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ORIGINAL ARTICLE

Sprint exercise snacks: a novel approach to increase aerobic fitness

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Abstract

Purpose Sprint interval training (SIT), involving brief intermittent bursts of vigorous exercise within a single training session, is a time-efficient way to improve cardiorespiratory fitness (CRF). It is unclear whether performing sprints spread throughout the day with much longer (≥ 1 h) recovery periods can similarly improve CRF, potentially allowing individuals to perform "sprint snacks" throughout the day to gain health benefits.

Methods Healthy, young, inactive adults (~ 22 years, peak oxygen uptake [VO_2peak] ~ 35 ml kg^{-1} min^{-1}) were randomly assigned to one of two groups and performed 18 training sessions over 6 wks. Sprint snacks (SS) involved 3 × 20-s 'all out' cycling bouts separated by 1–4-h rest ($n = 12$, 7 females). Traditional SIT involved 3 × 20-s bouts interspersed with 3-min rest within a 10-min training session ($n = 16$, 7 females). The primary outcome was CRF determined by a VO_2peak test conducted before and after training. Secondary outcomes included a 150 kJ cycling time trial and exercise enjoyment.

Results Absolute VO_2peak increased by ~ 6% after SIT and ~ 4% for SS (main effect of time $P = 0.002$) with no difference between groups (group × time interaction, $P = 0.52$). 150 kJ time trial performance improved by ~ 13% in SIT and ~ 9% in SS (main effect of time, $P < 0.001$) with no difference between groups (group × time interaction, $P = 0.36$).

Conclusion CRF was similarly increased by a protocol involving sprint snacks spread throughout the day and a traditional SIT protocol in which bouts were separated by short recovery periods within a single training session.

Keywords HIIT · High-intensity interval training · Physical activity · Maximal oxygen uptake · Exercise performance

Abbreviations

CIHR	Canadian Institutes of Health Research
CRF	Cardiorespiratory fitness
CSEP	Canadian Society for Exercise Physiology
EES	Exercise enjoyment scale
HR	Heart rate
MET	Metabolic equivalent
NSERC	Natural Science and Engineering Research Council
PAR	Physical activity recall
PAR-Q+	Physical Activity Readiness Questionnaire-Plus
RPE	Ratings of perceived exertion
SIT	Sprint interval training
SS	Sprint snacks
VO_2	Oxygen uptake
VO_2peak	Peak oxygen uptake
W	Watts

Introduction

Sprint interval training (SIT) has been touted as an exercise modality that improves cardiorespiratory fitness and endurance performance in a time-efficient manner (Gibala et al. 2012). The method involves brief intermittent bursts of very high intensity exercise, which are typically performed in an 'all-out' manner or at an absolute intensity that exceeds the intensity required to elicit peak oxygen uptake (VO_2peak) and are separated by periods of recovery. Positive adaptations to SIT include improvements in VO_2peak, endurance exercise performance, oxidative capacity in skeletal muscle, and cardiovascular function (Vollaard et al. 2017; Boyd et al.

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2013). Two recent meta-analyses report that SIT leads to similar improvements in $\dot{V}O_2$peak when compared to traditional moderate-intensity aerobic exercise (Milanović et al. 2015; Vollaard et al. 2017). Sprint interval training is, therefore, promoted as an exercise strategy suited for individuals who cite lack of time as a perceived barrier to participating in more traditional and time-consuming aerobic training methods (Vollaard et al. 2017).

A common SIT protocol involves 4–6 × 30 s 'all-out' Wingate cycling sprints with 4-min recovery intervals (Burgomaster et al. 2005, 2006). Repeated Wingate protocols are known to be very strenuous and the applicability, as well as true time efficiency (due to prolonged rest periods and/or session recovery time), has been questioned (Gillen et al. 2014; Vollaard et al. 2017). The extreme effort required for repeated Wingate SIT requires a high level of motivation and could present a safety risk for inactive or clinical populations at risk for cardiovascular disease (Metcalfe et al. 2012; Boyd et al. 2013). To maintain time efficiency while improving applicability and tolerability, researchers have begun testing "reduced exertion" SIT protocols involving shorter duration sprints and less repeats within a workout (Vollaard et al. 2017; Gillen et al. 2014; Metcalfe et al. 2012). In line with this, recent studies have shown that protocols involving 2–3 × 10–20 s cycling sprints within a 10-min SIT workout can increase $\dot{V}O_2$peak in various populations including inactive healthy adults, individuals with obesity, and patients with type 2 diabetes (Songsorn et al. 2016; Gillen et al. 2014; Metcalfe et al. 2012). Determining the optimal application of SIT for time efficiency, efficacy, and applicability is an area of intense research and practical interest.

It is currently unclear whether it is the "all-out" intensity of sprints or the extreme effort required when sprints are repeated in a fatigued state over a short training session that make SIT effective (Cochran et al. 2014). One option that could potentially make SIT more appealing, even more time efficient, and potentially easier to implement, is to increase the rest periods between sprints. Such a protocol could involve each sprint being performed several hours apart as exercise "snacks" within the same day. We define a "sprint snack" (SS) as an isolated single sprint performed during the day that is not a part of a traditional SIT workout. Sprint snacks could be the SIT analogy to classic aerobic exercise training studies demonstrating similar health benefits of 30 min of moderate-intensity exercise performed as one prolonged bout or as 3 × 10-min shorter bouts throughout the day (Jakicic et al. 1995) or the concept of exercise "snacks" described by Francois et al. (2014) using separate bouts of interval training performed before meals. The concept of sprint snacks could also be viewed as in line with recently revised Physical Activity Guidelines for Americans (Piercy et al. 2018). Whereas the previous recommendation called for bouts, or sessions, of at least 10 min duration, the revised guidelines state that episodes of any duration may be included in the accumulated total volume of physical activity, and emphasize that even small changes can contribute to health-enhancing effects of physical activity. Recently, an unregistered single arm study by Ho et al. (2018) reported that distributing three, 30-s Wingate cycling sprints throughout the day with 4-h rest periods in between (3 days/week for 8 weeks) led to significant improvements in $\dot{V}O_2$peak in middle-aged females. It is possible that the high degree of effort, muscle fiber recruitment, or ATP demand from isolated sprints performed in this manner contribute to aerobic adaptations. Exercise training using SS could allow an individual to accumulate the benefits of SIT with presumably less extreme effort or fatigue.

The purpose of this study was to determine whether performing SS (3 × 20-s cycling sprints with 1–4-h rest in between, three times per week over a 6-week period) could increase $\dot{V}O_2$peak and aerobic exercise performance in healthy yet inactive individuals. We hypothesized that individuals would be able to complete the SS protocol and that it would lead to improvements in $\dot{V}O_2$peak and 150 kJ cycling time trial performance. We included a more traditional SIT protocol (3 × 20 s cycling sprints with 3 min rest in between performed within a single 10-min training session) to assess the novel SS protocol against an established and relevant time-efficient exercise intervention. The study was not designed or powered to test the superiority of SS or SIT but including such a comparator group allowed for a preliminary exploration of the effect size of each intervention within the same study and lab.

Materials and methods

Study design

The present study was a 6-week parallel-group randomized pilot trial comparing sprint interval training (SIT) to sprint snacks (SS). The experimental protocol was approved by the University of British Columbia Clinical Research Ethics Board, and all participants provided written informed consent. The trial was registered on ClinicalTrials.gov (NCT03159949).

Participants

Sample size calculations were computed to detect an anticipated change of 3.5 ml/kg/min (i.e., 1 MET) following 6 weeks of SS training using means and standard deviations for $\dot{V}O_2$peak from pooled data of young males and females aged 18–35 ($n = 29$) from previous studies in our lab. With a mean of 40.3 ml/kg/min and SD of 6.6 ml/kg/min, and a correlation between repeated measures of $r = 0.85$ (conservatively estimated from previous training studies where the correlation was $r = \sim 0.9$), 13 participants were required. To preserve power and account for potential dropout we aimed to recruit and randomize at least 15 participants per group. Across two waves of recruitment from May to September 2017, we recruited 33 young, healthy males and females with 17 randomized to SIT and 16 to SS. Twenty-eight participants completed the intervention and were included in the analyses. In the SS group, one male revealed to study staff that they were too active following randomization but prior to baseline testing and three males withdrew from the study due to incorporating interval training into their daily routine ($n = 1$) and failing to maintain time commitment ($n = 2$). In SIT, one female participant was lost to follow-up due to a medical reason not related to the study. The CONSORT flow diagram is shown in Fig. 1. All participants were between the ages of 18 and 35, aerobically inactive (defined as completing less than two 30-min bouts of aerobic exercise per week) and none had competed in competitive sports or interval training within the 3 months prior to participation in the study. Pre-study physical activity status was determined in preliminary screening using the Godin Leisure-Time Exercise Questionnaire (Godin and Shephard 1985) and more directly as an outcome measure using a 7-day physical activity recall (PAR) administered by a trained researcher (Sallis et al. 1985). Participants were cleared for participation in vigorous exercise by the Canadian Society for Exercise Physiology (CSEP) Physical Activity Readiness Questionnaire-Plus (PAR-Q+). Exclusion criteria included any chronic condition that could be made worse from participating in vigorous physical activity. Randomization was

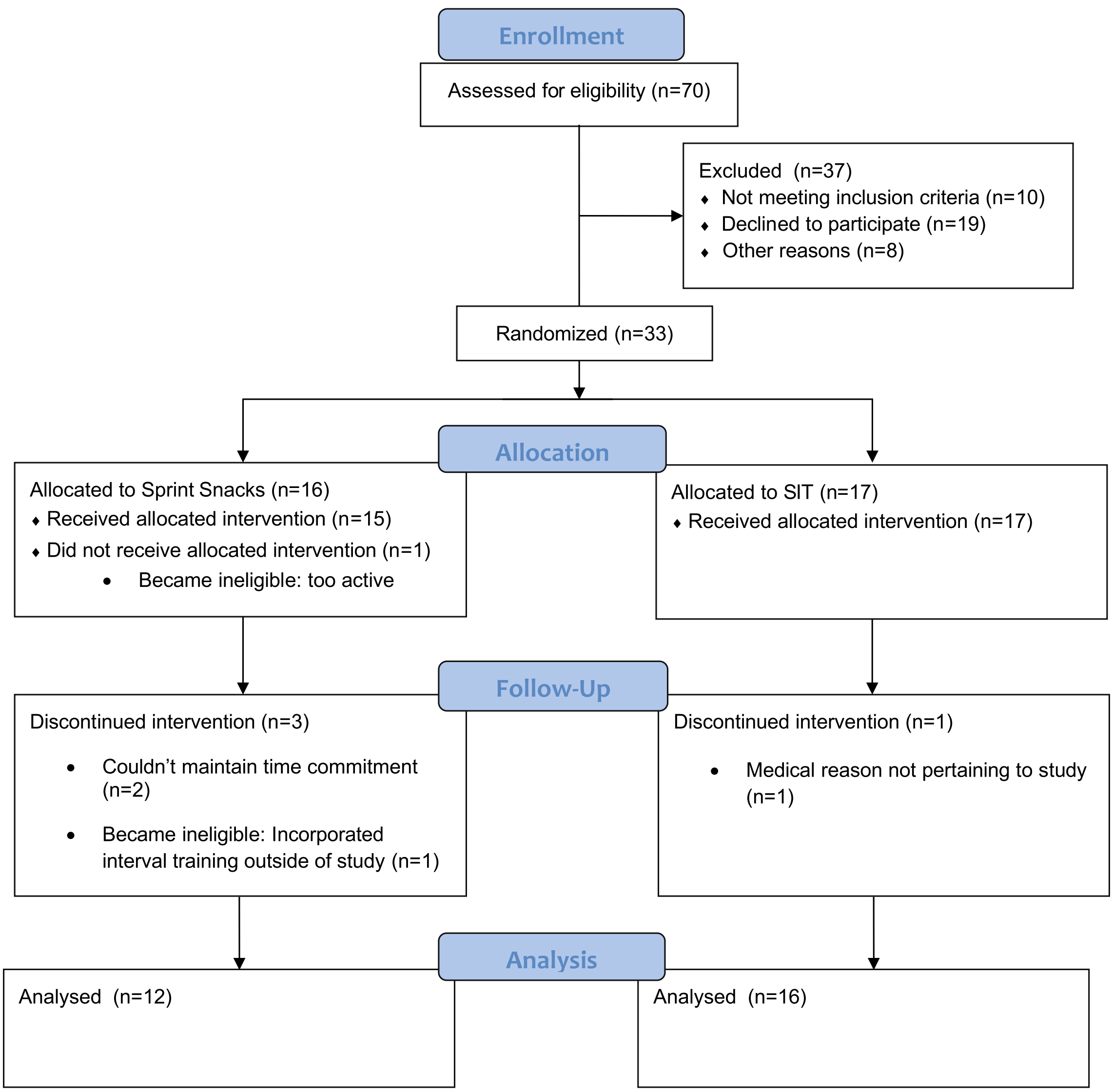

Fig. 1 CONSORT flow diagram

accomplished by a computer random number generator with variable permuted block sizes, stratified for sex. Participant randomization was concealed with opaque envelopes and group assignment was revealed after baseline testing.

Experimental protocol

The experimental protocol consisted of (1) baseline testing, (2) a 6-week supervised training intervention, and (3) post-training procedures.

Baseline testing

Baseline testing consisted of two separate testing days with a minimum of 24-h between tests. During the first visit, baseline anthropometrics were taken (height, weight and waist circumference) and participants performed an incremental cycling exercise test to exhaustion with expired gas collection and a verification phase to determine VO_2peak (details below). After testing was completed participants were given a 24-h diet recall to complete 24 h prior to their next baseline testing visit. A second baseline testing visit was completed 24–48 h later and involved a 150 kJ time trial performed on a cycle ergometer (details below). All participants completed a familiarization time trial prior to the initial baseline testing day to gauge intensity and length of time for this test.

Training

All training sessions for both groups were directly supervised by a research assistant and total duration of training (warm-up/recovery/cooldown plus sprints) was matched. Training began at least 7 days after the first baseline testing visit and consisted of 18 training sessions over the course of 6 weeks. There was 24–72 h of recovery between training sessions (e.g., aiming for Monday, Wednesday, and Friday each week). For the SIT group, training consisted of a 2-min warm-up followed by 3 × 20-s sprints interspersed with a 3-min recovery, with a 1-min cooldown (total workout time of 10 min). For the SS group, training consisted of three separate exercise bouts separated by 1–4 h. The 1–4-h recovery time was not standardized between or within participants. The SS exercise bouts consisted of a 2-min warm-up followed by a 20-s sprint and then a 1-min cooldown (i.e., three separate workout sessions each lasting 3 min 20 s). The warm-up, cooldown, and recovery periods were all performed at 50 Watts. All training was performed on an electromagnetically braked cycle ergometer (Lode Excalibur Sport V2.0, Groningen the Netherlands) controlled by the Lode Ergometry Manager Software (v9.4.0.0). Each sprint was performed at a resistance of 0.21 N m/kg and included a 10-s “ramp up” period whereby participants were instructed to accelerate pedal revolutions per minute (rpm) as high as possible such that each sprint was performed at an “all-out” effort. Mean and peak power of each sprint were recorded by the software and total work (in kJ) was calculated by multiplying mean power by time. Rating of perceived exertion [RPE; Borg category- ratio 0–10 scale (Borg 1982)] was assessed directly following each sprint. A summary of the training protocol for each group is shown in Table 1.

During the cooldown phase of the last sprint on the first and last days of training, participants in both groups were asked about their exercise enjoyment on a seven-point scale (Stanley et al. 2009). On the final training day, participants also indicated their intention to continue this type of exercise on a seven-point scale and list how they would intend to do this exercise regimen on their own.

In the event that a participant missed a training session, they were contacted and the training was made up on an alternate day on the same week such that three training days were completed each week.

Post-training procedures

The nature and timing of the post-training tests was identical in all respects to the pre-training procedures with the VO_2peak test performed ~ 48–72 h following the final training session and the time trial performed ~ 24–48 h following this. Participants performed the tests at the same time of day 1–3 h after consuming a meal.

Details of measures

Anthropometrics

Height and weight were measured using a physician’s scale (Seca 700, Hamburg, Germany). Height was recorded to the nearest 0.5 cm and weight recorded to the nearest 0.1 kg.

Table 1 Description of training sessions in the sprint snacks (SS) and sprint interval training (SIT) groups

	SS	SIT
Training weeks	6	6
# of training sessions per week	9	3
# of training sessions each training day	3	1
Length of each training session (min:s)	3:20	10:00
Sprints per training day	3	3
Sprint length (s)	20	20
Rest between sprints	1–4 h	3 min

$\dot{V}O_2$peak test

All participants completed a cardiorespiratory fitness test to exhaustion on an electromagnetically braked cycle ergometer (Lode Excalibur Sport V2.0, Groningen the Netherlands) to determine $\dot{V}O_2$peak and peak power output. Expired gas was collected by a metabolic cart (Parvomedics TrueOne 2400). Following a 2-min warm-up at 50 W, the test began at a resistance of 50 W with an increase in workload of 1 W every 2 s (30 W per minute) until volitional exhaustion. Following a 10-min passive recovery period, the load was set at 102.5% of the participants' peak power output in an attempt to perform a verification test based on recent guidelines (Poole and Jones 2017). The participants were instructed to maintain their cadence at 80–100 rpm until volitional exhaustion to verify they had reached a true $\dot{V}O_2$peak. In practice, this verification test was not successful or useful as the inactive participants in this trial could only maintain 102.5% of power output obtained in the ramp test for 119 ± 25 s and did not reach steady state for $\dot{V}O_2$. Thus, the value used for $\dot{V}O_2$peak corresponded to the highest value achieved over a 30 s collection period from the ramp test. Peak power output was defined as the highest power achieved during the test.

Time trial

Participants were instructed to complete a 150 kJ self-paced laboratory time trial on the aforementioned cycle ergometer as quickly as possible with no temporal, verbal or external physiological feedback. The only feedback provided during the time trial was work completed, which was presented as 'distance covered' on a computer monitor (150 kJ was equated to 10 km, such that visual feedback at any point during the time trial was presented in units of distance rather than work completed). Exercise duration and average power output were recorded upon completion of the test. All participants completed a 3-min warm-up at a load of 50 W prior to the test. A familiarization trial performed prior to the baseline test allowed participants' to gauge the intensity and effort required to complete the 150 kJ time trial. The coefficient of variation for this test in our laboratory was previously determined to be 2.6% ($n = 6$ males, performed 3–7 days apart; O'Malley et al. 2017).

Enjoyment

The Exercise Enjoyment Scale (EES) developed by Stanley et al. (2009) is a single-item seven-point scale to assess exercise enjoyment and was administered during the cooldown phase of either the SIT or SS protocol on the first and last days of training. The form was presented to them on a scale of 1 = "not at all" and 7 = "extremely" and participants were asked "How much did you enjoy this exercise session?"

Intention

Consistent with procedures developed in previous research (Bray et al. 2005) participants were asked (within 5 min of their last training session) to rate how likely it was that they would partake in a similar exercise routine in the future using a seven-point scale from "Most likely never do this form of physical activity again (1)" to "Will likely do three times per week every week (7)".

Physical activity and nutritional controls

Participants were instructed to maintain their regular dietary and physical activity practices throughout the experiment. Participants completed a 24-h diet recall prior to their second baseline testing day (time trial). This form was then reviewed by the research assistant and given back to the participant for them to replicate on the day prior to their post-time trial testing. During the final week of training participants completed a second 7-day PAR interview with the same trained researcher. Total kcal/day was calculated for both the baseline and final training week 7-day PAR to determine if physical activity outside of the intervention was altered. Prescribed sprint training sessions were omitted from the calculation for the second 7-day PAR.

Statistical analysis

R (R Development Core Team 2018) and the lme4 package (Bates et al. 2015) were used to perform a linear mixed effects analysis of the effect of exercise type (SIT or SS) and training timepoint (pre- versus post-training) on time trial performance, $\dot{V}O_2$peak, and peak power. As fixed effects, exercise type (group) and training timepoint (without the interaction term) were entered into the model. Random intercepts for subjects were used. Visual inspection of residuals plots was used to assess homoscedasticity and normality. In cases where heteroscedasticity was noted, log-transformations of the data were used to satisfy this assumption. P values were obtained by likelihood ratio tests of the full models with the effect in question compared to models without the effect in question. All individuals were included in the intention-to-treat analyses and missing data were not imputed. The mean difference over time along with 95% confidence interval and Cohen's d effect sizes were calculated to provide insight into the magnitude of the effect comparing pre-training versus post-training values within groups. Mean heart rate (HR), RPE, mean power, and peak power for Sprint 1, Sprint 2, and Sprint 3 across all 18 training days were averaged for all participants in SS and SIT and analyzed with a linear mixed effects analysis described above with the exercise type (group) and sprint as fixed effects. Significant interactions are followed up with Bonferroni adjusted post hoc tests comparing sprints within each group. Intention to engage in SIT or SS measured at the end of training was analyzed with an unpaired *t* test. Data are presented as mean ± SD unless specified and statistical significance was set at $P<0.05$.

Results

Descriptive characteristics of training

Descriptive characteristics of participants who completed the SIT and SS interventions are shown in Table 2 and the details of variables measured during training are shown in Table 3. Participants took on average 41 ± 7 days to complete the 18 training days. In SS, the average rest between sprints was 108 ± 14 min (range 60–350 min). No adverse events were reported. There was a significant group × sprint interaction for mean HR ($P<0.001$), RPE ($P=0.001$), mean power output ($P<0.001$), and work ($P<0.001$) indicating group differences across sprints. Mean HR and RPE increased with each successive sprint from Sprint 1–3 in SIT whereas both of these variables were not changed across sprints in SS. Mean power output and work were maintained across Sprint 1–Sprint 3 in SS whereas mean power output and work decreased with successive sprints in SIT. For peak power output, there was a main effect of sprint ($P=0.012$) but no interaction ($P=0.08$), with SIT tending to decrease peak power from Sprint 1 to Sprint 3.

Table 2 Descriptive characteristics of study participants who completed the sprint snacks (SS) and sprint interval training (SIT) interventions

	SS	SIT
n	12	16
Age (years)	22 (4)	21 (4)
Sex (m:f)	5:7	9:7
Weight (kg)	70 (10)	71 (17.0)
BMI (kg/m^2)	23.5 (2.8)	24.1 (4.9)
Absolute VO_2peak (L/min)	2.5 (0.9)	2.4 (0.8)
Relative VO_2peak (ml kg^{-1} min^{-1})	35.6 (11.4)	34.3 (7.6)
Baseline time trial (min)	21.7 (10.6)	20.9 (8.7)

Anthropometrics

Body mass in SS (pre: 70.2 ± 9.8, post: 70.4 ± 9.7) and SIT (pre: 70.8 ± 16.9, post: 71.3 ± 17.1) did not significantly change following either training intervention (main effect of time, $P=0.216$; group × time interaction, $P=0.529$).

Cardiorespiratory fitness

Absolute VO_2peak increased compared to pre-training by ~6% after SIT and ~4% for SS (main effect of time $P=0.002$) with no difference between groups (group × time interaction, $P=0.52$, Fig. 2a). The mean increase with 95% confidence interval after SIT was 0.15 L/min (0.04–0.27 L/min, $d=0.72$) and after SS was 0.10 L/min (−0.03–0.24 L/min, $d=0.51$). Relative VO_2peak increased by ~5% after 6 weeks of SIT and ~4% after SS (main effect of time, $P=0.004$) with no difference between groups (group × time interaction, $P=0.72$, Fig. 2b). The mean increase with 95% confidence interval after SIT was 1.9 ml/kg/min (0.2–3.5 ml/kg/min, $d=0.54$) and after SS was 1.5 ml/kg/min (−0.4–3.4 ml/kg/min, $d=0.57$). There was a significant main effect of time for peak power output ($P<0.001$) with no interaction ($P=0.81$). Following SIT peak power output increased by 14 W (95% CI 2–25, $d=0.65$) and after SS peak power output increased by 15 W (95% CI 11–19, $d=2.4$).

Table 3 Descriptive characteristics of training for participants who completed SIT ($n=16$) or SS ($n=12$)

	Sprint 1		Sprint 2		Sprint 3		Group × Sprint	Sprint
	SIT	SS	SIT	SS	SIT	SS	*P* value	*P* value
HR	162 ± 10	162 ± 10	168 ± 11[a]	161 ± 10	170 ± 11[a,b]	161 ± 11	< 0.001	0.001
RPE	4.8 ± 1.5	6.6 ± 1.8	6.3 ± 1.4[a]	7.2 ± 3.3	7.4 ± 1.4[a,b]	6.6 ± 2.2	0.001	0.001
Mean power	387 ± 110	397 ± 127	338 ± 95[a]	403 ± 134	314 ± 92[a,b]	401 ± 130	< 0.001	< 0.001
Peak power	691 ± 222	689 ± 190	679 ± 235	686 ± 194	641 ± 214[a]	682 ± 191	0.08	0.012
Work (kJ)	7.7 ± 2.2	7.9 ± 2.5	6.8 ± 1.9[a]	8.1 ± 2.7	6.3 ± 1.9[a,b]	8.0 ± 2.6	< 0.001	< 0.001

[a]Significantly different from Sprint 1 within group

[b]Significantly different from Sprint 2 within group (Bonferroni adjusted pairwise comparisons)

HR heart rate, *RPE* ratings of perceived exertion, *SIT* sprint interval training, *SS* sprint snacks

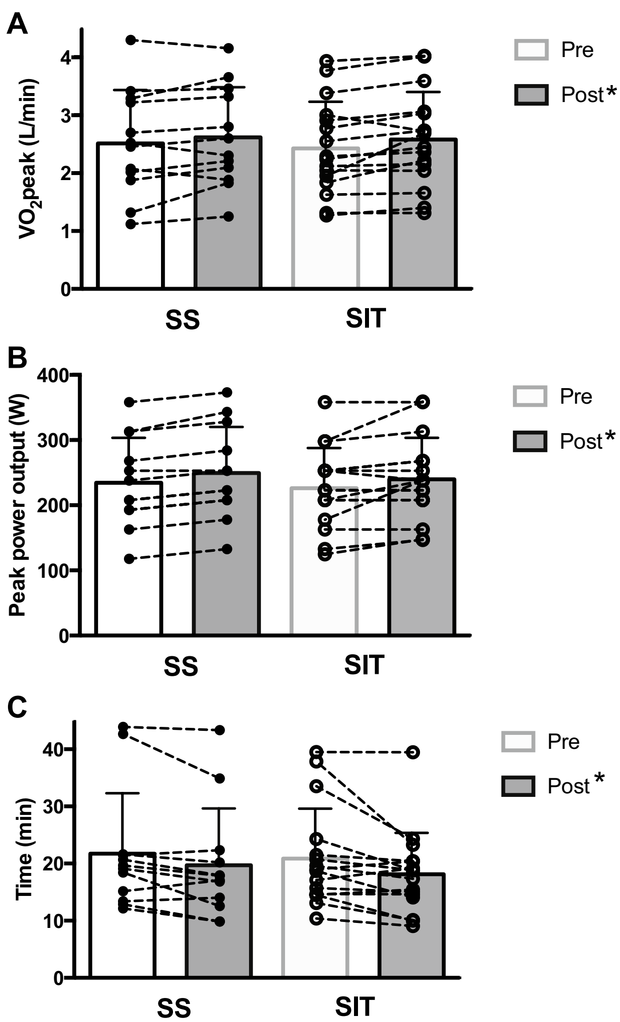

Fig. 2 Both sprint interval training (SIT) and sprint snacks (SS) promote aerobic adaptations. **a** VO_2peak (L/min). **b** Peak power output (W) and **c** 150 kJ time trial performance assessed on a cycle ergometer before (Pre) and after (Post) 6 weeks fo SIT or SS. Both groups trained 3 days per week for 6 weeks. For each variable a significant main effect of time was observed (all $P < 0.01$, denoted with an asterisk) with no group × time interaction (all $P > 0.36$). Group means and standard deviations are shown in the bars and individual values for each participant are shown with the connecting lines

Time trial performance

Time to complete the 150 kJ time trial was reduced by ~13% from 20.9 ± 8.7 min to 18.1 ± 7.2 min in SIT and reduced by ~9% from 21. 7 ± 10.6 min to 19.7 ± 10.0 in SS (main effect of time, $P < 0.001$, Fig. 2c) with no difference between groups (group × time interaction, $P = 0.36$). The mean improvement with 95% confidence interval after SIT was 2.8 min (0.5–5.0 min, $d = 0.57$) and after SS was 2.0 min (0.3–3.7 min, $d = 0.66$).

Physical activity recall

Physical activity assessed by 7-day PAR was not different when comparing baseline to the last week of training (SIT Pre = 2304 ± 575, SIT Post = 2303 ± 527; SS Pre = 2332 ± 303, SS Post = 2345 ± 308 kcal/day, main effect of time $P = 0.87$, group × time interaction, $P = 0.88$), indicating that physical activity patterns outside of the intervention did not change as a result of participating in SIT or SS.

Intention and enjoyment

A significant group × time interaction ($P = 0.029$) was found for exercise enjoyment, indicating the groups responded differently over time. Exercise enjoyment increased for SIT from first training session (3.8 ± 1.4) to last training session (5.2 ± 1.2; mean difference (95% CI) of 1.3 units (0.6–2.0 units), $d = 1.05$). In contrast, enjoyment of SS from pre (4.8 ± 1.9) to post (4.5 ± 1.4) did not appear to change (mean difference − 0.4 units (− 1.0–1.7 units), $d = 0.17$). When assessed after the final training session, there was a tendency that intention to engage in SIT (4.8 ± 1.5) was higher than SS (3.3 ± 2.5); $P = 0.053$.

Discussion

The purpose of this study was to determine if the novel exercise training strategy of SS could be completed by previously inactive individuals and lead to improvements in aerobic fitness and performance. In support of our overall hypothesis, we found that SS led to improvements in VO_2peak, peak aerobic power output, and 150 kJ cycling time trial performance that were comparable to the benchmark of low-volume SIT. Thus, the novel exercise training strategy of "sprint snacks" appears to be efficacious for previously inactive young healthy males and females and may represent a novel way to incorporate sprint-based exercise into an individual's daily routine.

Aerobic adaptations

The improvements in VO_2peak and peak power output provide evidence that both "traditional" SIT and the novel SS training methods result in beneficial aerobic adaptations. Given the link between higher VO_2peak and reduced morbidity/mortality (Myers et al. 2002), this suggests that performing low-volume sprints using either SIT or SS methods may be health-enhancing training options. The most recent meta-analyses from Vollaard et al. (2017) included 34 studies and reported improvements in absolute VO_2peak of 7.8% ± 4.0% (likely large effect) after SIT. The results from this study for both SIT and SS show modest improvements in aerobic fitness (increases of ~6% and ~4%, respectively, corresponding to effect sizes of 0.72 and 0.51) that are generally consistent with this meta-analyses, albeit on the lower end. Gillen et al. (2016) reported a ~19% increase in VO_2peak after 12 weeks of cycling SIT similar to the protocol employed in our 6-week training study. In the context of our findings and other shorter duration studies (Metcalfe et al. 2012, 2016; Gillen et al. 2014), this suggests that VO_2peak improvements with SIT will continue to accrue at least up to 12 weeks of training. In the context of the SIT literature, our findings add to the growing evidence that low-volume sprint-based training can result in modest improvements in cardiorespiratory fitness in previously untrained individuals. The findings that similar aerobic adaptations can be achieved from 20-s sprints with an extended rest duration (i.e., SS) versus traditional SIT is novel. Ho et al. (2018) reported ~14% improvements in VO_2peak following 8 weeks of dispersed 30-s Wingate tests (three sprints per day, separated by 4 h) using a concept similar to our SS. The idea of prolonged rest periods between sprints extends ideas from previous studies employing moderate-intensity exercise showing that it may be possible to spread exercise across multiple times throughout the day while still maintaining efficacy (Jakicic et al. 1995; 2018 Physical Activity Guidelines Advisory Committee).

In addition to an increased VO_2peak, 150 kJ time trial performance improved in both SIT and SS groups. This is consistent with a systematic review highlighting the benefits of SIT on aerobic performance (Sloth et al. 2013) and to our knowledge this is the first study to show that sprint training with prolonged rest (i.e., SS) leads to improvements in aerobic exercise performance. The increase in performance is likely related to the improved VO_2peak and also could be attributed to enhanced capacity for fat oxidation and reduced lactate accumulation as a result of increased muscle oxidative capacity, as shown previously following SIT (Gibala et al. 2006; Burgomaster et al. 2006). Performing sprints may also lead to performance adaptations due to the high degree of muscle fiber recruitment or high ATP demand experienced throughout training. However, we did not directly measure these variables in the present study so we cannot conclude whether specific or similar muscle metabolic adaptations are seen following SS when compared to SIT. Future work will be needed to determine whether SS elicits all the same physiological benefits that have been reported for SIT.

Characteristics and perceptions of training

Performing three 20-s "all-out" cycling sprints with a shorter rest period (i.e., "traditional" low-volume SIT) resulted in progressively higher HR, increased RPE, and lower mean power output from Sprint 1 to Sprint 3, which is indicative of greater cardiovascular stress, effort and fatigue when compared to SS. Thus, the longer rest period in between SS, as designed, appeared to result in a perceptually different training stimulus throughout the 6-wk training period. This extends the findings of Ho et al. (2018) who used a fixed 4-h recovery period between sprints and only reported weekly RPE averaged across all sprints/sessions without a comparator group. In an absolute sense, enjoyment was generally high for both SIT and SS in our sample of previously inactive participants. However, there was an increase in enjoyment of SIT from the first to the last training session whereas SS showed no increase over time. It is possible this was related to the constraints of the study design as across the 6-wk training period it became relatively inconvenient for participants to perform sprint snacks on a cycle ergometer in the laboratory under supervised conditions 3 d per week (i.e., participants had to report to the lab three times per day, which after 6 weeks may hinder enjoyment). We asked participants in open-ended exit interviews about intention to perform SIT or SS exercise in the future and responses from the SS group were generally positive but indicated they would prefer to perform sprint exercise snacks in a more real-world setting instead of the lab. Future work should, therefore, determine if SS is effective and enjoyable if performed in a real-life setting. Previous research by Stork et al. (2018) provides evidence that interval-based exercise may be seen as more enjoyable and less boring than traditional moderate-intensity continuous training. Thus, the high level of enjoyment and intentions following SIT or SS suggest that both of these training styles could be potential options for healthy, yet previously inactive, young adults.

Strengths and limitations

Training sessions in this study were performed in a controlled laboratory environment to ensure compliance to training and accurately quantify sprint power output and training variables. However, the need for a specialized cycle ergometer and relative inconvenience of reporting to the lab three times per day limit the direct application of the SS protocol as deployed in this study. Given the preliminary efficacy, it will be of interest to explore potential adaptations to sprint snacks performed in a more real-world setting. Notably in this regard, a recent brief report (Jenkins et al. 2019) demonstrated the potential for stair climbing sprint snacks to improve VO_2peak. Inactive young adults were randomly assigned to perform three bouts per day of vigorously ascending a three-flight stairwell (60 steps), separated by 1–4-h recovery, three days per week for six weeks, or a non-training control group ($n = 12$ each). VO_2peak was significantly higher in the stair climbing group post-intervention with the magnitude of increase (~5%) comparable to that observed in the SS group in the present study. Although there were no apparent differences seen between males and females, our study was not powered to detect sex differences. Unfortunately, four male participants dropped out of the SS group, the reasons for which did not appear directly related to dislike or dissatisfaction with the protocol, although two of these participants cited lack of time to report to the laboratory three times per day. Future studies will be needed to explore potential sex differences in efficacy or applicability of sprint snacks or other SIT approaches. In addition, this study was designed to examine efficacy of SS for aerobic adaptations and was not powered to compare SS to SIT; such a comparison would necessitate an a priori estimation of the effect size for the difference between approaches and this was not available prior to running this study. Potentially due to the constraints of a lab environment there was a higher dropout rate in the SS group, which should be noted. If sprint exercise "snacking" can be translated into free-living conditions it could represent an attractive exercise option for some people but it may not be an optimal solution for all. Our study was conducted in young, inactive but otherwise healthy participants, so it remains to be determined if SS are appropriate or attainable for older adults or those with chronic conditions.

Perspective

SIT has emerged as a time-efficient and effective strategy to promote aerobic adaptations. Our findings suggest that performing single isolated sprints throughout the day with prolonged rest period in between, which we term "sprint snacks", leads to similar aerobic adaptations when compared to a time-efficient SIT protocol involving the same number, intensity, and length of sprints performed in a single 10-min session. Whether exercise sprint snacking is applicable or appealing in a free-living setting or can be adhered to outside of the laboratory will require further research.

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Author contribution statement JPL and MJG conceived the study design with assistance from MEJ, JL and EMC. JL, ML, GJ, EMC, and CD collected data, performed statistical analyses, and prepared figures. JPL, JL and ML wrote the first draft of the manuscript with input from all authors. All authors edited and approved the final version.

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