalent to 10% of the subject’s body weight (kg) during SIT, which is greater than the traditional 7.5% recommended for a lower body Wingate test. The mechanisms behind positive anaerobic adaptations in the upper body are unclear given the lack of changes in muscle morphology (including muscle fiber types and cross sectional area), muscle enzymes, or glycogen content (Zinner et al., 2016). Perhaps a greater resistance during repeated efforts (Forbes et al., 2014) or a longer SIT intervention is needed to further stimulate anaerobic performance in the upper body.

This investigation offers a novel examination of the upper body musculature with traditional and modified SIT and shows that the traditional protocol (30:4) elicits positive aerobic performance in a relatively short training period. Investigators should exercise caution, as the total amount of active muscle mass during upper body cycling is difficult to quantify while taking into consideration the lower limb and trunk stabilization. In order to better account for these discrepancies, participants may need to be restrained to avoid any undesired movement that can influence the outcome variables. Given the demanding physical exertion of SIT, protocols are susceptible to individual effort while knowledge of sprint duration and the number of repetitions may result in reduced neuromuscular and power generation (Ansley et al., 2004; Billaut et al., 2011; Gibson et al., 2001), therefore participants should be blinded to these factors. In addition, the effect of training is influenced by the amount of metabolic stress during ‘all-out’ exercise (Mann et al., 2014), thereby potentially limiting to the ability to tolerate critical values of metabolite accumulation (Foster et al., 2004). Therefore, individuals may pace themselves during repeated ‘all-out’ efforts to avoid critical metabolic levels as a type of neural control regulation (Foster et al., 2004; Gibson et al., 2001). Perhaps future studies should implement strategies that quantify metabolic stress during training to ensure participants are working maximally.

4.1. Conclusions

The traditional SIT protocol appears to enhance aerobic adaptations in the upper body over a short-term two-week intervention. However, there was no improvement in submaximal performance as denoted by fatigue thresholds or anaerobic performance via Wingate assessment. A faster crank rate may have increased muscle efficiency to determine fatigue thresholds more clearly. Subsequent research should investigate the progression of larger work-to-rest ratios in order to increase ED rather than increasing the number of repetitions.

Conflict of interest statement

The authors have no conflicts of interest to report.

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