Effects of short-term inactivity on glucose tolerance, energy expenditure, and blood flow in trained subjects

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Effects of short-term inactivity on glucose tolerance, energy expenditure, and blood flow in trained subjects. J. Appl. Physiol. 84(4): 1365–1373, 1998.—The purpose of this investigation was to examine the effects of 7–10 days of inactivity (IA) on glucose tolerance (GT), resting metabolic rate (RMR), thermic effect of a meal (TEM), and limb blood flow in endurance-trained men. Eight high-trained (peak O2 consumption 64 ± 2 ml.kg–1.min–1) endurance athletes participated in this study involving two identical test days, one ~24 h after a normal training bout (Tr) and the second after 7–10 days of IA. The following tests were conducted at each visit: 75-g oral glucose tolerance test (OGTT), RMR, and TEM and measurements of calf and forearm blood flow (BF) by using venous occlusive plethysmography. Body weight remained unchanged during this short period of IA (Tr, 78.5 ± 1 kg; IA, 78.7 ± 1 kg). The area under the glucose and insulin curves increased 65% (Tr, 3,375 ± 877 vs. IA, 5,559.4 ± 621 mg·dl–1·180 min–1) and 73% (Tr, 2,182.5 ± 270 vs. IA, 3,793.1 ± 739 µU·ml–1·180 min–1) after IA, respectively (P < 0.01). RMR decreased significantly (4%, 1.5 ± 0.2% vs. 1.44 ± 0.02 kcal·min–1·kg–1; P < 0.05) and respiratory exchange ratio during the OGTT increased (4%, 0.812 ± 0.011 vs. 0.842 ± 0.005; P < 0.05) after IA, whereas TEM increased similarly in the Tr and IA states. In the Tr state, mean calf BF increased by 22% (3.17 ± 0.22 vs. 3.87 ± 0.38 ml·100 ml–1·min–1; P < 0.05) during the OGTT but remained unchanged after IA, whereas no differences at rest or during OGTTs existed between the two conditions for forearm BF. Incremental calf area above fasting during the OGTT was correlated with mean calf BF in the Tr (r = 0.76, P < 0.05) and IA (r = 0.72, P < 0.05) states. In conclusion, 7–10 days of IA results in a deterioration in GT and a reduction in RMR. After glucose ingestion, calf BF was elevated compared with resting levels in the Tr state but was unchanged in the IA state; however, limb BF was not related to GT or RMR. Thus our findings raise questions regarding the relative contribution of BF in modulating glucose tolerance and energy expenditure in endurance athletes in their habitual Tr or IA state.subjects.

Methods

Subjects

Eight healthy endurance-trained athletes volunteered to participate in this study after being briefed on all testing procedures and risks and after signing an informed consent. All subjects at the time of the study were exercising vigorously, by rowing (n = 6), cycling (n = 1), or swimming (n = 1), at least 5–7 days/wk for 45 min/day for the previous 3 yr. Peak oxygen consumption (VO2peak) and maximal heart rate were determined on a Monark cycle ergometer, by using a continuous incremental protocol involving a 5-min warm-up at 50 W and increments of 25 or 50 W every 2 min thereafter. Oxygen consumption (VO2) and carbon dioxide production were measured by indirect calorimetry throughout the test. Subject characteristics are shown in Table 1. This study was...
Skidmore College, expending as little energy as possible and drive or be driven to the Human Performance Laboratory at instructed to wake slowly, minimize movement, and promptly each test day, after a 12-h overnight fast, subjects were familiarized with the procedures and equipment used in conflicts) days detrained.

On two separate visits to the laboratory, oral glucose tolerance (OGTT), resting metabolic rate (RMR), thermic effect of a meal (TEM), and venous occlusive plethysmography tests were performed; one set of tests was performed with the subjects in their habitual trained state, ~24 h after a typical exercise bout [trained (Tr)], and the second set was performed after 7–10 days of IA. Thus our study design cannot differentiate the relative contribution of the residual effects of the subjects’ last exercise bout in the Tr state from their chronically trained condition to changes in glucose tolerance (11). Each participant was instructed to avoid exercise and to not modify their diet during the period of IA.

Order of testing. Before the first testing day (Tr), all subjects had their fat-free mass (FFM) and fat mass determined by skinfold analysis and performed a \( V_{\text{O2peak}} \) test on a stationary cycle ergometer. Subjects were instructed to abstain from exercise, caffeine, and alcohol for 24 h before returning for their first test (Tr). Within 1 mo after their initial visit and having maintained their normal training regimen, subjects returned to the laboratory between 0530 and 0600 for their first test day. Subjects were also instructed to fast for 12 h before each test day and to standardize the meal each night before the 2 test days, i.e., to use the same meal the evening before the first test day (Tr) as the standard meal for the second test day (IA). For the second test day (IA), subjects underwent the same procedures performed during the first visit (Tr) but were 7 (n = 6) or 10 (n = 2, due to scheduling conflicts) days detrained.

Testing procedures. At the initial visit, each subject was familiarized with the procedures and equipment used in testing during the 2 test days (Tr and IA). On the morning of each test day, after a 12-h overnight fast, subjects were instructed to wake slowly, minimize movement, and promptly drive or be driven to the Human Performance Laboratory at Skidmore College, expending as little energy as possible and drive or be driven to the Human Performance Laboratory at instructed to wake slowly, minimize movement, and promptly each test day, after a 12-h overnight fast, subjects were familiarized with the procedures and equipment used in conflicts) days detrained.

The following resting baseline measurements were collected for the next 30 min: forearm (FBF) and calf (CBF) blood flow (10, 20, and 30 min); fasting plasma glucose, insulin, and free fatty acids (FFAs; 30 min); and RMR (0–30 min). Between 0630 and 0645, each subject was administered a 75-g oral glucose load, which was consumed within 5 min, followed by 180 min of serial measurements of FBF and CBF and plasma insulin, FFA, and glucose levels at 30 min increments and by six 15-min-interval measurements of TEM.

Body composition. Body density was calculated from skinfold thicknesses determined with a Lange caliper at the chest, abdomen, and thigh by using the Jackson and Pollock equation (13). Body fat percent was calculated according to the Siri equation (29).

\[ V_{\text{O2peak}} \] and leisure time physical activity. \( V_{\text{O2peak}} \) was determined by a progressive and continuous test to exhaustion on a cycle ergometer (Monark ergometer model 884) by using an open-circuit gas-analysis system. The initial work rate for each subject at 60 revolutions/min (rpm) was 50 W for the first 3 min and was increased 25 W every 2 min until volitional exhaustion or until the subjects were unable to maintain 60 rpm. All subjects reached their age-predicted maximal heart rate (192 ± 1.2 beats/min) and a maximal respiratory exchange ratio (RER) greater than unity (1.10 ± 0.01). \( V_{\text{O2peak}} \) was the highest minute \( V_{\text{O2}} \) recorded during the test. The energy expended in leisure time physical activity during the past year was assessed by a structured interview by using the Minnesota Leisure Time Physical Activity Questionnaire (30).

Estimated daily energy intake. Energy and carbohydrate intakes were determined from a 3-day food diary while the subjects were in the Tr state, and they were provided a copy of the diary and instructed to maintain similar compositions and intakes during the period of IA. Briefly, each subject was asked to weigh and record all foods and beverages ingested for 2 weekdays and 1 weekend day. Particular emphasis was placed on the importance of maintaining typical eating habits and describing foods and method of preparation in accurate detail. The Nutritionist III computer program (N-Squared Computing, version 4.0) was used to analyze all diets for energy intake as well as relative and absolute quantities of macronutrients.

OGTTs. A 75-g OGTT was administered to establish the level of glucose tolerance and the insulin response to the oral glucose load in the Tr and IA states. Volunteers were instructed to consume at least 150 g/day of carbohydrate for 3 days before the OGTT. These instructions were given orally and in writing and were verified with a 3-day food record (see Estimated daily energy intake and RESULTS). Venous blood samples (~10 ml) were obtained with the subjects in the fasted state and 30, 60, 90, 120, and 180 min after glucose ingestion for the determinations of plasma glucose by using a Yellow Springs Instruments glucose analyzer (Yellow Springs Instruments, Yellow Springs, OH), of insulin by modification of the radioimmunoassay technique of Starr et al. (29) and of FFA concentrations with a modification of an enzymatic technique (Wako Chemicals, Richmond, VA).

RMR and TEM. RMR was established for each subject by indirect calorimetry for 30 min, and TEM was calculated by using six 15-min intervals after glucose ingestion (Fig. 1). Briefly, subjects were positioned supine and fitted with a Hans-Rudolph face mask (model 7900, Kansas City, MO) connected to corrugated tubing that was, in turn, attached to the metabolic cart. A constant fraction of expired air was withdrawn, dried, and delivered to a zirconium cell oxygen analyzer (Ametek, Pittsburgh, PA) and an infrared carbon dioxide analyzer (Ametek). Energy expenditure (kcal/min) was calculated from the equation of Weir (34). The intraclass correlation for RMR by using test retest in 20 female volunteers averaged 0.90 in our laboratory.

LBF. Testing was conducted in a thermal-neutral laboratory (mean temperature = 18.6°C, relative humidity = 58.5%). All blood flow measurements were obtained with a Hokanson EC-5R plethysmograph (Bellevue, WA). Subjects

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**Table 1. Subject characteristics**

| Age, yr | 21 ± 1 |
| Height, cm | 184.5 ± 1.7 |
| Weight, kg | 78.9 ± 3.1 |
| Body fat, % | 9.8 ± 0.84 |
| Fat-free mass, kg | 71.1 ± 0.76 |
| \( V_{\text{O2peak}} \) | 5.09 ± 0.15 |
| ml·kg\(^{-1}\)·min\(^{-1}\) | 63.5 ± 1.9 |
| \( \text{HR}_{\text{max}}, \text{beats/min} \) | 192 ± 1.2 |
| \( \text{RER}_{\text{max}}, V_{\text{O2}}/V_{\text{CO2}} \) | 1.1 ± 0.01 |

Values are means ± SE. \( V_{\text{O2peak}} \): peak \( V_{\text{O2}} \) consumption; \( \text{HR}_{\text{max}} \), maximal heart rate; \( \text{RER}_{\text{max}} \), maximal respiratory exchange ratio.
were supine, and an arterial inflow test was performed on the calf and forearm while the subjects' arms and legs were supported with foam-rubber blocks in a comfortable, elevated position. Mercury-filled strain gauges were placed around the maximum circumference of the calf and forearm. A 10-cm venous occlusion cuff was placed around the upper arm, and a 12-cm venous occlusion cuff was placed around the upper thigh. The occlusion cuff was inflated to ~60 mmHg for 5–8 s to impede outflow to the distal part of the limb by using a rapid cuff inflator (forearm model no. SC12; calf model no. CC22), which achieved inflation in <0.5 s. The changes in limb circumference were recorded on the EC-5R graph recorder. Blood flow was calculated as milliliters per 100 ml per minute. The intraclass correlation and coefficient of variation for FBF and CBF by using test retest in 15 volunteers reached 0.79 and 5.5% and 0.97 and 4.0%, respectively, in our laboratory.

Statistics. Baseline measures of LBF (forearm and calf) and RMR before and after IA were compared with paired t-tests (P < 0.05). The total areas under the glucose and insulin curves were determined by computer analysis with a trapezoidal model that summated only the areas above the fasting baseline level. To compare trends in plasma glucose and insulin and LBF responses from baseline to peak during the OGTT, the subjects' fasting plasma glucose concentrations increased significantly after the period of IA (Tr, 88.6 ± 1.4; IA, 92.5 ± 1.8 mg/dl; P < 0.05). Fasting insulin concentrations remained unchanged. As seen in Fig. 2, glucose tolerance was significantly reduced after 7–10 days of IA. Plasma glucose and insulin concentrations at 60 and 120 min were significantly (P < 0.05) elevated, and there was a tendency (P < 0.10) for glucose at 90 and insulin at 180 min to be elevated after detraining. The areas under the glucose and insulin curves increased 65% (Tr, 3,375 ± 777 vs. IA, 5,559.4 ± 621 mg·dl⁻¹·180 min⁻¹) and 73% (Tr, 2,182.5 ± 270 vs. IA, 3,793.1 ± 739 µU·ml⁻¹·180 min⁻¹) after IA, respectively (P < 0.01). Plasma FFAs tended to be higher in the Tr than in the IA state at baseline (Tr, 0.29 ± 0.07 vs. IA, 0.20 ± 0.04 meq/l; P = 0.08). During the OGTT, FFA levels were significantly lower than baseline in the Tr and IA states, with the exception of 180 min in the Tr state when FFA levels returned back to baseline (data not shown).

RMR and TEM

Mean values for energy expenditure (RMR and TEM) are presented in Fig. 3. Baseline RMR was significantly higher (P < 0.05) in the Tr (4%) compared with the IA state. Glucose ingestion significantly increased (P < 0.05) energy expenditure (TEM) on both test days and was significantly greater (5%) at 15–30 min in the Tr vs. IA state (Tr, 1.61 ± 0.04 vs. IA, 1.52 ± 0.03 kcal/min; P < 0.05).

Table 2. Self-reported energy intake and expenditure

<table>
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<th>LTA, kcal/day</th>
<th>Energy intake, kcal/day</th>
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<tbody>
<tr>
<td>Carbohydrate</td>
<td>704 ± 145</td>
<td>3,664 ± 315</td>
</tr>
<tr>
<td>Fat</td>
<td>554 ± 42</td>
<td>61 ± 2</td>
</tr>
<tr>
<td>Protein</td>
<td>180 ± 29</td>
<td>19 ± 2</td>
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</table>

Values are means ± SE. LTA, leisure time physical activity.
RERs at rest (Tr, 0.76 ± 0.02; IA, 0.77 ± 0.01) were not significantly different between conditions. However, during the OGTT in the IA state, the mean RER was significantly elevated (3.6%) compared with the Tr state (IA, 0.84 ± 0.01 vs. Tr, 0.81 ± 0.01; \( P < 0.05 \)) (Fig. 4).

FBF and CBF (Fig. 5)

Basal CBF (Tr, 3.17 ± 0.31; IA, 3.24 ± 0.31 ml·100 ml\(^{-1}\)·min\(^{-1}\)) and FBF (Tr, 4.28 ± 0.63; IA, 3.83 ± 0.56 ml·100 ml\(^{-1}\)·min\(^{-1}\)) rates were not different in the Tr and IA states (\( P > 0.05 \)). In the Tr state, after glucose ingestion, CBF increased progressively to a peak rate of 4.28 ± 0.54 ml·100 ml\(^{-1}\)·min\(^{-1}\) at 150 min (\( P < 0.05 \) vs. basal) and remained significantly elevated at the end of the 180-min test period. In addition, the time period from 90 to 135 min showed a strong trend to be elevated from baseline in the Tr state (\( P < 0.07 \)). In contrast, in the IA state, CBF was statistically unchanged from baseline at all time points. Thus, in the Tr but not in the IA state, glucose ingestion resulted in a 22% increase
(P < 0.05) in CBF rate despite a significantly reduced plasma insulin and glucose response. FBF was unchanged after glucose ingestion in the Tr and IA states.

Relationship of Glucose Tolerance, Energy Expenditure, and LBF

Table 3 shows the Pearson product-moment correlation coefficients among the glucose, insulin, energy expenditure, and blood flow variables assessed in the present study. The only significant metabolic correlate to LBF was the total area for insulin with glucose-stimulated CBF in the Tr (r = 0.76) and IA (r = 0.72) states (P < 0.05).

DISCUSSION

The major findings of this study are 1) glucose tolerance is enhanced and resting metabolic rate (Figs. 2–4) is increased in the Tr compared with the IA state.
in highly trained endurance athletes; 2) RERs, although similar at rest, were ~4% higher during an OGTT in the IA vs. the Tr state; 3) in response to glucose ingestion, CBF increased significantly (22%) from baseline levels in the Tr state but remained unchanged in the IA state; and 4) despite the improved glucose tolerance and increased RMR with training, there was no association among these variables with the increase in LBF in the Tr state. These findings imply that, in endurance-trained athletes, 7–10 days of physical IA result in a significant deterioration in glucose tolerance and energy metabolism. The mediation of these changes through hemodynamic changes in the periphery was not supported in the present study.

LBF
To date, there have been no longitudinal training studies to examine the time course of changes in LBF with endurance-exercise training, and thus only cross-sectional (trained vs. control subjects) data are available for comparison. This research has suggested that both basal and insulin-stimulated LBFs are increased in lean and endurance-trained individuals (3, 9, 10, 32) compared with untrained (10) and obese subjects (3, 16), although the latter finding is not universal (6). The increase in LBF with exercise training appears to be mediated by various factors, including endothelial cell nitric oxide synthesis (32), increased cardiac output, and decreased vascular resistance (10). This adaptive increase in LBF contributes to insulin-mediated glucose uptake by increasing glucose and insulin delivery to skeletal muscle, the major site of glucose disposal, and as a result may enhance replenishment of muscle glycogen stores after exercise. The significant increase in LBF (10), in addition to previous findings of increased GLUT-4 protein content (8), with exercise training may partially explain the improvements in insulin action and glucose tolerance that have been observed in non-insulin-dependent diabetic patients in response to 7 days of exercise (26).

It has been proposed that an enhanced LBF in endurance-trained compared with control subjects is due to a greater ability of insulin to increase cardiac output, primarily via an increased stroke volume and decreased vascular resistance (10). In the present study, despite significantly lower (73%) plasma insulin concentrations during the OGTT in the Tr compared with the IA state, CBF was significantly increased (22%) from basal levels in the Tr state, whereas no change occurred in the IA state. These findings confirm the enhanced insulin sensitivity in the Tr state, even when the hemodynamic actions of insulin are described. Although this investigation cannot elucidate the mechanism(s) for the increased LBF with training, a recent study found that endothelial cell nitric oxide synthesis is an independent determinant of insulin-mediated blood flow (32). In the present study, exercise training was associated with a greater glucose-stimulated than baseline CBF, although there was no difference in OGTT-stimulated LBF between the Tr and IA states. However, it is important to note that in the present study CBF in the Tr state was still elevated from baseline at the end of the 180-min test period, suggesting an understimation of the actual blood flow response. Thus our study design cannot determine whether differences existed in total glucose-stimulated blood flow between the Tr and IA states. This issue warrants further study.

Glucose Tolerance
Our finding of significantly higher plasma insulin levels during a glucose stimulus after 7–10 days of detraining is consistent with previous reports showing an elevated secretory response of the pancreatic β-cells during hyperglycemia in the detrained (5–14 days)

<table>
<thead>
<tr>
<th>RMR, kcal/day</th>
<th>Total-Area Glucose, mg·dl⁻¹·180 min</th>
<th>Total-Area Insulin, µU·ml⁻¹·180 min</th>
<th>Basal Forearm BF, ml·100 ml⁻¹·min⁻¹</th>
<th>Basal Calf BF, ml·100 ml⁻¹·min⁻¹</th>
<th>OGTT Forearm BF, ml·100 ml⁻¹·min⁻¹</th>
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<tr>
<td>Trained state</td>
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<td>RMR</td>
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<tr>
<td>Total-area insulin</td>
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<tr>
<td>Basal forearm BF</td>
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<tr>
<td>Basal calf BF</td>
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<td>0.61</td>
<td>0.56</td>
<td>0.79</td>
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<tr>
<td>OGTT forearm BF</td>
<td>0.29</td>
<td>0.28</td>
<td>0.29</td>
<td>0.94</td>
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<td>0.62</td>
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<td>RMR</td>
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<tr>
<td>Total-area insulin</td>
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<tr>
<td>Basal forearm BF</td>
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<td>0.60</td>
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<tr>
<td>Basal calf BF</td>
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<td>OGTT forearm BF</td>
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<td>OGTT calf BF</td>
<td>0.27</td>
<td>-0.04</td>
<td>0.72</td>
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<td>0.77</td>
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Values are for 8 men. RMR, resting metabolic rate measured from indirect calorimetry; BF, blood flow; total-area glucose and total-area insulin determined by computer analysis with a trapezoidal model that summated only areas above fasting; forearm BF and calf BF were measured from venous occlusive plethysmography. Statistical significance: r = 0.667, P < 0.05; r = 0.798, P < 0.01.
state (15, 20). Moreover, our finding of similar changes in glucose tolerance in subjects after 7 days of IA with those tested after 10 days of IA is in agreement with previous investigations, that used periods of IA ranging from 5 to 14 days, that also found changes of similar magnitude (11, 15, 20). Exercise training results in an increase in insulin clearance by the liver (7), whereas detraining results in a reduction in insulin binding to receptors (11). Thus these higher insulin concentrations in response to a glucose challenge in the IA state are likely the combination of increased secretion from the pancreatic ß-cells and decreased insulin clearance secondary to decreased binding to insulin receptors and/or decreased clearance by the liver.

The plasma glucose concentration was also significantly elevated at rest and during the 180-min OGTT after the 7–10 days of IA. We have previously reported that increased glucose concentrations after short-term IA (6 days) are partly due to decreased glucose disposal rates, indicative of a significant reduction in insulin action (33). The deterioration observed in glucose tolerance in the present study may also be due to hemodynamic alterations in the periphery. Laakso et al. (17) suggest that the blunted hemodynamic response to physiological insulin levels in subjects with non-insulin-mediated diabetes mellitus vs. control subjects is partly responsible for decreased muscle glucose uptake, whereas others have shown a relationship between impaired LBF and postprandial hyperglycemia (32). Specifically, Baron et al. (3) found that, in obese subjects, a blunted or absent peripheral skeletal muscle blood flow response after an oral glucose load is associated with a reduced glucose disposal compared with that observed in lean subjects. Moreover, Hardin et al. (10) showed that endurance training is associated with significantly greater whole body glucose uptake and insulin-stimulated LBF, concluding that blood flow to the periphery, as a function of fitness level, is a major factor leading to greater insulin sensitivity. Taken together, these previous findings, as well as others (32), have confirmed the independent contribution of fitness level to improved insulin-stimulated blood flow and thus glucose metabolism. The present study extends these previous investigations by simultaneously examining the effects of detraining on glucose tolerance and LBF and shows that the incremental insulin area under the curve but above the fasting value during an OGTT is correlated with CBF. Of interest is the finding that, although the incremental insulin area under the curve in the Tr state was 73% lower than in the IA state, a significant correlation persisted. It could be argued that the reduced plasma insulin response in endurance-trained individuals after a glucose challenge suggests that regular exercise may result in an enhanced sensitivity of insulin to mediate peripheral hemodynamic effects.

RMR and TEM

The present study examined RMR and the thermogenic response to a physiological dose of glucose (~300 kcal) in the Tr and IA states (Fig. 3). We found that RMR was 4% higher in the Tr than IA state but that the increase in TEM after the oral glucose load was similar during both test days. These findings suggest that, on the whole body level, glucose-induced thermogenesis is less sensitive than fasting thermogenesis (RMR) to short-term changes in physical activity status in healthy subjects. The role of endurance-exercise training in influencing RMR remains controversial because of the lack of longitudinal studies that have been performed (21). However, previous findings (21) suggest that a VO2peak > 60 ml·kg⁻¹·min⁻¹ is needed to observe a higher RMR in trained compared with untrained subjects. Thus our subjects were above the threshold needed to observe a higher endurance-trained RMR, and the 7–10 days of IA were sufficient to elicit a reduction in RMR. Our present findings disagree with those of Mikines et al. (20), who found no difference in resting VO2 in the trained vs. detrained subjects even though the mean VO2peak of their subjects was similar to ours. The plausible reason for the discrepancy between the findings of Mikines et al. and our study may be due to their detraining period of 5 days compared with our 7–10 days; however, this issue clearly warrants further study. From a practical standpoint, the 4% decline in RMR after the short period of IA amounts to an energy conservation of ~80 kcal/day and may have a significant impact on body weight homeostasis and body fat regulation if the IA is extended for longer periods.

We originally hypothesized that the thermic response to glucose would be reduced in the Tr state, but this was not found in the present study. There is sufficient evidence showing that, after meal ingestion, highly trained subjects (> 60 ml·kg⁻¹·min⁻¹) exhibit a lower postprandial thermogenic response compared with less-trained subjects (18, 22, 31). However, little information is available regarding the effects of detraining on TEM. Similar to our findings, Mikines et al. (20) found no difference in glucose-induced thermogenesis in highly trained athletes after a brief period (5 days) of physical IA. However, it is important to note that, in the present study, energy expenditure (TEM) was still, similarly, elevated at the end of the 180-min test period on both test days, suggesting an underestimation of the actual thermic response to oral glucose ingestion. Thus our study design is not able to completely address whether differences in the thermic response to glucose were present in the Tr vs. IA state during the postmeasurement period.

The metabolic factors responsible for the increase in energy expenditure after food ingestion include those that increase energy expenditure (e.g., glucose storage) as well as those that suppress the contribution of various metabolic pathways (e.g., gluconeogenesis). One possible mechanism for the metabolic effects of glucose is the subsequent increase in insulin secretion, resulting in an increase in energy expenditure by enhancing rates of glucose disposal (23). However, this mechanism was not completely supported in the present study because there was no difference in TEM between the Tr and IA days despite a 73 and 65% greater plasma insulin and glucose response, respec-
tively, in the IA state. These findings suggest that the action of insulin to dispose of the glucose was greatly impaired with IA and that there was less of a reduction in the rate of the more energetically costly pathway of gluconeogenesis (31). Furthermore, it is possible that some other mechanism, such as sympathetic nervous system activation (1), is responsible for increasing postprandial thermogenesis in the detrained state.

Although the postprandial thermogenic response to glucose was similar between the 2 test days, the RER, a proxy measure of substrate utilization, differed significantly between the Tr and IA days (Fig. 4). A significantly lower RER in the Tr vs. IA state during the OGTT is in agreement with others (20), providing evidence for increased lipid oxidation with training and increased glucose oxidation with inactivity. The implications for this elevated RER in the detrained state on body composition remain to be elucidated.

In summary, 7–10 days of IA resulted in a decline in glucose tolerance as evidenced by an increase in the glucose response during an OGTT, despite a significant increase in the plasma insulin response. RMR was also increased glucose oxidation with inactivity. The implications for increased lipid oxidation with training and detraining on cardiovascular responses to exercise: role of blood flow and lack of exercise on glucose tolerance and insulin sensitivity.

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