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Research article

Acute effects of three different circuit weight training protocols on blood lactate, heart rate, and rating of perceived exertion in recreationally active women

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Abstract
Interval and circuit weight training are popular training methods for maximizing time-efficiency, and are purported to deliver greater physiological benefits faster than traditional training methods. Adding interval training into a circuit weight-training workout may further enhance the benefits of circuit weight training by placing increased demands upon the cardiovascular system. Our purpose was to compare acute effects of three circuit weight training protocols 1) traditional circuit weight training, 2) aerobic circuit weight training, and 3) combined circuit weight-interval training on blood lactate (BLA), heart rate (HR), and ratings of perceived exertion (RPE). Eleven recreationally active women completed 7 exercise sessions. Session 1 included measurements of height, weight, estimated VO_{2max}, and 13 repetition maximum (RM) testing of the weight exercises. Sessions 2-4 were held on non-consecutive days for familiarization with traditional circuit weight training (TRAD), aerobic circuit weight training (ACWT), and combined circuit weight-interval training (CWIT) protocols. In sessions 5-7, TRAD, ACWT, and CWIT were performed in a randomized order ≥ 72 hr apart for measures of BLA, HR, and RPE at pre-exercise and following each of three mini-circuit weight training stations. Repeated-measures ANOVAs yielded significant interactions ($p < 0.05$) in BLA, HR, and RPE. Combined circuit weight-interval training (CWIT) produced higher BLA (7.31 ± 0.37 vs. TRAD: 3.99 ± 0.26, ACWT: 4.54 ± 0.31 $mmol·L^{-1}$), HR (83.51 ± 1.18 vs. TRAD: 70.42 ± 1.67, ACWT: 74.13 ± 1.43 $beats·min^{-1}$) and RPE (8.14 ± 0.41 vs. TRAD: 5.06 ± 0.43, ACWT: 6.15 ± 0.42) at all measures. Aerobic circuit weight training (ACWT) elicited greater RPE than traditional circuit weight training (TRAD) at all measures. Including combined circuit weight-interval training (CWIT) workouts into exercise programming may enhance fitness benefits and maximize time-efficiency more so than traditional circuit training methods.

Key words: Interval training, repetition maximum, resistance training.

Introduction

Well-organized programs that promote time efficiency are integral to those working with clients whose time is limited, and traditional training methods frequently require long periods of training to achieve desired goals (Jones et al., 2011). Exercise professionals aspire to obtain maximal results in minimal time; therefore, they continually seek training methods and protocols that will achieve set training goals in less training time (Paton et al., 2005). A training program that meets goals of performance- or health- based fitness over a shorter period is desirable for those wishing to achieve a higher fitness level quickly. Such a trend has become evident by the increased popularity and marketing of particular formulated training programs like CrossFit™, P90X™, and Insanity™. While programs such as the aforementioned are becoming more widespread, they have been relatively understudied. A common thread among them is the use of interval training in addition to or in place of more traditional aerobic training, thereby permitting greater energy expenditure and more work accomplished in a shorter time period over a single exercise session. Such training programs also adhere to the basic *overload principle* of training, wherein "plateaus" that might have been reached in traditional aerobic training are overcome by increasing the intensity of the work performed, thus resulting in improved cardiovascular and muscular adaptations to training.

Traditional circuit weight training (TRAD) (Garbutt et al., 1994; Gettman et al., 1980; Kaikkonen et al., 2000; Paoli et al., 2010; Wilmore et al., 1978), and interval training (Burgomaster et al., 2005; Fernandez-Fernandez et al., 2012; Gibala et al., 2006) are two popular exercise methods that can maximize time-efficiency while addressing several aspects of fitness. The appeal of TRAD is in the theoretical ability to enhance muscular strength and endurance as well as cardiorespiratory fitness, all in one exercise session (O'Shea, 1987; Simonson, 2010; Wilmore et al., 1978). Many have reported increased strength with only small to modest increases in maximal aerobic capacity following a TRAD program (Gettman et al., 1979; Gotshalk et al., 2004; Harber et al., 2004; Paoli et al., 2010; Waller et al., 2011). Different forms of TRAD programs have been shown to increase both blood lactate (BLA) concentrations (Garbutt et al., 1994), and heart rate (HR) values (Gotshalk et al., 2004). No studies were located that included the rating of perceived exertion (RPE) as a measured variable during TRAD.

In an attempt to increase the cardiovascular component of a TRAD session, aerobic activity has been substituted in place of the typical resting periods between sets of lifting, referred to as aerobic circuit weight training (ACWT). Studies with ACWT protocols have yielded results similar to those observed with TRAD (Gettman et al., 1982; Mosher et al., 1994), that is, increased strength, with only moderate increases in aerobic capacity. While effects of an acute ACWT protocol are similar to those of TRAD, an improved BLA response was noted following

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12 weeks of training with an ACWT program (Paoli et al., 2010).

Interval training involves performing repeated exercise bouts at maximal or supramaximal levels for short periods with each bout followed by a predetermined rest period (Burgomaster et al., 2005; Fernandez-Fernandez et al., 2012; Gibala et al., 2006; Harmer et al., 2000; Karp, 2000; Laursen et al., 2005; MacDougall et al., 1998). Interval training has been shown to increase aerobic capacity beyond that of traditional, long-duration, submaximal endurance training (Burgomaster et al. 2005; Harmer et al., 2000; MacDougall et al., 1998). In addition, interval training has resulted in increased BLA (Serpiello et al., 2011) and HR values (Gibala et al., 2006; Serpiello et al., 2011) when compared to traditional endurance training and resting values. Furthermore, high-resistance interval training (Taylor-Mason, 2005) and high-intensity interval and explosive resistance training (Paton & Hopkins, 2005) have resulted in improved cycling performance in well-trained cyclists and competitive distance runners (Hamilton et al., 2006). As a result, both athletes and recreational exercisers employ interval training as a time-efficient means of achieving greater cardiorespiratory adaptations over a shorter time frame (Fernandez-Fernandez et al., 2012; Karp, 2000).

Lactate is a key measure of exercise intensity, as high blood lactate levels are indicative of the accumulation of lactate and anaerobic energy production (Brooks et al., 2000). Blood lactate removal is one of the causes of excess post-exercise oxygen consumption (EPOC); therefore, workouts inducing high levels of blood lactate might resultantly increase EPOC, since the extent of EPOC is directly related to the intensity of the exercise (Lavinas Da Silva et al., 2010).

Though TRAD and interval training have been examined as isolated programs (Burgomaster et al., 2005; Focht, 2007; Gibala et al., 2006; Gotshalk et al., 2004; Harber et al., 2004; Paoli et al., 2010), combining both training methods into one acute workout (CWIT) has yet to be investigated. It has been suggested that adding interval training into a TRAD workout may further enhance the benefits of circuit weight training by placing increased demands upon the cardiovascular system (Abel et al., 2011; Mosher et al., 1994). While the implications of adding this level of exercise intensity to TRAD have not yet been clearly defined, it is believed that such a method may hold promise in terms of maximizing fitness benefits in a reduced amount of time (Abel et al., 2011; Mosher et al., 1994).

In summary, TRAD and interval training are commonly used methods that have recently grown in popularity among athletes and recreational exercisers alike. Yet, despite this popularity, the effect of combining the two methods into one circuit workout (CWIT) has been understudied. The purpose of this study was to determine if differences existed in BLA, HR, and RPE responses during exercise with three different circuit weight-training protocols (TRAD, ACWT, CWIT). It was hypothesized that a workout including high-intensity sprint bouts, like CWIT, would produce increased measures of BLA, HR, and RPE when compared to TRAD and ACWT protocols.

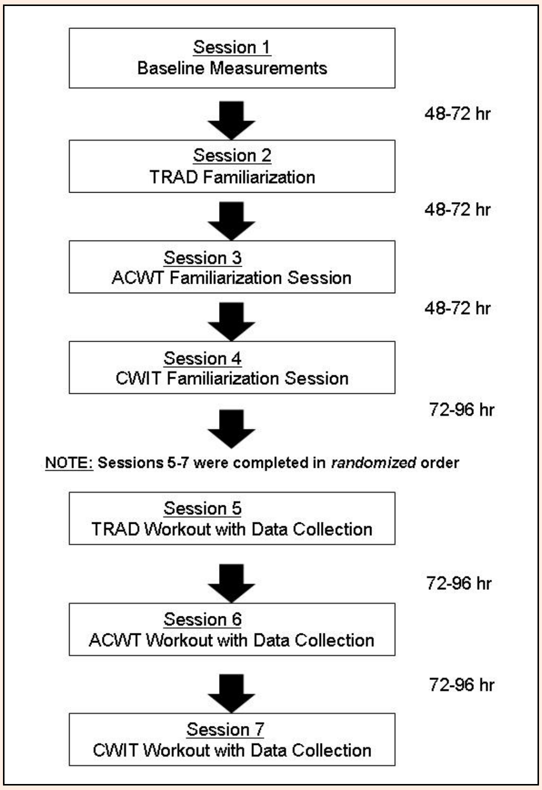

Figure 1. An overview of the study.

Methods

Experimental overview

This study was designed to examine the acute effects of three variations of circuit weight training on blood lactate (BLA), heart rate (HR), and ratings of perceived exertion (RPE) in recreationally active women. Three acute workouts of similar duration (approximately 40 minutes) included a traditional circuit weight training (TRAD) workout, an aerobic circuit weight training (ACWT) workout, and a combined circuit weight-interval training (CWIT) workout. Completion of each acute protocol took approximately 40 minutes, which represents commonly allotted exercise time by "recreationally active" individuals, but exercise intensity was higher during CWIT compared to ACWT and TRAD, respectively. During the TRAD protocol BLA and HR were recorded at pre-exercise, and following completion of each of three mini-circuit weight training stations (A^1, B^2, C^3) within the workout while RPE was recorded following completion of each of three mini-circuit stations. Measures of BLA, HR and RPE were taken immediately following completion of the aerobic bike (ACWT) or bike sprint (CWIT) for the other 2 protocols. The subjects completed 7 total exercise sessions with each separated by 48 – 96 hours. Following the initial collection of baseline measurements (Session 1), subjects completed each of the three exercise protocols (ACWT, CWIT, TRAD) on non-consecutive days for exercise familiarization purposes (Sessions 2-4). Sessions 5-7 consisted of the ACWT, CWIT, and TRAD workouts performed in randomized order (one per session) with data collection. All testing sessions were scheduled at the same time of day for each subject (see Figure 1 for the flowchart of testing sessions). Subjects were asked to refrain from making dietary modifications and were instructed not to perform any moderate or heavy exercise on the days preceding data collection sessions.

Subjects

Eleven healthy, recreationally active women (age 34.0 ± 5.3 yr, height 1.62 ± 0.05 m, mass 74.2 ± 10.6 kg, BMI 28.1 ± 3.5 $kg \cdot m^{-2}$, predicted VO_{2max} 23 ± 4 $ml \cdot kg^{-1} \cdot min^{-1}$) volunteered to participate in this study. Recreationally active was defined as ≥ 6 months aerobic exercise participation (30 min per session, 3 days per week) prior to the start of the study. All had the risks and benefits explained to them beforehand, signed an institutionally approved consent form to participate, and completed a medical history form. The Institutional Review Board for Human Subjects approved all study procedures. Current pregnancy, a severe spinal injury, or lower limb musculoskeletal injury within 6 months prior to the study was grounds for exclusion.

Procedures

Baseline measures (Session 1): Each subject reported for an initial session to attain baseline measurements, including age, height, weight (Tanita, Arlington Heights, IL, USA) and estimated VO_{2max}. The YMCA Cycle Ergometer Test was administered as a measure of aerobic fitness. This submaximal test uses age predicted HR_{max} to assist in workload determination. Estimated VO_{2max} was calculated from the American College of Sports Medicine's metabolic equations (Whaley, 2006). Additionally, at this session a 13 repetition maximum (RM) was obtained for each of the free weight exercises to be used in the three protocols (TRAD, ACWT, CWIT). Although the 13-RM test was not used to allocate percentage loads for the exercise sessions, it was necessary to determine this weight for each individual in order to determine a weight that would allow for the completion of 13 repetitions to fatigue for each exercise in the circuit.

Familiarization sessions (Sessions 2-4): Each subject reported for familiarization with the three circuit weight training exercise protocols on three separate occasions ranging from 48-72 hrs apart. Outlines of the three different workout protocols (TRAD, ACWT, CWIT) and descriptions of mini-circuit weight exercises (A[1], B[2], C[3]) are presented in Table 1.

A warm-up (5 min @ 60-70% HR_{max}) and cool down (5 min easy pedal) on the cycle ergometer (Monark, Sweden) preceded and followed each familiarization session. The TRAD workout involved 30 sec weightlifting, with the inclusion of 30 sec rest periods in between lifting exercises for a 1:1 work to rest ratio. The ACWT workout involved the same free weight exercises and mini-circuit stations (A[1], B[2], C[3]) as TRAD, but consisted of 15 sec rest intervals following 30 sec weightlifting, and also included four 2:30 min submaximal aerobic bouts on the cycle ergometer (55-65 rpm @ 65-75% HR_{max}). The CWIT workout was similar to the ACWT routine, and differed only in the performance of the cycling bout.

Table 1. Format for each workout protocol.

TRAD Protocol (30 sec lift: 30 sec rest) Total Time: 38 min	**ACWT Protocol (30 sec lift: 15 sec rest) Total Time: 41 min**	**CWIT Protocol (30 sec lift: 15 sec rest) Total Time: 41 min**
1. Data collection (rest)	1. Data collection (rest)	1. Data collection (rest)
2. Bike Warm up (5 min @ 60-70% HRmax)	2. Bike Warm up (5 min @ 60-70% HRmax)	2. Bike Warm up (5 min @ 60-70% HRmax)
3. STATION A[1] (9 min)	3. Bike: 2:30 min @ 65-75% HRmax	3. STATION A[1] (6:45 min)
4. Data collection	4. STATION A[1] (6:45 min)	4. Bike: 30 sec max effort sprint, 3 min easy pedal
5. STATION B[2] (9 min)	5. Bike: 2:30 min @ 65-75% HRmax	5. Data collection
6. Data collection	6. Data collection	6. STATION B[2] (6:45 min)
7. STATION C[3] (10 min)	7. STATION B[2] (6:45 min)	7. Bike: 30 sec max effort sprint, 3 min easy pedal
8. Data collection	8. Bike: 2:30 min @ 65-75% HRmax	8. Data collection
9. Cool down (5 min easy pedal)	9. Data collection	9. STATION C[3] (7:30 min)
STATION A[1] (3 x 13 reps each) -Triceps bench dips -Hip lifts -Prone planks (3 x 30 sec hold)	10. STATION C[3] (7:30 min)	10. Bike: 30 sec max effort sprint, 3 min easy pedal
STATION B[2] (3 x 13 reps each) -Standing biceps curl -Dumbbell (DB) squats -Pushups	11. Bike: 2:30 min @ 65-75% HRmax	11. Data Collection
STATION C[3] (3 x 13 reps each) -Standing DB lateral raise -DB split squat R leg -DB split squat L leg -Standing DB bent-over row	12. Data collection 13. Cool down (5 min easy pedal)	12. Cool down (5 min easy pedal)

Data collection consisted of heart rate, blood lactate, and rating of perceived exertion.

In between mini-circuit stations, subjects completed three 30 sec max effort sprint intervals on the cycle ergometer. The sprint intervals were preceded by a 1-min brisk pedal at a self-selected cadence with no resistance. At the cue of the tester, the subject began to pedal as fast as possible for approximately 3 s. Resistance equivalent to 0.055 kg of the weight of the subject was then added to the flywheel, and all-out effort continued for 30 s (similar to a Wingate test). The sprint interval was followed by an active recovery of pedaling with no resistance for 3 min. Both CWIT and ACWT protocols used a 2:1 work to rest ratio, which has been reported as optimal for eliciting adaptations in aerobic capacity and strength (Gettman et al., 1982; Mosher et al., 1994).

Data collection (Sessions 5-7): In sessions 5-7, TRAD, ACWT, and CWIT were performed by all subjects in a counterbalanced order ≥72 hr apart for measures of BLA, HR, and RPE at pre-exercise and following completion of each of three mini-circuit stations (A^1, B^2, C^3).

A warm-up (5 min @ 60-70% HR_{max}) and cool down (5 min easy pedal) on the cycle ergometer (Monark, Sweden) preceded and followed each workout. TRAD, ACWT, CWIT consisted of the same free weight exercises, and each workout was approximately 40 min duration. To control lifting tempo and the total number of repetitions (reps) completed, exercise speed was paced by a calibrated metronome (Seiko DM-33, Taiwan) that was set to 52 beats per minute, allowing for 13 reps per exercise. The program administrator gave the cue to switch exercises at the end of 30 s. The subjects rotated through the exercises within the specific mini-circuit station (A^1, B^2, C^3) until three sets had been completed for each exercise. Measurements of BLA (Accutrend Lactate; Sports Resource Group, Hawthorne, NY, USA) and HR (Polar Electro, Inc., Lake Success, NY, USA) were made at pre-exercise and immediately following the completion of each of the three mini-circuit stations for the TRAD protocol. These same measures were taken immediately following completion of the aerobic bike (ACWT) or bike sprint (CWIT) for the other 2 protocols. A blood drop was obtained via a capillary puncture under aseptic conditions. Blood sample analyses done in this manner have been shown to have a high degree of reliability (Bishop 2001). Values of RPE were obtained using the Borg category (0–10) RPE scale (Wallace et al., 2008). The scale was explained during the familiarization sessions and again, during the data collection sessions. The subjects were asked to rate how hard they felt the total exercise period was following the completion of each of the three mini-circuit stations (TRAD protocol) or mini-circuits and bike intervals (ACWT, CWIT protocols).

Statistical analyses

Descriptive statistics ($M \pm SD$) were reported for all dependent variables. Two 3 x 4 repeated measures analysis of variance (ANOVA) were used to analyze BLA and HR, and one 3 x 3 repeated measures ANOVA was used to analyze RPE. If an interaction existed, a simple effects test was computed. Statistical significance was set at $p \leq 0.05$ for all tests. All data were analyzed using SPSS (version 18.0; SPSS, Inc., Chicago, IL, USA).

Results

Data from subjects who completed all workouts ($N = 11$) were used to determine the effect of the three different circuit weight-training protocols on BLA, HR, and RPE. For each dependent variable, significant interactions ($p < 0.05$) were found for the three different circuit weight training exercise protocols (TRAD, ACWT, CWIT) across time. Effect size calculations were interpreted using Cohen's D (Cohen 1988) effect size measures. Effect sizes for BLA, HR, and RPE are as follows: 1.05 (large), 1.45 (large), and 0.53 (medium).

Blood lactate

Blood lactate (BLA) values for pre-exercise, and immediately following completion of each of the three circuits (EX A^1, EX B^2, EX C^3) are presented in Figure 2A. No differences existed in BLA at pre-exercise across the three exercise protocols ($p > 0.05$). Values of BLA at EX C^3 increased 2.3 (TRAD), 4.8 (ACWT), and 6.7 (CWIT) times above pre-exercise levels. The interaction between time and workout was significant ($F_{6,54} = 10.11$, $p < 0.001$). Post hoc Bonferroni pairwise analyses showed BLA was higher for CWIT at EX A^1 ($p < 0.001$, SE = 0.52), EX B^2 ($p < 0.001$, SE = 0.79), and EX C^3 ($p < 0.001$, SE = 0.91) than TRAD. Post hoc Bonferroni pairwise analyses showed BLA was higher for CWIT at EX A^1 ($p = 0.006$, SE = 0.74), EX B^2 ($p = 0.003$, SE = 1.03), and EX C^3 ($p = 0.005$, SE = 1.09) than ACWT. There was no difference in BLA between TRAD and ACWT at EX A^1 ($p = 0.80$, SE = 0.62) or EX B^2 ($p = 0.22$, SE = 0.64), but at EX C^3 the BLA was higher for ACWT compared to TRAD ($p = 0.006$, SE = 0.61). BLA levels for CWIT at EX C^3 were 132% greater than TRAD and 60% above ACWT protocols.

Heart rate

Heart rate (HR) values for pre-exercise, and immediately following completion of each of the three circuits (EX A^1, EX B^2, EX C^3) are presented as $\%HR_{max}$ in Figure 2B. No differences existed in HR at pre-exercise across the three exercise protocols ($p > 0.05$). Values of HR at EX C^3 increased 2.2 (TRAD), 2.2 (ACWT), and 2.6 (CWIT) times above pre-exercise levels. The interaction between time and workout was significant ($F_{6, 60} = 21.33$, $p < 0.001$). Post hoc Bonferroni pairwise analyses showed HR was higher for CWIT at EX A^1 ($p < 0.001$, SE = 2.71), EX B^2 ($p < 0.001$, SE = 2.57), and EX C^3 ($p < 0.001$, SE = 1.60) than TRAD. Post hoc Bonferroni pairwise analyses showed HR was higher for CWIT at EX A^1 ($p < 0.001$, SE = 1.29), EX B^2 ($p < 0.001$, SE = 1.39), EX C^3 ($p < 0.001$, SE = 1.32) than ACWT. The only observed difference in HR between TRAD and ACWT was at EX A^1 ($p = 0.02$, SE = 2.35), where ACWT elicited the higher value when compared to TRAD. No differences were found at EX B^2 ($p = 0.07$, SE = 2.37) or EX C^3 ($p = 0.34$, SE = 1.41) between TRAD and ACWT. HR for CWIT at EX C^3 was 14% greater than HR values for TRAD and ACWT protocols.

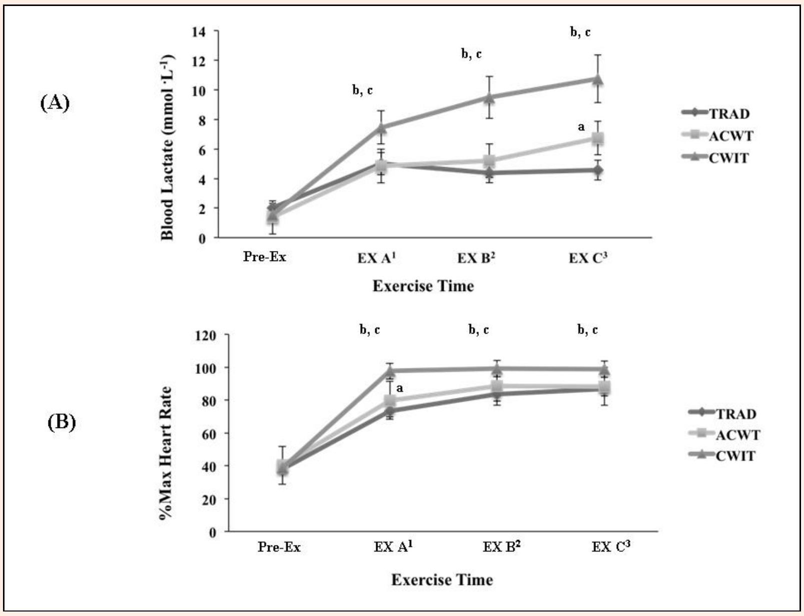

Figure 2. (A) BLA concentrations at pre-exercise (PRE) and following completion of each circuit: EX A¹, EX B², and EX C³. (B) %HR$_{max}$ at pre-exercise (PRE) and following completion of each circuit: EX A¹, EX B², and EX C³. Values are *M* ± *SE*.[a] ACWT >TRAD, [b] CWIT > TRAD, [c] CWIT > ACWT, (p < 0.05)

Ratings of perceived exertion

Ratings of perceived exertion (RPE) values immediately following completion of each of the three circuits (EX A¹, EX B², EX C³) are presented in Figure 3. Values of RPE at EX C³ increased 1.7 (TRAD), 1.6 (ACWT), and 1.6 (CWIT) times above EX A¹ levels. The interaction between time and workout was significant ($F_{4, 40}$ = 2.77, p = 0.04). Post hoc Bonferroni pairwise analyses showed RPE was higher for CWIT at EX A¹ (p < 0.001, SE = 0.37), EX B² (p < 0.001, SE = 0.43), and EX C³ (p < 0.001, SE = 0.39) than TRAD. Post hoc Bonferroni pairwise analyses showed RPE was higher for CWIT at EX A¹ (p < 0.001, SE = 0.46), EX B² (p = 0.002, SE = 0.51), and EX C³ (p = 0.003, SE = 0.41) than ACWT. Additionally, RPE was higher for ACWT at EX A¹ (p = 0.03, SE = 0.21), EX B² (p = 0.003, SE = 0.25), and EX C³ (p < 0.001, SE = 0.38) than TRAD. RPE measures for CWIT at EX C³ were 38% greater than TRAD and 8% above ACWT protocols.

Discussion

This is the first study designed to examine differences in BLA, HR, and RPE responses during exercise with three different variations of circuit weight-training protocols (TRAD, ACWT, CWIT) in recreationally active women. The overall findings supported the hypothesis that including high-intensity sprint bouts into the weight-training protocol (i.e., CWIT) would elicit increased measures of BLA, HR, and RPE when compared to the TRAD and ACWT protocols.

Previous researchers have noted increased BLA concentrations during TRAD workouts when compared to

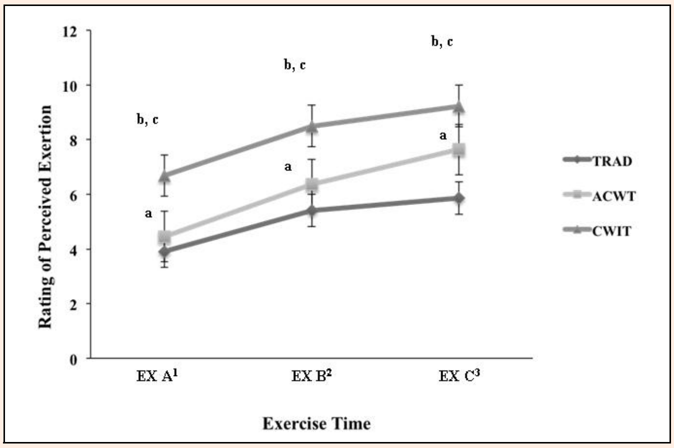

Figure 3. RPE following completion of each circuit: EX A¹, EX B², and EX C³. Values are *M* ± *SE*.[a] ACWT > TRAD, [b] CWIT > TRAD, [c] CWIT > ACWT (p < 0.05).

controls and more traditional weightlifting protocols (Garbutt et al., 1994; Marx, et al., 2001). To our knowledge, no researchers have examined the acute BLA response to ACWT and CWIT protocols. In the current study, both TRAD and ACWT resulted in similar BLA levels until EX C^3, at which point the ACWT protocol produced higher concentrations. The CWIT protocol resulted in higher BLA levels at all exercise time intervals throughout the workout compared to TRAD and ACWT. Measuring BLA provides researchers with a way to evaluate the immediate physiological effects of an exercise protocol (Brooks et al., 2000). As indicated by the higher BLA levels, CWIT was found to be a higher intensity exercise when compared to the more customary forms of TRAD previously investigated (Garbutt et al., 1994). Traditional circuit training (TRAD) has been suggested as a way to increase excess post-exercise oxygen consumption or EPOC (Lavinas Da Silva et al., 2010). Since EPOC is directly related to the exercise intensity, it is possible that CWIT may elicit a higher EPOC than TRAD. High BLA levels, such as those observed with CWIT, are indicative of the accumulation of lactate and anaerobic energy production, and possibly higher EPOC.

The increased BLA concentrations found in the combined circuit weight-interval training (CWIT) protocol are evidence of possibly greater energy expenditure for this workout, when compared to TRAD (CWIT BLA 132% > TRAD BLA) and ACWT (CWIT BLA 60% > ACWT BLA) protocols of similar duration. The possibility of a single exercise session of CWIT allowing for greater energy expenditure than a single session of TRAD or ACWT is noteworthy. Increasing energy expenditure in an exercise session on a regular basis will result in an improved fitness level over a shorter time period. Though no method currently exists to directly measure caloric consumption based upon lactate production, a strong possibility remains that the often-ignored anaerobic metabolism contributes a significant portion of total body energy expenditure. Furthermore, the inclusion of high-intensity interval bouts in this type of exercise program is potentially advantageous for those attempting to lose weight, specifically body fat (Schoenfeld and Dawes, 2009).

The higher BLA concentrations found in CWIT may have occurred as a result of greater recruitment of Type II fast twitch muscle fibers. Fast twitch fibers produce greater amounts of lactate than slow twitch fibers, even when oxygen is present (Brooks et al., 2000). The substitution of sprint bouts for rest or moderately paced aerobic bouts in between mini-circuits may have stimulated greater fast twitch muscle fiber recruitment during the CWIT protocol, as evidenced by the higher BLA concentrations. Consequently, greater stimulation is possible for muscles and systems that are not otherwise adequately overloaded with more traditional forms of circuit weight training.

Exercise variables, such as frequency, intensity, and duration, must be manipulated in order to create an overload with which the body is unfamiliar and to achieve a subsequent training effect (Pollock et al., 1998). Heart rate is frequently used as a guide to set exercise intensity due to the relatively linear relationship between HR and VO_2, and HR and exercise intensity (Brooks et al., 2000; Whaley, 2006). Manipulation of intensity might be one factor differentiating the TRAD, ACWT, and CWIT protocols in the present study. All three workouts were of similar duration (i.e., 40 minutes), but only CWIT resulted in higher HR values at all exercise times compared to those of TRAD and ACWT (CWIT HR 14% > ACWT HR and TRAD HR). It is possible that individuals participating in CWIT were working at a higher intensity throughout the entire session, thereby creating an environment that could stimulate greater cardiovascular adaptations with regular use of the CWIT protocol. Caution should be employed when using HR alone in an attempt to assess the intensity of resistance exercise (Petersen et al., 1988). As noted by Gotshalk et al. (2004), traditional circuit weight training (TRAD) produced HR values within the recommended range for developing cardiovascular fitness; however, oxygen consumption does not follow the same linear path in such training. Increased HR is likely due to the inclusion of small muscle group exercises and may be caused by a greater static muscular load that occurs with TRAD, which is not seen in rhythmic aerobic exercise (Garbutt and Cable, 1998). While positive cardiovascular adaptations are indeed possible with higher intensities of exercise, HR should be interpreted carefully when resistance training is involved. Whereas resistance training may make the interpretation of exercise intensity slightly speculative, many have reported that sprint interval training, such as that included in the CWIT protocol, is sufficiently taxing to the cardiovascular system to elicit positive cardiovascular adaptations (Burgomaster et al., 2005; Gibala et al., 2006; Laursen et al., 2005).

The RPE scale is a widely used and accepted method of estimating exercise intensity and gauging an individual's exercise tolerance (Whaley, 2006). Ratings of perceived exertion have not been reported in previous research with circuit training protocols, yet RPE has been used with other resistance training protocols to monitor exercise intensity (Focht 2007; Gearhart 2001) and has been shown to be a valid measure (Gearhart 2001). In the current study, subjects perceived the exercise intensity for ACWT and CWIT as higher than that of the TRAD protocol. The RPE measures were higher at the three exercise time points for CWIT than for TRAD (CWIT RPE 38% > TRAD RPE) or ACWT (CWIT RPE 8% > ACWT RPE). Additionally, RPE was also higher at all three exercise time points for the ACWT protocol than the TRAD protocol. The three circuit training protocols in the current study consisted of identical resistance training exercises of similar load volumes. However, the ACWT and CWIT had 15 s rest periods compared to 30 s rest periods in the TRAD protocol. Both ACWT and CWIT protocols had exercise bouts included as part of their respective workouts, with ACWT using aerobic bouts of cycling and CWIT using maximal effort cycling sprints. It is likely that the limited rest and added cycling exercise resulted in the increased RPE measures for CWIT and ACWT. When interpreting RPE results from the current study it should be noted that subjects were asked to provide RPEs upon completion of each mini-circuit station (A[1], B[2], C[3]), which in the case of the ACWT and CWIT protocols also included the cycling exercise following each mini-circuit station. This method required subjects to consider all exercises involved in the respective mini-circuit station as well as any exercise that followed. Performing the three familiarization workouts (sessions 2-4) with each protocol prior to the actual data collection sessions gave the subjects an idea of what to expect within each protocol; therefore, the RPE values should be based upon all exercise components within the time period being evaluated as opposed to what exercise was last performed.

It is interesting to note that the shape of the HR and RPE curves are relatively similar across TRAD, ACWT, and CWIT protocols with gradual increases observed at each exercise time, albeit at varied extents. The BLA response differed from HR and RPE with concentrations decreasing over time during the TRAD protocol compared to the increases observed with the ACWT and CWIT exercise sessions. As researchers have previously noted, HR may not be the best indicator of cardiovascular load (Petersen et al., 1988), and in order to achieve an adequate VO_2 level during a TRAD protocol the workout must be of sufficient duration (Gotshalk et al., 2004). It is likely that when comparing circuit training protocols BLA may serve as the best indicator of exercise intensity.

We acknowledge some study limitations. First, although weight exercise volume and intensity were equalized across the TRAD, ACWT, and CWIT protocols, aerobic and interval training components were not equal. A main premise of the study rested on the theory of the inverse relationship between exercise intensity and exercise volume. Each protocol took approximately forty minutes to complete, but exercise intensity was higher during CWIT compared to ACWT and TRAD, respectively. Such unbalanced program comparisons have been made previously to investigate the same principle (Burgomaster et al., 2005; Gibala et al., 2006; Marx et al., 2001). Thus, the three protocols were different in order to compare the amount of fitness-related benefits that can be realized in one workout session, within three different programs of similar duration. Second, the average predicted VO_{2max} of the subjects is low (23 ± 4 $ml \cdot kg^{-1} \cdot min^{-1}$) for a recreationally active population. Even though subjects participated in familiarization sessions with all testing and training protocols, cycling may have been a relatively unfamiliar testing mode. Also, the use of a submaximal test may have underestimated the predicted VO_{2max} in the recreationally active women from the current study who were not highly trained (Whaley, 2006).

Finally, the subjects in this study were recreationally active women who exercised regularly but followed no sport-specific regimen. Thus, results may vary in athletes or others who are involved in specific training activities with consistent neuromuscular demands. CWIT training in a high-lactate environment may have application for athletes from sports that require performing for extended time periods at high intensities (i.e., crew, mixed-martial arts, wrestling). Also, CWIT may be used as an alternative method when athletes have become bored with the daily rigors of regular training. The weights used during CWIT are likely not heavy enough to stimulate sufficient strength gains; therefore, CWIT might be best utilized in a maintenance or pre-season conditioning phase, as opposed to a strength or power phase. Future research is needed to examine the effects of regular training with CWIT protocols.

Conclusion

The results of this study suggest the following in recreationally trained women:

(a) CWIT has the potential to elicit high levels of BLA, HR, and RPE values and can be recommended for recreationally active individuals. It is recommended that sufficient recovery be included between CWIT workout sessions to reduce overuse injury risk or overtraining.
(b) CWIT provides a potential method of accomplishing more work in less time through targeting multiple components of fitness within one exercise session.
(c) BLA may be a better indicator of exercise intensity when comparing different circuit weight training protocols.
(d) Regular CWIT training may induce gains in muscular endurance, strength, and cardiovascular endurance.

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Key points

- Combining circuit weight training with interval training requires people to exercise at a higher intensity.
- The moderately trained can obtain fitness benefits from including interval training as part of a circuit weight training protocol.
- Merging circuit weight training with interval training may be a desirable option for those with limited time to exercise.

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