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METABOLIC RESPONSES TO HIGH-SPEED TOTAL-BODY WORKOUTS

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Abstract

Introduction: A male and female subject performed a high-speed total body circuit-based workout on an Impulse (Impulse Training Systems; Newnan, GA) exercise machine for the purpose of examining their metabolic responses to this training modality.

Methods: Workouts occurred within a whole room calorimeter and entailed three circuits of ten exercises. Each subject's exercise repetitions were done against 4.5 kg of resistance. Per exercise, repetitions were done as rapidly as possible for 30 and 60 seconds for unilateral and bilateral movements respectively, with no rest between different exercises. Changes in O_2, CO_2 and heat were measured before, during and after workouts. Metabolic data were used to calculate energy costs, substrate utilization and the net volume of work.

Results: Net volumes of work done by our male and female subjects were 8124.5 and 6177.6 kilojoules respectively. Net energy costs for our male and female subjects were 405.5 and 339.7 kilocalories respectively. Despite the modest resistance employed, our energy expenditures are comparable to those from other resistive exercise studies, some of which entailed longer workouts and higher absolute loads. As compared to the male, our female subject had comparatively higher lipolysis during and after the workout, which may be due to several factors that include inter-gender differences in intramuscular triglyceride distribution and hormonal activity.

Conclusions: Despite its novelty and modest loads, it appears a circuit weight training bout on the Impulse elicits high energy costs and a relatively higher degree of post-exercise lipolysis in women.

Key words: *energy expenditure, substrate utilization, circuit training*

Introduction

Net energy costs, broadly defined as the metabolic balance between cellular anabolism and catabolism, are a major concern for persons interested in weight loss/management. A combination of increased physical activity and reduced energy intake results in a negative energy balance. However of the two, exercise is superior to caloric restriction to maximize energy costs, as the former's adaptations include higher metabolic rates [1]. Glycolytic and oxidative metabolism converts substantial amounts of carbohydrate and fat into ATP as metabolic rates rise [2,3]. While this is a desirable occurrence, persons interested in weight loss/management usually wish to maximize fat loss. Many exercise modes were examined to achieve this goal. Aerobic activity raises both net energy costs and oxidative metabolism to promote fat loss [4]. By comparison weight training elicits higher metabolic rates due to its greater absolute intensities, though it is presumed the relative contributions of oxidative metabolism to energy expenditures are less [5,6]. In addition weight training offers a variety of health benefits not achieved through aerobic exercise [7-9]. Recent trends in resistive exercise include circuit- and hybrid-style workouts that emphasize the best features of aerobic and weight training programs. Such workouts, which include a series of multi-planar exercises targeting muscles throughout the entire body done in rapid succession, have become popular with fitness enthusiasts who seek greater weight and fat loss.

Due to their rapid high-speed nature, such circuit training and hybrid-style workouts are routinely performed with calisthenics or against lighter (ankle and/or wrist weights, dumbbells, etc.) loads with standard resistive exercise equipment. Due to the popularity of weight loss programs, it is of interest to examine exercise/metabolic responses to workouts done on a device better suited to such high-speed activity. Such devices include the Impulse (Impulse Training Systems; Newnan, GA), which is an exercise machine equipped with a weight sled. Light masses are added to the sled to increase resistance as it travels on a 1.9 m track. The sled is mounted on four precision ground hardened tool steel wheels. The track and wheels are coated with a polyurethane polymer for extremely low coefficients of friction that in turn permit high-speed repetitions as evidenced by very fast sled velocities and acceleration rates [10]. A high-tensile very low-stretch cord connects the sled to an attachment handle that users grasp as they perform repetitions. Easily adjustable pulleys and attachment handles permit performance of a variety of exercises in rapid succession to provide users a high-speed total-body workout.

Given its novelty, workouts on the Impulse may yield metabolic responses that differ from paradigms done with calisthenics or against light resistance. Numerous metabolic responses to Impulse workouts have been examined [11-15]. Among them is a recent study that examined a single exercise done on the Impulse and thus does not likely reflect the energy costs and substrate utilization seen with total body workouts [11]. Furthermore that study did not quantify the effects of exercise via whole room calorimetry, which perhaps offers the most comprehensive assessment of energy costs and substrate utilization [2]. The Impulse and calorimeter are each specialized pieces of equipment; to date no study has combined them both, which offers a rare opportunity for investigation. Thus the purpose of our case report was to measure net energy costs and substrate utilization responses to high-speed total-body workouts done on the Impulse using a whole room calorimeter. Due to gender-based metabolic differences [16], our report will entail the same workout performed by one male and one female subject.

Methods

Participants

In accordance with the ethical guidelines for international standards for the collection of research data from humans, subjects were informed as to the nature and risks of the project before they gave their informed written consent [17]. At the time of data collection our male subject was 29 years old, 172.7 cm tall, weighed 79.5 kg and in good health. He routinely exercised 2-3 days per week and had two months of workout experience with the Impulse prior to his participation in this case report. Our female subject was 26 years old, 162.6 cm tall, weighed 76.8 kg and also in good health. In addition she also exercised 2-3 days per week and had two months of prior Impulse workout experience before her current project participation. Due to the relative similarities of our subject's physical characteristics and workout histories, we could compare metabolic and exercise performance differences without the typical limitations that sometimes compromise inter-gender assessments.

Calorimeter/Impulse features

For the current project an Impulse was mounted within a whole room calorimeter custom built for The United States Department of Agriculture (USDA). For the case report it was used in accordance to USDA guidelines and operated by a technician skilled in the collection of whole room calorimeter data. As atmospheric air entered the calorimeter occupied by one of our subjects, their expired breath samples were measured continuously for changes in O_2 uptake as well as CO_2 and heat production. Those metabolic data were used to calculate the energy expenditures and substrate (fat, carbohydrate) utilization for the total body workouts done on the Impulse. In addition the calorimeter measured heat increases produced by our subject's workouts. At the start of workouts the internal calorimeter temperature was 21°C and O_2, CO_2 and heat sensors were calibrated prior to data collection. Measured O_2 and CO_2 calorimetry data were deemed highly repeatable, as evidenced by coefficient of variation values of 1.4% [2].

The design of the Impulse (Fig. 1) is ideally suited for high-speed total-body resistive exercise workouts.

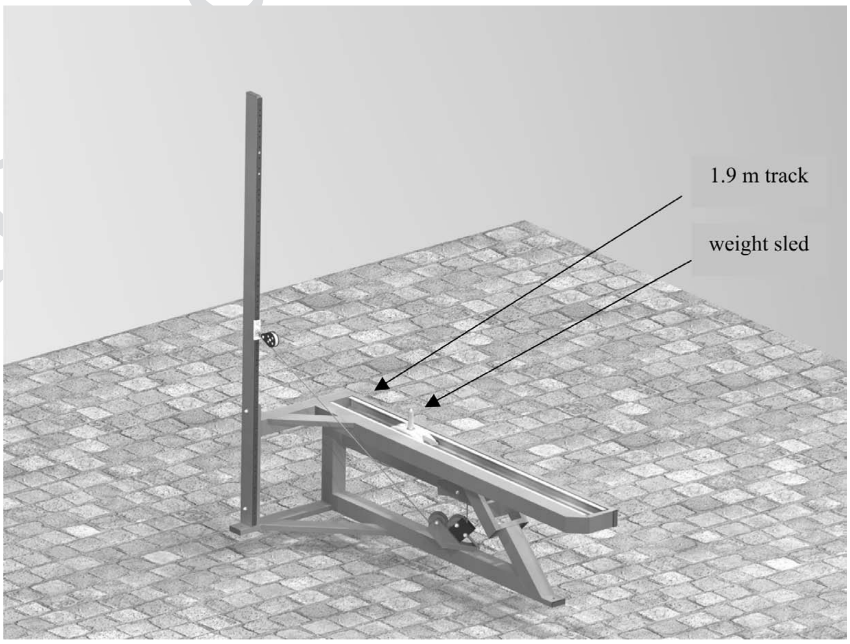


Figure 1. *Illustration of the Impulse used in the current project*

Its sled is mounted onto four wheels that adhere to the surface of the Impulse track as muscle forces are applied. The track's trajectory is perpendicular to Earth's gravitational pull, thus sled movement during repetitions is solely due to muscle force exertion. Due to the wheel and track features, very low forces (~0.45 N) induce movement when the weight sled is devoid of added mass [18]. Muscle forces are transferred to the sled along a high tensile/low stretch cord; 890 N of force are said to lengthen the cord less than 2.8 mm [18]. Prior research, whereby subjects performed Impulse workouts spaced seven days apart and whose data were analyzed for repeatability, showed the exercise device yields reproducible intra- and inter-workout data [13].

Procedures

Subjects were familiarized to the exact exercises and their sequence one week prior to data collection. A co-investigator well versed in the operation of the Impulse provided instructions on exercise technique and workout familiarization. Subjects refrained from exercise, alcohol and tobacco use 48 hours prior to data collection. They ingested an isocaloric diet 24 hours before their workout and ate their last meal (60% carbohydrate, 20% protein, 20% fat) three hours prior. Due to the time constraints involved with the use of the USDA calorimeter, for our case report the male subject entered the calorimeter first. After the attainment of his baseline metabolic measurements, he performed his workout and remained within the calorimeter until his O_2, CO_2 and heat values returned to pre-exercise values. After he left the calorimeter it was not used again until his metabolic remnants were expunged from the room; at that time our female subject entered the calorimeter and performed identical procedures before, during and after her workout.

At the start of data collection subjects individually entered the whole room calorimeter and, as they rested in horizontal supine posture for 32 (male) and 40 (female) minutes, their baseline (pre-exercise) O_2 and CO_2 values were recorded. Baseline measurements were deemed stabilized for the final 24 minutes of rest in our male subject, and the final 21 minutes of rest for our female subject. Those stabilized baseline gas values were recorded and used to determine net energy expenditures and substrate utilization. After all baseline values were recorded, subjects began their workouts. The Impulse exercises, and the sequence in which they were performed, appear in Table 1. Our male and female subjects performed identical workouts. The total sled mass was raised to 4.5 kg from an additional 3.4 kg that was applied for each exercise. The unilateral Table 1 movements were performed with each of the subject's limbs before they moved onto the next exercise. They performed three complete circuits of the Table 1 exercises. Repetitions were performed as rapidly as possible before they moved onto the next movement. With repetitions done for 30 seconds for each unilateral movement and 60 seconds per bilateral movement, three circuits lasted 30 minutes. After the workout subjects again rested in a horizontal supine posture within the calorimeter as their post-exercise metabolic (O_2, CO_2, heat) values stabilized.

Table 1. *Current project exercises*

EXERCISE	DESCRIPTION	RANGE OF MOTION
unilateral shoulderflexion	engaged arm supinated	~20° (from 20° shoulder hyperextension until arm reaches mid-coronal plane)
unilateral shoulder extension	engaged arm pronated	~20° (from 20° shoulder flexion until arm reaches mid-coronal plane)
unilateral internal shoulder rotation	elbow flexed 90°; engaged forearm perpendicular to body	~20° (humerus internally rotates toward mid-sagittal line)
unilateral external shoulder rotation	elbow flexed 90°; engaged forearm perpendicular to body	~20° (humerus externally rotates away from mid--sagittal line)
bilateral shoulder abduction/adduction	arms adducted in front of body	~30° (15° lateral displacement across each side of mid-sagittal line)
bilateral shoulder flexion/extension	arms adducted in front of body	~30° of shoulder flexion/extension; movement parallel to sagittal plane
unilateral hip adduction	engaged knee flexed ~10°	~40° movement at hip until leg reaches mid-sagittal line
unilateral knee extension	support knee flexed ~10°	~70° (from 90° to 20° of knee flexion for the engaged leg)
unilateral hip extension	engaged knee flexed ~25°	~20° (engaged leg hyperextends 20° at hip relative to support leg)
bilateral elbow extension	both arms adduct overhead	~35° (elbows extend from a 50° to a 15° angle of flexion)

For the current project our male and female subjects required 64 and 38 minutes respectively of post-exercise rest for their metabolic measurements to return to baseline values. They then exited the calorimeter. Per subject, baseline heat values were subtracted from those measured during and after workouts and then summed to calculate the net heat produced. We quantified the net heat value as an indirect index of the work produced by each subject. Net O_2 and CO_2 values were also calculated in a similar fashion as net heat, using the values collected for each of the corresponding gases. The net energy cost was calculated based on the net O_2 consumption as was done in prior resistive exercise studies [11,19]. O_2 and CO_2 values were also used to determine the relative contributions of fat and carbohydrate to the energy costs of the Impulse workout.

Results

Each subject successfully completed their workout in accordance to the current project's guidelines. The net volume of work done by our male and female subjects was 8124.5 and 6177.6 kilojoules respectively. Net energy expenditures for our male and female subjects were 405.5 and 339.7 kcals respectively. During workouts subject energy expenditure rates averaged 13.1 (male) and 11.3 (female) kcals · min^{-1}. Baseline and net O_2 and CO_2 values for each subject appear in Fig. 2. Substrate utilization measurements for each subject appear in Fig. 3. Baseline values for each gas were obtained before exercise; net values represent differences between absolute and baseline values per exercise and post-exercise time point examined. Figure 2 and 3 values were plotted as a function of time before,

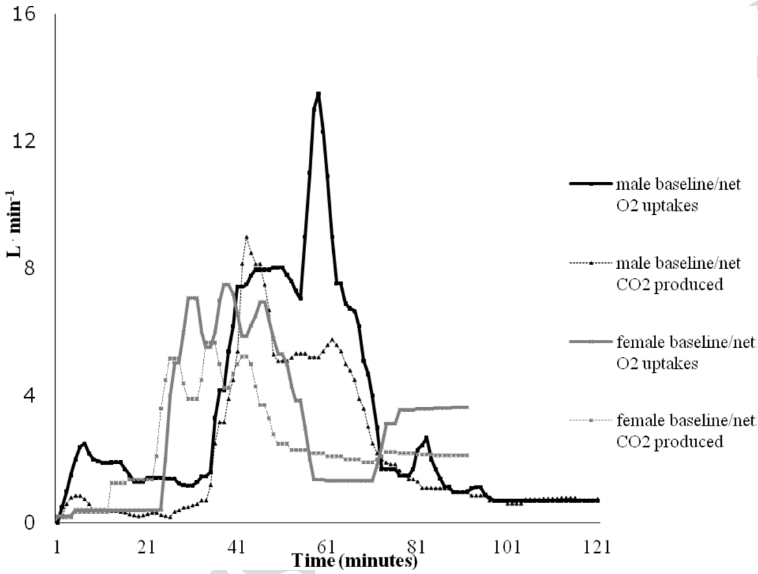
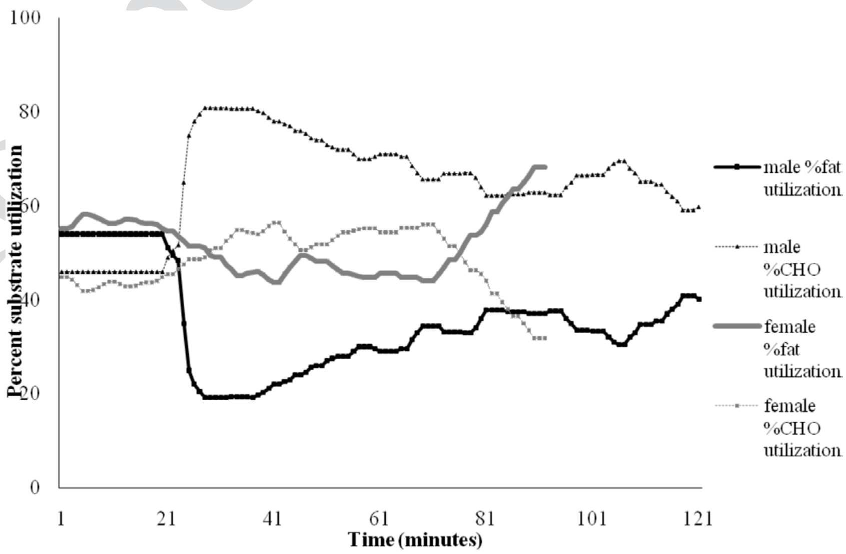


Figure 2. *Baseline/net O_2 and CO_2 values for our male and female subjects. Baseline and net values per gas are expressed in L . min-1. Gas values were obtained before (male: minutes 1-24; female: minutes 1-21), during (male: minutes 25-56; female: minutes 22-52) and after (male: minutes 57-121; female: minutes 53-91) exercise. Baseline values per gas were obtained before exercise; net values (measured from minutes 25-121 for our male subject; measures from minutes 22-91 for our female subject) represent differences between absolute and net values per time point examined.*



CHO: carbohydrate

Figure 3. *Percent fat and carbohydrate utilization for our male and female subjects. Values were obtained before (male: minutes 1-24; female: minutes 1-21), during (male: minutes 25-56; female: minutes 22-52) and after (male: minutes 57-121; female: minutes 53-91) exercise.*

during and after workouts. Comparative inter-subject results include higher O_2 and CO_2 values for our male subject which are representative of larger net work and energy cost values. Yet in terms of substrate utilization our female subject had comparatively higher fat oxidation, particularly during and after the workout.

Discussion

Our case report describes metabolic responses to a total-body high-speed workout done on a novel exercise device. Despite a small sample and limited time to utilize the calorimeter for post-exercise measurements, the return of such variables back to their baseline values typically occur within the post-exercise time frame used in our case report. Though some claim light loads, like those for our case report, may not elicit a sufficient training stimulus [20], a feature that makes high-speed resistive exercise attractive for weight loss is the energy costs associated with such activity. Resistive exercise is thought to rely primarily upon anaerobic glycolysis for ATP resynthesis, yet recent research notes aerobic metabolism also makes a considerable contribution to total energy costs [21,22].

In the past energy expenditures from anaerobic exercise were difficult to quantify [23]. More recent work implies O_2 debt and deficit values, lactate and CO_2 levels within the blood may each help predict total energy costs from intense bouts of exercise [22]. Prior research showed total-body resistive exercise workouts done in accordance to ACSM guidelines (a single set of eight exercises separated by two minute rest periods) elicited an average energy cost of 135 kcals in participants with a similar mean body mass to our test subjects [24]. With only minor body mass differences to the prior trial, current results are perhaps attributable to the higher intensity and work volume achieved through high-speed repetitions. While the current workout is a high-speed bout of circuit training done on a novel device, our results are similar to those from other circuit training trials that assessed net energy expenditures with standard strength training equipment. A synopsis of the prior results appear in Table 2.

Net energy expenditure values in Table 2 were generally achieved with workouts of a longer duration than those of our case report. Though exercise done against heavier absolute loads, even as part of a circuit training paradigm, may yield higher net energy costs [20], our results suggest faster repetition rates and no structured rest periods have a similar effect. In addition the manner in which our workouts were done also raised the volume of work performed. Thus the nature of our workouts, whereby high-speed repetitions occurred continuously, likely had a cumulative effect on the absolute intensity, net energy cost as well as the volume of work performed, which helps account for discrepancies between the current case report and Table 2 values.

Physical activity can create substantial energy deficits that promote weight loss. However an important weight loss concern is the amount of fat oxidized and factors that promote its usage [30]. Post-workout bicarbonate resynthesis [31] and glycogen depletion [32] encourages lipolysis after the cessation of exercise, which is thought to be intensity-dependent. However if intensity was the sole cause of greater fat oxidation we would have seen increased post-exercise lipolysis in our male subject, since his workout was more intense than his female counterpart as evidenced by a higher volume of work. Inter-gender substrate utilization differences that infer heightened post-workout lipolysis in women concur with the results from our female subject [16]. Yet contradictory evidence also exists [33]. Lipolysis was assessed in men and women before, during and after two different bouts of low intensity (45 and 65% $\dot{V}O_2$max) exercise [33]. Versus a non-exercise control condition, lipolysis rose as a result of exercise done by each gender, with 45% $\dot{V}O_2$max > 65% $\dot{V}O_2$max. Post-exercise results revealed higher lipolytic rates in men than women [33]. It was implied women utilize fat to a greater extent during exercise, yet men rely on fat more during recovery. This is in

Table 2. *Net energy expenditure results from prior circuit weight training studies*

[reference number]	Workout features	Net energy expenditures
[20]	1 circuit of free weight exercises done against light loads	men: 6.2 ± 1.0 kcal·min^{-1} women: 4.0 ± 1.0 kcal·min^{-1}
[25]	2 circuits of 8 exercises at 60% 1RM with 1-minute rest periods	male subjects: 215 kcals
[26]	3 circuits of 7 exercises; 30 second rests between sets and 60 second rests between exercises	male subjects: 236 kcals
[27]	repetitions done to voluntary failure with 20-second rest periods	men: 9.0 ± 1.0 kcal·min^{-1}
[28]	3 circuits of 10 exercises; 30-second sets separated by 15-second rest periods	men: 9.0 kcal·min^{-1} women: 6.1 kcal·min^{-1}
[29]	70-minute workout with 1-minute rest periods	male subjects: 448 kcals

contrast to our results; discrepancies are perhaps the result of differences in exercise intensity between the current and former [33] trials.

Unlike Henderson et al.'s outcomes [33], and in agreement with our results, high intensity physical activity done by women yielded greater post-workout lipolysis with various exercise modes [31,32,34]. Substrate utilization was assessed before, during and after a three-set ten-repetition resistive exercise workout done by women [32]. Results showed versus a control condition, post-workout gas exchange data saw a significant rise in lipolysis [32]. A longer (100-minute) and more intense weight training workout done by women caused a significant 62% rise in lipolysis the day after workouts as compared to pre-exercise values [34]. The effects of low- and high-intensity cycle ergometry on substrate utilization were also assessed in active women [31]. With the high- (75% $\dot{V}O_2$max) and low- (50% $\dot{V}O_2$max) intensity workouts matched for energy costs, results included a significantly higher lipolytic rate three hours after the high-intensity bout [31].

Since high intensity exercise increases post-workout lipolysis in women [31,32,34], it is of interest to identify factors that may explain this observance. As previously noted bicarbonate resynthesis [31] and glycogen depletion [32] likely have little to do with the greater post-workout fat oxidation in our female subject, thus lipolysis is due to other factors that include, but are not limited to, higher amounts of intramuscular triglycerides and inter-gender endocrine system differences. Regional inter-gender differences in fat distribution and lipolytic capacity may have led to our case report's divergent substrate usage results [16,35]. Higher average body fat values seen in women, with their accompanying greater intramuscular triglyceride levels, contribute to their increased reliance upon fat as a fuel during exercise. However inter-gender differences in endocrine system function also contribute to the greater preference for fat oxidation in women.

Higher sympathetic activity from exercise evokes greater catecholamine secretion and post-workout lipolysis [30,36]. Like bicarbonate resynthesis and glycogen depletion, exercise-induced catecholamine secretion is largely intensity-dependent. Thus inter-gender differences typically observe lower exercise-induced serum catecholamine values in women that may help facilitate a comparatively greater reliance upon fat, as compared to carbohydrate metabolism [16]. Catecholamines accelerate glycogenolysis and lipid mobilization rates [37]. They are fast-acting hormones secreted under stressful conditions such as "fight or flight" situations or high-intensity exercise [37]. Due to their fast acting nature and the higher energy demands seen with stressful conditions, substrates that induce more rapid ATP availability without the requirement for oxygen, glucose is used preferentially. Therefore in comparison to values seen in men, the lower catecholamine levels associated with women may cause a comparatively greater reliance on fat metabolism [16]. Exercise-induced growth hormone and lactate increases were also associated with higher O_2 uptakes during and after resistive exercise that contribute to greater post-workout lipolysis in women [12,32,33,38]. In conclusion despite its novelty and modest exercise loads, it appears a circuit weight training bout on the Impulse may elicit high energy costs and a relatively higher degree of post-exercise lipolysis in women. Our results may serve as an impetus for new work on the metabolic effects of high-speed resistive exercise with larger numbers of subjects.

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Declaration of interest

The authors report no conflicts of interest.

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