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Original Research

Randomized Controlled Study of Factors Influencing Body Composition and Exercise Quality of Male Adolescents Aged 13–15 Years Based on Cross-Lagged Models: Obesity Level, Salivary Testosterone, and Exercise Combined with Caloric Restriction Intervention

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Abstract

Background: Obesity is a worldwide health problem with many disadvantages for children and adolescents, especially for the sexual development of boys. Exercise and caloric restriction are effective in improving obesity; however, the factors influencing these improvements should be studied in detail. We conducted a randomized controlled study of factors affecting changes in body composition and physical capacity in males aged 13–15 years. **Methods**: Subjects were divided into three groups based on body fat percentage (BFP), and randomly divided into control and intervention groups. The experimental conditions of this study were based on an exercise camp with a 12-week closed training period. The intervention group received a combination of aerobic exercise, resistance exercise, and caloric restriction. All subjects were uniformly housed and had a standard time for diet and rest, whereas the control group performed their coursework during the exercise intervention time and had no dietary restrictions. The subjects were tested for body composition and physical capacity before and after the intervention. **Results**: The effect of exercise training and energy-restricted diets on fat loss and physical capacity was limited to relatively lower extremity explosive strength and cardiorespiratory endurance, with a significant effect on body composition. Fat mass reduction was influenced by obesity with a high level of individual variability, with higher levels of obesity resulting in greater reductions in fat mass. The reduction in BFP was not affected by the level of obesity, and there was a mild causal relationship with salivary testosterone (ST) in the intervention group but not in the control group. ST was predictive of future BFP in exercisers; individuals with high ST had a greater reduction in BFP under conditions of prolonged exercise and caloric restriction. **Conclusions**: More obese male adolescents can obtain greater fat mass reduction with the intervention, but fat-free mass and exercise quality are minimally affected by the level of obesity. Adolescent males with higher ST ground tend to gain improvements in body composition, and ST can be predictive of future BFP but needs to be in the context of an exercise intervention.

Keywords: obesity; exercise; salivary testosterone; body composition; physical capacity; cross-lagged analysis

1. Introduction

From 1980 to 2013, the global rate of overweight and above among children increased by 47.1%, and the rate among males in developed countries increased to 23.8% and 16.9%, respectively [1]. In China, the prevalence of obesity among children and adolescents aged 7–17 years was 13.2% [2]. Obesity is associated with weight gain and decrease in physical fitness. Studies have shown [3,4] that the level of obesity is negatively correlated with physical performance. Moreover, obesity is accompanied by abnormal changes in the endocrine environment of the body, affecting the level of sex hormones in the male blood circulation [5]. Obese men are often accompanied by hypogonadism, mainly manifested by androgen deficiency, with a lower serum total testosterone and free testosterone than normal weight population [6], leading to delayed pubertal development in males [7]. In addition, other negative correlations between androgen levels and obesity have been reported, particularly with body weight, BMI, and waist circumference [8]. These negative effects of obesity can persist during adolescence and negatively affect even mental health, education, and future income [9]. Interventions for obesity are proliferating, and although most published results use only aerobic training in their protocols, recent studies [10] have data suggesting that resistance training may be an effective alternative to aerobic training for improving body composition in obese individuals. A combination of aerobic and resistance training may improve body composition more than aerobic or resistance training alone. The effectiveness of exercise interventions can be ensured by caloric control in the diet [11], and exercise has been shown in sufficient studies to be effective in enhancing sex hormones, with high-intensity interval training or whole-body electromyographic stimulation significantly increasing dehydroepiandrosterone sulfate and free testosterone [12], even in older males [13]. Although most of the adverse effects caused by obesity and interventions to reduce them have been demonstrated, few studies have analyzed the factors influencing the effect of interventions aimed at reducing obesity, perhaps only comparing sex or age in the intervention group. However, these more superficial analyses are limited by their experimental design at the beginning, and the study objectives were not intended to analyze the factors influencing the effect of interventions. Therefore, we selected sex hormone levels (salivary testosterone, ST), obesity level, and exercise combined with dietary intervention as independent variables to analyze how body composition and exercise quality in adolescent males aged 13–15 years were influenced by the three factors and how they acted. On the other hand, ST, as a non-invasive biochemical index with a carrier of saliva that does not contain sex hormone binding proteins, better reflects free sex hormone (bioactive) concentrations [14,15] and is therefore more stable [16,17]. ST correlates well with serum testosterone levels [18] and is highly contributes to pubertal development than whole plasma test testosterone [19]. Consequently, individual differences in intervention effects due to obesity level are not only due to the correlation between obesity level and testosterone levels [6], but also associated with exercise dietary habits [20], dietary self-efficacy [21], and exercise self-efficacy [22]. Certainly, studies have found a relationship between obesity and influencing factors; however, the vast majority are cross-sectional investigations that fail to clearly show a causal relationship. Therefore, we conducted a longitudinal study of several factors affecting changes in body composition and exercise quality in males with different levels of obesity. The study combined exercise and caloric restriction, and analyzed the causal relationship with a cross-lagged model to provide a theoretical basis and practical suggestions for obesity prevention and improvement measures in adolescent males.

2. Materials and Methods

2.1 Study Subjects

Obese males with a BFP >25% were screened among middle school students aged 13–15 years in Beijing, China. The inclusion criteria were the following: (1) age 13–15 years; (2) passed the PAR-Q questionnaire screening and were in good health; (3) had no professional sports experience; (4) were able to understand the test, volunteered to the whole test process, and signed the informed consent form. The exclusion criteria were as follows: (1) serious organic pathologies of the heart, brain, lungs, kidneys, and exercise system; (2) chronic diseases taking medication; (3) history of psychiatric disorders; and (4) inability to complete the follow-up or poor compliance. The final number of participants included in the study was 111.

The World Health Organization defines adult male BFP ≥20% and female BFP ≥30% as obese; however, the difference in body composition between children in China and other countries, judging the current situation of obesity in Chinese children and adolescents by European and American obesity standards, may produce a large error [23]. In China, it is generally considered that 25%–30% of BFP in both sexes is overweight, 30%–35% is mild obesity, 35%–40% is moderate obesity, and more than 40% is severe obesity [24]. Therefore, in this study, subjects were divided into three groups according to body fat ratio as the grouping index: overweight and mildly obese (OM, N = 33), moderately obese (M, N = 47), and severely obese (S, N = 31). Further stratification within the three groups was done by randomly dividing into control and intervention groups, overweight and mild obesity intervention group (OMI, N = 17), moderate obesity intervention group (MI, N = 25), severe obesity intervention group (SI, N = 15), overweight and mild obesity control group (OMC, N = 16), moderate obesity control group (MC, N = 22), and severe obesity control group (SC, N = 15).

2.2 Intervention Methods

The participants were all school students, and the objective experimental conditions of this study were based on an exercise camp with a 12-week closed training period. Subjects signed an informed consent form the day before camp entry, were tested for body composition and exercise quality, and saliva was collected. The intervention group received a combination of aerobic exercise, resistance exercise, and caloric restriction. The intervention was conducted from 9:30–10:30 AM and 3:00–5:00 PM, with a relaxation break on Sunday. The housing and time for diet and rest were standardized, whereas the control group performed their coursework during the exercise intervention time and had no dietary restrictions. The study began on June 8, 2020, and ended on August 31, 2020, with all interventions stopped on August 30, and post-intervention testing was administered to all subjects on August 31. All subjects voluntarily entered a fat loss boot camp. Ethical approval was obtained from the China Institute of Sport Science, Beijing, China.

2.2.1 Training Method

To ensure 72 h of rest for the same muscles, we implemented triple split training (front of the upper body, back of the upper body, and lower body). The program involves a series of resistance exercises to train each muscle group, with the regression or progression of that training mode in parentheses, examples are as follows: (1) deep squat (standard/weighted), (2) crunch (elastic band assisted/standard/resistance), (3) push-up (upward slant/kneeling/standard/weighted), (4) Nordic hamstring curl (elastic band assisted/standard), (5) prone back-up (standard/weighted), (6) Pull-ups (elastic band assisted low bar supine pull-up/low bar supine pull-up/elastic band assisted pull-up, (7) shoulder press (weighted), (8) 50 m sprint run. Intensity was set at 70–80% × 1RM. Repetitions per set were 6–12 with 4 sets per movement. The interval between sets was 60 s. Muscle hypertrophy resistance training model [25]. The duration of the resistance exercise was 1 h (3:00–4:00 PM).

The maximum heart rate (MHR) was used to measure the training intensity, and Gellish *et al*. [26] formula: 206.9 – (0.67 * age) was used to calculate the aerobic training intensity: 57–67% MHR. Exercise intensity was monitored by an intelligent exercise bracelet, which can monitor the heart rate. The duration of aerobic exercise was 100 min (10:30–10:55 AM, 11:05–11:30 AM, 4:00–4:25 PM, 4:35–5:00 PM).

2.2.2 Caloric Restriction Method

Before the intervention, according to the physical examination, age, height, and weight of the subjects were substituted by the Harris-Benedict formula [27] to calculate the basic calorie consumption. The dietary intervention framework was a balanced meal that included six different types of food. Additionally, a balanced hypocaloric diet (500–1000 kcal wk^{-1}) with 25–30 kcal kg^{-1}, 30–50% fat, 50–60% carbohydrate, and 20–60% protein was prescribed to each participant [28].

2.3 Study Indicators

Radioimmunoassay has the advantages of high accuracy, specificity, simplicity, and low cost and is a commonly used method for large sample measurements [29]. Saliva specimens were collected from 8:00 to 11:00 AM, and subjects collected 2–5 mL of saliva using a non-stimulating saliva collection method after rinsing their mouth with water while fasting, and then stored in a low-temperature refrigerator at –20 °C for testing by an immunochemiluminescence assay for testosterone (XH6080 exonerator, Dongfangyuantong, Beijing, China).

Electronic height and weight meters and electronic spirometers were used to measure height, weight, and spirometry and to calculate body mass index (BMI). Body composition tests used bioelectrical impedance (InBody260, Korea) to obtain fat mass (FM), fat-free mass (FFM), and body fat percentage (BFP) and to calculate the fat-free mass index (FFMI).

Physical capacity using standing long jump, 4 × 10 m folding run, push-ups, 50 m running, 1000 m running reflecting the individual's physical strength, speed, agility, were difficult to complete since the subjects were obese men; hence, the standard action of the feet touching the ground was changed to the simplified action of the knees touching the ground.

2.4 Data Analysis Methods

Independent sample *t*-tests were performed on the baseline data of the intervention and control groups within the same obesity level group to ensure that there were no significant differences in the indicators between the groups. An independent sample test was performed for the experimental and control groups within each obesity level group and testosterone level group, respectively. One-way ANOVA was used to assess the variability between each obesity level within the experimental and control groups. Two-by-two comparisons between the three groups were performed using the Bonferroni test, with an adjusted $p < 0.017$ as a significant criterion. An independent sample *t*-test was used to determine the variability between each testosterone level group within the experimental and control groups. A cross-lagged model of testosterone levels and BFP at baseline (T1) and post-intervention (T2) was analyzed.

3. Results

There were subjects who dropped out during the intervention (SI group = 1, OMC group = 1, SC group = 2), and after removing the data from the four individuals, there were no significant differences between the intervention and control groups (OMI *vs*. OMC, MI *vs*. MC, SI *vs*. SC) in all indicators within each obesity level group before the intervention ($p > 0.05$). The randomization grouping effect within each obesity level group was acceptable (Table 1).

In this study, only the intervention group was compared with the control group within the same obesity level (OMI *vs*. OMC, MI *vs*. MC, SI *vs*. SC). The intervention and control groups were divided into a high salivary testosterone intervention group (HSTI), low salivary testosterone intervention group (LSTI), high salivary testosterone control group (HSTC), and low salivary testosterone control group (LSTC) using the respective median ST at baseline as the cut-off value. Different obesity level groups and different testosterone grade groups within the same intervention group (OMI *vs*. MI *vs*. SI, OMC *vs*. MC *vs*. SC; HSTI *vs*. LSTI, HSTC *vs*. LSTC).

As shown in Table 2, there were no significant differences between groups in any of the post-intervention morphological indicators, but the difference showed extremely significant between-group differences in weight and BMI between the intervention and control group. FM and BFP decreased in the intervention group and decreased in the control group ($p < 0.001$).

The increases in BFP and FM in the SC group were significantly higher than those in the MC group, and the largest decrease in FM was in the SI group, followed by the MI group, and the lowest in the OMI group ($p < 0.01$). There was a significant increase in FFM in the SI group compared with the OM group, and after the calculation of FFMI by intervening height, the decrease in the OMI group and the increase in the MI and SI groups were significant among all three groups.

For physical capacity, the increase in standing long jump performance was significantly higher in the MI group than in the MC and OMI groups. Compared to the control group, there was a significant increase in spirometry and 1000 m run in the intervention group for each level of obesity. Exercise training for fat loss alone and energy-restricted diets was effective only in cardiorespiratory

Table 1. Descriptive statistics.

	OMI (n = 17)	OMC (n = 15)	*p*	MI (n = 25)	MC (n = 22)	*p*	SI (n = 16)	SC (n = 13)	*p*
	$\bar{X}$ (SD)	$\bar{X}$ (SD)		$\bar{X}$ (SD)	$\bar{X}$ (SD)		$\bar{X}$ (SD)	$\bar{X}$ (SD)	
Age	13.94 (0.827)	14.00 (0.845)	0.844	13.96 (0.841)	14.05 (0.785)	0.722	14.06 (0.77)	13.92 (0.86)	0.650
Hight (cm)	165.33 (10.72)	165.72 (11.25)	0.921	165.45 (6.30)	165.59 (6.48)	0.941	166.08 (10.06)	162.98 (7.20)	0.359
Weight (kg)	85.62 (21.57)	87.25 (22.47)	0.836	89.90 (20.07)	88.88 (20.55)	0.865	92.53 (25.10)	87.34 (18.93)	0.543
FFM (kg)	58.76 (14.04)	59.70 (14.72)	0.855	57.06 (11.32)	55.57 (12.11)	0.664	52.35 (14.59)	49.33 (9.44)	0.524
FM (kg)	26.86 (7.86)	27.55 (8.08)	0.809	33.72 (8.48)	33.32 (8.59)	0.871	40.18 (11.09)	38.01 (9.86)	0.587
BFP (%)	31.11 (2.31)	31.33 (2.29)	0.788	37.32 (1.57)	37.29 (1.54)	0.956	43.39 (2.45)	43.27 (2.28)	0.895
BMI	30.93 (5.21)	31.34 (5.42)	0.827	32.67 (6.12)	32.24 (6.25)	0.811	33.16 (6.44)	32.62 (5.68)	0.818
FFMI	21.25 (3.32)	21.47 (3.48)	0.858	20.76 (3.42)	20.16 (3.66)	0.568	18.75 (3.56)	18.42 (2.61)	0.787
Salivary testosterone (nmol/L)	1.362 (0.905)	1.444 (0.925)	0.801	1.128 (0.896)	1.172 (0.941)	0.869	0.936 (0.797)	0.936 (0.864)	0.998
50 m-running (s)	10.06 (1.79)	10.37 (1.39)	0.596	10.19 (1.43)	9.90 (1.72)	0.533	10.65 (1.66)	10.42 (1.70)	0.712
Plank (s)	53.22 (26.20)	46.88 (19.39)	0.448	50.44 (25.43)	56.01 (29.52)	0.491	42.38 (18.53)	44.94 (15.96)	0.697
Push-up	28.9 (14.1)	30.3 (16.2)	0.788	29.1 (12.9)	30.0 (13.7)	0.587	29.4 (16.5)	32.8 (12.8)	0.539
Standing Long Jump (m)	1.48 (0.27)	1.41 (0.24)	0.425	1.44 (0.22)	1.46 (0.22)	0.745	1.37 (0.23)	1.48 (0.26)	0.213
4 × 10 m folding run (s)	16.02 (4.84)	17.98 (5.08)	0.276	16.88 (4.36)	15.66 (4.44)	0.342	17.08 (4.40)	16.06 (3.40)	0.498
Spirometry (mL)	3271.1 (875.8)	3366.5 (1333.2)	0.810	3273.4 (770.6)	3951.4 (1750.8)	0.104	3364.3 (632.0)	3157.8 (1026.3)	0.534
1000 m running (s)	337.47 (37.85)	343.12 (21.41)	0.613	343.80 (24.16)	331.79 (34.29)	0.168	344.65 (17.03)	347.40 (18.86)	0.686

p values are independent sample *t*-tests for the intervention group compared to the control group.

OMI, overweight and mild obesity intervention group; MI, moderate obesity intervention group; SI, severe obesity intervention group; OMC, overweight and mild obesity control group; MC, moderate obesity control group; SC, severe obesity control group.

Table 2. Post-intervention test and its difference from baseline (rate).

Indicators		Obese group	Post-intervention			Differential value		
			Intervention group	Control group	p	Intervention group	Control group	p
			$\bar{X}$ (SD)	$\bar{X}$ (SD)		$\bar{X}$ (SD)	$\bar{X}$ (SD)	
Morphological index	Hight (cm)	OM	166.34 (10.77)	166.78 (11.27)	0.911	1.01 (0.86)	1.06 (0.90)	0.878
		M	165.82 (6.47)	165.91 (6.64)	0.961	0.72 (0.59)	0.73 (0.62)	0.985
		S	167.01 (9.90)	163.95 (7.03)	0.357	0.93 (0.68)	0.98 (0.69)	0.860
	Weight (kg)	OM	79.30 (19.72)	88.51 (21.60)	0.217	–6.32 (3.37)	1.26 (2.66)	<0.001
		M	83.08 (18.36)	89.91 (19.11)	0.219	–6.81 (2.83)	1.03 (2.7)	<0.001
		S	85.56 (22.93)	88.76 (18.46)	0.687	–6.98 (2.63)	1.42 (1.43)	<0.001
	BMI	OM	28.61 (4.83)	31.45 (5.10)	0.116	–2.32 (1.05)	0.11 (0.95)	<0.001
		M	30.32 (5.48)	32.47 (5.52)	0.187	–2.35 (1.17)	0.24 (1.25)	<0.001
		S	30.67 (5.97)	32.79 (5.47)	0.333	–2.48 (0.72)	0.16 (0.49)	<0.001
Body composition	FM (kg)	OM	21.54 (7.42)	28.84 (8.52)	0.015	–5.32 (3.18)	1.29 (1.31)	<0.001
		M	25.41 (8.53)	34.08 (8.20)	0.001	–8.32 (3.48)	0.76 (1.37)	<0.001
		S	30.83 (8.23) ^{aa}	39.85 (9.82) ^{aa}	0.012	–9.35 (5.38) ^{a}	1.83 (0.77) ^{b}	<0.001
	FFM (kg)	OM	57.76 (13.79)	59.67 (13.64)	0.697	–1.00 (3.26)	–0.02 (2.16)	0.333
		M	58.01 (11.28)	55.83 (11.44)	0.515	0.95 (3.65)	0.27 (2.79)	0.479
		S	54.72 (16.74)	48.91 (9.16) ^{a}	0.273	2.37 (3.58) ^{a}	–0.41 (0.90)	0.008
	BFP (%)	OM	26.76 (5.00)	32.29 (2.77)	0.001	–4.35 (3.64)	0.96 (0.97)	<0.001
		M	30.03 (5.49)	37.77 (2.34) ^{aa}	<0.001	–6.14 (4.83)	0.48 (1.55)	<0.001
		S	36.40 (5.21) ^{a}	44.71 (2.52) ^{aabb}	<0.001	–6.99 (4.26)	1.44 (0.72)	<0.001
	FFMI	OM	20.64 (3.16)	21.24 (3.15)	0.596	–0.62 (1.07)	–0.24 (0.76)	0.259
		M	21.01 (3.30)	20.18 (3.38)	0.402	0.25 (1.46)	0.02 (1.15)	0.555
		S	19.34 (4.25)	18.06 (2.49) ^{aa}	0.344	0.60 (1.22) ^{a}	–0.37 (0.31)	0.010
Physical capacity	50 m-run (s)	OM	10.03 (1.71)	10.39 (1.45)	0.524	–0.03 (0.95)	0.03 (0.45)	0.828
		M	10.09 (1.73)	10.11 (2.07)	0.971	–0.10 (1.29)	0.21 (0.88)	0.349
		S	10.42 (1.92)	10.19 (1.47)	0.734	–0.24 (1.08)	–0.23 (0.56)	0.976
	Plank (s)	OM	54.68 (29.13)	46.93 (17.09)	0.375	1.45 (22.68)	0.05 (5.98)	0.809
		M	51.67 (21.91)	49.92 (25.94)	0.803	1.23 (19.07)	–6.09 (22.73)	0.236
		S	39.46 (16.69)	45.72 (17.34)	0.332	–2.92 (27.57)	0.78 (6.58)	0.610
	Push-ups	OM	31.65 (20.74)	26.00 (8.29)	0.332	2.76 (18.89)	–4.33 (15.38)	0.257
		M	35.56 (19.88)	31.50 (19.50)	0.484	6.44 (17.08)	1.50 (12.20)	0.260
		S	30.44 (13.88)	26.69 (10.43)	0.428	1.06 (19.7)	–6.15 (11.31)	0.252
	Standing Long Jump (m)	OM	1.49 (0.30)	1.40 (0.24)	0.382	0.00 (0.20)	–0.01 (0.10)	0.829
		M	1.56 (0.19)	1.46 (0.21)	0.108	0.12 (0.18) ^{a}	0.01 (0.10)	0.010
		S	1.48 (0.24)	1.51 (0.30)	0.786	0.12 (0.16)	0.03 (0.14)	0.128

Table 2. Continued.

Indicators		Obese group	Post-intervention			Differential value		
			Intervention group	Control group	p	Intervention group	Control group	p
			$\bar{X}$ (SD)	$\bar{X}$ (SD)		$\bar{X}$ (SD)	$\bar{X}$ (SD)	
	4 × 10 m folding run (s)	OM	14.88 (2.90)	18.20 (4.62)	0.020	–1.14 (3.24)	0.22 (1.28)	0.125
		M	16.50 (3.80)	16.94 (5.20)	0.745	–0.38 (3.38)	1.28 (4.22)	0.139
		S	15.54 (2.40)	16.94 (4.24)	0.270	–1.54 (3.70)	0.88 (1.90)	0.041
	Spirometry (mL)	OM	3864.6 (509.1)	3409.2 (1244.1)	0.202	593.5 (788.4)	42.68 (294.3)	0.014
		M	3786.0 (501.0)	3979.2 (1624.9)	0.574	512.6 (643.9)	27.8 (269.1)	0.002
		S	4078.1 (560.9)	3198.4 (1077.5)	0.009	713.8 (724.8)	40.6 (268.2)	0.003
	1000 m run (s)	OM	316.38 (33.83)	342.82 (20.73)	0.014	–21.08 (23.21)	–0.31 (7.90)	0.003
		M	325.28 (21.59)	332.12 (30.89)	0.379	–18.52 (14.30)	0.33 (7.04)	<0.001
		S	319.17 (25.79)	347.78 (19.55)	0.003	–25.48 (18.96)	0.37 (6.41)	<0.001
Biochemical indicator	Salivary Testosterone (nmol/L)	OM	1.344 (0.853)	1.414 (0.875)	0.820	–0.86 (14.79)	–2.15 (15.38)	0.810
		M	1.186 (0.906)	1.230 (0.952)	0.873	8.04 (10.68)a	8.02 (11.56)	0.996
		S	0.100 (0.845)	1.004 (0.923)	0.985	7.02 (11.66)	7.33 (11.32)	0.943

(1) OM, overweight and mildly; M, moderate; S, severe.

(2) p-values are independent sample t-tests for the intervention group compared to the control group.

(3) Within the same group (intervention or control), “a” indicates $p < 0.017$ compared with the OM group; “b” indicates $p < 0.017$ compared with the M group.

Table 3. Changes of body composition in different salivary testosterone groups.

Indicators	Group of salivary testosterone	Intervention group	Control group	p
		$\bar{X}$ (SD)	$\bar{X}$ (SD)	
Height (m)	LST	0.74 (0.68)	0.74 (0.71)	0.989
	HST	0.99 (0.72)	1.04 (0.74)	0.801
Weight (kg)	LST	–6.46 (2.96)	0.94 (2.67)	<0.001
	HST	–6.97 (2.88)	1.46 (2.09)	<0.001
FFM (kg)	LST	0.06 (3.45)	–0.10 (2.81)	0.852
	HST	1.48 (3.85)	0.11 (1.49)	0.100
FM (kg)	LST	–6.52 (3.80)	1.04 (1.56)	<0.001
	HST	–8.92 (4.43) ^{c}	1.35 (0.92)	<0.001
BFP (%)	LST	–4.91 (3.86)	0.80 (1.66)	<0.001
	HST	–6.79 (4.77)	0.95 (0.67)	<0.001
BMI	LST	–2.41 (1.03)	0.08 (1.01)	<0.001
	HST	–2.35 (1.01)	0.28 (0.99)	<0.001
FFMI	LST	–0.14 (1.28)	–0.21 (1.06)	0.848
	HST	0.32 (1.41)	–0.11 (0.68)	0.165
Salivary testosterone (nmol/L)	LST	9.617 (12.129)	9.020 (13.216)	0.863
	HST	0.679 (11.766) ^{cc}	0.559 (12.252) ^{c}	0.971

Compared with low Salivary testosterone group (in intervention group and control group), "cc" represents $p < 0.01$, "c" represents $p < 0.05$.

HST, high salivary testosterone; LST, low salivary testosterone.

endurance (1000 m, spirometry) for all obese levels, with no effectiveness in trunk stabilization qualities (plate), anterior trunk muscle strength, and endurance (push-ups). On the other hand, standing long jump scores were significantly improved in the MI group compared to the MC group, and 4 × 10 m folding run scores in the SI group showed significant improvement compared to the SC group. The other obesity grade groups showed insignificant differences in changes between the intervention group and the control group.

The changes in weight, FM, BFP, and BMI in the HSTI and LSTI groups were significantly reduced compared to those in the HSTC and LSTC groups, but there was no change in lean body mass and FFMI. The HSTI group had greater FM reduction than the LSTI group, and the high ST group within the group had a lower rate of ST change than the low ST group in both the exercise and control groups (Table 3).

Cross-lagged models were established for the exercise and control groups, T1 = June 8, 2020, and T2 = August 31, 2020, in which the fit of the models established with T1-ST, T1-FM, T2-ST, and T2-FM was not up to the standard, and the model fit was improved and acceptable after replacing the amount of BFM with BFP (Table 4). The fitting results are shown in Fig. 1. Chi-square/df <3 ($p > 0.05$), RMSEA <0.08, GFI, AGFI, NFI, IFI,TLI,CFI >0.9, SRMR <0.05.

In the overall and control models (Fig. 1 and Table 5), there was no statistically significant effect of T1-ST on T2-BFP (β = 0.007, p = 0.842, β = –0.112, p = 0.12) and T1-BFP had no statistically significant effect on T2-ST (β = 0.041, p = 0.122, β = 0.040, p = 0.056). However, in the intervention group model, T1-ST had a significant effect on T2-BFP (β = –0.256, p = 0.004) but T1-BFP had no effect on T2-ST (β = 0.039, p = 0.109), showing a causal effect of ST on BFP as a significant negative effect of ST on BFP with time progression, but this causal relationship was only observed in the intervention group.

4. Discussion

This study found that the effect of exercise training and energy-restricted diets on fat loss and physical capacity was limited to relatively lower extremity explosive strength and cardiorespiratory endurance, with a significant effect on body composition. This change was influenced by obesity with a high level of individual variability, with higher levels of obesity resulting in greater reductions in FM. The reduction in BFP was not affected by the level of obesity, and there was a mild causal relationship with ST in the intervention group, but not in the control group. ST was predictive of future BFP in exercisers; individuals with high ST had a greater reduction in BFP under conditions of prolonged exercise and caloric restriction.

4.1 The Effects of Exercise Training and Energy-Restricted Diets on Men with Different Obesity Levels

In the present study, fat loss aimed exercise training and energy-restricted diet were more effective in improving cardiorespiratory endurance in male adolescents of all obesity level groups. Aerobic exercise combined with re-

Table 4. Model goodness of fit index.

Model	GFI	AGFI	NFI	IFI	TLI	CFI	RMSEA	SRMR	Chi-square/df (P)
ARC group	0.99	0.900	0.995	0.999	0.995	0.999	0.057	0.025	1.187 (0.276)
Control group	0.997	0.965	0.999	1.000	1.000	1.000	0.000	0.004	0.345 (0.557)
Total	0.999	0.985	0.999	1.000	1.000	1.000	0.000	0.002	0.317 (0.574)

RMSEA, root mean square error of approximation; GFI, goodness-of-fit index; NFI, normed fit index; CFI, comparative fit index; AGFI, adjusted goodness-of-fit; SRMR, standardized root mean square residual; IFI, incremental fit index; TLI, Tucker–Lewis index.

Table 5. Cross-lagged panel analysis results.

		T1-ST		T1-BFP	
		β	p	β	p
Intervention group	T2-ST	0.995	<0.001	0.039	0.109
	T2-BFP	–0.256	0.004	0.650	<0.001
Control group	T2-ST	0.997	<0.001	0.041	0.122
	T2-BFP	0.007	0.842	0.975	<0.001
Total	T2-ST	0.996	<0.001	0.040	0.056
	T2-BFP	–0.112	0.120	0.663	<0.001

T1-BFP, body fat percentage at T1; T1-ST, salivary testosterone at T1; T2-BFP, body fat percentage at T2; T2-ST, salivary testosterone at T2.

sistance training significantly increased cardiorespiratory fitness in patients with coronary heart disease [30], adults [31] and young men [32]. The study by Pacholek Martin *et al*. [32] also stated that aerobic exercise combined with resistance training can be more effective in improving lower limb explosive power. Contradictory to the results of the present study, there was improvement in standing long jump distance in moderate obese boys compared to the control group, and the 50 m running time was not significantly reduced in boys with all levels of obesity. In addition, Schroeder Elizabeth *et al*. [31] concluded that exercise increased whole-body muscle strength in adults, which was only slightly reflected in the lower extremity muscle strength in the present study. While upper extremity strength test (push-ups) scores were not significantly improved, some studies have suggested that resistance exercise increases muscle mass in the lower extremities more than the upper extremity in adolescents [33]. This may be because the participants in the current study did not have a substantial increase in FFM after the intervention. There is a high positive correlation between FFM and muscle strength [34], and even though our exercise training involved a lot of resistance training, too low caloric intake [35] and high volume aerobic training [36] limited the increase in FFM while ensuring a reduction in FM in the subjects. However, we found that only boys with severe obesity showed a significant increase in FFM in this intervention, and the increase was much higher than in the other obesity level groups. The increase in FFMI was greater in those with high levels of obesity, which could also be related to the slightly lower FFM in individuals with high levels of obesity [37]. Accordingly, in our study, fatter boys were also more likely to lose a greater mass of fat. The extant study [38] found that both indicators of adipose tissue insulin resistance (fasting and meal) increased with increasing obesity, whereas systemic insulin sensitivity decreased with obesity, but this was above a certain threshold, ultimately manifesting as suppressed lipolysis [39]. To sum up, this may be because exercise improved the level of insulin resistance in male adolescents with higher obesity helping them to reduce FM more, but leaner individuals had lower or no changes in insulin resistance improvement, in the end, it caused the phenomenon in our experiment.

4.2 Effect of ST on Body Composition Changes

Our study found that male adolescents in the high ST group had more FM with an exercise intervention, and numerous studies [40–42] have shown that ST has different effects on fat accumulation by sex. Higher ST in women result to higher levels, but in men, higher ST appears to have beneficial effects on obesity and glucose metabolism [40] and even predicts cardiovascular disease risk. Exogenous androgens are often administered clinically to patients with low ST, and Groti, A.K., *et al*. [43] found that 2 years of exogenous testosterone treatment normalized serum ST levels, improved glycemia, endothelial function, lipids and insulin sensitivity, quelled the symptoms of hypogonadism, and reduced cardiovascular risk in obese men with functional hypogonadism and type 2 diabetes. Although the effects were not long-lasting, men treated with a combination of caloric control and testosterone showed a substantial reduction in FM [44]. The accumulation of testosterone leads to lower expression of androgen-responsive genes in *ex vivo* experiments, which are involved in lipolytic and antilipoly-

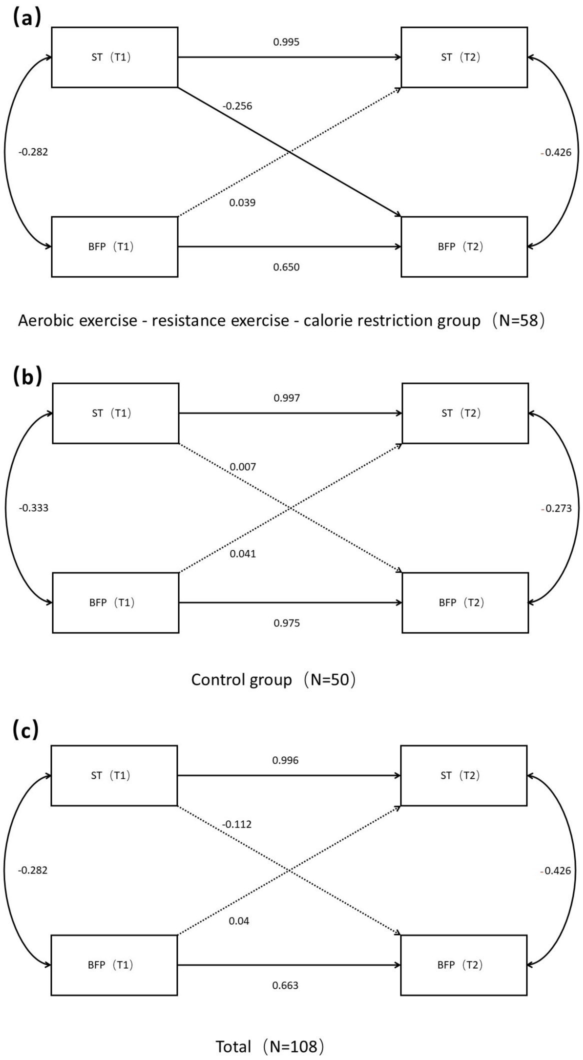

Fig. 1. Cross-lagged model. (a) model for the intervention group, (b) model for the control group, and (c) model for the overall; dashed lines indicate $p > 0.05$, solid lines indicate $p < 0.05$; one-way arrows are labeled with β and two-way arrows are labeled with correlation coefficients. ST, salivary testosterone; BFP, body fat percentage; T1 = June 8, 2020, T2 = August 31, 2020.

tic pathways, and dysfunctional adipocytes have an altered response to testosterone stimulation. Testosterone stimulation usually favors lipolysis and induces antilipolytic effects [45]. In our combined cross-lagged model analysis, we found that own ST levels had a predictive effect on future BFP only in the presence of the exercise intervention. In contrast, men with high ST levels under this intervention had a greater reduction in BFP in the second test compared to baseline, but not in the control group. Hayes *et al.* [4] found a decrease in BFP and body weight, but no significant difference in fat mass, and ST was inversely related to BFP in 28 previously sedentary men after a six-week aerobic exercise intervention. Some studies have shown that significant weight loss with bariatric surgery (BS) improves erectile function, hormonal profile, and testosterone deficiency symptoms, but did not describe a causal relationship between testosterone and weight loss [46]. As a complement, the restoration of circulating testosterone levels during weight loss is not only a result of normalization of circulating SHBG levels but also contributes to the production and alteration of testosterone metabolism. More specifically, a relative decrease in aromatization and 5α-reductase activity may also be involved in the recovery of testosterone levels in obese men [47]. ST elevation during weight loss is unquestionable, but its longitudinal prediction of future BFP can be briefly summarized as a predictive effect of ST on future BFP in men under exercise intervention. It cannot be excluded that ST is elevated under exercise intervention, ultimately triggering the predictive effect. As stated by previous studies on the promotion of testosterone by exercise [13], considering the lower ST in men with higher levels of obesity [47,48] combined with our finding that the level of ST improvement was influenced by the level of individual obesity, high ST increased at a much lower rate in the ST group than in the low ST group. It is hypothesized that greater ST elevation in the more obese men with the intervention was associated with a greater reduction in body fat mass. In our study, it was shown that the increased rate of salivary testosterone in the high ST group was significantly lower than that in the low ST group, and the mean value of testosterone increased with the increase in obesity. It can be seen that men with lower BFP did not achieve significant results in fat consumption because of the higher level of ST and the lack of promotion rate under exercise intervention; thus, men with higher obesity grade have reduced higher FM. However, it is not reflected in the BFP index, which indicates that the T1 BFP of the cross-lag model has no predictive effect on T2ST.

4.3 Advantages and Limitations

This study is a randomized controlled study specifically for adolescent males, which avoids the complex factors brought about by sex in the selection of packaged subjects, since the sex hormones and body composition of adolescents change in a larger magnitude; hence, influencing factors in the study was considered. In the grouping, we carried out randomized experimental and control grouping after stratification by obesity degree, and the scientificity and rationality of the subsequent analysis were guaranteed. Centralized diet-exercise management in the form of summer camps avoided most of the confounding factors in human studies. The dissection of causality using cross-lagged models as an analytical method allowed us to make new discoveries and to increase the contribution of our study. However, this study had some limitations. The study of the causality of the factors of dynamic changes in body composition intervened in the cross-lagged model. However, a follow-up study was not conducted to investigate the changes after the intervention, which was also due to the impact of COVID-19 on the original experimental plan. It is recommended for future studies to be conducted at three or more time points to consolidate the findings of this study. In addition, we studied objective factors such as sex hormones and obesity levels but did not address subjective psychological factors, and we will subsequently introduce some psychological indicators for further study.

5. Conclusions

More obese male adolescents can obtain greater FM reduction with the intervention, but FFM and exercise quality are minimally affected by the level of obesity. Males with higher ST ground tend to gain improvements in body composition, and ST can be predictive of future BFP but needs to be in the context of an exercise intervention.

Author Contributions

XP and YZ designed the study. XP performed the study and analyzed the data. XP and TX wrote the manuscript. YG and LJ visualized the data. All authors contributed to the editorial changes in the manuscript. All authors have read and approved the final manuscript.

Ethics Approval and Consent to Participate

Full ethical approval was obtained from China Institute of Sport Science, Beijing, China (CISS20190611).

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Conflict of Interest

The authors declare no conflict of interest.

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