The effects of exercise intensity on energy expenditure, weight, and lee's index in adolescent obese rats

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Abstract: Objective: To investigate the effects of different intensity exercise prescriptions on immediate energy expenditure, body weight, and Lee's Index in adolescent obese rats immediately after exercise during an 8-week weight loss process. Methods: After 7 weeks of modeling, 32 obese rats were randomly divided into 4 groups, with 8 rats in each group: obese control group, low-intensity exercise group, moderate-intensity exercise group, and high-intensity exercise group. The running speeds on the treadmill for the three intensity levels were set at 15–18 m/min, 21–25 m/min, and 28–32 m/min, respectively, with 5 sessions per week and 60 minutes per session for 8 weeks. Body weight was measured and Lee's Index was calculated weekly. A rat metabolic system was used to measure the immediate oxygen uptake and energy expenditure in rats after exercise. Results: During the 8-week intervention, the exercise groups showed significantly higher immediate post-exercise muscle oxygen uptake and total oxygen uptake, as well as muscle energy expenditure and total energy expenditure compared to the control group ($P<0.05$, $P<0.01$). The high-intensity group had higher values than the low-intensity group ($P<0.05$). Weight gain was significantly lower in the intervention groups compared to the control group ($P<0.05$, $P<0.01$). Lee's Index was significantly lower in the intervention groups at week 8 compared to the control group ($P<0.05$, $P<0.01$), with no significant differences between different exercise intensities ($P>0.05$). In adolescent obese rats, body weight tends to increase with age, while muscle oxygen uptake, total oxygen uptake, muscle energy expenditure, and total energy expenditure tend to decrease. After 8 weeks of exercise intervention, different intensity exercise prescriptions can increase immediate post-exercise oxygen uptake and energy expenditure in adolescent obese rats, with the most significant effects observed in the high-intensity group. Weight gain and Lee's Index were reduced, but the effects were less influenced by exercise intensity.

Keywords: Exercise intensity, Adolescent obesity, Immediate post-exercise energy expenditure, Body weight, Lee's Index

1. Introduction

In recent years, unhealthy lifestyles have swept across the globe, leading to a continuous increase in the incidence of obesity, which has become a common epidemic [1-2]. Obesity is a major risk factor for the development of various chronic diseases such as hypertension, diabetes, dyslipidemia, coronary heart disease, and myocardial infarction, and has been identified by the World Health Organization as the fifth leading risk factor affecting health [3]. Due to the rapid growth and development during adolescence, which requires a large amount of energy, the potential risks of obesity in adolescents are even greater than in adults if there is a significant excess of energy intake. The long-term impact is more pronounced, and the risk of developing obesity in adulthood is extremely high. Many obesity-related chronic diseases may occur earlier and can affect individuals for life [4].

Weight loss has become one of the most widely discussed topics in the fields of sports and medicine. Currently, there are many popular weight loss methods, including pharmacological interventions and surgical procedures, which can lead to weight reduction but may also cause harm to the body. Therefore, these methods are rarely accepted by the general population [5]. Scientific exercise-based weight loss not only has no side effects but also improves physical fitness and enhances overall health, which has been recognized in both clinical practice and academic circles [6]. However, there is still no consensus on

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whether different intensities of exercise can affect immediate post-exercise energy expenditure, body weight, and Lee's Index. Therefore, this study investigates the effects of different exercise intensities on immediate post-exercise energy expenditure, body weight, and Lee's Index in adolescent obese rats through exercise interventions, aiming to provide theoretical and practical guidance for selecting appropriate exercise intensities for weight loss in adolescents.

2. Research methods

2.1. Establishment of the obesity model

This study selected 110 male Sprague-Dawley (SD) rats, aged 3 weeks, of clean grade, purchased from Shanghai Slaccas Laboratory Animal Co., Ltd. [License No.: SCXK (Hu) 2012-0002, Certificate No.: 2007000546402]. The SD rats were first acclimated to the feeding conditions for 1 day, with an initial body weight of 75.52±7.64 g. They were then randomly divided into a control group and a high-fat group, with no significant difference in body weight between the groups (P>0.05). The control group consisted of 12 rats fed a standard diet (dietary energy composition: 52.5% carbohydrates, 4.62% fat, 20.5% protein), while the high-fat group consisted of 98 rats fed a high-fat diet. The first phase lasted for 4 weeks, during which the rats were fed a high-fat diet providing 36% of energy from fat (dietary energy composition: 45.2% carbohydrates, 16.2% fat, 18.8% protein). The second phase lasted for 3 weeks, during which the rats were fed a high-fat diet providing 40% of energy from fat (composition per 100 g: standard diet 54.6 g, lard 16.9 g, sucrose 14 g, casein 10.2 g, premix 2.1 g, maltodextrin 2.2 g). After 7 weeks, the obesity model was successfully established (success criterion: the body weight of the obese group was more than 20% higher than that of the control group) [7]. At the end of the modeling period, the body weight of the control group was (378.92±24.70) g, and that of the obesity-prone group was (469.82±19.25) g. During the intervention period, all groups were fed a standard diet, with a fixed daily supply of feed and free access to water. The rats were housed in separate cages, with the breeding room maintained at a temperature of 20℃±2℃ and a relative humidity of 50%-70%, and a 12-hour light cycle per day. This study was approved by the Animal Ethics Committee of Anhui Normal University.

2.2. Exercise grouping

Thirty-two obesity-prone rats were selected and randomly divided into four groups. The body weights of the groups were as follows: Obese Control Group (473.60±26.25) g, Low-Intensity Exercise Group (480.20±19.02) g, Moderate-Intensity Exercise Group (470.40±6.99) g, and High-Intensity Exercise Group (479.60±12.12) g. There were no significant differences in body weight among the groups (P>0.05).

Table 1 Specific Exercise Speed and Duration

Group	Low-Intensity Exercise Group		Medium-Intensity Exercise Group		High-Intensity Exercise Group	
Treadmill Speed and Duration	Preparation Period:15m/min(10min)		Preparation Period:21m/min(10min)		Preparation Period:28m/min(10min)	
	Exercise Period:	First: 18m/min(15min)	Exercise Period:	First: 25m/min(15min)	Exercise Period:	First: 32m/min(15min)
		Middle:15m/min(10min)		Middle:21m/min(10min)		Middle:28m/min(10min)
		Last:18m/min(15min)		Last:25m/min(15min)		Last:32m/min(15min)
	Cooling-Down Period: 15m/min(10min)		Cooling-Down Period: 21m/min(10min)		Cooling-Down Period: 28m/min(10min)	

2.3. Design and implementation of exercise protocol

A 6-lane rat treadmill (Wi32812/Beijing) was used, and the exercise intensity was designed at three levels: low, medium, and high (see Table 1). The rats underwent 2–3 sessions of adaptive treadmill training per day for 3 days. This exercise protocol was based on the previous animal exercise protocols from our laboratory [8]. The treadmill incline was set at 0°, with speeds ranging from 15m/min to 32m/min. The total

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daily exercise time was 60 minutes, with 5 sessions per week. Rest days were scheduled on Day 1 and Day 4 of each week, and the intervention lasted for 8 weeks.

2.4. Observation indicators and measurement methods

The water intake, food intake, mental state, and activity level of the SD rats were observed daily. The temperature and humidity of the breeding room were recorded on time each day. The rats were fed 28g of food per day. On the second day, the remaining amount from the previous day was weighed to record the intake of the previous day. The body weight of the rats was measured using an electronic scale (JM-A20001/China) at the same time point (3 p.m. on Wednesday) each week. The body length was measured once a week, which was defined as the distance from the tip of the nose to the anus. The Lee's index was calculated using the formula: Lee's index = body weight $(g)^3 \times 10^4$ / body length (cm) [9].

2.5. Energy metabolism indicators

Energy metabolism was measured using the German TSE animal metabolic measurement and analysis system (PROCESSCONTROL/Germany). Before the formal experiment, the stability of the entire system was tested. The measurement indicators included oxygen consumption and energy expenditure immediately after exercise. The measurement method involved placing the experimental rats back into the respiration chamber immediately after daily exercise to measure energy metabolism and record the observations. The data collection time points for the experimental rats were set at 9, 18, 27, 36, 45, and 54 minutes. The oxygen consumption immediately after exercise was selected from the second 9-minute interval. During the test, the rats were fixed using a rat fixation device. The metabolic laboratory was maintained at a temperature of 20℃ ± 2℃, humidity of 50%–70%, and a quiet environment. The main parameters of the energy metabolism measurement and analysis system were as follows: FlowSamp 0.72 ml/L, $RefO_2$ 20.92%–20.93%, $RefCO_2$ 0.054%–0.055%.

2.6. Statistical methods

During the experiment, data from a series of indicators were organized and analyzed using the statistical software package SPSS 17.0. Normally distributed data were expressed as mean ± standard deviation (X ± SD). For comparisons of differences among multiple groups, the LSD (Least Significant Difference) test in one-way ANOVA (analysis of variance) was used. A p-value greater than 0.05 indicated no significant difference, a p-value less than 0.05 indicated a significant difference, and a p-value less than 0.01 indicated a highly significant difference.

3. Results

3.1. Comparison of oxygen consumption changes

Table 2. Changes in total oxygen consumption immediately after exercise (n=8, X±SD) [ml/(h·kg)]

Week	Obese Control Group	Low-Intensity Exercise Group	Medium-Intensity Exercise Group	High-Intensity Exercise Group
Week 1	670.00±17.05	838.50±67.66**	836.25±29.55**	817.25±49.76**
Week 2	348.25±66.39	374.25±66.58	512.00±75.62°▲▲	404.50±12.36▲
Week 3	407.75±32.53	429.25±46.64	405.75±47.42	396.75±72.90
Week 4	282.38±25.08	458.38±88.87**	402.38±36.26**	381.88±19.97*
Week 5	353.05±45.06	346.00±26.50	389.00±78.59	318.00±29.73▲
Week 6	334.78±28.92	387.38±26.19	371.38±48.34	360.38±26.11
Week 7	316.50±15.63	428.75±28.56*	353.75±51.19▲	402.75±30.23*
Week 8	199.75±28.47	47376.50±43.94**	391.50±40.76**	442.25±38.064**▲

As shown in Table 2 and Figure 1, the total oxygen consumption after exercise is as follows:

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3.1.1. Compared with the obese control group

The low-intensity exercise group showed significant increases in the 1st, 4th, 7th, and 8th weeks ($P < 0.05$, $P < 0.01$). The medium-intensity exercise group showed significant increases in the 1st, 2nd, 4th, and 8th weeks ($P < 0.05$, $P < 0.01$). The high-intensity exercise group showed significant increases in the 1st, 4th, 7th, and 8th weeks ($P < 0.05$, $P < 0.01$).

3.1.2. Compared with the low-intensity exercise group

The medium-intensity exercise group showed a significant increase in the 2nd week and a decrease in the 7th week ($P < 0.05$, $P < 0.01$). The high-intensity exercise group showed significant increases in the 2nd and 8th weeks and a decrease in the 5th week ($P < 0.05$, $P < 0.01$). During the 8-week intervention, the total oxygen consumption in each group decreased as the weeks progressed.

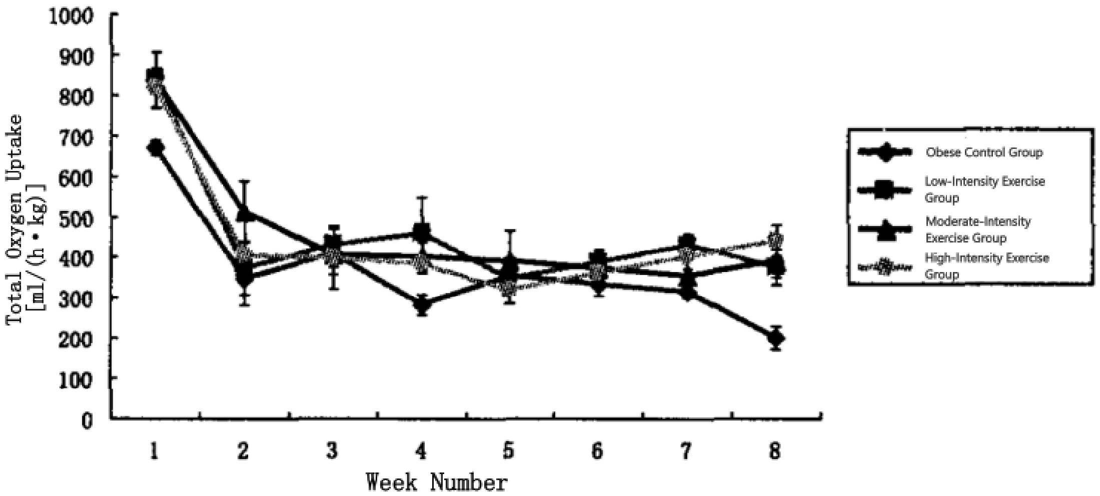

Figure 1. Changes in total oxygen consumption immediately after exercise (n=8, X±SD) [ml/(h·kg)]

The changes in muscle oxygen consumption after exercise are shown in Table 3 and Figure 2: Compared with the obese control group: The low-intensity exercise group showed significant increases in muscle oxygen consumption in the 1st, 4th, 7th, and 8th weeks ($P < 0.05$, $P < 0.01$). The medium-intensity exercise group showed significant increases in the 1st, 2nd, 4th, and 8th weeks ($P < 0.05$, $P < 0.01$). The high-intensity exercise group showed significant increases in the 1st, 4th, and 8th weeks ($P < 0.05$, $P < 0.01$).

Compared with the low-intensity exercise group: The medium-intensity exercise group showed significant decreases in the 4th and 7th weeks ($P < 0.05$, $P < 0.01$). The high-intensity exercise group showed a significant increase in the 8th week ($P < 0.05$, $P < 0.01$). During the 8-week intervention, muscle oxygen consumption in each group decreased as the weeks progressed.

Table 3. Changes in muscle oxygen consumption immediately after exercise (n=8, X±SD) [ml/(h·kg)]

Week	Obese Control Group	Low-Intensity Exercise Group	Medium-Intensity Exercise Group	High-Intensity Exercise Group
Week 1	568.50±14.47	701.25±57.69**	694.50±23.8**	687.25±42.26**
Week 2	293.75±57.00	316.75±57.21	429.75±63.6**	339.18±10.66
Week 3	348.75±29.32	358.25±39.04	340.25±41.29	328.75±63.00
Week 4	241.18±21.24	387.38±78.53**	335.63±30.90**▲	316.50±15.15*
Week 5	303.25±39.14	296.75±23.60	329.75±67.33	262.75±24.30
Week 6	292.50±31.32	329.50±21.84	313.88±40.97	300.00±21.93
Week 7	281.75±25.10	362.25±22.81*	298.00±43.86▲	337.25±23.61
Week 8	173.50±24.93	309.50±28.52**	335.25±38.01**	371.75±33.71**▲

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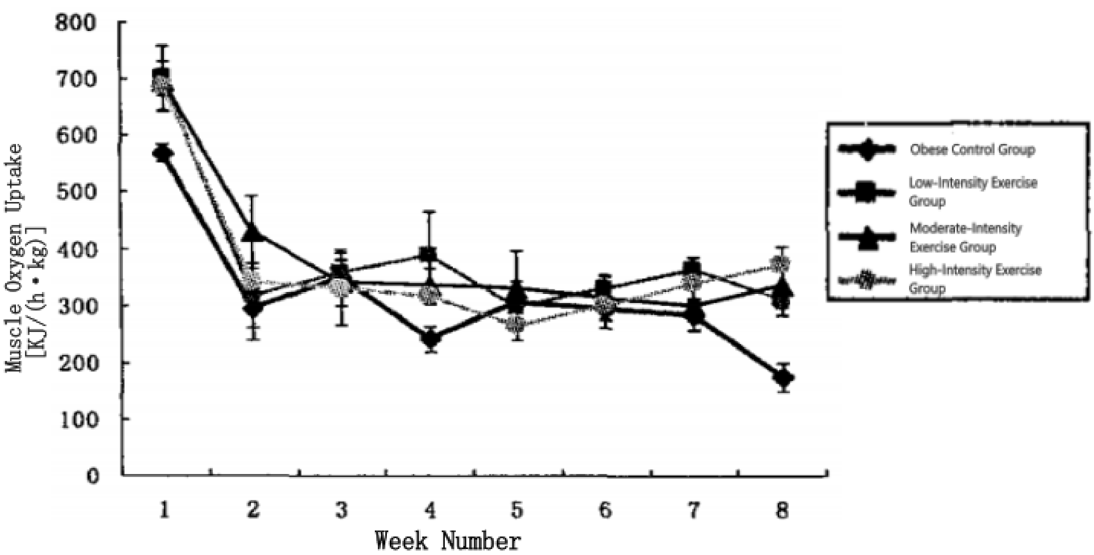

Figure 2. Changes in muscle oxygen consumption immediately after exercise (n=8, X±SD) [ml/(h·kg)]

3.2. Comparison of energy changes

As shown in Table 4 and Figure 3, the total energy expenditure after exercise is as follows:

Compared with the obese control group: The low-intensity exercise group showed significant increases in total energy expenditure in the 1st, 4th, 7th, and 8th weeks ($P < 0.05$, $P < 0.01$). The medium-intensity exercise group showed significant increases in the 1st, 2nd, 4th, and 8th weeks ($P < 0.05$, $P < 0.01$). The high-intensity exercise group showed significant increases in the 1st, 4th, and 8th weeks ($P < 0.05$, $P < 0.01$).

Compared with the low-intensity exercise group: The medium-intensity exercise group showed a significant increase in the 2nd week and a decrease in the 7th week ($P < 0.05$, $P < 0.01$). The high-intensity exercise group showed a significant decrease in the 4th week ($P < 0.05$, $P < 0.01$). During the 8-week intervention, the total energy expenditure in each group decreased as the weeks progressed.

Table 4. Changes in total energy expenditure immediately after exercise (n=8, X±SD) [kJ/(h·kg)]

Week	Obese Control Group	Low-Intensity Exercise Group	Medium-Intensity Exercise Group	High-Intensity Exercise Group
Week 1	13.92±0.35	17.2±1.40**	17.16±0.54**	16.80±1.09**
Week 2	7.06±1.42	7.49±1.41	10.26±1.52**▲▲	8.18±0.25
Week 3	8.42±0.65	8.48±1.03	8.09±0.99	7.75±1.48
Week 4	5.75±0.56	9.14±1.78**	7.97±0.69**	7.54±0.41*▲
Week 5	7.19±0.92	6.84±0.54	7.69±1.58	6.29±0.61
Week 6	6.92±0.73	7.71±0.52	7.37±0.94	7.18±0.52
Week 7	6.646±0.578	8.58±0.56*	7.06±1.00▲	8.07±0.59
Week 8	4.21±0.62	7.83±0.62**	7.90±0.90**	8.85±0.68**

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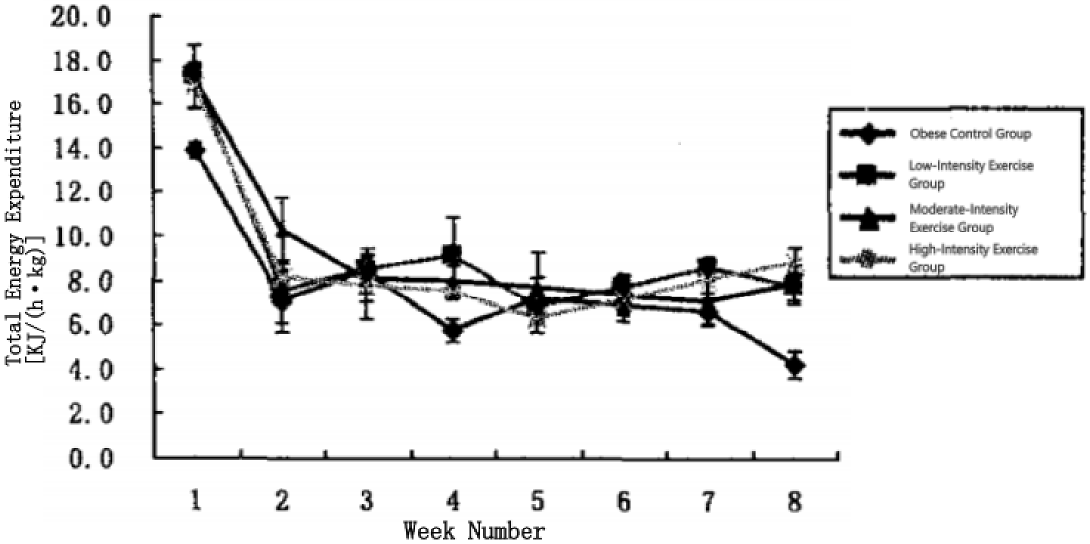

Figure 3. Changes in total energy expenditure immediately after exercise (n=8, X±SD) [kJ/(h·kg)]

As shown in Table 5 and Figure 4: Compared with the obese control group:The low-intensity exercise group showed significant increases in the 1st, 4th, 7th, and 8th weeks ($P < 0.05$, $P < 0.01$). The medium-intensity exercise group showed significant increases in the 1st, 2nd, 4th, and 8th weeks ($P < 0.05$, $P < 0.01$).The high-intensity exercise group showed significant increases in the 1st, 4th, and 8th weeks ($P < 0.05$, $P < 0.01$).

Compared with the low-intensity exercise group:The medium-intensity exercise group showed a significant increase in the 2nd week and decreases in the 4th and 7th weeks ($P < 0.05$, $P < 0.01$). The high-intensity exercise group showed no significant differences. During the 8-week intervention, muscle energy expenditure in each group decreased as the weeks progressed.

Table 5. Changes in muscle energy expenditure immediately after exercise (n=8, X±SD) [kJ/(h·kg)]

Week	Obese Control Group	Low-Intensity Exercise Group	Medium-Intensity Exercise Group	High-Intensity Exercise Group
Week 1	11.81±0.30	14.41±1.20**	14.25±0.43**	14.13±0.93**
Week 2	5.96±1.22	6.34±1.21	8.61±1.28**▲▲	6.86±0.21
Week 3	7.21±0.59	7.08±0.86	6.79±0.87	6.42±1.28
Week 4	4.91±0.48	7.73±1.58**	6.65±0.59*▲	6.25±0.31*
Week 5	6.18±0.80	5.87±0.48	6.52±1.35	5.20±0.50
Week 6	5.97±0.64	6.56±0.44	6.23±0.80	5.98±0.44
Week 7	5.76±0.52	7.25±0.44*	5.94±0.86▲	6.77±0.46
Week 8	3.65±0.54	6.51±0.44**	6.76±0.83**	7.44±0.60**

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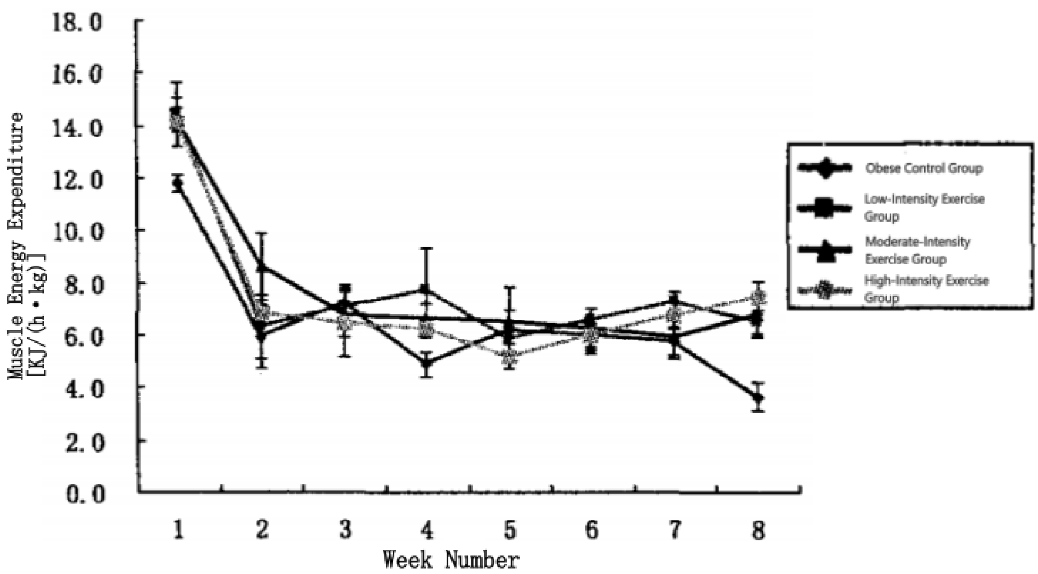

Figure 4. Changes in muscle energy expenditure immediately after exercise (n=8, X±SD) [kJ/(h·kg)]

3.3. Comparison of weight changes

As shown in Table 6 and Figure 5: Compared with the obese control group: The low-intensity exercise group showed significant weight reductions in Weeks 3, 4, 5, 6, 7, and 8 ($P < 0.05$, $P < 0.01$). The medium-intensity exercise group showed significant weight reductions in Weeks 3, 4, 5, 6, 7, and 8 ($P < 0.05$, $P < 0.01$). The high-intensity exercise group showed significant weight reductions in Weeks 3, 4, 5, 6, 7, and 8 ($P < 0.05$, $P < 0.01$). Compared with the low-intensity exercise group: The medium-intensity exercise group and the high-intensity exercise group showed no significant differences. During the 8-week intervention, body weight in each group increased as the weeks progressed.

Table 6. Changes in Rat Body Weight (n=8, X±SD) (Unit: g)

Week	Obese Control Group	Low-Intensity Exercise Group	Medium-Intensity Exercise Group	High-Intensity Exercise Group
Week 1	487.17±11.92	484.83±9.93	478.17±4.96	476.67±8.79
Week 2	489.83±27.17	489.00±23.49	484.33±13.85	483.50±20.31
Week 3	542.83±16.17	490.67±24.06**	490.33±17.72**	490.17±22.82**
Week 4	552.50±15.66	502.50±28.58*	495.67±11.71**	495.33±32.97**
Week 5	553.67±15.57	514.50±28.37*	509.17±9.37*	489.83±41.17**
Week 6	556.00±16.17	511.00±27.78*	509.50±14.60*	482.83±35.21**
Week 7	566.00±15.48	523.33±24.48*	517.67±14.88*	487.67±33.90**
Week 8	578.67±13.34	532.83±23.22*	537.00±21.08*	504.33±36.86**

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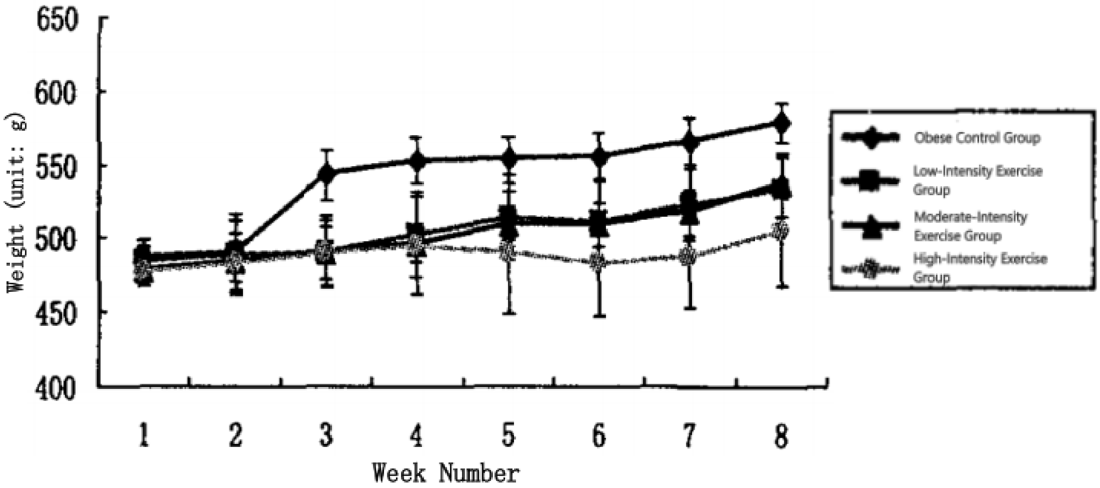

Figure 5. Changes in Rat Body Weight (n=8, X±SD) (Unit: g)

3.4. Comparison of changes in lee's index

As shown in Table 7 and Figure 6: Compared with the obese control group: The low-intensity exercise group showed a significant decrease in the 8th week ($P < 0.01$). The medium-intensity exercise group showed no significant difference ($P > 0.05$). The high-intensity exercise group showed a significant decrease in the 8th week ($P < 0.05$).

Compared with the low-intensity exercise group: The medium-intensity exercise group and the high-intensity exercise group both showed no significant differences ($P > 0.05$).

During the 8-week intervention, the Lee's index in each group decreased as the weeks progressed.

Table 7. Changes in Rat Lee's Index (n=8, X±SD)

Week	Obese Control Group	Low-Intensity Exercise Group	Medium-Intensity Exercise Group	High-Intensity Exercise Group
Week 1	347.18±10.66	346.59±6.53	345.11±8.10	349.86±9.80
Week 2	347.83±10.54	342.63±8.68	346.61±9.68	349.06±9.70
Week 3	347.56±8.74	343.02±8.87	348.03±10.26	348.07±10.97
Week 4	340.22±11.83	343.35±12.03	344.29±9.93	344.12±12.99
Week 5	339.74±8.73	341.12±9.04	340.29±13.70	337.95±11.90
Week 6	340.00±10.06	340.37±9.78	340.33±13.17	329.42±16.77
Week 7	342.49±9.06	335.86±8.29	339.92±15.97	328.51±19.36
Week 8	335.94±12.12	317.95±5.85**	320.34±9.40*	316.48±13.23**

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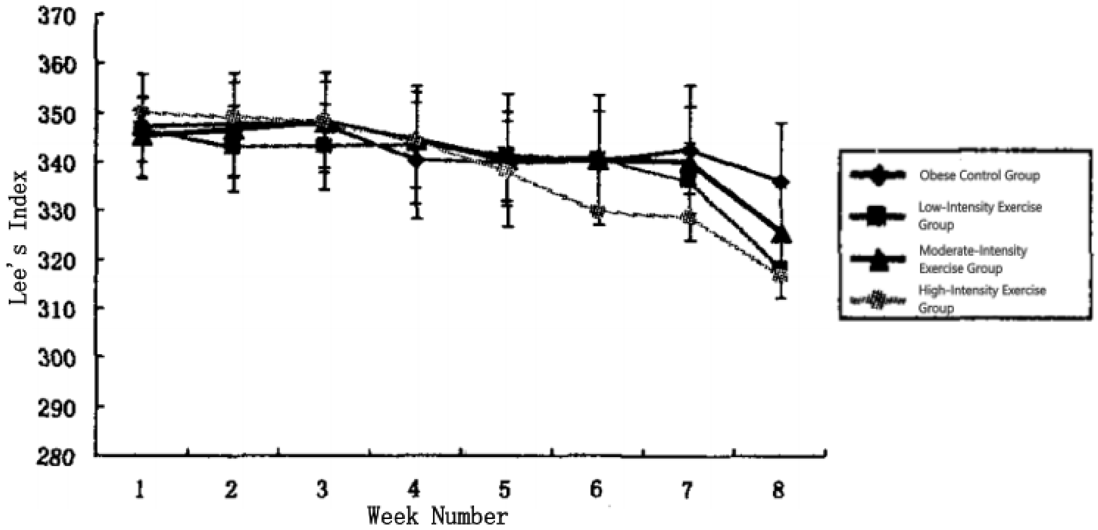

Figure 6. Changes in Lee's Index of Obese Rats After 8 Weeks of Intervention (n=8, X±SD)

4. Discussion

4.1. Analysis of exercise intensity effects on energy metabolism in adolescent obese rats

Energy metabolism is a complex process, and exercise can improve and promote the status of energy metabolism [10]. Any slight activity of the body can increase the metabolic rate, with muscle activity having the most significant impact. This is accompanied by energy expenditure, which requires the participation of oxygen. Therefore, oxygen consumption is commonly used to reflect the level of energy expenditure in the body [11]. For fat reduction through exercise, total energy expenditure after exercise is more important than energy expenditure during exercise alone [12]. Low- and moderate-intensity exercise primarily uses fat as an energy source and can burn a large amount of fat during exercise. However, during the 24-hour recovery period after high-intensity exercise, the increased basal metabolic rate requires more energy to promote bodily recovery, with fat again being the primary energy source [12]. Studies have shown [13] that low-intensity exercise can only cause the body to additionally expend 5–10 kcal of energy after exercise, moderate-intensity exercise can lead to an additional expenditure of 12–25 kcal, while high-intensity exercise can result in an additional expenditure of 180 kcal, equivalent to the energy of about 20 g of fat. Therefore, compared to low- and moderate-intensity exercise, high-intensity exercise can burn more body fat.

The results of this study show that during the 8-week growth and development process of obese rats, as they mature with increasing age, their energy metabolism levels significantly decrease. After 8 weeks of intervention with different exercise intensities, the changes in energy expenditure in rats were consistent with the changes in oxygen consumption. This indicates that exercise can increase the oxygen consumption and energy expenditure in adolescent obese rats. With increasing exercise intensity, the increase in energy expenditure in low- and moderate-intensity exercise rats was consistent with the aforementioned studies. High-intensity exercise can burn more energy after exercise, and the recovery period after exercise primarily involves fat consumption. Therefore, high-intensity exercise can achieve better weight loss effects. However, during the high-intensity exercise intervention in adolescent obese rats, the rats showed signs of fatigue and an inability to continue exercising earlier, and they exhibited aversion. Therefore, for adolescent obese populations, high-intensity exercise prescriptions are not recommended.

4.2. Effects of exercise intensity on weight and lee's index in adolescent obese rats

Body weight is an indicator that reflects the development of bones and muscles as well as the degree of obesity [14]. Exercise intensity is a decisive factor in the rate and extent of fat oxidation and decomposition [15]. Traditional weight loss concepts suggest that various forms of exercise increase fat oxidation and

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reduce body weight. Long-term moderate- and low-intensity aerobic exercise has the highest proportion of fat as an energy source and is considered the most effective for weight loss. Experiments have proven that weight loss exercise prescriptions at 60%–70% of functional capacity have significant weight loss effects [16–17]. However, many studies also suggest that high-intensity exercise is more conducive to fat consumption and achieving better weight loss effects, provided that the individual's physical condition permits [12]. Lee's index, as one of the indicators reflecting the degree of obesity in rats, has been shown by He Ming et al. to change with variations in rat body weight and is highly correlated [18]. The results of this experiment indicate that during adolescence, as growth and development gradually mature, weight gain is not affected by exercise. However, after 8 weeks of exercise intervention, the increase in body weight and Lee's index in the exercise groups of obese rats was lower than that in the control group. Although changes in body weight and Lee's index were observed with increasing exercise intensity, the differences were not significant. It can be seen that exercise can reduce the increase in body weight and Lee's index, but different exercise prescriptions have minimal impact on changes in body weight and Lee's index.

5. Conclusion

During adolescence, the body weight of obese rats increased with age, while muscle oxygen consumption and total oxygen consumption, as well as muscle energy expenditure and total energy expenditure, decreased. After 8 weeks of exercise intervention, different exercise intensities improved the immediate post-exercise oxygen uptake and energy expenditure in adolescent obese rats, with the most significant effects observed in high-intensity exercise. The increase in body weight and Lee's index was reduced, but these changes were less influenced by exercise intensity.

6. References

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