Extremely low volume, whole-body aerobic–resistance training improves aerobic fitness and muscular endurance in females

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Abstract: The current study evaluated changes in aerobic fitness and muscular endurance following endurance training and very low volume, whole-body, high-intensity, interval-style aerobic–resistance training. Subjects' enjoyment and implementation intentions were also examined prior to and following training. Subjects (22 recreationally active females (20.3 ± 1.4 years)) completed 4 weeks of exercise training 4 days per week consisting of either 30 min of endurance treadmill training (~85% maximal heart rate; $n = 7$) or whole-body aerobic–resistance training involving one set of 8 × 20 s of a single exercise (burpees, jumping jacks, mountain climbers, or squat thrusts) separated by 10 s of rest per session ($n = 7$). A third group was assigned to a nontraining control group ($n = 8$). Following training, $\dot{V}O_{2peak}$ was increased in both the endurance (~7%) and interval (~8%) groups ($p < 0.05$), whereas muscle endurance was improved ($p < 0.05$) in the interval group (leg extensions, +40%; chest presses, +207%; sit-ups, +64%; push-ups, +135%; and back extensions, +75%). Perceived enjoyment of, and intentions to engage in, very low volume, high-intensity, whole-body interval exercise were both increased following training ($p < 0.05$). No significant changes were observed for any variable in the control (nontraining) group. These data demonstrate that although improvements in cardiovascular fitness are induced by both endurance and extremely low volume interval-style training, whole-body aerobic–resistance training imparted addition benefit in the form of improved skeletal muscle endurance.

Key words: VO_{2peak}, exercise training, whole-body exercise, high-intensity interval training, muscle endurance.

Résumé : Cette étude évalue les modifications de la condition aérobie et de l'endurance musculaire à la suite d'un programme d'entraînement à l'endurance et d'un programme d'entraînement aérobie–contre résistance à faible volume mobilisant tout l'organisme au moyen d'exercices d'intensité élevée effectués par intervalles. Avant et après les programmes d'entraînement, on évalue le plaisir et les intentions de s'y mettre. Les sujets (22 femmes actives par loisir et âgées de 20,3 ± 1,4 an participent à 4 semaines d'entraînement physique à raison de 4 jours par semaine et comprenant soit 30 min d'endurance sur un tapis roulant (~85 % de la fréquence cardiaque maximale; $n = 7$) ou, en une séance, des exercices sollicitant tout l'organisme en mode aérobie–contre résistance et comprenant une série de huit exercices uniques (sauts de grenouille, sauts avec écart, grimper de montagne au sol ou des accroupissements suivis d'une poussée) réalisés en 20 s, mais intercalés de 10 s de repos ($n = 7$). Un troisième groupe ($n = 8$) ne s'entraînant pas et sert de contrôle. À la suite des programmes d'entraînement, on observe une augmentation du $\dot{V}O_2$ de crête ($p < 0,05$) chez le groupe d'endurance (~7 %) et le groupe d'exercices par intervalles (~8 %); on observe une augmentation de l'endurance ($p < 0,05$) chez le groupe par intervalles (extension des jambes, 40 %; développé pectoral, 207 %; redressements assis, 64 %; pompes, 135 %; et extension du dos, 75 %). À la suite des programmes d'entraînement, on observe une augmentation du plaisir et des intentions de s'entraîner par intervalles au moyen d'exercices d'intensité élevée à faible volume mobilisant tout l'organisme ($p < 0,05$). Dans le groupe de contrôle, on n'observe aucune modification significative de ces variables. D'après ces observations, l'amélioration de la condition physique cardiovasculaire est présente dans les deux programmes d'entraînement, mais le programme d'entraînement aérobie–contre résistance sollicitant tout l'organisme a l'avantage de susciter une amélioration de l'endurance musculosquelettique.

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Mots-clés : $V O_2$ de crête, entraînement physique, exercice global, entraînement par intervalle d'intensité élevée, endurance musculaire.

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Introduction

Regular exercise improves health and lowers risk of several chronic diseases (Blair et al. 1989, 1995, 1996). Improvements in both aerobic fitness and muscular performance (i.e., muscular strength and endurance) are linked with many of the beneficial effects of exercise (Brill et al. 2000; Warburton et al. 2006). Unfortunately, low rates of physical activity are prominent in North America (Colley et al. 2011). Lack of time has been reported to be the most frequent barrier to regular exercise participation regardless of age, sex, socioeconomic status, and ethnicity (Godin et al. 1994; Trost et al. 2002). Recent evidence indicates that high-intensity exercise may be a time-efficient exercise stimulus for improving aerobic fitness and health (Babraj et al. 2009; Burgomaster et al. 2008) and may also elicit greater adherence than more traditional, longer duration, low-intensity training (King et al. 1995; Bartlett et al. 2011).

Tabata et al. (1996) demonstrated that intermittent training on a cycle ergometer, utilizing a protocol consisting of 7–8 × 20 s intervals separated by 10 s of rest, induced improvements in both aerobic fitness and anaerobic capacity with a very minimal time commitment (i.e., a total exercise time of ~4 min). Although this protocol, subsequently termed the "Tabata protocol", has not been studied further in humans, the work-to-rest ratio utilized in this protocol can easily be adapted for use with whole-body exercises. Given the similarities between "Tabata intervals" and traditional resistance training (i.e., high-intensity exercise, short-duration intervals), it is possible that whole-body exercise utilizing Tabata intervals may represent both a potent aerobic stimulus and a form of resistance training. This form of training could therefore represent an attractive and time-efficient health-enhancing strategy targeting several components of fitness. It is currently unclear if the limited exercise dose (time and total work) associated with this protocol is sufficient to induce improvements in both aerobic capacity and muscular performance. If this style of aerobic–resistance interval training were able to induce such adaptations, it may represent an alternative exercise training paradigm that could improve health with minimal time and equipment requirements.

In addition, although females have been included in some mixed-sex exercise training studies (e.g., (Burgomaster et al. 2008; Gurd et al. 2010)), and the efficacy of several models of interval training has been demonstrated (Talanian et al. 2007; Metcalfe et al. 2012), there are few studies examining adaptations to fitness and (or) muscle performance following low-volume, high-intensity interval training in females. It is therefore unclear whether females might benefit from low-volume, high-intensity interval-style training.

The primary purpose of this study was to evaluate changes in aerobic fitness and muscular performance induced by whole-body exercise training — based on the protocol established by Tabata et al. (1996) — in young healthy females and compare these changes with those induced by traditional endurance training. We hypothesized that aerobic fitness would be improved following both endurance and whole-body interval training, but only interval training would improve muscle endurance.

The time efficiency of the Tabata protocol (~4 min of exercise per session) may also make it an appealing exercise alternative for increasing exercise adherence. At present, although there is some evidence that high-intensity interval training may be perceived as enjoyable (Bartlett et al. 2011; Little et al. 2011*a*), we are unaware of any data examining the impact of whole-body, high-intensity interval training on predictors of adherence to this form of training in females. Thus our secondary purpose was to examine subjects' enjoyment and implementation intentions (specific plans to engage in this exercise in the future) before and after training utilizing the Tabata protocol.

Methods

Study design

The study consisted of baseline assessment of physiological and psychological parameters, one of two 4-week exercise training interventions or a time-matched control period, and posttraining testing. The details of each phase are described below. Baseline testing was completed ~1 week before training. Posttraining testing was completed in an identical fashion to baseline testing ~48–72 h after the final training session. An additional control group was recruited wherein subjects completed pre- and post-testing 4 weeks apart with no exercise intervention. Control group subjects were of similar age and fitness to the training group subjects and were instructed to maintain their current levels of recreational physical activity throughout the study.

Subjects

Female students studying at Queen's University (n = 25) volunteered to participate in this study. All subjects were recreationally active (performing between 1 and 3 h of structured aerobic activity per week) prior to volunteering for the study. Subject characteristics are shown in Table 1. Two subjects in the endurance training group did not complete training due to foot and knee pain incurred during treadmill running that made completion of the study intolerable. One subject in the Tabata training group did not complete the study due to an injury that took place outside the study. All data associated with these subjects were excluded in the final analysis. The remaining subjects in the training groups (endurance, n = 7; Tabata, n = 7) completed all 16 training sessions over the 4-week training period. All subjects recruited to the control group (n = 8) completed both pre- and post-testing. To confirm that no change in activity occurred in the control group throughout their involvement in the study, repeated physical activity recall (PAR) questionnaires were ad-

Table 1. Subject characteristics before (pre) and after (post) training.

	Control		Endurance		Tabata	
	Pre	Post	Pre	Post	Pre	Post
Age, years	19.2±0.9	—	21.1±2.8	—	20.7±1.0	—
Height, cm	164±5	—	163±5	—	168±8	—
Mass, kg	60.4±4.8	59.9±5.2	63.8±2.9	63.0±2.8	66.7±15.6	66.7±14.7
$\dot{V}O_{2peak}$, mL·min^{-1}·kg^{-1}	47±4.5	46±6.1	45±5.0	48±3.0*	43±7.6	46±7.8*
Bruce protocol TTF, s	825±87.3	783±122.2	833±85.8	934±80.1*	805±121.4	879±94.9*
Cunningham–Faulkner, s	64±10.2	63±8.3	69±11.0	70±9.0	62±11.5	72±15.7

*Significantly different ($p < 0.05$) from pretraining value.

ministered. No change in the amount of activity reported by the control group was observed. The study was approved by the Health Sciences Human Research Ethics Board at Queen's University, and all subjects provided written informed consent.

Training protocol–intervention

The endurance group completed 30 min of treadmill running at ~85% of maximal heart rate (HR_{max}; determined as the highest HR observed during the pretesting $\dot{V}O_{2peak}$ or Cunningham–Faulkner tests) 4 days per week for 4 weeks. Speed and incline were adjusted throughout the training period such that the target HR was met in all training sessions. In the Tabata training group, subjects trained four times per week for 4 weeks using a novel model of exercise training similar to calisthenics or circuit-type training. Specifically, subjects completed a single set of whole-body aerobic–resistance training intervals (8 × 20 s intervals separated by 10 s of rest) on each training day. A different exercise was performed on each training day. Exercises utilized (burpees, mountain climbers, jumping jacks, and squat and thrusts (using a 2.25 kg dumbbell)) were chosen because they require no or minimal exercise equipment and target several large muscle groups. It is important to note that on each training day, only one exercise was performed, resulting in a total exercise time of ~4 min per session. Subjects were encouraged to perform as many repetitions (reps) per interval as possible while maintaining correct form. Prior to every training session, regardless of training group, subjects performed a standard warm-up that consisted of walking down and then up five flights of stairs.

Immediately following each set of eight intervals, subjects reported ratings of perceived exertion (RPE; scale of 6 (nothing) to 20 (maximal); Borg 1970), a fatigue rating for their upper body (from 1 (minimal) to 10 (maximal)), and a fatigue rating for their lower body (from 1 (minimal) to 10 (maximal)). Heart rate data were collected during the warm-up and throughout all training sessions (Polar Team^2 Pro, Lachine, Quebec, Canada).

Physiological testing

Prior to training, all subjects underwent two consecutive days of physiological testing. The order of testing days was randomized and counterbalanced such that half of participants completed testing day A first and the other half completed testing day B first (details of both testing days are below). All subjects were familiarized with fitness and muscular endurance tests prior to baseline testing. On the first day of testing, all subjects completed a series of questionnaires (described below), and anthropometric measures (height and body mass) were taken. Physiological testing was repeated 48–72 h after completion of the final training session. The order and time of day for testing days was the same for pre- and post-training within each subject. Subjects were instructed not to change dietary habits throughout the study and not to consume alcohol or caffeine or exercise for 24 h prior to any testing protocol. Water was provided freely during all testing days.

Testing Day A

Grip strength was assessed using a handgrip dynamometer (JAMAR Hydraulic Hand Dynamometer, Sammons Preston Inc., Bolingbrook, Illinois), while back and chest muscular endurance (reps completed before volitional fatigue) were assessed via pull downs (at 45% body mass) and chest-presses (at 30% body mass), respectively.

Tests were performed on a pull-down machine and a chest-press machine (Customized Equalizer 1000 series, Equalizer Exercise Machines, Red Deer, Alberta, Canada). Abdominal endurance was assessed by having subjects perform curl-ups (sit-ups) to volitional fatigue. All exercises were performed at a rate of 25 reps per minute (rpm), with subjects resting between tests until they felt comfortable with beginning the next test.

Following completion the muscle endurance testing, subjects were allowed to rest for as long as they wished (~30 min) before anaerobic capacity was assessed using the Cunningham–Faulkner test (6300 Treadmill, SportsArt Fitness, Tainan City, Taiwan, Republic of China). This rest time was recorded and kept the same within each subject for posttesting. Following a 3-min warm-up period (grade, 2%; speed, 3 miles per hour (mph)), the treadmill grade was increased to 15%, while speed was increased to 7 mph. Due to safety concerns, three participants were unable to complete the test at the original speed; for these subjects, the test was modified by decreasing the speed to 6 or 6.5 mph as appropriate. Where modifications were made, the modified speed was held constant for both pre- and post-training tests. Subjects were instructed to run for as long as possible, and the time at volitional fatigue was recorded.

Testing Day B

Quadricep endurance and hamstring endurance were assessed using leg extension (at 85% of body mass) and leg curl (at 75% of body mass) tests, respectively. Both tests were performed on a leg extension – leg curl machine (INSTINCT Dual Leg Extension/Leg Curl, STAR TRAC, Irvine, California). Subjects performed repetitions of either exercise at a rate of 25 rpm to volitional fatigue. Push-ups were performed at a rate of 30 rpm also to volitional fatigue. Back-extension endurance was tested by having participants lie in a prone position and extend both the hips and shoulders while maintaining the shoulders, hips, and ankles in line. The test was terminated when proper position could no longer be maintained or upon volitional fatigue.

As on testing day A, following muscle endurance testing, subjects were allowed to rest for as long as they wished (~30 min) before completing a maximal oxygen uptake ($\dot{V}O_{2peak}$) test performed on a treadmill, using a modified Bruce protocol (Bruce et al. 1973). Heart rate and gas exchange were collected throughout the entire test using a Moxus Modular $\dot{V}O_2$ system (Moxus metabolic cart, AEI Technologies, Pittsburgh, Pennsylvania). Resting data were collected for 3 min prior to warm-up. Warm-up was completed at an incline of 2% and a speed of 2.5 mph for 3 min. Following warm-up, grade increased 2% every 3 min, with speed increasing from 2 mph in warm-up to 4 mph in stage 1, 5 mph in stage 2, and 5.5 mph for the remainder of the test. The test was terminated when the subject reached volitional fatigue. Attainment of $\dot{V}O_{2peak}$ was verified by a RER value greater than 1.1 or by achieving age-predicted HR_{max} (220 – age). We did not consistently observe a plateau in the $\dot{V}O_2$ response during the ramp protocol. $\dot{V}O_{2peak}$ was calculated by averaging the $\dot{V}O_2$ values from the final 30 s of the protocol.

Activity and psychological surveys

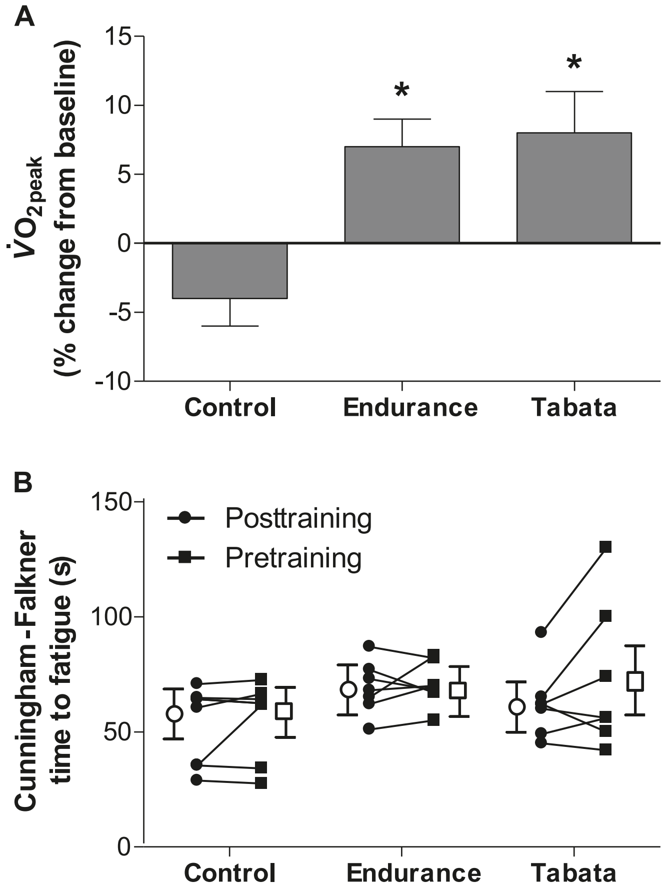
At baseline, on day 1 of each week of training (or control period), and during posttesting, participants were asked to complete a 7-day PAR questionnaire. Subjects were asked to recall any activity that they had undertaken outside the study training sessions over the previous 7 days. The questionnaire used was adapted from Sallis et al. (1985).

On the first testing day at baseline and posttraining, subjects assigned to the Tabata training group were asked to complete a questionnaire designed to examine enjoyment of, and implementation intentions for, whole-body interval training. Specifically, the following measures were taken at both time points. (*i*) Exercise enjoyment. Using a single-item measure of enjoyment, subjects were asked "how enjoyable is it for you to complete 4 min of whole-body, high-intensity exercise four times per week?" using a 10-point Likert-type scale, ranging from 1 (not enjoyable at all) to 10 (extremely enjoyable). (*ii*) Intentions. Subject's intentions to add the 4-min whole-body, high-intensity exercise routine performed in this study to their weekly schedule after the completion of the study was also examined. Two items were used to assess participant's intentions to implement this training into their routine: (*i*) once per week, and (*ii*) three times per week. Responses were made on a 10-point Likert-type scale, ranging from 1 (strongly disagree) to 10 (strongly agree).

Statistical analysis

All results are expressed as mean ± standard deviation, and the level of significance was established as $p < 0.05$. $\dot{V}O_{2peak}$, the Cunningham–Faulkner test, all strength–endurance measures, results of the psychological questionnaires, and the results of the 7-day PAR across the 4 weeks of training and control were analyzed by two-factor (group × time) ANOVA with repeated measures on the second factor. A two-factor (exercise × week) repeated measures ANOVA was used to analyze the HR response, RPE, fatigue index, and number of reps completed for each exercise across the 4 weeks of training within the Tabata group. For significant F tests, Student–Neuman–Keuls post hoc tests were used to make pairwise comparisons.

Fig. 1. $\dot{V}O_{2peak}$ is improved following both endurance and Tabata training. (A) Percent change in $\dot{V}O_{2peak}$ (expressed relative to baseline testing) is shown for the control, endurance, and Tabata groups, as well as (B) individual responses to the Cunningham–Falkner test. *, significantly different ($p < 0.05$) from pretraining testing.



Results

Physiological testing

Following training, the time to fatigue during the modified Bruce protocol increased significantly in both the endurance ($p < 0.05$) and Tabata ($p < 0.05$) groups (Table 1). This was accompanied by an associated increase ($p < 0.05$) in $\dot{V}O_{2peak}$ of ~7%–8% (Table 1; Fig. 1). The changes between pre- and post-testing observed in the endurance and Tabata groups were not different from each other ($p > 0.05$), and no change was observed between pre- and post-testing for $\dot{V}O_{2peak}$ in the control group.

No differences were observed between control and trained subjects at baseline, and there were no posttesting changes in the control group for any of the variables tested. In the endurance-trained group, a significant improvement for muscle endurance was only observed in a modest increase (+3.1 reps, ~17%; $p < 0.05$) for lat pulldowns. In the Tabata group, the maximum number of leg extensions increased ($p < 0.05$) by 40%, while the maximum number of leg curls remained unchanged (Fig. 2A). The maximum number of pulldowns was unchanged, while chest press reps increased ($p < 0.05$) by 207% and push-ups increased ($p < 0.05$) by 135% (Fig. 2B). Finally, there were significant increases ($p < 0.05$ for all) in the number of sit-ups performed (+64%) and for back extension time (+175%) (Fig. 2C). The increases observed for leg extensions, chest presses, push-ups, sit-ups, and back extensions in the Tabata group were significantly greater ($p < 0.05$ for all) than the changes in both the control and endurance groups. No changes were observed for time to fatigue during the Cunningham–Faulkner test (Table 1; Fig. 1) or maximal grip strength in any group.

Physical activity and psychological questionnaires

No differences were observed for self-reported physical activity performed outside the study between any of the weeks examined (pretraining, weeks 1–4 of the intervention, and posttraining) for any group (data not shown). Perceived enjoyment of high-intensity, whole-body exercise increased posttraining compared with pretraining ($p < 0.05$; Table 2). Subjects also reported greater intentions to engage in whole-body, high-intensity exercise once, but not three times, per week upon completion of the study ($p < 0.05$; Table 2).

Characterization of training sessions

Although the total number of burpees performed during each training session did not change (week 1, 33 ± 5; week 4, 37 ± 8), there were significant ($p < 0.05$) increases for the total number of mountain climbers (week 1, 29 ± 5; week 4, 38 ± 7), jumping jacks (week 1, 160 ± 39; week 4, 206 ± 56), and squat and thrusts (week 1, 76 ± 12; week 4, 95 ± 12).

The mean HR (presented as % HR_{max}) elicited by burpees was greater ($p < 0.05$) in week 1 (92 ± 4) than in weeks 2, 3, and 4 (88 ± 5). Across all four weeks of training, burpees elicited an average RPE of 16.9 ± 1.6, an upper-body fatigue index (UBFI) of 7.1 ± 1.2, and lower-body fatigue index (LBFI) of 6.8 ± 1.6. No significant differences across training weeks were observed for mountain climbers (HR, 84 ± 4; RPE, 17.3 ± 1.4; UBFI, 8.5 ± 1.0; LBFI, 6.8 ± 1.6), jumping jacks (HR, 86 ± 6; RPE, 13.3 ± 1.8; UBFI, 3.7 ± 1.4; LBFI, 4.3 ± 1.5), or squat and thrusts (HR, 83 ± 6; RPE, 16.1 ± 2.0; UBFI, 7.9 ± 1.5; LBFI, 6.5 ± 1.5). The mean HR response was significantly greater ($p < 0.05$) for burpees than for all other exercises, while RPE, UBFI, and LBFI were lower ($p < 0.05$) for jumping jacks than for the other three exercises.

Discussion

In the current study, we compared changes in aerobic and anaerobic fitness and muscular endurance induced by continuous endurance training with changes following training utilizing whole-body aerobic–resistance interval training based on the Tabata protocol (Tabata et al. 1996) in females. The major findings are that training using the modified Tabata protocol for 4 weeks (*i*) improved aerobic fitness ($\dot{V}O_{2peak}$) to the same degree as 30 min per day of continuous high-intensity treadmill running, and (*ii*) improved lower-body, upper-body, and core muscular endurance while endurance training had no effect. These findings demonstrate that whole-body interval training provides additional benefit (im-

Fig. 2. Changes in lower- and upper-body muscular endurance following endurance and Tabata training. Changes in maximal repetitions (max reps) from pretraining testing for (A) lower-body muscular endurance (leg extensions and leg curls), (B) upper-body muscle endurance (lat pulldowns, chest press, and push-ups), and (C) core strength (sit-ups and back extensions) are shown. *, significantly different ($p < 0.05$) from pretraining testing.

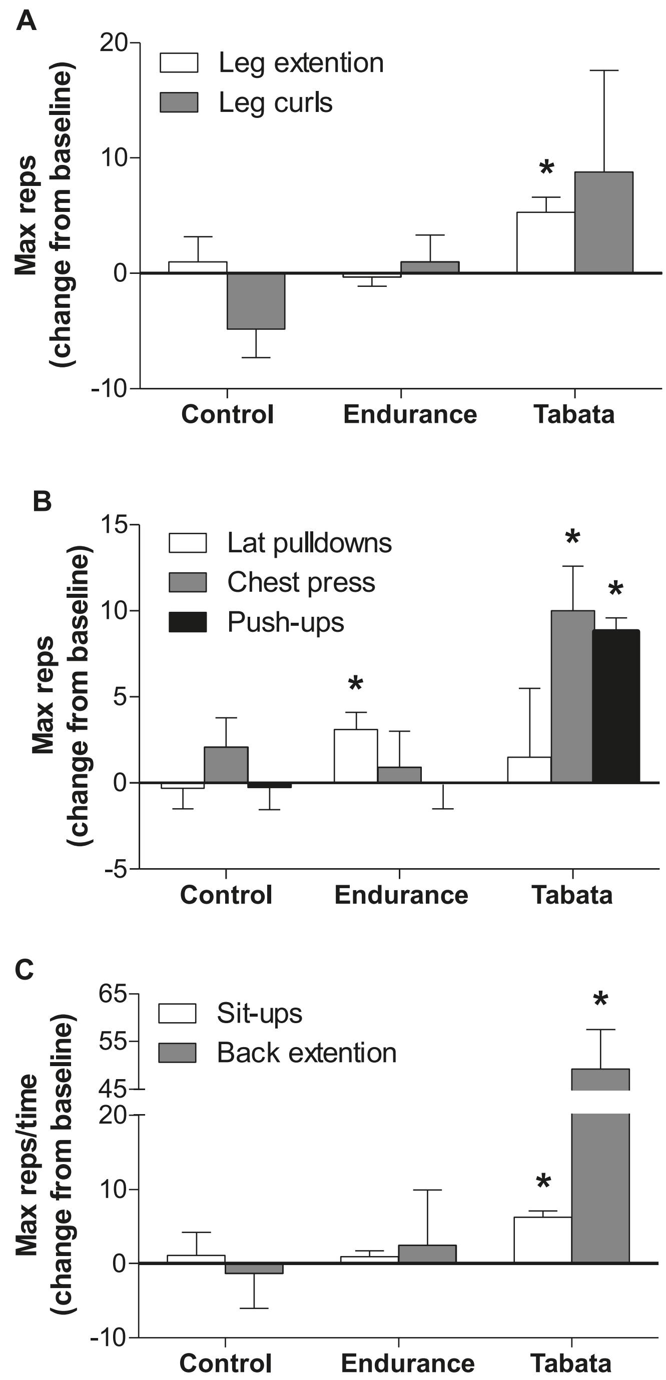


Table 2. Perceived enjoyment and intentions to implement from before (pre) and after (post) training for the Tabata group.

	Tabata	
	Pre	Post
Perceived enjoyment	6.1±1.4	7.1±1.6*
Intentions to implement (once per week)	7.4±1.1	8.7±1.1*
Intentions to implement (three times per week)	6.7±1.6	7.0±1.2

*Significantly different ($p < 0.05$) from pretraining value.

proved muscle endurance) when compared with continuous exercise. Further, it would appear that the minimal dose of high-intensity exercise required to improve both aerobic capacity and muscle performance lies at or below 4 min per day, 4 days per week.

Whole-body interval training and aerobic fitness

Although the ability of endurance training to increase aerobic fitness is well established (Blair et al. 1989, 1995, 1996), an emerging body of evidence suggests that high-intensity interval training is as effective, if not more effective, at inducing improvements in aerobic fitness ($\dot{V}O_{2peak}$) (Poole and Gaesser 1985; Gorostiaga et al. 1991; Burke et al. 1994; Tabata et al. 1996; MacDougall et al. 1998; Harmer et al. 2000; Burgomaster et al. 2008; McKay et al. 2009; Gurd et al. 2010; Macpherson et al. 2011). In the current study, we utilized a training protocol consisting of 8 × 20 s intervals of whole-body aerobic–resistance exercise separated by 10 s of rest. Although the work-to-rest ratio utilized was adapted from the work of Tabata et al. (1996), we have demonstrated that this protocol is able to enhance aerobic capacity using a novel mode of exercise (whole-body aerobic–resistance exercise). While the original work utilized a work rate corresponding to 170% $\dot{V}O_{2peak}$, we are unable to comment with certainty on the intensity of the current protocol except to state that subjects were instructed to perform as many reps as possible and that all exercises elicited mean HR responses above 80% HR_{max}. These results are consistent with the notion that short-duration, high-intensity interval training is an effective stimulus to increase aerobic fitness. Our novel findings extend previous work by indicating that improvements in aerobic fitness can occur following extremely low volume (4 min per day, 4 days per week), whole-body aerobic–resistance training that is not specific to the modality of exercise used for testing.

At present, the mechanisms underlying this increase in $\dot{V}O_{2peak}$ are unclear. Interestingly, improvements in skeletal muscle markers of mitochondrial content and function in swim-trained rats have been demonstrated following a similar protocol to that used in the current study (Terada et al. 2001, 2004, 2005). Similar metabolic adaptations have also been observed in humans performing 2–6 weeks of training involving three weekly sessions of 4–6 × 30 s bouts of maximal exertion on a cycle ergometer (Burgomaster et al. 2005, 2007, 2008; Gibala et al. 2006). These metabolic adaptations within skeletal muscle following high-intensity interval training occur through complex pathways including the signaling molecules CAMK, AMPK, SIRT1, and PGC-1α (Gibala 2009; Wright et al. 2007; Little et al. 2011*b*; Gurd et al. 2011). Although these pathways were likely activated during whole-body intervals resulting in elevated muscle oxidative capacity contributing to the improvements in aerobic capacity observed in the present study, these increases in muscle metabolic function have yet to be confirmed. In addition, cardiovascular adaptations may also contribute to the observed improvements in aerobic fitness; however, recent evidence suggests that short-duration interval training does not appear to improve maximal cardiac output (Macpherson et al. 2011). Further research is needed before the mechanisms underlying aerobic adaptations to short-term, whole-body aerobic–resistance interval training are fully understood.

In contrast to the results of Tabata et al. (1996), anaerobic capacity was not increased in the current study. Other studies utilizing high-intensity interval training on a cycle ergometer have demonstrated increases in anaerobic power (Linossier et al. 1993; MacDougall et al. 1998). These discrepant findings may be a result of the different modes of exercise utilized in these studies (cycling vs. whole-body exercise) or due to different tests being used to measure anaerobic capacity. In the current study, we utilized the Cunningham–Faulkner treadmill sprinting test, while Tabata et al. (1996) calculated the maximal accumulated oxygen deficit, and others calculated maximal power during a Wingate cycle ergometer test (Linossier et al. 1993; MacDougall et al. 1998). The lack of increase in anaerobic capacity may also be the result of training mode specificity, as subjects did not perform sprint running during training.

Whole-body interval training and muscular endurance

In addition to the marked increase in aerobic fitness, 4 weeks of whole-body, high-intensity interval training also resulted in an increase in muscular endurance across a variety of muscle groups (Figs. 2). We did not specifically assess muscular strength on each exercise (i.e., 1 repetition maximum), but handgrip strength did not increase following training. These finding are consistent with whole-body interval training fitting on the “strength–endurance continuum” theory of resistance exercise (Campos et al. 2002). This theory proposes that high-weight, low-repetition exercise will improve muscular strength, whereas low-weight, high-repetition exercise (similar to that performed in the current study) will improve muscular endurance (Campos et al. 2002). Although the mechanisms underlying this increase in muscle endurance were not investigated, we speculate that improvements in oxidative capacity typically observed following high-intensity interval training in skeletal muscle (Burgomaster et al. 2008; Gibala et al. 2006; Little et al. 2010) likely contributed to a decreased reliance on substrate level phosphorylation (decreased PCr breakdown, glycogen turnover, and lactate accumulation) and subsequent delays in the development of muscle fatigue. Although these mechanisms require further research, our findings demonstrate that whole-body, short-duration, high-intensity intervals, originally designed to improve aerobic fitness, can also impact muscular endurance in previously untrained females.

Predictors of behavior change before and after whole-body interval training

Regardless of how drastic the physiological changes are following any exercise training intervention, the general public is not likely to choose to engage in such activities unless they find them inherently enjoyable (Emmons and Diener 1986; Ekkekakis et al. 2008). High-intensity interval exercise has been shown to be perceived as enjoyable (Bartlett et al. 2011; Little et al. 2011*a*). Reports of physical activity enjoyment were higher after a single bout of intervals performed on a treadmill as compared with perceived physical activity enjoyment after a single bout of continuous running on a treadmill in a sample of fit, active young adults ($\dot{V}O_{2max}$ = ~57 mL·kg^{-1}·min^{-1}; Bartlett et al. 2011). To our knowledge, this is the first study to examine enjoyment and intentions for whole-body aerobic–resistance training. In the present study, perceived enjoyment of the whole-body aerobic–resistance exercise protocol increased from pre- to post-training, as did intentions to engage in this type of exercise in the future. This is a noteworthy finding given that much of the affective response – exercise intensity literature would suggest that the higher intensity prescribed in this study would be rated as not enjoyable (Ekkekakis et al. 2008). It would be informative for future work to examine and compare changes in enjoyment and implementation intentions during, and following, both interval and endurance training.

Conclusion

In recreationally active females, four weeks (4 days·week^{-1}) of very low volume, whole-body, high-intensity interval training elicited similar improvements in aerobic capacity as endurance training, but resulted in the additional benefit of increased muscular endurance. Additional research is required to examine the contributing factors and cellular pathways (presumably in skeletal muscle) that mediate these adaptations. Further studies may also wish to examine whether this type of exercise can improve markers of health in individuals at risk for developing inactivity-related diseases such as cardiovascular disease and type 2 diabetes. Given the minimal requirement for exercise equipment and the low time commitment, studies exploring adaptations and adherence to this whole-body, high-intensity interval training protocol could facilitate application to home-based exercise programs. This could have widespread impact for encouraging exercise participation and resultant improvements in health.

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