Original Article

Environmental Temperature Affects Fat and Carbohydrate Oxidations During Recovery Period After Moderate Intensity Exercise in Obese Women

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Background: Obesity has been related to a decrease in fat oxidation. The metabolisms of fat and other substrates are increased during exercise and continue even after the exercise session. Ambient temperature possibly affects substrate oxidations during post exercise recovery.

Objective: To investigate the rates of fat and carbohydrate oxidation during post exercise recovery in the thermo-neutral versus hot environments.

Materials and Methods: Twenty-four obese female participants (age 26.9±3.9 years, BMI 36.5±7.3 kg/m^2) underwent two different experimental conditions in separate visits, 5 to 7 days apart. The participants performed two sessions of 30 minutes moderate intensity (at 45% to 50% of heart rate reserve) treadmill exercise in a thermo-neutral condition (24°C to 25°C) followed by two different conditions of 1-hour recovery period. The recovery period was randomized, either a hot (31°C to 32°C) or thermo-neutral condition in the first visit, then the other condition in the second visit or vice versa. Substrate oxidations were determined by indirect calorimetry during the recovery period.

Results: There was no difference in the total energy expenditure between the hot (81.0±16.5 kcal/hour) and the thermo-neutral (87.0±21.3 kcal/hour) conditions (p=0.29). When compared to the hot condition, total fat oxidation during recovery in the thermo-neutral condition was significantly higher (5,716.25±2,358.42 mg/hour versus 4,288.18±1,415.22 mg/hour, p<0.001); while carbohydrate oxidation was significantly lower (8,793.71±4,049.77 mg/hour versus 10,420.84±3,040.17 mg/hour, p<0.05).

Conclusion: After exercise, recovery in a thermo-neutral environment results in a higher rate of fat oxidation. Thermo-neutral condition during the recovery period appears to be more beneficial than a hot condition in promoting fat oxidation in obese women.

Keywords: Moderate intensity exercise, Exercise recovery, Environmental temperature, Fat and carbohydrate oxidation, Obesity

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Obesity is a serious health problem because of its associations with chronic conditions including diabetes, hypertension, and cardiovascular diseases[1]. The highest prevalence of obesity is in female adults[2]. Obesity is associated with a decreased in fat oxidation[3]. However, exercise can increase the fat oxidation rate that enhances weight loss in obese individuals[4,5]. Exercise intensity influences the proportion of fat oxidation per carbohydrate oxidation. During high intensity exercise, the proportion of fat oxidation is lower than during moderate intensity exercise[6]. This emphasizes one of the important roles of moderate intensity exercise, which is recommended by the American College of Sports Medicine, for weight reduction and prevention of weight regain in obesity[7].

Elevations of oxygen consumption and energy

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expenditure occur not only during exercise but also continue during the recovery phase. Energy expenditure both during the exercise and post exercise recovery are affected by the duration and intensity of the exercise[8-13]. During recovery, the elevated oxygen consumption and increased metabolism have been linked to many metabolic restoration processes, including adenosine triphosphate (ATP) replenishment, lactate removal, glycogen re-synthesis, and the recoveries of heart rate and body temperature[14-17]. A higher total body fat oxidation, indicated by a lower respiratory exchange ratio, was reported during post exercise[14,18].

Ambient temperature influences energy expenditure and the rates of substrate metabolism[15,19,20]. Cold exposure (10°C) during rest results in greater rates of oxygen consumption and fat oxidation than sitting quietly in a 28°C environment[19]. However, carbohydrate oxidation rate is higher in a hot (32.6°C) environment when compared to a thermo-neutral (22.2°C) environment[15]. Additionally, exercising in a cold condition is associated with an increase in the rate of fat oxidation[21,22]. Exercising in the heat (35°C) results in a greater rate of subsequent oxygen consumption during recovery than in the cold (0°C)[20]. This finding seems to disagree with the other reports. The conflicting effect of temperature on energy expenditure and fat oxidation may be due to different levels of temperature exposure and other conditions (e.g., exercise, recovery, quiet rest) in the studies. Oxidation of fat after an exercise session may be altered by changing the ambient temperature in the recovery phase.

Although the effects of temperature on metabolism have been investigated, the effects of temperature during post exercise recovery on oxygen consumption and fat oxidation are still unclear. Most of the previous studies were conducted in populations living in the temperate zone and the ranges of studied temperature were relatively extreme[19,20,23]. The effect of temperature during post exercise recovery on fat oxidation has not been established in obese participants living in tropical zones. This climate is warm with relatively high humidity. Such climate can impair heat dissipation particularly in the obese individuals whose thermoregulatory function may be limited. The aim of the present study was to investigate the effects of temperature on fat oxidation in obese women during the recovery period after moderate intensity exercise in the air-conditioned thermo-neutral temperature (24°C to 25°C) versus the outdoor temperature (31°C to 32°C). The influence of ambient temperature on fat oxidation during recovery may have implications in the recovery processes and weight control in obese individuals.

Materials and Methods

Study population

Sedentary obese women between 21 and 35 years old were screened. The sedentary status was defined as no regular physical exercise longer than 10 minutes per session and less than three sessions per week for the past month. All participants were premenopausal women with body mass index (BMI) values of 30 kg/m² or more, and waist circumferences of 80 cm or more. Exclusion criteria were chronic or acute cardiovascular diseases, diabetes, hypertension (blood pressure greater than 140 over 90 mmHg), thyroid disorder, dyslipidemia (triglycerides greater than 400 mg/dL or taking lipid lowering medications) and menstrual irregularities. The informed consents were obtained from all participants prior to participating in the study.

Experimental protocol

Study design: The present study followed the ethical principles of the Declaration of Helsinki and was approved by the Institutional Review Board of the Faculty of Medicine, Chulalongkorn University (IRB No.600/58). Twenty-four obese women underwent two separate experimental sessions in a two-treatment, randomized-sequence cross-over fashion. The sample size was obtained according to the authors' pilot study. Each experimental session included a 30-minute moderate intensity treadmill exercise followed by a 1-hour of quiet recovery in one of the two conditions, thermo-neutral condition (TN; 24°C to 25°C, 70% to 80% humidity) or hot condition (HT; 31°C to 32°C, 70% to 80% humidity). The recovery condition was randomly assigned. Each participant was assigned to one condition at the first visit, then the other condition at the second visit. The outcomes were fat and carbohydrate oxidations determined by an open-circuit, indirect calorimetry during the recovery period.

Screening and preliminary testing: The screening visit before the eligible participants were enrolled in the study included an initial screening questionnaire, physical examination, electrocardiography, body composition measurements using bioelectrical impedance analysis (Inbody 230, Korea), and a fasting blood sample for glucose and lipid profile. The participants performed a preliminary treadmill test at a thermo-neutral condition to familiarize them with the way of treadmill walking and to find the grade and speed corresponding to each participant's 45% to 50% of heart rate reserve.

Experimental trials

The participants reported to the laboratory in the morning between 7 a.m. and 9 a.m. after 12 hours fasting for two separate experimental visits. Both visits were within the follicular phase of their menstrual cycle. The washout between the visits was five to seven days. In the period before each visit, the participants abstained from alcohol (48 hours), caffeine (8 hours), and vigorous physical activity (24 hours). To minimize the effect on metabolism induced by variation of food intake, all participants received three standardized meals on the day before the experiment. To ensure adequate hydration, the participants consumed 600 mL of drinking water two hours before each experiment. Drinking water was offered at exercise completion and after 30 minutes of recovery.

At each visit, the participants completed 30 minutes of treadmill exercise followed by a 1-hour of recovery in the previously assigned condition. Both exercise sessions were performed at a pre-determined workload corresponding to the 45% to 50% heart rate reserve. At the end of exercise, a 5-minute active cool down was performed prior to sitting quietly in a climatic room for metabolic measurement in the recovery phase. Axillary temperature was continuously monitored using a tele-thermometer (Yellow Springs Instrument Co., Inc., USA) throughout the exercise and recovery periods.

Expired air and substrate oxidation

The expired air was collected for oxygen consumption rate (VO_2) and carbon dioxide production rate (VCO_2) and analyzed via a breath-by-breath portable metabolic measurement system (Oxycon Mobile, Jaeger, Germany). Mean VO_2 and mean VCO_2 were calculated for the estimation of substrate oxidation. Total energy expenditure was derived from non-protein substrate oxidation by combining the oxidation of fat and carbohydrate. Fat and carbohydrate oxidation rates were determined using VO_2 and VCO_2 values obtained from expired gas analyses, according to the Peronnet and Massicotte methods[24].

Blood analyses

An intravenous catheter (20-gauge, 32 mm, Nipro Corp., Japan) was placed in the antecubital vein for sequential blood sampling. During the recovery period after exercise, blood samples were obtained at 0, 20, 40 and 60 minutes for subsequent glucose and free fatty acid (FFA) analyses. Glucose levels were analyzed from fresh whole blood using an enzymatic reaction method (Accu-Chek Performa, Roche, Germany). Clotted blood samples from a subgroup of participants (n=7) were stored in ice and transferred to centrifuge to obtain serum. The serum was frozen at –80°C for FFA analyses. FFA levels were determined using Free Fatty Acid Quantification Kit (Abcam, Biomed Diagnostics Co., Ltd., Thailand).

Data processing and analysis

The data were analyzed using IBM SPSS Statistics software, version 22.0 (IBM Corp., Armonk, NY, USA). Total fat oxidation and carbohydrate oxidation rates were calculated from the average of breath-by-breath gas analyses records during the 30-minute exercise and the 60-minute post exercise recovery periods. Energy expenditure of the entire exercise period and the 60-minute recovery period were subsequently calculated, according to the energy equivalent for carbohydrate (4 kcal/g) and fat (9 kcal/g). Two-way (random factor) repeated measurement ANOVA was used to determine the outcomes between the hot and thermo-neutral conditions. Pairwise comparison with Bonferroni correction was used to determine the differences between the two conditions at each time point. All data were represented in mean ± standard deviation (SD). Standard error of means was used in all graphical presentation. Statistical significance was accepted at p-value of less than 0.05.

Results

Twenty-four sedentary obese women with a mean age of 26.9±3.9 years completed the study. The characteristics of participants are shown in Table 1.

During exercise

Energy expenditure during the 30 minutes of treadmill exercise in thermo-neutral temperature was similar between the two visits (TN 362.3±63.5 kcal/hour versus HT 365±55.8 kcal/hour, p=0.87). The rate of fat oxidation during exercise was not significantly different between both visits (TN 113.5±55.1 mg/kg/hour versus HT 128.3±76.1 mg/kg/hour, p=0.44). Carbohydrate oxidation rate during exercise was not different between the two visits (TN 704.5±187.8 mg/kg/hour versus HT 679.6±187.5 mg/kg/hour, p=0.65).

Table 1. Descriptive characteristics of the participants (n=24)

Characteristics	Mean±SD	Range
Age (years)	26.9±3.9	21.0 to 35.0
Weight (kg)	96.0±19.9	74.0 to 158.2
Height (cm)	161.9±4.9	153.0 to 170.0
Body mass index (kg/m^2)	36.5±7.3	30.2 to 61.8
Body fat (%)	47.3±3.9	39.4 to 56.0
Triglyceride (mg/dL)	122.2±54.0	45.0 to 263.0
Total cholesterol (mg/dL)	183.2±35.9	99.0 to 259.0
HDL-C (mg/dL)	44.9±8.0	33.0 to 61.0
LDL-C (mg/dL)	117.4±35.7	48.0 to 195.0
Fasting blood glucose (mg/dL)	90.8±8.1	80.0 to 111.0

HDL-C=high-density lipoprotein cholesterol; LDL-C=low-density lipoprotein cholesterol; SD=standard deviation

During recovery

During the one hour of recovery, the average skin temperature was not different between the two conditions (TN 36.2±0.6°C versus HT 36.5±0.6°C, p=0.07). The total energy expenditure was not different between the TN (87.0±21.3 kcal/hour) and HT (81.0±16.5 kcal/hour) conditions (p=0.29).

Fat oxidation rates between the two conditions during the recovery period are shown in Figure 1. Total fat oxidation rate in the TN (59.6±18.9 mg/kg/hour) was greater than the HT (46.2±13.2 mg/kg/hour, p=0.007) despite the similarity of total post exercise recovery energy expenditure. Pairwise comparisons of fat oxidation showed a significantly higher rate in the TN than the HT for the initial 40 minutes of recovery period (p<0.05 for each pair). Total carbohydrate oxidation during recovery in the TN was significantly lower than the HT (92.0±33.0 mg/kg/hour versus 108.1±21.6 mg/kg/hour, p<0.05) (Figure 2).

The average blood glucose level was not different between the two conditions (TN 90.0±7.8 mg/dL versus HT 88.6±7.7 mg/dL, p=0.24). The plasma FFA (n=7) showed no significant difference between the two conditions (TN 0.11±0.01 mmol.minute/L versus HT 0.10±0.01 mmol.minute/L, p>0.05) (Figure 3).

Discussion

The present study aimed to address the influence of ambient temperature on oxidation of substrates during post exercise recovery in obese women. The novel finding was that following an exercise bout in a thermo-neutral environment, obese women had a higher rate of fat oxidation during one hour of recovery in a thermo-neutral environment compared to a hot environment. In contrast, carbohydrate

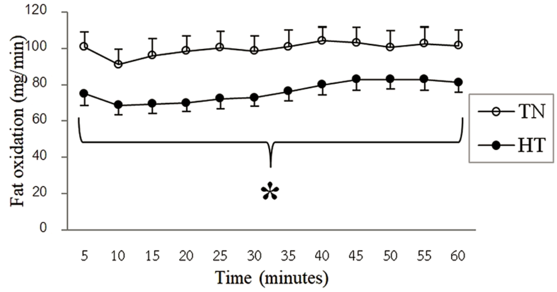

Figure 1. Fat oxidation during recovery period between hot (HT) and thermo-neutral (TN) temperature (n=24).

* p<0.05 significant difference between hot and thermoneutral temperature at each time point

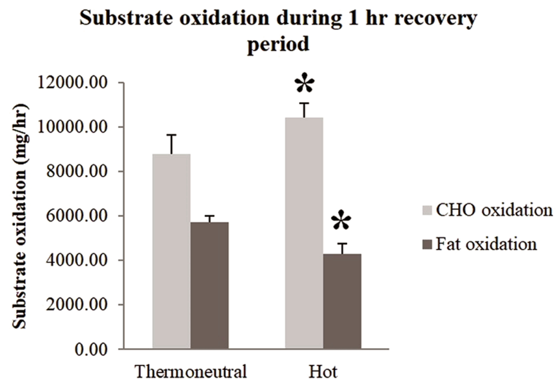

Figure 2. Total substrate oxidation during 1-hour recovery period between hot and thermoneutral temperature (n=24).

CHO=carbohydrate

* p<0.05 significantly different compared to thermoneutral temperature

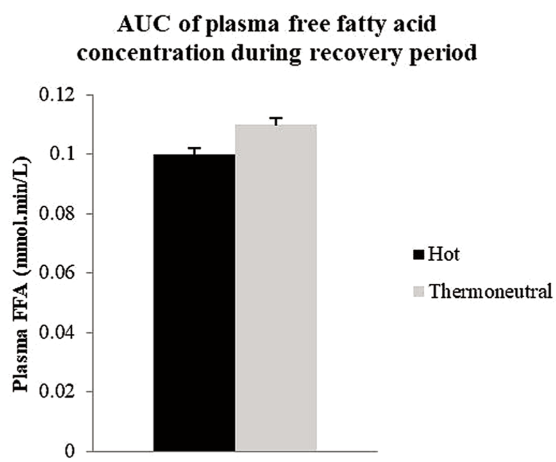

Figure 3. AUC of plasma free fatty acid concentration during recovery period between hot (HT) and thermo-neutral (TN) temperature (n=7, p=0.30).

AUC, area under curve; FFA, free fatty acid oxidation was higher when recovery was in the hot environment than the thermo-neutral environment. These findings suggested that in order to enhance fat oxidation, obese individuals may gain additional benefit from an exercise session by choosing to recover in a thermo-neutral room rather than in a hot environment after exercise. This knowledge may be important in weight management of obese individuals living in a tropical climate.

Exercise is well known to promote weight loss. A previous study revealed modest weight loss with exercise alone(25). Weight loss was enhanced when exercise was combined with diet control(25). One mechanism that may explain the effect of exercise on weight loss is the excess post exercise oxygen consumption (EPOC) that reflects an enhanced energy expenditure. During post exercise recovery, there is an elevation of oxygen consumption above resting level that is influenced by exercise duration and intensity(6,8-10,12). In the present study, all subjects performed equivalent exercise duration and intensity in both exercise sessions. Therefore, the influence of exercise on recovery energy expenditure should be equal. The results showed that the total amount of energy expenditure during the post exercise recovery was not different between the temperature conditions. Body metabolism, reflected by total body oxygen consumption, can be elevated for many hours post exercise(10). However, an EPOC is quite small when the exercise intensity is less than 50% of maximal oxygen uptake(13). It was difficult for the sedentary obese participants in the present study to exercise vigorously for an extended duration at the very first exercise session. Therefore, the exercise sessions in the present study were performed at moderate intensity for 30 minutes as recommended by the American College of Sports Medicine(7). An effective exercise program should be progressive in terms of duration, frequency, and intensity of activities. Although the EPOC is small, the long-term accumulation of energy expenditure from regular exercise may not be overlooked. The prospective impact of the present study would be the accumulative effect, over a long-term intervention, with the increase of the intensity and duration as the exercise program progresses.

It is also of interest to investigate the contribution of substrates in the energy metabolism during recovery under different conditions. Choices of substrates contributing to oxidation during recovery depend on exercise intensity and the total amount of energy expenditure during the exercise session(5). The intensity of exercise clearly affects not only the amount of energy expenditure both during exercise and post exercise recovery(10), but also the choices of substrates being utilized during post exercise recovery(8). As both exercise sessions in the present study were identical, it is reasonable that the total energy expenditure during recovery was also similar in both environmental conditions. As hypothesized, the present study showed that recovery in a thermo-neutral condition had a greater rate of fat oxidation. To the authors' knowledge, the present research is the first study to demonstrate the influence of environmental temperature on fat and carbohydrate oxidation despite the limited total energy expenditure during exercise and post exercise recovery in obese participants. Since a greater fat oxidation occurred in the thermo-neutral recovery, choosing the right environmental temperature during post-exercise recovery would likely add more benefit on long-term weight management.

The heat generated from metabolic processes during exercise induces body heat dissipation. Obese individuals have a risk of heat injury associated with exercise, particularly in hot environments, due to difficulties in heat dissipation limited by the subcutaneous barrier. It is well known that when the surrounding temperature increases, the heat transferring from cutaneous to environment is more difficult because the gradient temperature between the skin and ambient air is narrow(26). The ambient condition in the current study had a relatively high humidity (75±5%) which is typical in Thailand, resulting in a limitation of heat dissipation via evaporative heat loss(26). With the awareness of the insufficient heat dissipation risk in this obese population, the present study was designed to perform exercise in a thermo-neutral condition rather than in a hot condition, in order to lower the risk of heat injury during exercise.

Carbohydrate oxidation during post exercise recovery in the present study was higher in the hot condition than in the thermo-neutral condition. This finding is similar to a study investigating recreationally active men during post exercise recovery(15). Although it is uncertain how environmental temperature mediates the substrate oxidations during post exercise recovery, there is evidence that the body core temperature affects the choice of substrates being oxidized during post exercise recovery(15). Other studies in healthy men, as well as in well-trained men, reported that the glycogenolysis and carbohydrate oxidation were elevated and related to an elevated core temperature during exercise in hot environments[27-29]. The core body temperature was not measured in the present study. However, the authors believe that core temperatures of the participants were likely similar in both conditions for the following reasons. Firstly, the intensity, duration, and environment of both exercise bouts performed by the subjects prior to the different recovery sessions were identical. Thus, the magnitude of metabolism should be similar. Secondly, the axillary skin temperature was measured throughout the recovery period and there was no difference between the two conditions. It is well known that core temperature is more tightly regulated than cutaneous temperature, which is more likely to be altered by environmental factors. The authors chose to measure the axillary skin temperature to avoid thermistor being directly exposed to ambient air. A previous study has shown that exercise in a hot environment, similar to the present study, did not increase the rectal core temperature in obese male participants[30]. Therefore, the authors assume a normal range of core temperature in the present study subjects. Despite no changes in body temperature, exposure to a hot environment resulted in greater carbohydrate oxidation and lower fat oxidation in obese women. The responsible mechanism(s) await future research.

The present study was designed to limit the effects of potential confounding factors. Factors such as dietary components and calorie intake that may largely affect the outcomes were tightly controlled by providing standardized meals to all participants for the day prior to each experiment. Additionally, the study design was randomized crossover to balance any effect of the previous session. Next, it is suggested that the female menstrual cycle should be controlled because it can influence body metabolism[12]. Only participants with regular menstruation were included in the present study. The experiments were performed twice at five to seven days apart during the first week of follicular phase of each participant to minimize the effect of hormonal changes associated with the menstrual cycle. Both experiments were performed at the same time of the day in an attempt to avoid a possible circadian effect.

The proposed mechanisms of recovery were the replenishment of body energy in the form of ATP or creatine phosphate and other metabolic restorations such as lactate removal[12,16]. In the present study, the difference in carbohydrate oxidation between hot and thermo-neutral conditions could not be explained by the levels of plasma glucose. The plasma glucose levels were quite stable throughout the 1-hour recovery period in both conditions. This may be the role of hepatic gluconeogenesis that maintains constant blood glucose levels during post exercise recovery regardless of different temperatures. Therefore, the finding of higher contribution of carbohydrate oxidation in hot environment may be explained by glucose uptake from plasma or intramuscular glycogenolysis. The lower contribution of carbohydrate oxidation during recovery in the thermo-neutral environment is a reciprocal control to maintain similar recovery energy expenditure as a consequence of similar exercise sessions between the two sessions.

It has been suggested that fat from the circulating pool e.g., plasma free fatty acids and triglycerides, contributes to the oxidation of fat during post exercise recovery[14]. The finding from a subgroup of obese participants in the present study showed that plasma levels of free fatty acid was not different between the hot and thermo-neutral conditions. This is inconsistent with a study that reported an increase in plasma free fatty acid examined in healthy women during rest in a hot sauna[31]. The role of circulating free fatty acid as a contributor to recovery fat oxidation could not be excluded. A constant level of circulating pool of free fatty acid simply reflects the balance of FFA being released to the circulation and clearance by the peripheral tissues. In addition to circulating fatty acid, intramuscular fat is also a possible source of fat oxidation during post exercise recovery[14]. There was a lack of power to detect the relationship, since the authors only took this issue as an exploratory relationship in a subgroup of small number of participants. Other specific study designs are needed for more information to better answer this question.

Conclusion

Post exercise recovery in a thermo-neutral environment results in a higher rate of fat oxidation in obese women. In order to enhance fat oxidation, obese individuals may gain additional benefit from an exercise session by choosing to recover in a thermo-neutral room rather than in a hot environment. This knowledge may be helpful in a long-term weight management for obese individuals living in a tropical climate.

What is already known on this topic?

Energy expenditure from fat and carbohydrate continues to increase after an exercise session for a period of time.

What this study adds?

The present study demonstrated that energy expenditure from fat oxidation can be enhanced when obese women spent a recovery period after exercise at the thermoneutral environments. The finding is potentially benefit to obese individuals who want to maximize the fat contribution of energy expenditure, which can continue even after the cessation of the exercise.

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Authors' contributions

Kulaputana O contributed substantially to the conception and design of the study. Kulaputana O and Soythong T interpreted the data and drafted the manuscript. Sanguanrangsirikul S contributed to the design and methodology of the study. Soythong T and Suksiriworaboot T were responsible for data collection. Soythong T was responsible for data analysis. All authors approved the final version submitted for publication and take responsibility for the statements therein.

Conflicts of interest

The authors declare no conflict of interest.

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