Metabolic response of trained and untrained women during high-intensity intermittent cycle exercise

E. Gail Trapp, Donald J. Chisholm, and Stephen H. Boutcher

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Trapp EG, Chisholm D, Boutcher SH. Metabolic response of trained and untrained women during high-intensity intermittent cycle exercise. Am J Physiol Regul Integr Comp Physiol 293: R2370–R2375, 2007. First published September 26, 2007; doi:10.1152/ajpregu.00780.2006.—The metabolic response to two different forms of high-intensity intermittent cycle exercise was investigated in young women. Subjects (8 trained and 8 untrained) performed two bouts of high-intensity intermittent exercise: short sprint (SS) (8-s sprint, 12-s recovery) and long sprint (LS) (24-s sprint, 36-s recovery) for 20 min on two separate occasions. Both workload and oxygen uptake were greater in the trained subjects but were not significantly different for SS and LS. Plasma glycerol concentrations significantly increased during exercise. Lactate concentrations rose over the 20 min and were higher for the trained women. Catecholamine concentration was also higher postexercise compared with preexercise for both groups. Both SS and LS produced similar metabolic response although both lactate and catecholamines were higher after the 24-s sprint. In conclusion, these results show that high-intensity intermittent exercise resulted in significant elevations in catecholamines that appear to be related to increased venous glycerol concentrations. The trained compared with the untrained women tended to show an earlier increase in plasma glycerol concentrations during high-intensity exercise.

intermittent exercise; catecholamines; glycerol; lactate

STEADY-STATE, MODERATE-INTENSITY aerobic exercise has been recommended for fat loss because the proportion of lipid in the fuel oxidized during low-intensity physical activity is greater than during high-intensity exercise (25). However, it has been shown that individuals engaging in vigorous exercise were leaner than those participating in less intense exercise (31). The ability of high-intensity exercise to cause negative energy balance was also shown by a 15-wk high-intensity intermittent exercise (HIIE) program that resulted in a greater decrease in skinfold thickness relative to energy expenditure compared with 20 wk of endurance exercise (32). The HIIE in this study consisted of short (15–30 s) and long (60–90 s) sprints separated by recovery periods (1–2 min) allowing the heart rate (HR) to return to 120–130 beats/min. The energy cost of the HIIE was less than half of that of the endurance program. Thus, despite using half the energy, the impact of the HIIE program, compared with steady-state exercise, on subcutaneous adiposity was significantly greater. However, the effects of HIIE on the components of energy balance were undetermined. Thus how HIIE may cause significant reductions in adiposity is unknown. Possible mechanisms include factors affecting energy intake (24) and postexercise energy expenditure (32).

It is feasible that participating in repeated bouts of HIIE could influence postexercise energy expenditure. For example, HIIE is likely to result in a significant elevation of catecholamines (35), which have been shown to elevate postexercise energy expenditure. However, the metabolic response during one bout of HIIE is unclear. For example, when and if free fatty acids (FFAs) are utilized during HIIE is undetermined. Also the catecholamine response and the time course of the lactate response has not been established. Finally, whether the metabolic response to HIIE is influenced by regular cycle training is also undetermined. Therefore, the purpose of this study was to compare the oxygen uptake (VO2), catecholamine, lactate, and glycerol responses of trained and untrained women to short-sprint (SS; 8-s sprint, 12-s recovery) and long-sprint (LS; 24-s sprint, 36-s recovery) 20-min bouts of HIIE. We hypothesized that an acute 20-min bout of HIIE would result in significant increases in plasma glycerol and catecholamine levels.

METHODS

Subjects. Subjects in the untrained (U) group (n = 8) were healthy, active young students in a Health and Exercise Science degree who engaged in recreational sport. The trained (T) subjects (n = 8) were athletes recruited from cycling and triathlon clubs. Women were chosen for this study to avoid any confounding effects of sex on study outcome. Approval was granted from a University Ethics Committee and informed consent was obtained from each subject. All subjects were healthy and none were obese (Table 1.) T subjects possessed significantly greater peak VO2 (VO2 peak), but there were no significant differences in mass, height, % skinfolds, percent body fat, or blood lipids.

Study design. Each subject visited the laboratory on three separate occasions. On the first visit VO2 peak, mass, height, anthropometric measures, resting lactate, HR, and blood pressure were recorded. On the second and third occasions subjects performed an HIIE bout (SS or LS) in counterbalanced order.

Peak physical work test. This test was a ramp test on an electrically braked, computer-controlled Monark 839 cycle ergometer with 3-min stages following a 3-min warm-up. Work increments for each stage were 15 W (U) and 25 W (T), at 90 rpm. Capillary blood samples were taken in the last 30 s of each stage of the test and at the end of a 5-min cool down. VO2 (l/min), ventilation (l/min), carbon dioxide production (VCO2, l/min), and respiratory exchange ratio (VCO2/VO2) were measured via an open-circuit indirect calorimetry system (ParvoMedics, 2003).

High-intensity intermittent cycle exercise protocol. The HIIE bouts were completed early in the morning after an overnight fast. Subjects were instructed to eat a meal that was 60–70% carbohydrate the night before and to arrive at the laboratory having consumed nothing other than water for at least 4 h before the test. The baseline metabolic rate was determined via open circuit indirect calorimetry before the start of the exercise protocol. During the 20-min HIIE protocol, HR was recorded every 30 s using a Polar heart rate monitor and recorded on a chart recorder. On the first visit and at the end of each HIIE bout, HR was recorded for 1 min to determine heart rate recovery.

It is crucial to understand that the metabolic response to HIIE may provide a new paradigm for fat loss intervention. This study demonstrates that HIIE is a promising strategy for weight loss that requires further investigation.
Table 1. Subject characteristics

<table>
<thead>
<tr>
<th></th>
<th>Age, yr</th>
<th>Mass, kg</th>
<th>Height, cm</th>
<th>( \text{VO}_{2}\text{peak}), l/min</th>
<th>BMI</th>
<th>( \Sigma \text{9 skin folds} )</th>
<th>% Body fat</th>
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<tbody>
<tr>
<td><strong>Untrained (n = 8)</strong></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Mean</td>
<td>21.2</td>
<td>62.2</td>
<td>167.8</td>
<td>2.8</td>
<td>22.0</td>
<td>115.5</td>
<td>22.6</td>
</tr>
<tr>
<td>SE</td>
<td>± 0.1</td>
<td>± 2.2</td>
<td>± 2.1</td>
<td>± 0.2</td>
<td>± 0.9</td>
<td>± 9.0</td>
<td>± 1.1</td>
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<tr>
<td>Range</td>
<td>19–24</td>
<td>56.6–66.6</td>
<td>163–174.5</td>
<td>2.1–3.3</td>
<td>18.5–26.7</td>
<td>80.7–164</td>
<td>18.8–28.3</td>
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<tr>
<td><strong>Trained (n = 8)</strong></td>
<td></td>
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<tr>
<td>Mean</td>
<td>25.3</td>
<td>68.2</td>
<td>171.5</td>
<td>3.7</td>
<td>23.2</td>
<td>101</td>
<td>21.1</td>
</tr>
<tr>
<td>SE</td>
<td>± 1.5</td>
<td>± 2.5</td>
<td>± 2.3</td>
<td>± 0.1</td>
<td>± 0.8</td>
<td>± 7.7</td>
<td>± 1.2</td>
</tr>
<tr>
<td>Range</td>
<td>20–30</td>
<td>52.9–72.2</td>
<td>163–182.5</td>
<td>3.2–4.2</td>
<td>19.9–26.3</td>
<td>67.4–127.4</td>
<td>15.4–24.9</td>
</tr>
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\( \text{VO}_{2}\text{peak} \), peak oxygen uptake; BMI, body mass index.

RESULTS

Power output. T cyclists produced a significantly higher power output than U for both SS and LS. The mean power output across both exercise modalities was 153.2 ± 6.9 W for T and 96.1 ± 7.1 W for U. When power output between the SS and LS bouts was compared there was a significantly higher power output for LS (\( P < 0.03 \)). T and U produced a mean power output of 167.1 ± 3.8 and 105.4 ± 4.2 W, respectively, for the LS exercise and a mean power output of 139.4 ± 1.7 and 86.6 ± 2.6 W, respectively, for the SS exercise.

Heart rate. The only significant finding for HR was that it increased over the 20 min of exercise so that it was significantly higher at the end of exercise compared with the beginning in both the SS and LS (\( P < 0.0001 \)). There was no difference in HR when T and U were compared, for either SS or LS (Fig. 1).

\( \text{VO}_{2} \) response. There were no significant differences in \( \text{VO}_{2} \) between the two exercise protocols. There was a significant difference (\( P < 0.0001 \)) between baseline measures, the \( \text{VO}_{2} \) of the work bouts, and recovery (Fig. 2). The absolute \( \text{VO}_{2} \) for both exercise protocols was significantly higher (\( P < 0.0001 \)) in T than U (Fig. 2). However, when examined as a percentage of \( \text{VO}_{2}\text{peak} \), mean oxygen cost was not significantly different for T (69% \( \text{VO}_{2}\text{peak} \)) and U (65% \( \text{VO}_{2}\text{peak} \)).

Glycerol. T subjects tended to increase glycerol concentrations earlier than U and the values tended to be higher (Fig. 3),
however, these differences did not achieve significance. There was a significant difference ($P < 0.0001$) between baseline and exercise glycerol levels for both groups during both exercise bouts (Fig. 3).

**Lactate.** There was a significant increase ($P < 0.0001$) in lactate production from baseline to exercise for both exercise protocols and both groups (Fig. 4). In U there was no significant difference between SS and LS exercise with regard to lactate levels (Fig. 4). In T, however, there were significantly greater lactate levels ($P < 0.01$) in the LS compared with the SS exercise (Fig. 4).

**Catecholamines.** Epinephrine and norepinephrine levels were significantly higher ($P < 0.001$) postexercise compared with baseline (Figs. 5 and 6). In both exercise protocols the trained tended toward higher postexercise epinephrine and norepinephrine levels, but this difference was not significant.

**RPE.** For both T and U, RPE gradually increased over the 20 min of exercise in both cycling protocols so that there was a significant difference ($P < 0.0001$) in RPE between the first 5 min of exercise and the last 5 min. In U subjects, the RPE for both protocols was not different. Nor was there a difference when RPE for the SS exercise was compared between groups. RPE was significantly higher ($P < 0.001$) in LS compared with SS exercise for T subjects.

**DISCUSSION**

The major finding of this study was that for both groups plasma glycerol concentrations increased over the 20 min of HIIE. Both SS and LS forms of intermittent exercise produced similar metabolic responses although both lactate and catecholamines were higher after the LS condition. Catecholamine concentrations were also higher postexercise compared with preexercise for both groups. T differed from U women by displaying a tendency for peak glycerol concentrations earlier during exercise and higher lactate concentrations throughout both exercise conditions.

An increase in glycerol concentration suggested an increasing reliance on fats as a fuel despite increased lactate concentrations. There are limitations associated with using glycerol concentrations to estimate fat oxidation, but Børsheim et al. (5) have suggested that it is marker of lipolysis and Greer et al.
at which to inhibit carnitine-acyl CoA transferase, which limits the rate of
intermittent exercise. High lactate concentrations are thought to inhibit
glyceride stores during, as well as recovering from, repeated
release of fatty acids from adipose and intramuscular triacyl-
venous blood glycerol levels in the present study could reflect an
indicant of intramuscular triglyceride contribution to the en-
ergy requirements of repeated Wingate tests. Also Medbo and
Jebens (20) have shown that skeletal muscle releases glycerol
during recovery from intense cycle exercise. Thus the rise of
venous blood glycerol levels in the present study could reflect
release of fatty acids from adipose and intramuscular triacyl-
glyceride stores during, as well as recovering from, repeated
intermittent exercise. High lactate concentrations are thought
to inhibit carnitine-acyl CoA transferase, which limits the rate
at which β-oxidation can occur (29). That lactate was higher
throughout LS for the T women supports this notion. However,
its been suggested that the lactate threshold is attained at
blood concentrations of 3.5 mmol/l (8) or 4.0 mmol/l (15). So,
in spite of lactate concentrations elevated above that consid-
ered as the lactate threshold, glycerol concentrations in the
present study still increased. The effect of high levels of blood
lactate on the ability of the exercising muscle to utilize FFA
was not examined in this study but is an important issue for
future research.

Tremblay et al. (32) have suggested that the ability of
exercising muscle to utilize FFAs, despite high lactate levels, is
due to the intermittent nature of the HIIE. For example, it has
been demonstrated that during the intensive component of
HIIE, ATP and creatine phosphate are broken down to produce
energy and are resynthesized during the nonintensive rest
periods via the aerobic system (11). Because the rest periods
were comparatively short (12 s in the present study), this
resynthesis is likely to be incomplete; thus anaerobic glycolysis
has been suggested to provide the remainder of the required
energy (12). Glycogen is the substrate for the anaerobic gly-
colytic system and has been shown to be depleted to some extent
during HIIE (11). Research using muscle biopsy has shown
that phosphocreatine recovery was incomplete after 15 s
of rest in a 15 s work, 15 s rest intermittent exercise bout (12).
These authors suggest that progressive depletion of phospho-
creatine and glycogen, in conjunction with increased cytosolic
citrate, act to inhibit glycolysis and lead to lowered lactate
accumulation and enhanced fatty acid oxidation. Myoglobin
oxygen usage during the work bouts has been estimated to
contribute to ~44% of the oxygen deficit and has been shown
to be resaturated during the rest periods (12). Astrand et al. (1)
have suggested that myoglobin plays a contributory role as an
oxygen store, which supports aerobic metabolism and, presum-
ably, the use of FFAs as a substrate. The source of these FFAs
is undetermined, but it has been suggested that intramuscular
triacylglycerols (IMTG) stores provide some substrate (32, 34).
Other possible sources of FFAs are plasma FFAs, triglycerides,
low-density lipoprotein, very-low-density lipoprotein, chylom-
icros, and adipocytes (13, 17, 30, 33).

Catecholamine response to these exercise protocols was
typical of high-intensity exercise (16, 27) in that postexercise
levels were significantly higher than preexercise values. How-
ever, the epinephrine response was greater than levels reported
by Christmass et al. (6), who measured catecholamine response
to long- and short-bout intermittent treadmill exercise and found
that norepinephrine was elevated postexercise but epi-
 nephrine was unchanged. Also typical of HIIE was the trend
for the LS exercise, which produced higher lactate concentra-
tions, to have higher catecholamine concentrations (7, 27). In
the Christmass et al. study, fat oxidation decreased over time in
the LS exercise, which may be a function of the higher lactate
concentrations and lower epinephrine concentrations because
epinephrine is known to stimulate lipolysis (18, 21). In the
present study, glycerol concentrations were maintained above
basal levels in the LS exercise (although it was lower than the
SS exercise), and this may be the result of higher epinephrine
concentrations. Catecholamines were collected before and after
exercise, whereas glycercol was assessed during exercise, cre-
ating a temporal mismatch between these variables. However,
Greer et al. (14), examining repeat Wingate tests, did assess
both catecholamines and glycerol levels at the same time and
showed that they increased simultaneously.

It is feasible that HIIE creates a “substrate shuttle” whereby
there are repeated shifts from anaerobic to aerobic energy
sources. As discussed previously, there is evidence that ATP,
creatine phosphate, glycogen, and myoglobin oxygen are partly
depleted during the high-intensity work phases. During the rest
periods, there appears to be a resynthesis of ATP and creatine
phosphate, a resaturation of myoglobin oxygen, and a recycling
of lactate (12). Glycogen does not appear to be resynthesized
during the rest periods, and ongoing diminution has been
shown to occur over the exercise session (4). Also, it has been
reported that repeated exercise impairs glycolysis because of
cytosolic citrate accumulation that inhibits phosphofructoki-
nase activity (11). These factors permit repeated bouts of
exercise at high-intensity and reduce the amount of lactate
accumulation. The lower lactate accumulation accompanied by
aerobic metabolism may allow the use of fats as a fuel. This
hypothesis is supported by the present data showing an in-
crease in plasma glycerol over the 20 min of exercise in both
bouts that suggests increasing release of FFAs. Why high
lactate levels do not prevent the ability of the exercising muscle
to utilize FFA in HIIE appears to be unknown.

Chronic HIIE appears to impact on adipose tissue stores and
has led to greater fat loss (19, 23, 28, 36). What is unknown is
the source of the FFAs during acute HIIE. If IMTGs were
utilized during HIIE, they would likely be restored postexer-
cise along with glycogen. So, restoration of glycogen and
IMTGs combined with this “shuttle” effect may have meta-
bolic consequences in the recovery from exercise and be
partially responsible for an elevated postexercise oxygen con-
sumption. Studies assessing actual muscle measurements need to be performed to identify the mechanisms of the above mentioned effects.

T participants had greater aerobic power and power output, and this was reflected by the differences in lactate concentrations between the two exercise bouts. For U, there was no difference, metabolically or perceptually, between the LS and SS exercise. Although U were able to work significantly harder in the long-bout exercise, it was not sufficiently intense to alter the metabolic responses to the exercise protocols. All the measured metabolic parameters ($V_\text{O}_{2}$, HR, glycerol, lactate, glucose, and catecholamines) and RPE were not significantly different for U when the two bouts were compared. This finding probably reflects the lack of experience of U subjects with cycling exercise and their perception that they were working as hard as they could in both bouts. The situation was different for the T group. During the LS exercise they were able to generate sufficiently greater power outputs to alter the metabolic responses to the activity. The LS exercise produced significantly higher lactate concentrations as expected and, after the first 5 min of exercise, the increased lactate was associated with a lower level of glycerol production. These results are supported by the perceived exertion response that showed for T the LS exercise resulted in higher RPE. However, that $V_\text{O}_{2}$ was not significantly different for T between the two exercise bouts adds support to the notion that, for this group, the energy source for the additional demand was supplied by anaerobic glycolysis.

In conclusion, despite increased lactate levels during HIIE, both groups showed an increase in plasma glycerol levels. HIIE resulted in significant elevations in catecholamines. Trained compared with untrained women showed a trend for an earlier increase in plasma glycerol during high-intensity exercise.

Perspectives and significance. Repeated bouts of high-intensity, intermittent exercise led to increased lactate and catecholamine levels. The accompanying increase in glycerol levels suggests that fat stores may supply a significant amount of energy during this form of exercise. Consequently, it is possible that high-intensity intermittent training may contribute to programs designed to promote fat loss.

REFERENCES


