The Effect of Resistance Exercise on the Thermic Effect of Food

Charlene M. Denzer and John C. Young

Purpose: The thermic effect of food (TEF) is the increment in energy expenditure above resting metabolic rate associated with the cost of absorption and processing of food for storage. Previous studies have shown that TEF is enhanced by aerobic endurance exercise of sufficient duration and intensity. The purpose of this study was to determine if a similar effect occurs with a single bout of resistance exercise (weightlifting). Methods: VO$_2$ was measured in 9 healthy volunteers (3 males and 6 females) for 2 hours after ingestion of a 2760 kJ (660 kcal) carbohydrate meal with and without prior completion of a resistance training regimen (2 sets of 10 repetitions of 10 different exercises). Results: The meal caused an immediate and persistent thermic effect in both the control and the exercise trial. Mean oxygen consumption over baseline increased 20% in the control trial and 34% in the exercise trial. TEF calculated from VO$_2$ and RER (total area under the response curve above baseline) was 73% greater in the exercise trial compared with the control trial (159 ± 18 vs. 92 ± 14 KJ/2 hrs, p < .02). Conclusion: These results indicate that TEF in response to a carbohydrate meal is enhanced following a single bout of resistance exercise.

Key Words: weightlifting, diet-induced thermogenesis

Introduction

Dietary-induced thermogenesis or the thermic effect of food (TEF) represents the increment in energy expenditure above resting metabolic rate associated with the energy cost of storing glucose as glycogen (1) and is, in large part, mediated by insulin (18). The thermogenic effect of insulin has been attributed to its ability to enhance glucose storage in skeletal muscle (18) and to stimulate the sympathetic nervous system (1, 6). As with other insulin-sensitive processes such as oral glucose tolerance, skeletal muscle glucose uptake, and glycogen synthesis (21), TEF is enhanced when a carbohydrate meal is ingested following a bout of aerobic, endurance-type exercise, when the exercise is of sufficient intensity and duration to deplete muscle glycogen (13, 15, 26, 30). Similarly, insulin-stimulated glucose uptake and oral glucose tolerance are enhanced by anaerobic, resistance-type exercise (5, 8, 14). Although anaerobic exercise is typically of higher intensity and shorter duration than aerobic exercise, glycogen is the primary substrate used by
muscle. To determine if another insulin-sensitive process (TEF) is enhanced by resistance exercise, this study examined the effect of a preceding weightlifting session on the thermic response to a carbohydrate meal.

**Methods**

Participants were 3 males and 6 females, with physical characteristics described in Table 1. This study was reviewed and approved by the UNLV Institutional Review Board, and all participants gave informed consent. Participants were physically active, having engaged in aerobic exercise at least 2 hours per week and weight-training at least twice per week for 2 months prior to entering the study. Participants were asked to keep a daily journal for 3 days prior to testing to determine if they were maintaining energy balance within a normal range. Participants were asked to refrain from using alcohol or tobacco products for 24 hours prior to testing and to forego systematic physical activity for 36 hours prior to testing.

Participants reported to the laboratory on three separate occasions. On the 1st day, skinfold measurements were taken at the abdomen, iliac, triceps, and thigh for the determination of body fat according to the Jackson-Pollock generalized equation for men and women (11). The appropriate amount of weight to be lifted by each participant was then determined. Initial weights were prescribed based on gender and body mass and adjusted to create a 10-repetition maximum.

For the determination of energy expenditure, participants were fitted with a facemask, and oxygen consumption was measured by indirect calorimetry using a Vista Metabolic Measurement System (Vacumed, Ventura, CA, USA). On the day of the experiment, participants reported to the laboratory following an overnight fast (12–15 hours), having performed no systematic training on the previous day. Following a 5–10 min equilibration period, resting VO$_2$ was measured for 15–20 min, during which time a steady state was observed. Participants then completed the prescribed weight-training regimen, which consisted of 2 sets of 10 exercises, 10

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<th>Height (cm)</th>
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<td>22 ± 1</td>
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<td>169 ± 2</td>
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repetitions per exercise. The exercises included bench press, biceps curl, triceps extension, lunges, twisted trunk curl, pullover, low pulley, bent over row, leg press, and seated press. The cadence for each lift was set by a metronome, and each exercise took 20 s to complete. Forty seconds of rest were allotted between each individual exercise. The total time for the exercise program was 20 min. Heart rate was measured by a Polar heart rate monitor (Polar Electro Inc., Woodbury, NY, USA) every 30 s during the exercise program. After completing the exercise regimen, participants sat relaxed in a chair while wearing a facemask, and respiratory exchange measurements were recorded every 10–15 min until participants had recovered to their pre-exercise resting VO₂ (average time, 40 min). Participants were considered to have recovered when the post-exercise VO₂ returned to within 5% of the pre-exercise resting VO₂ value. At this time, participants ingested the 2760 kJ (660 kcal) meal. The meal (80% CHO, 13% protein, 7% fat; 1380 kJ/237 ml) consisted of instant pudding made with 1% milk. Respiratory exchange measurements were made at 10, 30, 60, 90, and 120 min after ingestion to determine the thermic effect of the meal. At each time point, participants were measured for 8–10 min under steady state conditions. On a separate day, participants also completed a control trial that consisted of the test meal without the prior bout of resistance exercise. The meals were ingested at approximately the same time of day in both trials. Energy expenditure at each time point was calculated from measurement of VO₂ and respiratory exchange ratio by the Weir formula (28). TEF was calculated as the area under the response curve for VO₂ above baseline for the 2-hour period following meal ingestion. For the exercise trial, the post-exercise recovery VO₂ was used as the baseline.

Resting oxygen consumption and respiratory quotient were each analyzed statistically using a one-way analysis of variance with the three factors being pre-exercise, post-exercise, and control condition. A dependent t test was performed to evaluate the changes in total TEF above baseline in the exercise trial compared with the control trial. Area under the curve above baseline for the thermic effect of the test meal was calculated using the trapezoid method. Results are presented as mean ± SE.

Results

Pre-treatment resting VO₂ was not different between the exercise and control trials (Table 2). The post-exercise recovery VO₂ used as the baseline for calculation of the TEF did not differ from the pre-exercise VO₂ or from the value obtained on the control day (Table 2). Pre-treatment RER values were similar for control and exercise trials, as were pre-exercise and post-exercise RER values (Table 2). Intensity of the resistance exercise was estimated from heart rates taken during the intervals between the various exercises. Heart rate for the exercise trial averaged 122 ± 5 beats/min, which represented 63% of age-predicted maximal heart rate for these participants.

Ingestion of the test meal caused a rapid and persistent thermic effect in both the control and exercise trials, resulting in an average increase in oxygen consumption over baseline of 20% in the control trial and 34% in the exercise trial (Figure 1). Absolute VO₂ and RER values were used to calculate energy expenditure. The thermic effect of the carbohydrate meal, expressed as the total energy expenditure over baseline, was 73% greater in the exercise trial compared with the control trial (159 ± 18 vs. 92 ± 14 kJ/2 hrs, p < .02; Figure 2).
Discussion

This study was designed to determine if a prior bout of resistance exercise (weightlifting) affected the thermic response to a carbohydrate meal. The results suggest that the potentiation of TEF by prior resistance exercise is comparable to that found with aerobic, endurance exercise. In previous studies of the potentiation of TEF by prior exercise, participants exercised at 75% of VO\(_{2\text{max}}\) and consumed a meal ranging in energy content from 1675 to 3350 kJ, 2 hours post-exercise (13, 15, 26, 30). Despite the difference in energy content of the test meal in these studies, TEF increased by 19–24 kJ/hr over control when exercise preceded the meal. The results of the present study are in keeping with these findings. Exercise intensity, based on heart rate measured during the interval between exercises averaged 63% of age-predicted maximal heart rate in these participants. This value most likely under-
estimates the actual exercise intensity for these individuals, since heart rate could be expected to decrease during the recovery period between exercises. In addition, self-reports of participants indicated a high level of fatigue at the end of the exercise session. TEF increased by 33 kJ/hr in response to the prior resistance exercise, relative to the control condition, an increase similar in magnitude to that previously observed with a similar size meal following endurance exercise (29).

TEF is comprised of two components, the energetic cost of processing and storage of glucose as glycogen in muscle and liver (1), and an additional effect due to insulin-mediated stimulation of the sympathetic nervous system (1, 6). Previous studies have shown that TEF is enhanced by prior endurance exercise only when the exercise is of sufficient intensity and duration to deplete muscle glycogen stores (13, 15, 26, 30). While glycogen depletion was not measured in this study, previous findings indicate that resistance exercise results in a significant increase in muscle glycogen utilization. Tesch et al. (24) found that glycogen concentration decreased by 25% (40 mmol/kg) following 5 sets of 6–12 repetitions of 4 different leg exercises. A similar decrease was reported by Robergs et al. (19) following 6 sets of leg extension exercise at either 70% of 1 RM (6 repetitions/set) or 35% of 1 RM (13 repetitions/set) with equal force applied by the lever arm of the dynamometer between the two trials, and by Pascoe et al. (17) following sets of 6 repetitions of one-legged extensions at 70% of 1 RM to fatigue. The total number of repetitions performed in the present study was comparable to that of these two studies. From the data in the present study, oxygen consumption attributable to glycogen synthesis was estimated by assuming direct conversion of glucose to muscle glycogen, and 1 mol O$_2$ is used to generate the ATP necessary for the incorporation of 3 mol of glucose into glycogen (22), the principal fate of glucose ingested after exercise (1, 16). Assuming that 20% of the glucose ingested by the participants was oxidized (18), the energy requirement to convert the remaining 80% of the glucose load (0.6 mol) to glycogen would be 94 kJ, or 100% of the thermic effect of the carbohydrate load on the control day, but only 60% after exercise.

The factors responsible for the increase in oxygen consumption not attributable to glycogen resynthesis remain to be determined. In the rat hindquarter, insulin itself mediated such an increase (4). Although the exact mechanism for this is unknown (3), the finding of an increased thermic effect of a carbohydrate meal with
high-intensity exercise is in keeping with insulin stimulation of the sympathetic nervous system. Catecholamines may increase cellular respiration by stimulating the activity of the Na/K-ATPase pump (9), the rate of futile cycling (16), the recycling of glucose through 3-carbon compounds, primarily lactate (6), and perhaps by other means. Insulin infusion stimulates norepinephrine release (20), and carbohydrate feeding has been shown to enhance the turnover rate of norepinephrine (12). Norepinephrine infusion causes a larger increase in $O_2$ consumption in dog skeletal muscle following exercise than it does at rest (10). In addition, propranolol partially inhibits the increase in thermogenesis observed during an euglycemic clamp (1, 6), and, in some studies (2, 27) but not others (23, 25), after carbohydrate ingestion. Finally, insulin has been shown to increase circulating norepinephrine independent of changes in blood glucose (7). It should be noted, however, that muscle from exercised rats perfused with insulin did not display greater rates of glucose cycling before glycolgen synthesis or an uncoupling of mitochondrial oxidative-phosphorylation (3). Since glucose incorporation into glycogen appears to take place with minimal energy wasting (3), these results suggest that other, as yet unidentified energy-requiring processes may account for the increase in TEF observed with carbohydrate feeding after a prior bout of exercise.

In summary, the results of this study indicate that TEF in response to a carbohydrate meal is enhanced following a single bout of resistance exercise. This response can be attributed to the energy cost of resynthesizing muscle glycogen. An additional contributing factor may be an insulin-induced increase in the activity of the sympathetic nervous system. The increase in TEF with prior exercise, although small (33 kJ/hr), when combined with the increase in lean body mass, which typically accompanies resistance exercise training, could be a factor in energy balance over a prolonged period of time.

References


