Accumulating Short Bouts of Running Exercise Throughout the Day Reduces Postprandial Plasma Triacylglycerol Concentrations and Resting Blood Pressure in Healthy Young Men

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Background: This study examined the effect of accumulating short bouts of exercise on postprandial plasma triacylglycerol and resting blood pressure in healthy young men. Methods: Nineteen subjects underwent two 2-d trials in a randomized counterbalanced order. On day 1, subjects either rested or performed multiple 6 min running bouts (30 min rest between each) until they had accumulated an energy expenditure of 4.2 MJ (1000 kcal). On day 2, subjects rested and consumed test meals for breakfast and lunch. Blood pressure was measured throughout days 1 and 2. Venous blood samples were obtained throughout day 2. Results: Systolic and diastolic blood pressure was lower for the exercise compared with the control trial on day 1. Postprandial plasma triacylglycerol concentrations and systolic blood pressure were lower throughout day 2 on the exercise compared with the control trial. Conclusion: Accumulating short bouts of exercise throughout the day may modify cardiovascular disease risk.

Key Words: physical activity, lipid metabolism, cardiovascular disease risk

In 1995 the Centers for Disease Control and Prevention and the American College of Sports Medicine introduced the unique concept of accumulation in their public health guidelines for physical activity. This was encapsulated in the statement that “every US adult should accumulate 30 min or more of moderate-intensity physical activity on most, preferably all, days of the week.”1 This recommendation attained wide publicity the following year with the publication of the Surgeon General’s report on Physical Activity and Health2 and the concept of accumulation has been endorsed recently by the Department of Health in the UK.3

When the concept of accumulation was introduced it was recognized that the health benefits were “unproved”2 and that “more research is needed” to elucidate the health effects of accumulated activity.1 Recent studies have addressed this issue by
examining a variety of health-related outcomes. The findings from these studies support the concept that accumulating activity is beneficial to health.

The majority of accumulation studies have employed exercise bouts with a minimum duration of 10 min. This is not surprising since physical activity and health guidelines recommend a minimum of 10 min per bout when accumulating activity. However, if total energy expenditure is the most important factor for health benefits, as is suspected, then the duration of exercise should not matter provided that sufficient energy is expended. This issue is important not just from an academic standpoint but also for practical reasons because research suggests that even among people not classed as sedentary, the majority do not exercise continuously for 10 min at a time.

Postprandial lipemia is considered an emerging risk factor for cardiovascular disease and a single bout of continuous aerobic exercise lowers postprandial lipemia. Therefore, the present study evaluated the hypothesis that accumulating short bouts of activity would lower postprandial triacylglycerol concentrations. In addition, resting arterial blood pressure was measured since it is a major cardiovascular disease risk factor and previous research suggests that it may be lowered following the accumulation of short bouts of activity.

**Subjects and Methods**

**Subjects**

Nineteen healthy males (age 19 to 26 y) volunteered to participate in this study. All subjects were recreationally active and had been weight stable (± 2.5 kg) for at least 3 months before the study. To minimize risks, subjects were only recruited if they met the following criteria: were non-smoking, were free of known cardiovascular disease or abnormalities, were not taking any medication known to influence lipid or carbohydrate metabolism, had resting arterial blood pressure < 160/95 mm/Hg, and had a BMI < 35 kg/m². Mean (± standard error of the mean) values for the subjects’ age, height, weight, BMI, waist circumference, and maximal oxygen uptake (VO₂max) were: 22.7 ± 0.5 y, 177.8 ± 1.5 cm, 75.9 ± 3.5 kg, 23.8 ± 0.8 kg/m², 83.3 ± 2.3 cm and 60.3 ± 2.0 mL · kg⁻¹ · min⁻¹, respectively. Loughborough University’s Ethical Advisory Committee approved the study and each subject gave a statement of informed consent.

**Anthropometry**

Height (to the nearest 0.1 cm) and weight (to the nearest 0.1 kg) were measured with standard methods. BMI was calculated as the weight in kilograms divided by the square of the height in meters. Waist circumference was determined as the widest diameter between the xiphoid process of the sternum and the iliac crest.

**Preliminary Exercise Tests**

Subjects participated in two preliminary exercise tests performed on a motorized treadmill (RUNRACE, Technogym, Gambettola, Italy). First, a 16-min submaximal
treadmill test was conducted to determine the relationship between running speed and oxygen uptake ($V_{O_2}$). Second, $V_{O_2\text{max}}$ was measured directly using an incremental uphill test at a constant speed until the subjects reached volitional fatigue.\textsuperscript{21}

**Main Trials**

Each subject underwent two 2-d trials (exercise and control) separated by at least an interval of 7-d in a randomized, counterbalanced design. On day 1 of each trial, subjects reported to the laboratory between 0830 and 0900 having eaten breakfast. Upon arrival in the laboratory subjects were asked to sit quietly for 10 min after which resting arterial blood pressure was measured. On the control trial, subjects were required to continue resting throughout the day in the laboratory. On the exercise trial, subjects performed 6 min bouts of treadmill running throughout the day with 30 min rest between each bout. The exercise intensity for the running bouts was set at 70\% of $V_{O_2\text{max}}$ as determined by the preliminary exercise tests. Heart rate was monitored during exercise and expired air was collected for the last 2 min of each exercise bout. This pattern continued until subjects had accumulated a gross energy expenditure of 4.2 MJ (1000 kcal) (this expenditure was chosen because previous research—with continuous exercise—indicates that it is effective in lowering postprandial lipemia).\textsuperscript{22} This required between 9 and 15 bouts depending on the subject. The expired air samples—collected throughout day 1—were used to determine the actual energy expenditure accumulated during exercise. Resting arterial blood pressure was measured 15 min after the termination of each exercise bout (or at an equivalent time point during the control trial). Subjects consumed a packed lunch midway through the day. Subjects left the laboratory between 1600 and 1700 and they were instructed to consume an early evening meal and rest for the remainder of the evening.

On day 2 of each trial, subjects reported to the laboratory between 0800 and 0830 after a 10 h overnight fast (no food or drink except water). Subjects sat in a semi-supine position on a bed for 5 min following 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. Following this, resting arterial blood pressure was measured. Subjects then consumed a standardized test meal for breakfast. A clock was started when subjects began eating and they were required to remain in the laboratory for 7 h following the initiation of breakfast. A second test meal (identical to the first) was consumed 3 h after the initiation of the first meal. Resting arterial blood pressure was measured at hourly intervals throughout the day. Venous blood samples were also collected at hourly intervals throughout the day for the measurement of triacylglycerol, glucose, insulin, and non-esterified fatty acids (NEFA). Additional samples were collected at 0.5, 0.75, 3.5, and 3.75 h for measurement of glucose and insulin. The first 3 mL of blood withdrawn was always discarded and 10 mL of non-heparized saline (0.9\% v/w, B. Braun Medical, Sheffield, UK) was used to flush the cannula after each blood collection.

**Standardization of Diet and Exercise**

For purposes of standardization, subjects weighed and recorded all food and drink consumed during the day before each trial and on day 1 of each trial. Subjects
abstained from drinking alcohol during this time. Subjects were asked to replicate their intake from their first trial on their second trial. In addition, subjects were asked to remain inactive on the day before day 1 of each trial and throughout the main trials (other than the exercise performed as part of the experiment). Food diaries were analyzed using computer software (Comp-EAT Version 5.0, Nutrition Systems, London, UK) to determine caloric intake and macronutrient content.

Energy Expenditure During Exercise

During the preliminary exercise tests and during exercise in the main trials, expired air samples were collected into Douglas bags (Plysu Protection Systems, Milton Keynes, UK). Oxygen consumption and carbon dioxide production were determined from these expired air samples using a paramagnetic oxygen analyzer and an infra-red carbon dioxide analyzer, respectively (Series 1400; Servomex, Crowborough, East Sussex, UK). Expired air volumes were measured using a dry gas meter (Harvard Apparatus, Edenbridge, Kent, UK) and corrected to standard temperature and pressure (dry). Oxygen consumption and carbon dioxide production values were used to estimate energy expenditure.

Resting Arterial Blood Pressure

Blood pressure was measured by auscultation using a mercury sphygmomanometer (Accoson freestyle stand 0042, CardioHinetics, Salford, UK). Subjects were seated during the measurements. Two measurements were taken at each time point and the mean of these values recorded. Since blood pressure was measured 15 min after each exercise bout the total number of post-exercise recordings for day 1 varied from 9 to 15 depending on the subject. For day 2 the total number of blood pressure recordings was eight.

Test Meals

The test meal consisted of white bread, Cheddar cheese, butter, mayonnaise, potato crisps, whole milk, and milkshake powder. The meal was prescribed according to body weight and provided 0.69 g fat, 0.95 g carbohydrate, 0.31 g protein, and 46 kJ (11 kcal) energy per kilogram body mass. The average macronutrient content of each test meal was 52.4 ± 2.4 g fat, 72.1 ± 3.4 g carbohydrate, and 23.5 ± 1.1 g protein which provided 3.49 ± 0.2 MJ (831 ± 48 kcal) energy (56% fat, 33% carbohydrate, and 11% protein). All subjects consumed the test meals within 20 min and none of the subjects reported nausea or any gastrointestinal discomfort. Subjects consumed water ad libitum during the first trial and the volume ingested was replicated in the subsequent trial.

Analytical Methods

Venous blood samples were collected into pre-cooled 9-mL potassium-EDTA-coated Monovette tubes (EDTA 1.6 mg/mL) (Sarstedt, Leicester, UK) and samples were immediately centrifuged, (GS-15R centrifuge, Beckman Coulter, Fullerton, CA) at 1968 × g for 10 min at 4 °C. After separation, plasma was dispensed into plain micro tubes, and stored at −80 °C. The plasma concentrations of triacylglycerol,
glucose (Randox laboratories, County Antrim, UK) and NEFA (Wako Chemicals, Neuss, Germany) were determined by enzymatic, colorimetric methods. Plasma insulin concentration was measured by radioimmunoassay (MP Biomedicals, Orangeburg, NY). All samples from the same individual were assayed in a single run. Accuracy and precision were monitored using quality-control sera (Randox laboratories, County Antrim, UK; Nycomed Pharma AS, Billingstad, Norway, and MP Biomedicals, Orangeburg, NY). Intra-assay CVs were 0.5% for triacylglycerol, 1.0% for glucose, 1.4% for NEFA, and 7.4% for insulin. Hemoglobin concentration and hematocrit were measured at baseline and the end of observation period for estimating changes in plasma volume.

Statistical Analysis

Data were analyzed using the Statistical Package for the Social Science (SPSS) software version 11.0 for Windows (SPSS, Inc., Chicago, IL). Area under the curve values for blood pressure versus time and for plasma concentrations versus time were calculated using the trapezium rule. Student’s t-tests for correlated data were used to assess trial differences between fasting plasma concentrations and area under the curve values. Two-way ANOVA with repeated measures was used to examine differences in plasma concentration responses between trials over time. Statistical significance was accepted at the 5% level. Results are presented as mean ± standard error of the mean.

Results

Exercise Responses

The total gross energy expenditure during accumulated exercise bouts was 4.2 ± 0.3 MJ (1000 ± 71 kcal). Average percentage VO$_{2\text{max}}$ and heart rate attained during the accumulated exercise bouts were 69.7 ± 0.6% and 161 ± 3 beats/min, respectively. The total accumulated exercise duration was 64.8 ± 2.2 min and the average number of exercise bouts performed was 11.1 ± 0.3.

Dietary Data

Analysis of food diaries revealed that energy and macronutrient intake did not differ significantly in the 48 h preceding day 2 of the control and exercise trials. Average energy intake for the day prior to the trials was 10.4 ± 0.7 MJ (2476 ± 167 kcal). Average energy intake for day 1 of the trials was 11.7 ± 0.9 MJ (2786 ± 214 kcal). Average dietary intake of fat, carbohydrate, and protein was 88.2 ± 8.9 g, 359.4 ± 27.9 g, and 105.3 ± 9.2 g respectively, for the pre-trial day, and 97.3 ± 12.7 g, 400.6 ± 33.1 g, and 116.4 ± 11.8 g respectively, for day 1.

Plasma Concentrations in the Fasted State

Plasma concentrations in the fasted state prior to the test meals on day 2 of each trial are shown in Table 1. There was no difference in fasting plasma triacylglycerol,
glucose, and insulin between the exercise and control trials. Fasting plasma NEFA concentrations were higher on the exercise trial compared with the control trial.

**Table 1  Fasting Plasma Concentrations of Triacylglycerol, Glucose, Insulin, and NEFA for Day 2 of the Exercise and Control Trials**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Triacylglycerol mmol/L</th>
<th>Glucose mmol/L</th>
<th>Insulin pmol/L</th>
<th>NEFA mmol/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercise</td>
<td>0.97 ± 0.12</td>
<td>5.35 ± 0.20</td>
<td>131.38 ± 37.11</td>
<td>0.53 ± 0.05b</td>
</tr>
<tr>
<td>Control</td>
<td>1.08 ± 0.15</td>
<td>5.46 ± 0.23</td>
<td>116.51 ± 21.46</td>
<td>0.44 ± 0.05</td>
</tr>
</tbody>
</table>

a Mean ± standard error of the mean; n = 19. Means were compared using Student’s t-tests for correlated data; b significantly different from the control trial, P = 0.039

**Plasma Concentrations in the Postprandial State**

Changes in plasma volume during the observation periods were small (exercise, 1.3 ± 1.6%; control, 4.2 ± 2.0%) and did not differ significantly between trials. Thus, plasma concentrations were not adjusted for changes in plasma volume. Plasma triacylglycerol responses to the test meals are shown in Figure 1 and the total and incremental areas under the triacylglycerol concentration versus time curve are given in Table 2. The total area under the plasma triacylglycerol versus time curve was 18% lower on the exercise trial compared with the control trial.

![Figure 1](attachment:image.png)  
**Figure 1**—Mean (± standard error of the mean) fasting and postprandial plasma triacylglycerol concentrations for exercise (circle) and control (triangle) trials (n = 19); black rectangles indicate consumption of the test meals. Data were analyzed using two-way ANOVA with repeated measures. Main effect of trial (P = 0.009), main effect of time (P < 0.0005), trial × time interaction (P = 0.043).
Plasma glucose, insulin, and NEFA responses to the test meals are shown in Figure 2. The total area under the concentration versus time curves for these parameters is given in Table 2. Plasma glucose concentrations did not differ between trials. The area under the curve value for plasma insulin tended to be lower on the exercise trial than the control trial but this difference was not significant ($P = 0.07$). Plasma NEFA concentrations were higher on the exercise trial compared with the control trial.

### Table 2 Seven-Hour Area Under the Plasma Concentration Versus Time Curve for Triacylglycerol, Glucose, Insulin, and NEFA on the Exercise and Control Trials

<table>
<thead>
<tr>
<th>Trial</th>
<th>Total Triacylglycerol mmol.7h/L</th>
<th>Incremental Triacylglycerol mmol.7h/L</th>
<th>Glucose pmol.7h/L</th>
<th>Insulin pmol.7h/L</th>
<th>NEFA mmol.7h/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercise</td>
<td>10.02 ± 1.24$^b$</td>
<td>3.24 ± 0.63</td>
<td>37.50 ± 1.02</td>
<td>2481.71 ± 465.03</td>
<td>1.73 ± 0.12$^c$</td>
</tr>
<tr>
<td>Control</td>
<td>12.15 ± 1.62</td>
<td>4.83 ± 0.99</td>
<td>36.75 ± 1.08</td>
<td>2758.37 ± 475.06</td>
<td>1.48 ± 0.12</td>
</tr>
</tbody>
</table>

*Means ± standard error of the mean, $n = 19$. Means were compared using Student’s $t$-tests for correlated data; $^b$significantly different from the control trial, $P = 0.009$; $^c$significantly different from the control trial, $P = 0.014$.

### Blood Pressure Responses

Area under the curve values for blood pressure versus time on days 1 and 2 are shown in Table 3. Total area under the curve values have been divided by the number of observations so that values are meaningful. On day 1, systolic and diastolic blood pressures were lower for the exercise trial compared with the control trial. On day 2 systolic blood pressure, but not diastolic blood pressure, was lower for the exercise trial compared with the control trial.

### Discussion

The present study demonstrates that by accumulating short bouts of exercise throughout the day postprandial triacylglycerol concentrations are lowered on the following day. Furthermore, resting systolic and diastolic blood pressures were lower in the periods between bouts of exercise in comparison to equivalent time points in the control trial and for systolic blood pressure the lowering effect of exercise was maintained throughout the following day. Since postprandial lipemia and resting blood pressure are both markers for cardiovascular disease risk these findings have important implications with respect to guidelines for physical activity and health.

Many studies have demonstrated that postprandial lipemia is lowered following a single bout of aerobic exercise. The energy expended during exercise is an important determinant of the extent to which triacylglycerol is lowered.$^{19, 22}$ To our knowledge, only three studies have examined the effects of accumulated/
Figure 2—Mean (± standard error of the mean) fasting and postprandial plasma concentrations of glucose, insulin, and non-esterified fatty acids (NEFA) for the exercise (circle) and control (triangle) trials (n = 19); the black rectangles indicate consumption of the test meals. Data were analyzed using two-way ANOVA with repeated measures. For glucose and insulin, there is a main effect of time (P < 0.0005). For NEFA, there are main effects of trial (P = 0.014) and time (P < 0.0005). There were no significant interactions.
intermittent activity on postprandial lipemia. However, the present study is the first to examine the effects of accumulating short (< 10 min) bouts of activity on postprandial lipemia.

Two mechanisms have been proposed to explain the reduction of postprandial triacylglycerol concentrations following exercise. One is increased muscle lipoprotein lipase activity, which is a major factor for the removal of triacylglycerol from the circulation. Another is reduced secretion of hepatic VLDL. It is impossible to tell which of these mechanisms predominates in the present study. The lower insulin concentrations during the exercise trial would suggest reduced inhibition of muscle lipoprotein lipase activity and therefore increased triacylglycerol clearance via the muscle. However, this would also indicate reduced uptake of insulin-mediated fatty acids into adipose tissue. Moreover, the elevated NEFA concentrations on the exercise trial could provide material for hepatic VLDL synthesis but this could be averted by increased fatty acid oxidation in the liver, leading to a reduced hepatic VLDL-triacylglycerol production.

Most studies examining postprandial triacylglycerol responses following exercise have employed a single test meal. In the present study, two test meals were consumed during a 7-h period. The aim was to more accurately mimic a real life situation where several meals are consumed throughout the day. The data demonstrate that the reduction in postprandial lipemia with exercise is more marked following the second meal compared with the first meal. This is consistent with the findings of a previous study. This attenuation could be protective against atherosclerosis since repeated daily disturbances of postprandial triacylglycerol concentration are related to the progression of atherosclerosis.

Resting systolic and diastolic blood pressure was reduced in the periods between exercise bouts throughout day 1 in the present study. The average reductions were 5 mm Hg for systolic blood pressure and 3 mm Hg for diastolic blood pressure in comparison to the control trial. Blood pressure was not measured during exercise in this study but it should be recognized that systolic blood pressure probably increased during this time. Systolic (but not diastolic) blood pressure was also reduced (by 3 mm Hg on average) on day 2 in the present study when no exercise was performed. Previous studies have shown that single bouts of low or moderate intensity exercise reduce systolic and diastolic blood pressure for at least 22 h

### Table 3

<table>
<thead>
<tr>
<th>Trial</th>
<th>Systolic blood pressure</th>
<th>Diastolic blood pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 1</td>
<td>Day 2</td>
</tr>
<tr>
<td></td>
<td>mm Hg</td>
<td>mm Hg</td>
</tr>
<tr>
<td>Exercise</td>
<td>115.2 ± 1.9b</td>
<td>117.4 ± 1.9b</td>
</tr>
<tr>
<td>Control</td>
<td>120.6 ± 1.6</td>
<td>120.4 ± 1.6</td>
</tr>
</tbody>
</table>

*Means ± standard error of the mean; n = 19. Means were compared using the Student’s t-test for correlated data; bsignificantly different from the control trial, P < 0.0005; csignificantly different from the control trial, P = 0.003; dsignificantly different from the control trial, P = 0.035
after exercise in hypertensive subjects.\textsuperscript{30,31} Accumulated exercise training has also been shown to reduce resting systolic and diastolic blood pressure in hypertensive postmenopausal women (following 8 wk of training)\textsuperscript{13} and in normotensive men and women\textsuperscript{20} (following 16 wk of training). The present study confirms these findings and demonstrates a blood pressure lowering effect following the accumulation of short bouts of exercise over a single day. The mechanism for this blood pressure reduction may involve decreases in stroke volume and left ventricular end-diastolic volume.\textsuperscript{30} It is also possible that reduced insulin concentrations contribute to the blood pressure lowering effect of exercise since hyperinsulinemia is associated with hypertension.\textsuperscript{32}

The energy expended during accumulated exercise in the current study was high [4.2 MJ (1000 kcal)] as was the exercise intensity (70\% of VO\textsubscript{2max}). An energy expenditure of 4.2 MJ (1000 kcal) was chosen because previous research indicates that this level of expenditure is effective in lowering postprandial lipemia with continuous exercise.\textsuperscript{22} We wanted to be sure that if we did not find an influence of accumulated activity on postprandial lipemia it was not because of insufficient energy expenditure. It is important to note, however, that this expenditure is up to five times higher than that which would occur following adherence to the minimal recommended guideline of 30 min of moderate-intensity exercise per day.\textsuperscript{1-3} In fact, some dispute that adherence to the minimum guidelines (both in terms of volume and intensity) would have the desired impact on health.\textsuperscript{33} The present study has advanced understanding of intermittent/accumulated activity by demonstrating that the accumulation of very short (< 10 min) bouts of activity can be effective in lowering postprandial lipemia.

One final issue worthy of mention before concluding this discussion is the nature of the study subjects. We elected to study lean, fit subjects because such a group provided a convenient sample to test the hypothesis that accumulating very short bouts of activity would be effective in lowering postprandial lipemia and blood pressure. It could be speculated that since triacylglycerol concentrations and blood pressure were low in this group that the potential for reductions in these variables was limited and greater reductions may be seen in those with hypertriacylglycerolemia and/or hypertension. Conversely, subjects with lower fitness and higher levels of body fat would have greater difficulty expending 4.2 MJ (1000 kcal) in accumulated activity and therefore changes in triacylglycerol and blood pressure may be less dramatic. This illustrates the need for further research employing sedentary individuals performing a volume and intensity of activity, which more closely resembles the current guidelines.\textsuperscript{1-3}

In conclusion, our data show that performing multiple 6 min bouts of running during a single day reduces postprandial plasma triacylglycerol concentrations and systolic blood pressure on the following day in healthy young men. Our study provides further support for the concept of accumulating exercise and suggests that a minimum exercise duration of 10 min may be unnecessary. However, our study was an efficacy study employing high intensity and high volume exercise. Additional research will be required to determine if similar results can be obtained with short bouts of moderate intensity exercise, and with lower total daily energy expenditure accumulated from the short bouts. If these efficacy trials provide similar results, then effectiveness studies can be done to determine if sedentary free-living individuals can obtain similar benefits with exercise programs that they can maintain.
Acknowledgments

The first author was involved in study design and implementation, data collection, and analysis. The second author was involved in data collection and blood biochemistry. The third author conceived the study and performed the cannulations. All three 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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References