Cardiorespiratory fitness and muscular endurance responses immediately and two-months after a whole-body Tabata or vigorous-intensity continuous training intervention

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Abstract

Young adults ($n=68$ [52 F]; age=$21\pm3$ y; VO$_2$peak: $41\pm6$ mL/kg/min) were randomized into a no-exercise control (CTL: $n=15$), Tabata ($n=26$), or vigorous-intensity continuous training (VICT; $n=27$) group for a four-week supervised training period (4 sessions/wk). VO$_2$peak, time-to-fatigue (TTF), 5 km time-trial performance (TT), and muscular endurance were assessed at baseline, post-training (POST) and two-month follow-up (FU). Response confidence intervals (CI) were used to classify individuals as likely responders (R; CI>0). Both exercise interventions increased TTF and TT at POST (both $p<0.01$), but these benefits were maintained at FU after VICT only ($p<0.01$). Push-up performance was increased at POST and FU (both $p<0.01$) after Tabata. VICT resulted in a greater proportion of TTF R versus both groups at POST (CTL: 1/15; VICT: 19/26; Tabata: 9/27) and versus Tabata at FU (3/15; 13/26; 4/27). VICT also had a greater proportion of TT R versus CTL at POST (2/15; 17/26; 10/27). Tabata had a greater proportion of R for max push-up repetitions versus both groups at POST (3/15; 6/26; 18/27) and versus CTL at FU (2/15; 10/26; 18/27). Collectively, VICT appears to be more effective for improving cardiorespiratory fitness, whereas whole-body Tabata confers larger improvements in push-up performance following short-term training.

Novelty bullets:

- Vigorous-intensity continuous training elicits larger improvements in cardiorespiratory fitness versus whole-body Tabata.
- Individual response profiles parallel group-level changes in cardiorespiratory fitness and muscular endurance.

Keywords: individual responses, non-responders, sprint interval training, endurance training, physical activity, cardiometabolic health.
Introduction

A large body of research has focused on the efficacy of high-intensity and sprint interval training (HIIT and SIT, respectively) for improving indices of cardiometabolic health (Gibala et al. 2012, 2014). In fact, several recent meta analyses have concluded that HIIT/SIT interventions promote similar improvements in cardiorespiratory fitness (Gist et al. 2014; Milanović et al. 2015), body composition (when energy expenditure is matched) (Keating et al. 2017; Viana et al. 2019b), exercise performance (Sloth et al. 2013), and health outcomes (Weston et al. 2014; Batacan et al. 2017) in healthy and clinical populations when compared to traditional exercise regimes such as moderate- and/or vigorous-intensity continuous training (MICT and VICT, respectively). The time-efficiency of certain HIIT and SIT protocols also makes these protocols attractive from a public health standpoint because a perceived lack of time is a prominent barrier to physical activity involvement (Trost et al. 2002), which remains low among the general population (Hallal et al. 2012). Additionally, the positive psychological responses (e.g. affect, enjoyment) associated with interval exercise (Jung et al. 2014; Stork et al. 2017; Townsend et al. 2017) further supports the notion that these protocols may be readily adopted by and adhered to by sedentary individuals. However, at present there is limited evidence supporting the adoption and adherence to HIIT/SIT by sedentary individuals in free living environments.

The Tabata protocol represents a unique form of SIT originally prescribed as 7-8 repeated bouts of cycling at a target intensity of 170% of peak oxygen uptake (VO$_2$max) interspersed with 10-second rest periods (Tabata et al. 1996; Viana et al. 2019a; Tabata 2019). Much like other variations of HIIT/SIT, we (Scribbans et al. 2014; Bonafiglia et al. 2016) and others (Tabata et al. 1996; Foster et al. 2015; Viana et al. 2019a) have demonstrated similar training adaptations using the Tabata protocol in comparison to traditional forms of prolonged continuous exercise such as...
MICT or VICT. Although the attainment of the specific target intensity (i.e. 170% VO\(_2\)max) in Tabata requires the use of specialized laboratory equipment, we have also previously demonstrated that a variation of this protocol using whole-body exercises is sufficient to augment cardiorespiratory fitness and indices of muscular endurance in recreationally active females (McRae et al. 2012). Importantly, this whole-body Tabata protocol does not necessitate the use of specialized equipment, thereby alleviating the need for access to facilities, while still providing a time-efficient alternative to MICT or VICT for achieving similar training induced adaptations. However, whether individuals will continue to engage in this exercise regime after the cessation of a structured and supervised training intervention (as reflected by the maintenance of training adaptations after cessation of structured training) remains unknown.

As such, the purpose of this study was to examine group-level and individual changes in cardiorespiratory fitness and muscular endurance responses to a four-week whole-body Tabata and VICT intervention immediately after and two-months following training in young adults who did not meet current physical activity guidelines. We hypothesized that improvements in cardiorespiratory fitness and muscular endurance would be similar between groups at follow-up, but would be sustained two months following completion of supervised training in the Tabata group only, presumably due to increased engagement in physical activity as a result of the time-efficient and accessible nature of this protocol. Accordingly, based on a recent review highlighting expected similarities between mean responses and individual rates of response (Atkinson et al. 2019), we speculated that the number of individuals who could be classified as likely “responders” for cardiorespiratory fitness and muscular endurance would be similar at post-test, but greater at two-month follow-up in the Tabata group as compared to VICT.
Methods

Experimental design

The current study involved a repeated measures parallel-arm design where 79 participants were randomized and 68 completed all aspects of the intervention in one of the following groups: 1) no-exercise control group (CTL; \(n=15\)), 2) whole-body Tabata (\(n=27\)), or 3) vigorous-intensity continuous training (VICT; \(n=26\)). Both exercise groups performed four weekly supervised training sessions over a four-week period (see Training protocols section) whereas individuals in CTL were asked to maintain their current lifestyle habits for the duration of the intervention. Peak oxygen uptake (\(VO_2\)peak), ramp-test time-to-fatigue (TTF), 5 km time-trial performance (TT), and muscular endurance (back extension, push-up, sit-up, right plank, left plank) were assessed at baseline (PRE), post-test (POST) and two-month follow-up (FU). Response confidence intervals (CI) were used to classify individual responses for each variable at POST and FU.

Participants

A total of 142 individuals were screened for participation and 68 completed all aspects of the study (see Figure 1 for flowchart detailing, recruitment, screening, exclusion, and drop outs and Table 1 for participant characteristics). Participants were healthy young adults (52 females and 18 males) that self-reported as being previously inactive (<150 minutes of moderate-to-vigorous weekly physical activity). Participants were only included if they met the following criteria: between the ages of 18 and 30, non-smokers, no previous history of cardiometabolic disease, not current taking any medication, not involved in a training program at the time of study, and had observed \(VO_2\)peak values of <50 mL/kg/min (males) or <45 mL/kg/min (females).
Experimental procedures were approved by the Health Sciences Human Research Ethics Boards at Queen’s University in accordance with the Declaration of Helsinki. Participants were provided with verbal and written explanation of all procedures and provided written informed consent prior to any data collection.

**Screening and familiarization**

All participants completed a preliminary laboratory visit during which they were interviewed about their physical activity habits and completed a 7-day Physical Activity Recall Survey (PAR) (Sallis et al. 1985). Participants that self-reported engaging in less than 150 minutes of moderate-to-vigorous weekly physical activity and met the inclusion criteria described above were then provided with details of the study protocol before signing an informed consent form. Participants then completed an adapted VO<sub>2</sub>peak test to exhaustion on a treadmill (Sports Art Fitness 6300HR) according to the following protocol: 3 minutes of resting gas exchange measurement (standing still on the treadmill), 5-minute warm-up (2.5 mph at an incline of 2), step increases in incline or speed every 2 minutes until volitional exhaustion. Gas exchange and heart rate (HR) were collected continuously throughout the test with a metabolic cart (Moxus AEI Technologies, Pittsburgh, PA) that was calibrated before each test using known gas concentrations and a 3-L syringe for flow. VO<sub>2</sub>peak and HRpeak were calculated as highest 30-second average during the protocol and TTF was recorded as the time from the start of the test to volitional exhaustion. Participants whose VO<sub>2</sub>peak values were below the cut-offs described above were asked to report back to the laboratory approximately 1 week after familiarization to complete PRE testing.
Physiological testing

On the first day of PRE, participants repeated the adapted VO$_2$-peak test protocol described above. Participants then returned to the laboratory approximately 24 hours later for muscular endurance testing. Specifically, participants completed a series of strength exercises including a modified Biering-Sorensen test (back-extension; measurement endurance of back extensor muscles), a stationary flexor endurance test (sit-up; measurement of abdominal muscles endurance), a side bridge test (right/left-plank; measurement of oblique endurance) (Frost et al. 2013) and 1 set of push-ups to volitional fatigue at a rate of 30 push-ups per minute. The muscular endurance tests utilized in the current study were adopted from a previous study (Frost et al. 2013). Isometric plank tests have been shown to be a valid and reliable measure for assessing muscular performance of the trunk in participants of varying age and fitness levels (ICC: 0.92 [95%CI: 0.88-0.94]) (Bohannon et al. 2018). After completion of muscular endurance testing, participants were given approximately ten minutes of rest before completing a 5 km time trial at a self-selected speed and 0% incline on a treadmill. Prior to starting the time to completion trial participants were instructed to complete the test as quickly as possible. During the trial participants were given no temporal, verbal or physiological feedback other than distance completed, which was displayed on the treadmill. Participants were instructed to refrain from holding onto the treadmill handrails during the test. The self-paced 5 km treadmill time-trial has been used previously (McKie et al. 2018) and is a reliable method for assessing endurance exercise performance (Driller et al. 2017).

POST testing was completed the week following the completion of training using identical procedures to PRE. Before leaving the lab after completion of POST, each participant was given a pamphlet that outlined the Canadian Physical Activity Guidelines (Tremblay et al. 2011). No further instructions were provided regarding exercise expectations during the two-month post-
intervention period. Participants were contacted approximately six weeks later to set up appointments for their final FU testing sessions. FU testing was completed two months after POST using identical procedures to PRE/POST.

*Training protocols*

Participants performed four weekly supervised training session over a four-week period. Each training session began with a standardized warm-up (walking down, and then up, 4 flights of stairs; ~2 minutes total warm-up time) as reported previously (McRae et al. 2012). Participants in the VICt group exercised on a treadmill at 85% HR peak for 30 minutes (American College of Sports Medicine 2014). Participants in the Tabata group completed a total of eight, 20-second intervals of “all-out” exercise separated by 10-second rest periods, for a total exercise duration of 4 minutes. Briefly, each training day consisted of one of four different whole-body exercises: burpee push-ups, mountain climber push-ups, jumping jacks, and squat and thrusts (females starting with 5 lb dumbbells with the option of 3 lbs, and males starting with 10 lbs weights with an 8 lbs dumbbell option). Detailed descriptions of each exercise performed during whole-body Tabata can be found in the Supplementary Information File S1.

*Statistical analyses*

Statistical analyses were performed using Prism Version 8.1 (GraphPad Software Inc., La Jolla, CA). One-way ANOVAs were used to examine between-group differences for each variable at baseline. Two-way repeated measures ANOVAs were used to compare the effects of group (CTL, Tabata, VICt) and time (PRE, POST, FU) on each variable. Bonferroni post-hoc tests were used to compare group means where significant main effects or interactions were observed.
Individual responses were classified at POST and FU for each variable using response CIs relative to a zero threshold as we have done previously (Bonafiglia et al. 2018) using the framework proposed by Swinton and colleagues (Swinton et al. 2018). A zero-based threshold was used as opposed to a larger/more conservative threshold (e.g. 0.2 times the standard deviation of baseline values) (Swinton et al. 2018) due to the short-duration of the training intervention (4 weeks) and the small (7-8%) magnitude of increase in VO$_2$peak previously observed using the training protocols included in the current study (McRae et al. 2012). As recommended by Williamson et al. (Williamson et al. 2017), the typical error (TE) was calculated for each variable using the following equation: 

$$\text{TE} = \frac{\text{SD}_{\text{diff}}}{\sqrt{2}}$$

where SD$_{\text{diff}}$ is the standard deviation (SD) of the PRE-POST change scores in CTL (Hopkins 2000; Swinton et al. 2018). Calculated TE values were as follows: 3.39 mL/kg/min (VO$_2$peak), 34.30 sec (TTF), 113.94 sec (TT), 19.57 sec (back-extension), 4.74 reps (push-up), 54.55 sec (sit-up), 28.80 sec (right-plank), 22.92 sec (left-plank). TE multiples were then used to calculate 50% response CIs (75% certainty that true response lies above 0) using the following equation: 

$$50\%\text{CI} = \text{OCS} \pm (0.67 \times \sqrt{2}\text{TE})$$

where OCS is the observed change score from PRE to POST or PRE to FU and $\sqrt{2}\text{TE}$ is the SD of the OCS for a given variable (Swinton et al. 2018). Individuals were classified as likely being “responders” (R) if the 50% CI was completely above 0, likely being “uncertain responders” (UR) if the 50% CI overlapped 0, and likely being “non-responders” (NR) if the 50% CI was completely below 0. As an example, for an individual with a VO$_2$peak OCS of 3.67 ml/kg/min from PRE to POST training, the upper and lower bounds of the 50% CI were calculated as: $3.67 \pm (0.67 \times \sqrt{2}\cdot3.39)$. Since the calculated CI (0.45-6.88) was completely above 0, this individual was classified as a “likely responder” (R) (see Bonafiglia et al. 2018 for a visual representation of this approach). For all subsequent analyses, UR and NR were pooled (UNR). Chi-squared tests were used to compare the proportion of
individuals that were classified as R and UNR at POST and FU and the Marascuilo procedure was used to compare proportions between groups where a significant Chi-squared test statistic was observed (Marascuilo and Slaughter 1981). Significance was accepted at $p<0.05$. All data are presented as mean±SD.

Results

Group level responses

Group means for all variables at each time-point are shown in Table 2. No significant between-group differences were observed for any variable at PRE ($p>0.05$), with the exception of back extension time and max push-up repetitions, both of which were significantly lower in the VICT group ($p<0.05$). A main effect of time was observed for VO$_2$peak ($p<0.01$) and exploratory post-hoc analysis revealed a significant increase in VO$_2$peak from PRE to POST in the VICT only ($p<0.05$). Significant main effects of time ($p<0.01$) and interaction effects ($p<0.01$) were observed for TTF and TT, both of which increased from PRE to POST in the VICT and Tabata groups ($p<0.05$). Improvements in TTF and TT were sustained at FU in the VICT group only ($p<0.05$) and were greater after VICT versus Tabata at both time-points (Figure 2D and 2G; $p<0.05$).

No significant main effects or interactions were observed for changes in back extension and sit-up time ($p>0.05$). Significant main effects ($p<0.01$) and an interaction ($p<0.01$) was observed for changes in max push-up repetitions, with significant increases observed at POST and FU in the Tabata group ($p<0.05$). The improvement in push-up performance after Tabata was also greater than VICT at POST ($p<0.05$). There was also a main effect of time for right plank time
($p=0.01$), with exploratory post-hoc analysis indicating an increase from PRE to POST in the Tabata group ($p<0.05$). A near significant interaction was observed for changes in left plank time from PRE to POST ($p=0.07$), with exploratory post-hoc analysis indicating a trend for an increase in the Tabata group ($p=0.10$).

**Individual responses**

Individual changes in indices of cardiorespiratory fitness and muscular fitness at each time-point are shown in Figures 2 and Supplementary Figure S1, respectively, and the number of R and UNR in each group at POST and FU are shown in Table 3. The between-group difference in the proportion of R and UNR for VO$_2$ peak approached significance at POST ($p=0.08$) with the highest number of R observed in the VICT group, but was not different at FU. The proportion of R and UNR for TTF was significantly different between groups at POST ($p<0.01$) and FU ($p=0.01$), with VICT eliciting more favorable response profiles for TTF versus both groups at POST and versus Tabata at FU. Significant between-group differences were also observed for individual TT responses at POST ($p<0.01$), with a greater proportion of R in VICT versus CTL. The difference in proportion of R and UNR for TT performance at FU approached significance ($p=0.09$) with the highest number of R observed in the VICT group.

No significant between-group differences were observed for the proportion of R and UNR for back extension, sit-up, and right plank time at either time-point ($p>0.05$). However, there was a significant difference in the proportion of R and UNR for changes in max push-up repetitions at POST and FU (both $p<0.01$), with more favorable response profiles observed in Tabata versus both groups at POST and versus CTL at FU. The difference in the proportion of R and UNR for
left plank approached significance at POST (p=0.08), with the highest number of R observed in
the Tabata group.

**Discussion**

The current study tested the hypothesis that four weeks of VICT or whole-body Tabata will
similarly improve cardiorespiratory fitness and muscular endurance at POST but that these
adaptations would be sustained at two-month FU after Tabata only. Contrary to our hypothesis,
we found that VICT was more effective for improving indices of cardiorespiratory fitness (TTF
and TT) at POST and FU (Figure 2), though Tabata resulted in greater improvements in push-up
performance at POST that were sustained at FU (Supplementary Figure S1). Moreover, we found
that individual responses paralleled group-level changes in the adaptive outcomes examined, with
VICT eliciting more favorable response profiles for indices of cardiorespiratory fitness and Tabata
eliciting more favorable response profiles for push-up performance (Figure 2; Table 3). Altogether,
our findings refute the notion that whole-body Tabata is a time-efficient alternative to
VICT for improving cardiorespiratory fitness in young adults not meeting current physical activity
guidelines. Further, although we did not measure physical activity directly during the period
between POST and FU, the lack of improvement in cardiorespiratory fitness and most indices of
muscular endurance at FU suggests a lack of exercise engagement and adherence, despite the
apparent time-efficiency and feasibility of the whole-body Tabata protocol.
Training-induced improvements in cardiorespiratory fitness

Cardiorespiratory fitness is a strong and independent predictor of all-cause mortality and morbidity (Ross et al. 2016) and the effectiveness of guideline-based physical activity (e.g. MICT) for improving cardiorespiratory fitness is well-established (Garber et al. 2011). Furthermore, several recent systematic reviews and meta-analyses have concluded that HIIT/SIT interventions are equipotent (if not superior) to MICT and/or VICT for improving indices of cardiorespiratory fitness in healthy and clinical populations (Gist et al. 2014; Weston et al. 2014; Milanović et al. 2015; Batacan et al. 2017). In the present study, we compared changes in cardiorespiratory fitness following four weeks of VICT and whole-body Tabata (adapted from the original cycling Tabata protocol; Tabata et al. 1996) and found that although both protocols improved indices of cardiorespiratory fitness, these adaptations were more pronounced in the VICT group. Although this finding refutes our hypothesis that both exercise protocols would lead to similar increases in cardiorespiratory fitness, it should be noted that the whole-body Tabata protocol implemented in this study is distinct from more popular (and perhaps more potent) SIT protocols that promote similar training adaptations to traditional endurance training (Gibala et al. 2006; Burgomaster et al. 2008; Macpherson et al. 2011; Gillen et al. 2016). Nevertheless, we have previously reported similar improvements in VO\textsubscript{2peak} after VICT and whole-body Tabata protocol in recreationally active adults (McRae et al. 2012) and while VO\textsubscript{2peak} was unaltered following whole-body Tabata in the present study, other indices of cardiorespiratory fitness (TTF and TT) were significantly improved versus baseline. Altogether, our findings suggest that although VICT is superior to whole-body Tabata for improving indices of cardiorespiratory fitness following short-term training in adults who do not meet current physical activity guidelines, improvements in aerobic exercise performance can be achieved in a time-efficient and feasible manner using whole-body Tabata.
The apparent differences in VO₂max responses to whole-body Tabata between adults not meeting physical activity guidelines (present study) and recreationally active females (McRae et al. 2012) warrant further investigation.

Training-induced improvements in muscular endurance

Similar to cardiorespiratory fitness, enhanced muscular fitness (e.g. strength, endurance) is associated with improved cardiometabolic risk profiles, lower risk of all-cause mortality, and a decreased probability of developing functional limitations later in life (Warburton et al. 2001; Katzmarzyk and Craig 2002; Garber et al. 2011). Contrary to previous observations of improved muscular endurance across several muscle groups following whole-body Tabata (McRae et al. 2012) and low volume aerobic resistance training (Myers et al. 2015), only push-up performance and right (and potentially left) plank time were improved following Tabata in the cohort examined in the present study. Although the reasons for these discrepant findings are not immediately clear, it is possible that the insufficient physical activity involvement of the participants in the current study and/or their inexperience with tests of muscular endurance may have impacted their performance. Nevertheless, the increase in max push-up repetitions in the whole-body Tabata group (versus both CTL and VICT) is noteworthy as a large-scale prospective cohort study recently reported an inverse association between push-up capacity and incidence of adverse cardiovascular events in large cohort of healthy men (Yang et al. 2019). Future studies are warranted to further examine the efficacy of whole-body Tabata (and other variations of this protocol) for improving muscular endurance in different cohorts and using additional outcome measures.
**Maintenance of training-induced adaptations after cessation of supervised training**

Despite the abundance of evidence supporting improvements in various adaptive outcomes following supervised training interventions in a laboratory setting, there is limited evidence supporting continued exercise involvement and adherence after the cessation of supervised training (i.e. under “free-living” conditions). Given the time-efficient and feasible nature of whole-body Tabata and the positive psychological and affective responses associated with interval exercise (Jung et al. 2014; Stork et al. 2017; Townsend et al. 2017), we speculated that individuals in the Tabata group would continue to engage in this type of exercise resulting in the maintenance (or possible continued improvement) of training-induced adaptations at FU. However, training-induced improvements in cardiorespiratory fitness were diminished in the Tabata group at FU with only push-up performance remaining significantly elevated at FU. Since physical activity levels were not monitored between POST and FU it is unclear whether the maintenance of cardiorespiratory fitness at FU in VICT was attributable solely to a greater exercise adherence in this group (or vice versa for the Tabata group). For instance, it is also possible that the larger VICT-induced increases in aerobic exercise performance at POST may have facilitated the maintenance of training adaptations at FU, whereas the smaller improvements in the same variables after Tabata rapidly diminished after cessation of training. Nevertheless, the diminishment of training adaptations in the Tabata group at FU suggests that the time-efficient and feasible nature of this protocol does not necessarily lead to its adoption under free-living conditions.

We deliberately chose not to track physical activity levels during the period between POST and FU and instead chose to rely on indices of cardiorespiratory fitness as objective markers of exercise adherence. This decision was based on the rapidity by which aerobic power declines following cessation of training (Mujika and Padilla 2001), and the ability of both continuous
(Madsen et al. 1993) and intermittent (Rønnestad et al. 2014) exercise to mitigate this decline. Moreover, since training-induced gains in aerobic power can be maintained even when training frequency (Hickson and Rosenkoetter 1981) and/or duration (Hickson et al. 1982) are substantially reduced, we expected that any continued involvement in physical activity (even at a lower dose than that prescribed during the intervention period) would have been reflected in the maintenance of cardiorespiratory fitness at FU.

**Individual responses to VICT and Tabata**

The growing awareness of heterogeneity in the observed responses to standardized exercise training has led to considerable interest and debate surrounding the characterization of individuals as “responders”, “uncertain responders”, or “non-responders” (Hecksteden et al. 2018; Bonafiglia et al. 2018; Ross et al. 2019; Atkinson et al. 2019). Although numerous recent reports have utilized a variety of methods to classify individual response profiles to training (Swinton et al. 2018; Hecksteden et al. 2018; Bonafiglia et al. 2018, 2019), these approaches have been criticized based on the notion that responder counts are simply a reflection of differences in mean responses and do not provide information regarding true inter-individual variability in the responsiveness to exercise *per se* (Atkinson et al. 2019). Our observations of more favorable response profiles for indices of cardiorespiratory fitness in the VICT group, and for push-up performance in the Tabata group at POST and FU (Table 3) mirror the between-group differences in mean responses for these variables (Figure 2). Importantly, these results highlight the issues with making inferences regarding trainability and/or responsiveness to exercise *per se* based on responder counts and provide a physiological example of the coupling between the magnitude of mean response and the proportion of individual responders (Atkinson et al. 2019).
Limitations

Although the present work provides important information regarding the maintenance of training-induced adaptations following cessation of supervised training in young adults who fail to meet current physical activity guidelines, the findings reported must be interpreted with the following limitations in mind. First, as we did not track free living physical activity during the two-month period between POST and FU, we are unable to confidently comment on the reasons for the between-group differences in the maintenance/diminishment of training adaptations at FU. One explanation could be the absence of recommendations regarding interval exercise protocols (e.g. Tabata) in the Canadian Physical Activity Guidelines pamphlet leading to differential adherence to VICT and Tabata from POST to FU. Second, the short duration of the training period and the resulting magnitude of training adaptations observed in the current study likely limited our ability to make between-group comparisons with the current sample size. Third, although our VO₂peak protocols produce low coefficients of variation and high test-retest reliability (Edgett et al. 2018), it is possible that the VO₂peak value for the VICT group at POST constitutes an extreme and random data point and thus represents regression to the mean. However, the lack of relationship between baseline and training-induced changes in VO₂peak in the VICT group \( (r=-0.20, p>0.05) \), suggests that the increase in VO₂peak following VICT is not attributable to regression to the mean. It should also be noted that order of muscular endurance tests was not randomized making it possible that test order may have influenced our findings. Finally, although the predominantly female population in the current study is a strength of the current work (as this population is relatively understudied compared to males), we acknowledge that the lack of standardization of menstrual phase may have impacted our findings due to potential of sex
differences in the adaptive responses to SIT (Gibala et al. 2014). Thus, future work examining physiological adaptations to training in females should consider and control for the potential impact of menstrual cycle phase on trainability.

**Conclusions**

Taken together, our findings suggest that both VICT and whole-body Tabata are useful exercise strategies for improving indices of cardiorespiratory fitness in adults who do not meet physical activity guidelines. However, the apparent time-efficiency of whole-body Tabata for achieving similar adaptive outcomes as VICT is not supported by the current work as improvements in cardiorespiratory fitness were more pronounced and only sustained at FU in the VICT group. Nevertheless, whole-body Tabata did confer greater benefit for some indices of muscular endurance, which is noteworthy given the low-volume, time-efficient, and feasible nature of this protocol and the importance of muscular fitness for cardiometabolic health. In addition, we found that individual response profile paralleled group-level changes in cardiorespiratory fitness and muscular endurance. Future studies are warranted to further explore the comparative benefits of whole-body Tabata and VICT for the improvement and maintenance of training-induced adaptations using longer training interventions, larger sample sizes, and additional outcome measures.

**Conflict of interest**

None.
References


Sloth, M., Sloth, D., Overgaard, K., and Dalgas, U. 2013. Effects of sprint interval training on VO\textsubscript{2max} and aerobic exercise performance: A systematic review and meta-analysis: Effects of


Table 1. Participant characteristics.

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<tr>
<th></th>
<th>CTL</th>
<th>Tabata</th>
<th>VICT</th>
</tr>
</thead>
<tbody>
<tr>
<td>n (M)</td>
<td>15 (2)</td>
<td>27 (6)</td>
<td>26 (8)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>21±4</td>
<td>21±3</td>
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<td>Height (cm)</td>
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<td>Weight (kg)</td>
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<td>71±13</td>
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<tr>
<td>BMI (kg/m^2)</td>
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<td>25±4</td>
<td>28±6</td>
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<tr>
<td>VO_{peak} (mL/kg/min)</td>
<td>42±6</td>
<td>43±6</td>
<td>39±7</td>
</tr>
</tbody>
</table>

Note: values are mean±SD. BMI: body mass index; CTL: control; M: males; VICT: vigorous-intensity continuous training; VO_{peak}: peak oxygen uptake.
Table 2. Group means and statistics for all variables at baseline (PRE), post-test (POST), and 2-month follow-up (FU).

<table>
<thead>
<tr>
<th>Variable</th>
<th>PRE</th>
<th>POST</th>
<th>FU</th>
<th>RM ANOVA (p-value)</th>
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<tbody>
<tr>
<td></td>
<td>CTL</td>
<td>VICT</td>
<td>Tabata</td>
<td>CTL</td>
</tr>
<tr>
<td>VO$_{2peak}$ (mL/kg/min)</td>
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<td>39±7</td>
<td>43±6</td>
<td>43±5</td>
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<td>TTF (sec)</td>
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<td>1000±103</td>
<td>1057±102</td>
<td>1031±86</td>
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<td>TT (sec)</td>
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<td>2425±396</td>
<td>2227±417</td>
<td>2183±272</td>
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<td>Back extension (sec)</td>
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<td>60±35</td>
<td>93±53a</td>
<td>90±49</td>
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<td>Push-up (reps)</td>
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<td>Right plank (sec)</td>
<td>79±35</td>
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<td>83±49</td>
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Note: values are mean±SD. CTL: control; VICT: vigorous-intensity continuous training; TT: 5 km time-trial; TTF: ramp test time-to-fatigue; VO$_{2peak}$: peak oxygen uptake. a significantly different from VICT at PRE (one-way ANOVA); * significant within-group difference versus PRE; † significant within-time-point different versus the other exercise group (Bonferroni post-hoc); p<0.05.
Table 3. Number of likely responders (R), and uncertain/non-responders (UNR) in each group.

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Note: * denotes significant between-group differences in the proportion of R and UNR based on the Marascuilo procedure.
Figure Legends

**Figure 1.** Flow chart depicting participant, recruitment, randomization, drop-outs, and completion. *Note:* CTL: control; VICT: vigorous-intensity continuous training. Participants were excluded for not meeting the inclusion criteria for one or more of the following reasons: were not between 18-30 years of age, were current smokers, had a history of cardiometabolic disease, were currently on medication, were currently involved in a training program, and/or had observed VO\(_2\)peak values of <50 (males) or <45 (females) ml/kg/min.

**Figure 2.** Group-level and individual changes in peak oxygen uptake (VO\(_2\)peak) (A: group means; B: VICT; C: Tabata), time-to-fatigue (TTF) (D: group means; E: VICT; F: Tabata), and 5 km time-trial performance (TT) (G: group means; H: VICT; I: Tabata) from baseline to post-test (PRE-POST) and two-month follow-up (PRE-FU). *Note:* Likely “responders” (CI>0), “uncertain responders” (CI overlap with 0) and “non-responders” (CI<0) are represented by grey, white, and black circles, respectively. * significant between-group differences in change scores (p<0.05).
Figure 1. Flow chart depicting participant, recruitment, randomization, drop-outs, and completion. Note: CTL: control; VICT: vigorous-intensity continuous training. Participants were excluded for not meeting the inclusion criteria for one or more of the following reasons: were not between 18-30 years of age, were current smokers, had a history of cardiometabolic disease, were currently on medication, were currently involved in a training program, and/or had observed VO2peak values of <50 (males) or <45 (females) ml/kg/min.

337x189mm (300 x 300 DPI)
Figure 2. Group-level and individual changes in peak oxygen uptake (VO$_{2}$peak) (A: group means; B: VICT; C: Tabata), time-to-fatigue (TTF) (D: group means; E: VICT; F: Tabata), and 5 km time-trial performance (TT) (G: group means; H: VICT; I: Tabata) from baseline to post-test (PRE-POST) and two-month follow-up (PRE-FU). Note: Likely “responders” (CI>0), “uncertain responders” (CI overlap with 0) and “non-responders” (CI<0) are represented by grey, white, and black circles, respectively. * significant between-group differences in change scores ($p<0.05$).