

# Exercise and postprandial lipemia: effect of continuous compared with intermittent activity patterns<sup>1-3</sup>

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## ABSTRACT

**Background:** Guidelines state that accumulated physical activity is beneficial for health, but a minimum duration of 10 min per activity bout is recommended. Limited information regarding the effects of short (<10 min) bouts of activity on health is available, and no studies of the effects of such short bouts of activity on postprandial lipemia have been conducted.

**Objective:** The objective was to compare the effects of accumulating ten 3-min bouts of exercise with those of one 30-min bout of exercise on postprandial plasma triacylglycerol concentrations.

**Design:** Ten men aged 21–32 y completed three 2-d trials  $\geq 1$  wk apart in a randomized repeated-measures design. On day 1, the subjects rested (no exercise) or ran at 70% of maximum oxygen uptake in either ten 3-min bouts (30 min rest between each) or one continuous 30-min bout. On day 2, the subjects rested and consumed test meals (0.69 g fat, 0.95 g carbohydrate, 0.31 g protein, and 46 kJ/kg body mass) for breakfast and lunch. Venous blood samples were obtained in the fasted state and for 7 h postprandially on day 2.

**Results:** Postprandial plasma triacylglycerol concentrations were lower throughout day 2 of both the accumulation exercise trial and the continuous exercise trial than during the control trial (main effect of trial:  $P < 0.001$ , 2-factor analysis of variance).

**Conclusions:** Accumulating multiple short bouts of exercise throughout the day effectively reduce postprandial plasma triacylglycerol concentrations to an extent similar to that of a single 30-min session of exercise in healthy young men. *Am J Clin Nutr* 2006;83:24–9.

**KEY WORDS** Accumulating exercise, physical activity, postprandial lipemia, triacylglycerol, lipid metabolism, coronary heart disease

## INTRODUCTION

The Centers for Disease Control and Prevention and the American College of Sports Medicine advise that adults should accumulate  $\geq 30$  min of moderate-intensity physical activity on most, preferably all, days of the week (1). The proposal that accumulated physical activity is beneficial for health is based partly on evidence from observational studies, which suggest that individuals who perform intermittent activity (eg, walking, stair climbing, gardening, golf, and housework) are at reduced risk of morbidity and mortality from disease (1). In addition, the findings of at least one prospective study indicate that accumulating short bouts of physical activity reduce coronary heart disease risk to the same extent as does one longer bout, provided that the total amount of energy expended is similar (2). The concept of the

health benefits of accumulating physical activity is relatively recent, however, and a minimum duration of 10 min has been proposed for each bout of activity (1, 3, 4).

In recent years several laboratory-based studies have been completed in an attempt to provide support for the hypothesis that accumulated physical activity has health benefits (5–8). Three of these studies examined the influence of accumulated activity on postprandial triacylglycerol concentrations (6–8). The findings of these studies are consistent in suggesting that accumulated physical activity is effective in lowering postprandial triacylglycerol concentrations (6–8). This is significant because high postprandial triacylglycerol concentrations indicate an increased risk of cardiovascular disease (9, 10). However, none of these studies examined exercise bouts lasting <10 min. Therefore, it remains to be determined whether accumulating short (<10 min) bouts of physical activity are effective in lowering postprandial triacylglycerol concentrations. It is important to address this issue because activities that are intermittent in nature often involve bouts lasting <10 min. Moreover, most people not classed as sedentary do not exercise continuously for 10 min at a time (11).

Therefore, the purpose of the present study was to compare postprandial triacylglycerol concentrations in a group of young healthy men after either 30 min of continuous exercise or 30 min of accumulated activity, ie, ten 3-min bouts performed throughout a single day. An exercise volume of 30 min was chosen because it is consistent with current guidelines regarding physical activity and health (1, 3, 4). Exercise durations of 3 min were selected for the accumulated activity trial so that bouts could be performed throughout the day with a 30-min rest interval between each bout.

## SUBJECTS AND METHODS

### Subjects

Ten healthy men aged 21–32 y volunteered to participate in this study. All subjects were recreationally active and had been

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weight stable ( $\pm 2.5$  kg) for  $\geq 3$  mo before the study. To minimize risks, subjects were recruited only if they met the following criteria: were nonsmoking, were free of known cardiovascular disease or abnormalities, were not taking any medication known to influence lipid or carbohydrate metabolism, had a resting arterial blood pressure  $< 140/90$  mm/Hg, and had a body mass index (BMI; in  $\text{kg}/\text{m}^2$ )  $< 35$ . Mean ( $\pm$ SEM) values for the subjects' age, height, weight, BMI, waist circumference, percentage body fat, and maximum oxygen uptake were as follows:  $25.0 \pm 1.3$  y,  $177.4 \pm 1.4$  cm,  $80.2 \pm 4.8$  kg,  $25.4 \pm 1.2$ ,  $87.2 \pm 3.5$  cm,  $9.4 \pm 0.7\%$ , and  $56.3 \pm 1.8$   $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ , respectively. The university's Ethical Advisory Committee approved the study, and written informed consent was obtained from all subjects before their participation in the study.

### Anthropometric measures

Height (to the nearest 0.1 cm) and weight (to the nearest 0.01 kg) were measured with the use of a stadiometer (Seca, Hamburg, Germany) and a balance-beam scale (Avery, Birmingham, United Kingdom), respectively. BMI was calculated as weight in kilograms divided by the square of height in meters. Skinfold thickness was measured at 3 sites (chest, abdomen, and thigh) on the right hand side of the body with the use of calipers (John Bull; British Indicators, West Sussex, United Kingdom). Body density was calculated with the use of a 3-site formula (12) and percentage body fat was then estimated by using the Siri equation (13). Waist circumference was determined as the widest part of the torso between the xiphoid process of the sternum and the iliac crest.

### Preliminary exercise tests

Subjects participated in 2 preliminary exercise tests performed on a motorized treadmill (RUNRACE; Technogym, Gambettola, Italy). A 16-min, 4-stage, submaximal treadmill test was conducted to determine the relation between running speed and oxygen uptake. Initial running speed was set between 6 and 8 km/h depending on each subject's fitness level. The treadmill was level throughout the test. Speed was increased by 1 or 1.5 km/h every 4 min, depending on each subject's fitness level. Next, maximum oxygen uptake was measured directly with the use of an incremental uphill protocol at a constant speed until the subjects reached volitional fatigue (14). The initial incline of the treadmill was set at 3.5% for this test. Thereafter, the treadmill gradient was increased by 2.5% every 3 min. Heart rate was monitored throughout these tests by using short-range telemetry (Polar A3, Kempele, Finland). Ratings of perceived exertion (RPE) were assessed periodically during the tests by using the Borg scale (15).

### Main trials

Each subject underwent three 2-d trials: an accumulated exercise trial, a continuous exercise trial, and a control trial. Two-day trials were used because skeletal muscle lipoprotein lipase activity is thought to peak  $> 8$  h after exercise (16), and this enzyme facilitates the removal of triacylglycerol from the blood (17). There was a 7-d gap between each trial, and the trials were performed in a randomized design.

#### Day 1

On the first day of each trial, the subjects reported to the laboratory at 0900 after having eaten breakfast. For the accumulated exercise trial, the subjects performed ten 3-min bouts of

treadmill running throughout the day. A 30-min rest interval followed each bout. For the continuous exercise trial, the subjects performed one 30-min treadmill run in the afternoon. For both of these trials, the exercise was completed at 1530 so that the time interval between the cessation of exercise and the consumption of the first test meal (on the following day) was the same (ie, 17 h). The exercise intensity for the treadmill running was 70% of maximum oxygen uptake as determined by the preliminary exercise tests. For the control trial, the subjects rested throughout the day in the laboratory. During each trial, the subjects consumed a packed lunch midway through the day (1200–1300). The subjects left the laboratory at  $\approx 1600$  and were instructed to consume an early evening meal and to rest for the remainder of the evening.

#### Day 2

On the second day of each trial, the subjects reported to the laboratory at 0800 after a 10-h overnight fast (no food or drink except water). Subjects sat in a semisupine position on a bed for 10 min after their arrival at the laboratory. A cannula (Venflon; Becton Dickinson, Helsingborg, Sweden) was then inserted into an antecubital vein, and a baseline blood sample was collected. The subjects then consumed a standardized test meal for breakfast. A clock was started when subjects began eating, and they were required to rest (read, watch television) in the laboratory for 7 h after the initiation of breakfast. A second test meal (identical to the first) was consumed 3 h after initiation of the first meal. Venous blood samples were collected at hourly intervals throughout the day for the measurement of triacylglycerol, glucose, insulin, nonesterified fatty acids (NEFAs), and 3-hydroxybutyrate. Additional samples were collected at 0.5, 0.75, 3.5, and 3.75 h for the measurement of glucose and insulin. The first 3 mL blood withdrawn was always discarded, and 10 mL nonheparinized saline (0.9% vol:wt; B Braun Medical, Sheffield, United Kingdom) was used to flush the cannula after each blood sample collection. The subjects were always lying in a semisupine position for 5 min before the blood samples were taken.

### Standardization of diet and exercise

The subjects weighed and recorded all food and drink consumed for 2 d before any of the main trials. The subjects then consumed identical amounts of the same food and drink before each of the main trials. Thus, meals were standardized across trials, including the evening meal on day 1. The subjects refrained from drinking alcohol during this time. In addition, the subjects were asked to remain inactive on the day before day 1 of each trial and throughout the main trials (other than for the exercise performed as part of the experiment). Food diaries were analyzed with the use of computerized software (Comp-EAT Version 5.0; Nutrition Systems, London, United Kingdom) to determine caloric intake and macronutrient content.

### Estimation of energy expenditure during exercise

During the preliminary exercise tests, the accumulated exercise trial, and the continuous exercise trial, expired air samples were collected into Douglas bags (Plysu Protection Systems, Milton Keynes, United Kingdom). Samples were collected during the final minute of each stage of the preliminary exercise tests and during the final minute of each 3-min bout of exercise during



**TABLE 1**

Estimated energy expenditure, percentage of maximal oxygen uptake (% $\dot{V}O_2$ max), heart rate, ratings of perceived exertion (RPE), and respiratory exchange ratio during the accumulated and continuous exercise trials<sup>1</sup>

Trial	Energy expenditure	% $\dot{V}O_2$ max	Heart rate	RPE	Respiratory exchange ratio
	<i>MJ/30 min</i>	<i>mL · kg<sup>-1</sup> · min<sup>-1</sup></i>	<i>beats/min</i>		
Accumulated exercise <sup>2</sup>	1.96 ± 0.09	69.6 ± 1.0	153 ± 3	11 ± 0	0.97 ± 0.01
Continuous exercise <sup>3</sup>	2.01 ± 0.11	71.1 ± 2.3	167 ± 3 <sup>4</sup>	12 ± 1	0.99 ± 0.01

<sup>1</sup> All values are  $\bar{x} \pm \text{SEM}$ ;  $n = 10$ . Means were compared by using Student's  $t$  test for correlated data.

<sup>2</sup> Calculated from data collected during minutes 2–3 of all 10 exercise bouts.

<sup>3</sup> Calculated from data collected at 9–10, 19–20, and 29–30 min of exercise.

<sup>4</sup> Significantly different from the accumulated exercise trial,  $P < 0.0005$ .

the accumulated exercise trial. For the continuous exercise trial, 1-min expired air samples were collected at 9–10, 19–20, and 29–30 min. Oxygen consumption and carbon dioxide production were determined from these expired air samples with the use of a paramagnetic oxygen analyzer and an infrared carbon dioxide analyzer, respectively (series 1400; Servomex, Crowborough, United Kingdom). These analyzers were calibrated before analysis using gases of known concentration. Expired air volumes were measured with a dry gas meter (Harvard Apparatus, Edenbridge, United Kingdom) and corrected to standard temperature and pressure dry. Oxygen consumption and carbon dioxide production values were used to calculate energy expenditure (18).

### Test meals

The test meal consisted of white bread, Cheddar cheese, butter, mayonnaise, potato chips, whole milk, and milkshake powder. The meal was prescribed according to body mass and provided 0.69 g fat, 0.95 g carbohydrate, 0.31 g protein, and 46 kJ energy per kilogram body mass. The average macronutrient content of each test meal was  $55.5 \pm 3.2$  g fat,  $72.5 \pm 4.2$  g carbohydrate, and  $25.0 \pm 1.5$  g protein, which provided  $3.70 \pm 0.22$  MJ energy (56% fat, 33% carbohydrate, and 11% protein). The subjects were asked to consume each meal within 20 min. The time taken to consume each meal was recorded and replicated in subsequent trials. The average time taken to consume the first meal (breakfast) was  $12.0 \pm 1.0$  min. The average time taken to consume the second meal (lunch) was  $14.2 \pm 1.3$  min. None of the subjects reported nausea or any gastrointestinal discomfort during or after meals. The subjects consumed water ad libitum during the first trial, and the volume ingested was replicated in subsequent trials.

### Analytic methods

Venous blood samples were collected into precooled 9-mL potassium EDTA-coated Monovette tubes (1.6 mg/mL; Sarstedt, Leicester, United Kingdom), and the samples were immediately centrifuged (GS-15R Centrifuge; Beckman Coulter, Fullerton, CA) at  $1968 \times g$  for 10 min at 4 °C. After being separated, plasma was dispensed into plain microtubes and stored at  $-80$  °C. The plasma concentrations of triacylglycerol, glucose, 3-hydroxybutyrate (Randox Laboratories, County Antrim, United Kingdom), and NEFA (Wako Chemicals, Neuss, Germany) were determined by enzymatic, colorimetric methods with the use of a centrifugal analyzer (Cobas Mira Plus; Roche Diagnostic Systems, Basel, Switzerland). Plasma insulin concentrations were measured by radioimmunoassay (MP Biomedicals, Orangeburg, NY). All samples from the same individual

were assayed in a single run. Accuracy and precision were monitored by using quality-control sera [Randox Laboratories (County Antrim, United Kingdom), SERO AS (Billingstad, Norway), and MP Biomedicals (Orangeburg, NY)]. Intraassay CVs were 0.5% for triacylglycerol, 0.8% for glucose, 5.1% for 3-hydroxybutyrate, 1.7% for NEFAs, and 7.4% for insulin. The homeostatic model assessment (HOMA) was used to estimate whole-body insulin sensitivity, calculated as fasting insulin ( $\mu\text{U}/\text{mL}$ )  $\times$  fasting glucose (mmol/L)/22.5 (19). Hemoglobin concentration and hematocrit were measured at baseline and at the end of the observation period to estimate changes in plasma volume (20).

### Statistical analysis

Data were analyzed with the use of the Statistical Package for the Social Science (SPSS) software version 12.0 for WINDOWS (SPSS Inc, Chicago, IL). Areas under the curve for plasma concentrations versus time were calculated by using the trapezium rule. Student's  $t$  tests for correlated data were used to compare physiologic responses between exercise trials (energy expenditure, RPE, respiratory exchange ratio, oxygen consumption, and heart rate). Repeated-measures one-factor analysis of variance (ANOVA) was used to examine differences between the 3 trials for fasting plasma concentrations, areas under the curve, and percentage change in plasma volume. Repeated-measures 2-factor ANOVA was used to examine differences between the 3 trials over time for plasma constituents. Where significant interactions were found, post hoc multiple comparisons were made by using the Bonferroni method. Statistical significance was accepted at the 5% level. Results are presented as means  $\pm$  SEMs.

## RESULTS

### Responses to treadmill running

Exercise data are shown in **Table 1**. There were no significant differences between exercise trials in estimated gross energy expenditure, relative exercise intensity, RPE, or respiratory exchange ratio. Mean heart rates were significantly higher during the continuous trial than during the accumulated trial. For comparison, average heart rate on day 1 of the control trial (mean of 10 heart rate measurements collected at time points identical to those in the accumulated trial) was  $63 \pm 2$  beats/min.

### Dietary data

Average energy intakes for the pretrial day and for day 1 of the trials were  $10.83 \pm 1.12$  and  $10.94 \pm 1.12$  MJ, respectively. The



**TABLE 2**

Fasting plasma concentrations of triacylglycerol, glucose, insulin, nonesterified fatty acids (NEFAs), and 3-hydroxybutyrate (3-OHB) during the accumulated exercise, continuous exercise, and control trials<sup>1</sup>

Trial	Triacylglycerol <sup>2</sup>	Glucose <sup>2</sup>	Insulin	NEFA	3-OHB <sup>2</sup>
	mmol/L	mmol/L	pmol/L	mmol/L	mmol/L
Accumulated exercise	1.14 ± 0.19	5.05 ± 0.08 <sup>3</sup>	143.3 ± 19.8	0.38 ± 0.05	0.06 ± 0.01
Continuous exercise	1.10 ± 0.20	5.09 ± 0.08	141.3 ± 14.4	0.42 ± 0.04	0.06 ± 0.02
Control	1.35 ± 0.28	5.21 ± 0.97	158.5 ± 32.0	0.36 ± 0.04	0.02 ± 0.01

<sup>1</sup> All values are  $\bar{x} \pm \text{SEM}$ ;  $n = 10$ . Means were compared by using one-factor ANOVA for the main effect of trial followed by a Bonferroni multiple comparisons test.

<sup>2</sup> Significant main effect of trial,  $P < 0.04$ .

<sup>3</sup> Significantly different from the control trial,  $P = 0.04$ .

average dietary intakes of fat, carbohydrate, and protein were  $101.2 \pm 15.7$ ,  $317.1 \pm 39.5$ , and  $124.2 \pm 20.8$  g respectively, for the pretrial day and  $87.4 \pm 9.5$ ,  $372.6 \pm 151.1$ , and  $108.4 \pm 13.5$  g, respectively, for day 1.

### Plasma concentrations in the fasted state

Fasting plasma concentrations before the test meals on day 2 of each trial are shown in **Table 2**. One-factor ANOVA showed a main effect of trial on fasting plasma triacylglycerol, glucose, and 3-hydroxybutyrate concentrations between trials. Post hoc tests showed that the fasting plasma glucose concentration was lower during the accumulated exercise trial than during the control trial. Although post hoc tests did not show a significant difference in fasting plasma triacylglycerol concentrations between trials, plasma triacylglycerol concentrations tended to be lower during both exercise trials than during the control trial (accumulated exercise trial compared with the control trial,  $P = 0.180$ ; continuous exercise trial compared with the control trial,  $P = 0.096$ ). Similarly, post hoc tests showed no significant between-trial differences for fasting plasma 3-hydroxybutyrate concentrations, but the values tended to be higher during both exercise trials (accumulated exercise trial compared with the control trial,  $P = 0.057$ ; continuous exercise trial compared with the control trial,  $P = 0.193$ ) than during the control trial. There was no significant difference in fasting insulin concentrations between trials. Moreover, there was no significant difference in the HOMA insulin sensitivity index between trials (accumulated exercise trial:  $4.7 \pm 0.7$ ; continuous exercise trial:  $4.6 \pm 0.5$ ; control trial:  $5.4 \pm 1.2$ ).

### Plasma concentrations in the postprandial state

Changes in plasma volume during the observation periods were small and did not differ significantly between trials (accumulated exercise:  $-0.2 \pm 2.3\%$ ; continuous exercise:  $-0.3 \pm 1.9\%$ ; control:  $-1.5 \pm 1.5\%$ ). Thus, plasma concentrations were not adjusted for changes in plasma volume.

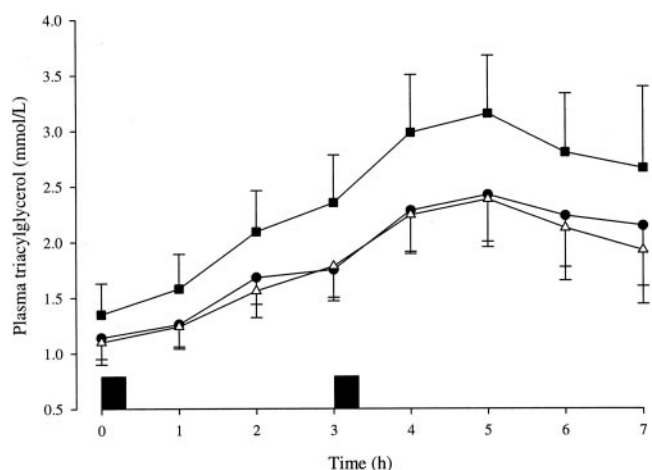
Plasma triacylglycerol responses to the test meals are shown in **Figure 1**. Two-way ANOVA showed significant main effects of trial and time and a significant interaction. Plasma triacylglycerol responses were lower during the exercise trials than during the control trial (post hoc tests: accumulated exercise trial compared with control trial,  $P = 0.019$ ; continuous exercise trial compared with control trial,  $P = 0.019$ ) with little difference between the accumulated and continuous exercise trials. Total and incremental areas under the plasma triacylglycerol concentration versus time curve are given in **Table 3**. There was a main effect of trial for both of these variables. The total area under the

plasma triacylglycerol versus time curve was 22% and 24% lower during the accumulated and continuous exercise trials, respectively, than during the control trial. The incremental areas under the plasma triacylglycerol versus time curve were 31% and 32% lower during the accumulated and continuous exercise trials, respectively, than during the control trial. There were no significant differences in plasma triacylglycerol concentration between the exercise trials.

Plasma glucose and insulin responses to the test meals are shown in **Figure 2**. There was a main effect of time for both glucose and insulin. For insulin, there was also a main effect of trial. Post hoc tests showed that the plasma insulin concentration was lower during the accumulated exercise trial than during the control trial ( $P = 0.047$ ). There was no difference in plasma insulin concentration between the continuous exercise and control trials or between the accumulated exercise and continuous exercise trials. No significant differences in plasma concentrations of NEFA and 3-hydroxybutyrate were observed between trials (data not shown).

### DISCUSSION

The main finding of the present study was that postprandial triacylglycerol concentrations are reduced to a similar extent



**FIGURE 1.** Mean ( $\pm$ SEM) fasting and postprandial plasma triacylglycerol concentrations during the accumulated exercise (●), continuous exercise (△), and control (■) trials ( $n = 10$ ). The black rectangles indicate the times that the test meals were consumed. Data were analyzed by using 2-factor ANOVA followed by a Bonferroni multiple comparisons test. There was a significant main effect of trial ( $P = 0.001$ ), main effect of time ( $P < 0.0005$ ), and trial  $\times$  time interaction ( $P = 0.046$ ).

**TABLE 3**

Seven-hour areas under the plasma concentration versus time curve for total triacylglycerol and incremental triacylglycerol (adjusted for fasting value) on the accumulated exercise, continuous exercise, and control trials<sup>1</sup>

Trial	Total triacylglycerol <sup>2</sup>	Incremental triacylglycerol <sup>2</sup>
	<i>mmol · 7 h/L</i>	
Accumulated exercise	13.25 ± 2.24 <sup>3</sup>	5.18 ± 1.05 <sup>3</sup>
Continuous exercise	12.82 ± 2.26 <sup>3</sup>	5.11 ± 0.91 <sup>3</sup>
Control	16.96 ± 3.09	7.49 ± 1.34

<sup>1</sup> All values are  $\bar{x} \pm \text{SEM}$ ;  $n = 10$ . Means were compared by using one-factor ANOVA followed by a Bonferroni multiple comparisons test.

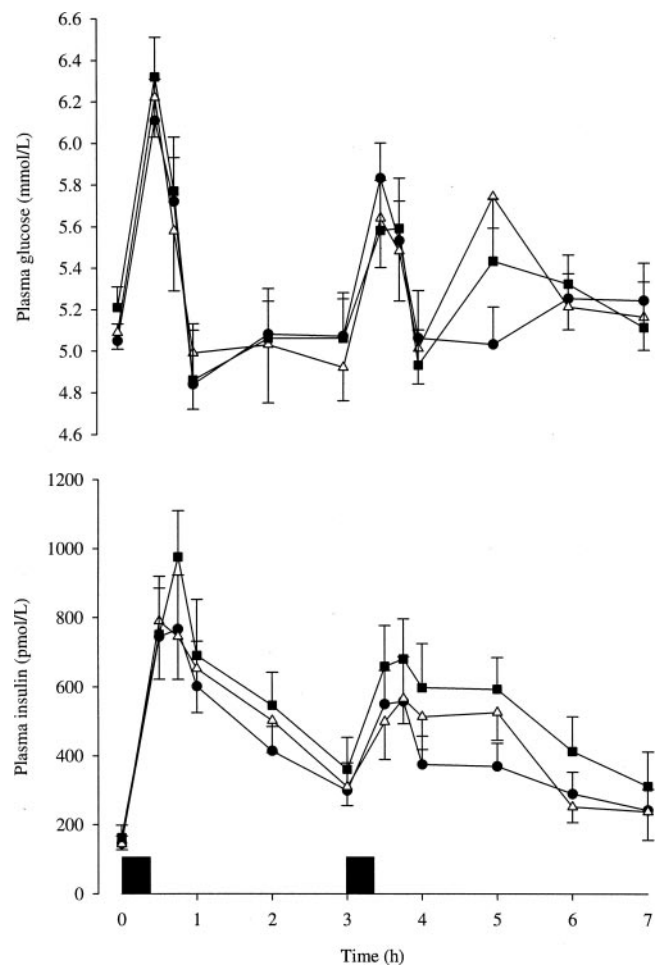
<sup>2</sup> Significant main effect of trial,  $P = 0.001$ .

<sup>3</sup> Significantly different from the control trial,  $P \leq 0.02$ .

when ten 3-min bouts of exercise are performed during the course of a day or when one continuous 30-min bout of exercise is performed. This finding suggests that health benefits may accrue from the accumulation of very short bouts of physical activity. Therefore, the current recommendation (1, 3, 4) that each individual exercise bout should last  $\geq 10$  min may be unnecessary—at least in the case of postprandial triacylglycerol concentrations. The completion of many short bouts of physical activity throughout the day may be easier and more appealing for many individuals than is a pattern involving longer activity bouts. Moreover, evidence suggests that for many people who manage to perform 30 min of physical activity per day, this is achieved by accumulating several short (<10 min) bouts (21).

Many studies have shown that postprandial triacylglycerol concentrations decrease after a single bout of aerobic exercise. The energy expended during exercise appears to be an important determinant of the extent to which triacylglycerol is lowered (22, 23). Three previous studies have examined the effects of accumulated or intermittent activity on postprandial triacylglycerol concentrations (6–8). The minimum duration of any one activity bout in these studies was 10 min. To our knowledge, the present study was the first to examine the effects of accumulating short (3 min) bouts of activity on postprandial lipemia. Taken together, these findings suggest that the duration of individual exercise bouts is unimportant for lowering triacylglycerol, provided that sufficient energy is expended throughout the day.

Two mechanisms have been proposed to explain reductions in postprandial triacylglycerol concentrations after exercise. One mechanism is the increased activity of the enzyme lipoprotein lipase located in the capillaries supplying skeletal muscle. This would facilitate the clearance of triacylglycerol from plasma into muscle to replace the intramuscular triacylglycerol oxidized during exercise (17). The other mechanism is a reduced synthesis and secretion of VLDL-triacylglycerol from the liver (24). It is impossible to tell which of these mechanisms was operating in the present study. NEFA concentrations did not differ significantly between trials in the present study, which suggests that substrate delivery to the liver for triacylglycerol synthesis and secretion in VLDLs was not significantly different between trials. However, fasting plasma 3-hydroxybutyrate concentrations were elevated during the exercise trials, which indicates that fatty acid oxidation in the liver was elevated, which in turn reduces the availability of triacylglycerol for incorporation into VLDL. In



**FIGURE 2.** Mean ( $\pm$ SEM) fasting and postprandial plasma concentrations of glucose and insulin during the accumulated exercise (●), continuous exercise (△), and control (■) trials ( $n = 10$ ). The black rectangles indicate the times that the test meals were consumed. Data were analyzed by using 2-factor ANOVA followed by a Bonferroni multiple comparisons test. For glucose, there was a main effect of time ( $P < 0.0005$ ). For insulin, there was a main effect of trial ( $P = 0.038$ ) and a main effect of time ( $P < 0.0005$ ).

contrast, the reduced plasma insulin concentrations in the accumulated exercise trial (and the tendency for reduced concentrations in the continuous exercise trial) suggest reduced insulin-mediated inhibition of skeletal muscle lipoprotein lipase activity and therefore enhanced triacylglycerol clearance at this site (17).

The exercise intensity used in the present study was high, ie, 70% of maximum oxygen uptake. This high exercise intensity necessitated a high rate of energy expenditure, ie, 67 kJ/min (16 kcal/min). This ensured that the total amount of energy expended in exercise was high, ie, 2 MJ (476 kcal) during 30 min of exercise. This is more than twice the expenditure that would be attained by the average adult completing 30 min of moderate-intensity physical activity, ie, 200 kcal according to Pate et al (1). Further research is required to ascertain whether 30 min of moderate-intensity physical activity (50–60% of maximum oxygen uptake) accumulated in very short bouts is effective at lowering postprandial triacylglycerol concentrations. It is worth noting, however, that for sedentary older and slightly overweight individuals, activities such as brisk walking may elicit moderate-to-high relative exercise intensities albeit with




a lower overall energy expenditure than that elicited in young, physically active individuals.

The participants in the present study were young, regularly active healthy men. Therefore, the findings cannot be generalized to young, sedentary adults or to middle-aged and older adults. However, it is possible that exercise-induced reductions in postprandial lipemia would be greater in these groups because perturbations in triacylglycerol concentrations after meals are more likely to be exaggerated in such individuals. Furthermore, Murphy et al (7) showed that postprandial triacylglycerol concentrations decrease in sedentary postmenopausal women after 30 min of brisk walking at an intensity equivalent to 60% of maximum oxygen uptake. In this study, exercise was undertaken in either one continuous session or accumulated in three 10-min bouts. Thus, a question that needs to be addressed in future studies is whether adherence to the minimal recommended volume of exercise (0.84 MJ = 200 kcal) through multiple short (<10 min) bouts of moderate-intensity physical activity is effective in lowering postprandial triacylglycerol concentrations in subjects of various ages with various habitual activity patterns.

The test meals used in this study were high in fat and low in carbohydrate (56% fat, 33% carbohydrate, and 11% protein). The macronutrient content of these test meals does not reflect that in a typical Western diet. However, the replacement of the fat content of the meals with carbohydrate could exacerbate the triacylglycerol response further because of carbohydrate-induced hypertriacylglycerolemia (25). Further investigation of the effects of accumulated physical activity on postprandial triacylglycerol concentrations after meals typically consumed by Western populations would be useful.

Two other findings of this study require explanation. First, we observed a higher mean heart rate during the continuous exercise trial than during the accumulated exercise trial. This difference may have been due to cardiovascular drift, which is known to occur as exercise progresses (26). Second, fasting blood glucose was lower on day 2 of the accumulated exercise trial than on day 2 of the control trial. A trend was also noted for lower fasting blood glucose concentration on day 2 of the continuous exercise trial than on day 2 of the control trial. It is possible that this was due to reduced liver glycogen concentrations after exercise and, hence, reduced hepatic glucose output.

In conclusion, the results of the present study show that, in young healthy men, 30 min of physical activity accumulated in ten 3-min bouts is equally as effective in lowering postprandial triacylglycerol concentrations as is 30 min of activity performed in one continuous bout. These findings suggest that it may be unnecessary for exercise guidelines for health to stipulate that physical activity be performed in bouts of  $\geq 10$  min. Further research is required to determine whether these findings can be generalized to the public at large. 

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MM was involved in the study design and implementation and data collection and analysis. SFB was involved in the data collection and blood biochemistry. DJS conceived the study and performed the venous cannulations. All authors contributed to the writing of the manuscript. None of the authors had a conflict of interest regarding any aspect of this research.

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