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The Effect of an Aerobic Exercise Session in Fasting Versus Satiety on Fat and Carbohydrate Oxidation in Hypoxia and Normoxia in Overweight Men

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ABSTRACT

Introduction: This study aimed to determine the effect of an aerobic exercise session during fasting versus satiety on fat and carbohydrate oxidation in hypoxia and normoxia in overweight men.

Methods: A total of 16 overweight men with a body mass index (BMI) ranging between 25-29.9 kg/m^2, a mean age of 30.75±6.79 years, and a maximum oxygen consumption of 24.67±4.61 liters per minute voluntarily participated in the study. Each participant underwent four conditions: fasting hypoxia, normal hypoxia, fasting normoxia, and normal normoxia. During the study, the participants completed a 30-minute aerobic test on a CUCLUS2 bike with a heart rate (bp/m) of 60-70% in a hypoxia tent at an altitude of 3000 meters and 14.5% oxygen or in normoxia condition in the laboratory facilities of Razi University of Kermanshah Sports Sciences Faculty. In the satiated state, the participants were given two pieces of toast, one tablespoon of peanut butter, and one glass of milk. The breathing gases were collected for 30 minutes to evaluate fat and carbohydrate oxidation.

Results: The study showed that fat oxidation was significantly higher in the fasted group compared to the satiety group ($p<0.05$) in both hypoxia and normoxia conditions. Moreover, fat oxidation in normoxia was significantly higher than in hypoxia ($p<0.05$). In contrast, carbohydrate oxidation and respiratory exchange ratio were significantly lower in the fasted group compared to the satiety group ($p<0.05$).

Conclusion: Based on the study's findings, training in a hypoxia state, regardless of fasting condition, is a suitable non-invasive method to tackle obesity and overweight.

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Introduction

Overweight and obesity have emerged as a critical public health concern globally (1). Although preventable, obesity is often linked with a host of chronic conditions such as type 2 diabetes, metabolic disorders, high blood pressure, cardiovascular diseases including atherosclerosis, endothelial dysfunction, and even cancer. When left unaddressed, obesity can lead to premature mortality (2). The prevalence of obesity has tripled worldwide since 1975, with 1.9 billion adults classified as overweight and 650 million as obese (3). Obesity is a public health concern that arises from inactivity and unhealthy diets. The prevention and treatment of obesity and overweight conditions require a proper diet and regular exercise. A low-calorie diet and sports activities are essential to achieve energy balance and lose weight (4). The high prevalence of obesity worldwide is attributable to increased calorie consumption and decreased energy expenditure (5). Aerobic activity effectively improves cardiovascular fitness, increases peak oxygen consumption, and prevents and treats obesity and its associated ailments, which enhances cardiovascular fitness without significant changes in physical strength (6). Therefore, it is an effective intervention that can be employed to promote healthy lifestyle changes for individuals dealing with obesity (7).

The human body relies on carbohydrates and fatty acids as fuel sources during low to moderate-intensity activities that last for several hours. The respiratory exchange ratio (RER) decreases gradually during such activities, leading to an increase in fatty acid (FA)

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utilization and a decrease in carbohydrate consumption (8). As the intensity of aerobic activity increases, the body reaches a peak level of fat oxidation and then shifts to prioritizing carbohydrate oxidation (9). The availability of carbohydrates as a substrate for skeletal muscle and brain metabolism is important and controversial in sports performance, particularly for long-term aerobic activities that exceed 90 minutes. Endogenous carbohydrate stores limit the performance of such activities, making them highly dependent on carbohydrate intake (10).

Respiratory rate (RQ) is the ratio of CO_2 production to O_2 consumption, with an RQ of 1 indicating 100% carbohydrate (CHO) oxidation and an RQ of 0.7 indicating 100% fat oxidation (11). Low-carbohydrate (LC) diets shift the body's fuel usage towards fat oxidation. However, maximal and submaximal markers of aerobic activity performance and muscle strength are not negatively impacted by LC diets compared to high-carbohydrate (HC) diets (12).

At the onset of physical activity, signals from within and outside the muscle cell are required to increase carbohydrate and fat fuel for ATP production (13). Fasting activity can increase the amount of fat oxidation at rest for up to 24 hours compared to the same activity performed after a meal (14). Exercise performed in the morning after a night of fasting may be more effective in reducing body fat than exercise performed after eating (15).

Several factors, including activity intensity and duration, training status, nutritional status, and gender, influence fat oxidation during exercise (16). Studies have shown that carbohydrate restriction results in a sustained increase in fat oxidation, whereas fat restriction does not affect fat oxidation significantly (17). The process of fat oxidation during exercise begins with the hydrolysis of triglycerides, releasing transported fatty acids that are transported to the muscle mitochondria for oxidation (18).

Exposure to hypoxia has been documented as a suppressor of appetite perception, leading to a subsequent reduction in energy expenditure compared to normoxia (19). As a result, the practice of training at altitude or hypoxia to enhance aerobic capacity and endurance performance has become increasingly common (20). Hypoxia becomes more prevalent at high altitudes, which decreases inspiratory oxygen, resulting in reduced alveolar oxygen pressure, arterial oxygen pressure, and arterial oxygen content. Conversely, decreasing the amount of oxygen in the blood results in changes in metabolism and the body. Research has shown that exercising in conditions of oxygen deficiency and hypoxia reduces blood pressure, fat mass, and peripheral vascular congestion (21). Hypoxia therapy is currently used as a general medical practice to treat obesity in most developed countries. Therefore, hypoxia therapy has the potential to be a practical new method and therapeutic approach to combat obesity and related diseases (22).

Lippel et al. (2010) examined the effects of passive exposure to an altitude of 2650 meters on obese individuals. The study reported significant reductions in caloric intake and body weight (1). The hypoxic environment resulted in the release of erythropoietin (EPO), a glycoprotein hormone that influences the production of red blood cells and enhances oxygen transfer to active tissues (23). Additionally, the AMPK system, an intracellular energy sensor, responds to metabolic stress by activating in response to an increase in the ATP/AMP ratio (24). The fasting state activates AMPK more than the fed state, and its activation persists for at least 150 minutes post-exercise (25).

Hypoxia has emerged as a new method for combating obesity, considering the high prevalence of obesity and related health conditions and the use of aerobic exercise as a therapeutic agent. Aerobic training is more effective due to the time limitations and physical constraints faced by obese individuals. Moreover, aerobic exercise is beneficial for reducing body fat and improving cardiovascular fitness (26). This research aims to determine the effect of an aerobic exercise session during fasting versus satiety on fat and carbohydrate oxidation in hypoxia and normoxia in overweight men.

Materials & Methods

The participants voluntarily agreed to participate in the study after completing the health and medical questionnaire and providing their written consent by filling out the consent form. None of the subjects had a history of smoking, anabolic steroid use, cardiovascular disease, or respiratory disease.

The present study was conducted after obtaining the necessary approval from the Ethics Committee of Razi University of Kermanshah under the ethics ID (IR.RAZI.REC.1402.013). Body composition factors such as body fat percentage before the commencement of the test and body mass index (BMI) were measured using a body composition analyzer model (ZEUS 9.9) manufactured in South Korea. The subjects' height was measured in centimeters using a height measuring device and model scale (FARS) made in Iran with an accuracy of 0.1cm. Furthermore, the subjects' weight was measured in kilograms with an accuracy of 0.1kg without shoes and with minimum clothes.

Hypoxic conditions were achieved using a height simulator tent manufactured in Germany, equipped with a device built into the tent wall that adjusted oxygen concentration to 14.5% at a simulated height of 3000 meters. The tent door was left open for at least an hour before the test commenced to ensure the homogenization of air. The tent was turned on, and the oxygen percentage was automatically adjusted. The tent door was then closed, and the hose was connected to the generator device on one side and the hypoxia tent on the other. The generator was turned on, and the tent was allowed to reach the desired height.

The subjects' exercise was performed on the CYCLUS2 bike for thirty minutes with a 60-70% heart rate (bp/m). They were first asked to ride the bike without load for 5 minutes to warm up. The test was conducted in hypoxic and normoxic states in the Razi University of Kermanshah Faculty of Sports Sciences laboratory. The test protocol consisted of four conditions: fasting hypoxia, normal hypoxia, fasting normoxia, and normal normoxia. Each subject repeated the research protocol with a one-week break. Each subject went to the laboratory fasting and performed the protocol. Those who were satiated were given two pieces of toast, a spoonful of peanut butter, and a glass of milk. Calorie 350, Fat% 25, Pro% 25, CHO% 50. The test started one hour after breakfast.

In hypoxia mode, the bicycle was taken into the tent, and the hose of the device was connected to the tent. The tent was then placed at the simulated height, and the device was turned on until the desired height was reached (1). The subjects performed the activity for thirty minutes with a 60 to 70% heart rate. A gas analyzer (Meta Max 3B), manufactured in Germany, was used to analyze the respiratory gases, calculate the oxidation of fat and CHO, and measure the subjects' maximum oxygen consumption (VO2max). The device enabled a moment-to-moment breath-by-breath method of breathing analysis and was equipped with a polar heart rate monitor, three masks (of different sizes), and a wireless transmitter and receiver device for portable field use. The device transmitted the data telemetrically to the computer and displayed the values of O_2 and CO_2 and the respiratory exchange ratio (RER) by recording moment-by-moment and breath-by-breath (27).

*Fat oxidation rate (g/min) = 1.695 * VO2 – 1.70 * VCO2*
*Carbohydrate oxidation rate (g/min) = 4.585 * VCO2 – 3.226 * VO2*

Statistical Analysis

The present study employed descriptive statistics to elucidate and interpret the findings. The Shapiro-Wilk test was used to check the normal distribution of the data. Furthermore, the ANOVA test with repeated measurement and the Bonferroni test were deployed to ascertain the location of the difference. The statistical level of P <0.05 was employed to analyze the research results. The sample size was calculated using Cochran’s formula, which had an 80% statistical power and 0.05 significance level. Based on the output of Cochran’s formula, the number of 16 subjects was considered a sufficient sample size for this research, considering the dropout rate of 15% in the subjects. Finally, 17 subjects participated in this research and were randomly placed in four states.

Results

The study included 16 overweight men with a mean age of 30.75±6.79 years (Table 1).

The results obtained from the repeated measurement test indicate a significant disparity between the measurement times (F=7318.59 and P=0.001). In hypoxia and normoxia, fat oxidation was significantly higher in the fasted group than in the satiety group (p0.05). Furthermore, fat oxidation in normoxia was significantly higher than in hypoxia (p0.05) compared to hypoxia and normoxia conditions (Figure 1).

The repeated measurement test shows a significant difference between measurement times (F=2245.03 and P=0.001). In hypoxia and normoxia, CHO oxidation in the satiety group was significantly higher than in the fasted group ($p<0.05$). In addition, CHO oxidation in normoxia was significantly lower than in hypoxia ($p<0.05$) (Figure 2).

The results of the repeated measurement test showed a significant difference between different measurement times (F=890.38 and P=0.001). In hypoxia and normoxia, RER in the satiety group was significantly higher than in the fasted group ($p<0.05$). In addition, RER in normoxia was significantly lower than in hypoxia($p<0.05$) (Figure 3).

The results of the repeated measurement test revealed a significant difference between different measurement times (F=5096.68 and P=0.001). In hypoxia and normoxia, heart rates in the satiety group were significantly higher than in the fasted group ($p<0.05$). Moreover, heart rates in normoxia were significantly lower than in hypoxia ($p<0.05$) (Figure 4).

Table 1. Descriptive characteristics of subjects as mean ± standard deviation.

attributes	Mean ± SD
Age (year)	30.75 ± 6.79
Height (cm)	177.63 ± 7.38
Weight (kg)	85.59 ± 11.20
Fat percentage	25.09 ± 2.39
BMI (kg/m2)	27.02 ± 1.93
VO2max (L/min)	24.67 ± 4.61

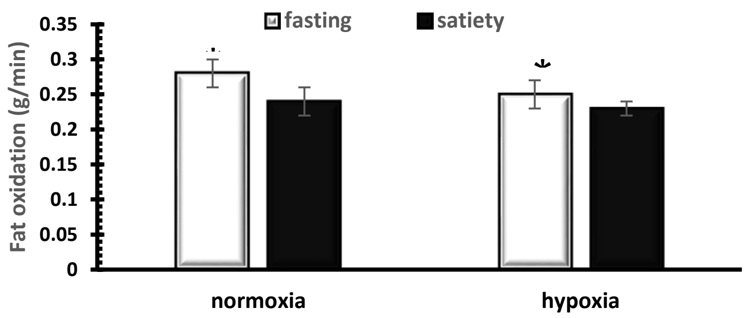

Figure 1. Investigation of fat oxidation changes in the studied groups
*Indicating a significant change compared to the satiety hypoxia group

Figure 2. investigation of carbohydrate oxidation changes in the studied groups
*indicating significant change compared to the satiety hypoxia group,#indicating significant change compared to the satiety normoxia group

Figure 3. Investigation of respiratory exchange ratio changes in the studied groups
*Indicating significant change compared to the fasting normoxia group

Figure 4. Investigation of heart rate changes in the studied groups
*Indicating significant change compared to the satiety normoxia group

Discussion

The present study demonstrated that hypoxia and normoxia conditions significantly change fat oxidation rates during sated and fasting states. Specifically, in the fasting state, the fat oxidation level was higher than that observed during satiety, irrespective of the oxygen availability. Moreover, physical activity was also observed to significantly affect fat oxidation levels in both hypoxia and normoxia conditions. In contrast, the satiety state significantly altered carbohydrate oxidation rates in response to activity in both hypoxia and normoxia conditions. Conversely, satiety or fasting was observed to influence carbohydrate oxidation rates significantly. These findings suggested that oxygen availability and nutritional state significantly influence the body's physiological response to physical activity, highlighting the importance of these factors in regulating energy metabolism.

Basami et al. (2013) explored the impact of satiety and fasting on substrate oxidation. The findings of the study were consistent with the current research, indicating that the amount of fat oxidation increases after a period of fasting and regular aerobic activity (28). Keli and Bassett align with the current research concerning the changes in carbohydrate and fat oxidation in hypoxia and normoxia conditions, while the findings of Lundby, Hall, and Sami et al. did not (29).

Furthermore, the present study revealed that the activity in normoxia and hypoxia conditions impacts fat and carbohydrate oxidation. Lundby and Hall (2002) investigated the effect of training in situations at sea level and 4100 meters altitude. The researchers concluded that acute activity at sea level and 4100 meters altitude does not affect the amount of fat and carbohydrate oxidation in normal-weight men. The difference in height, weight, and intensity of activity could be the reason for the disparity between their findings and the current research (30).

Kelly and Bassett (2017) indicated an increase in fat oxidation induced by cycling activity in normobaric hypoxia compared to normoxia. The type of activity could be a possible reason for the difference in the findings. Sami et al. did not observe a significant difference in carbohydrate oxidation in satiety in normoxia and hypoxia conditions. However, the type of nutrition consumed, such as materials with a high sugar index in Sami's research, and the normal weight of the participants could be factors contributing to the disparity between their findings and the current research (31).

Consuming a high-fat meal the previous evening may explain the changes in fat oxidation since carbohydrates after dinner, when glycogen stores are replenished, affect fat oxidation. (28). During exercise, the body responds to a rapid reduction in carbohydrates by increasing fat mobilization in skeletal muscle while maintaining blood sugar levels in the brain, similar to the effects of fasting (32). Triglyceride movement from fat tissue into the bloodstream results in free fatty acid (FFA) availability to metabolically active tissues, allowing muscle function to continue despite decreased blood glycogen and glucose concentrations (33). Regarding fasting and aerobic exercise, biochemical pathways involved in fat mobilization and burning are activated to increase FFA consumption. Short periods of fasting regularly expose active tissue to increased fat availability and consumption, leading to the adaptation of lipid consumption by tissues such as skeletal muscle (34).

Changes in glucose and insulin due to fasting and satiety may also account for differences in fat and carbohydrate oxidation. Blood glucose levels decrease after a few hours of fasting in healthy individuals, but the continuous decrease in blood glucose is halted by increased gluconeogenesis from the liver. This increase is due to decreased insulin secretion, increased glucagon secretion, and increased sympathetic nerve activity (35). Blood glucose levels have an inverse relationship with fat intake and a positive relationship with carbohydrate intake. The hours of fasting are an essential factor in the variability of blood glucose levels, and the amount of glycogen reserves, physical activity, and dietary patterns (amount and type of food consumed) of subjects can also affect serum glucose levels. Hormonal changes, such as an increase in fatty acids, may also contribute to fat and carbohydrate oxidation changes during fasting and satiety (28).

A contributing factor to the present findings may be the subjects of the study being overweight since recent studies have shown that overweight and obesity increase hepatic glucose and fatty acid production. Exercise in such conditions may increase insulin secretion from the pancreas, decrease insulin resistance, and alter carbohydrate metabolism (21). Some studies have shown a relative increase in glucose oxidation during physical activity following exercise in hypoxic conditions, which is due to the activation of hypoxia-inducible factor-1, which is responsible for the production of erythropoietin, vascular endothelial growth factor-1, and GLUT transporter-1 (36).

The present study's findings indicated a significant difference in the respiratory exchange ratio (RER) between the satiety hypoxia and fasting normoxia groups and between the exercise groups in satiety normoxia and fasting normoxia. The results showed a decline in carbohydrate oxidation in normoxia conditions compared to hypoxia, as evidenced by the decrease in RER between hypoxia and normoxia conditions.

The findings of Ofner et al. (2014) are consistent with those of the present study, which found that the RER was higher in hypoxic conditions after increasing aerobic activity in healthy men (37). However, Hozouri et al. and Hamlin et al. revealed nonaligned results. Hozouri et al. (2022) studied the effect of four weeks of polarized training on professional rowers' aerobic fitness and performance and observed no change in the RER. The disparity may be due to the duration of the exercise protocol, the level of physical fitness of the participants, and their weight (38). In Hamlin et al. (2010), sea dwellers performed cycling in hypoxia conditions. The participants performed the Wingate test for ten consecutive days, and the RER increased two days after the intervention. The causes of disparity may include the implementation protocol, the intensity and duration of the sports activity, and the level of preparation of the participants (39).

The present study examined the effect of fasting and hypoxia on the respiratory exchange ratio (RER), glucose metabolism, and heart rate during moderate-intensity exercise. The findings indicated that a reduction in glucose metabolism leads to an increase in endurance capacity during moderate-intensity exercises (38). Additionally, previous studies have suggested that the hypothalamus-pituitary-adrenal axis becomes stimulated in the presence of obesity and overweight, resulting in increased cortisol levels (40), (41), and (27).

Furthermore, the results indicated that heart rate changes significantly in response to fasting, satiety, and hypoxic conditions. The training group in fasting hypoxia and satiety normoxia conditions experienced more significant differences in heart rate compared to the training group in satiety hypoxia and satiety normoxia. Notably, the intensity of sports protocols, physical activity, and body weight could account for variations in results across studies.

According to Haddad et al. (2012), exposure to altitudes higher than 3000 meters leads to changes in the parasympathetic nervous system, whereas exposure to lower altitudes stimulates the sympathetic nervous system. In addition, the low partial pressure of oxygen (PaO2) at high altitudes may delay heart activity in unhealthy individuals. Chemoreflex activation appears to be a significant determinant of parasympathetic reactivation (42).

In summary, this study highlighted the importance of considering factors such as fasting, hypoxia, and exercise intensity when examining RER, glucose metabolism, and heart rate. The findings could have implications for individuals seeking to enhance their endurance capacity and those living at high altitudes or participating in activities involving hypoxia exposure.

Research limitations include two controllable and uncontrollable parts. The controllable limitations include subjects' nutrition, exercise, altitude, medical health questionnaire, and physical fitness. Uncontrollable limitations include subjects' motivation and anxiety, physiological characteristics, and sleeping and resting conditions.

One of the strengths of this research was the comparison of normoxia and hypoxia in fasting and satiety states. Much research has been conducted on obesity and overweight, but less research has been performed on the conditions presented in this study.

Declarations

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Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Author Contributions

RM and MA contributed to the conception and design of the research; RM, MA, and WT contributed to data collection; MA and WT contributed to the acquisition and analysis of the data; MA and WT contributed to the interpretation of the data; RM, MA, and WT contributed to draft the manuscript. All authors have read and approved the final manuscript, ensuring transparency in the research process.

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