Study on the Influence of Low-Load Blood Flow Restriction Training on Lower Limb Explosive Power of Young Female Judo Athletes

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Abstract: Objective: Based on the growth and training load traits of adolescent female judo athletes, this study examines low-load BFRT's effects on lower limb explosive power and sport-specific performance. Methods: Sixteen athletes were randomly divided into an experimental group (40% 1RM + 180 mmHg cuff pressure) and a control group (75–85% 1RM). Both groups underwent 6 weeks of intervention, three times per week. Results: Maximal lower limb strength: Both groups improved 1RM squat strength(P<0.01), the difference between groups was not significant. Lower limb explosive power: Experimental group outperformed control in CMJ height (P=0.042), peak power (P=0.028), and SJ height (P=0.019). Both groups improved reactive strength index (RSI). Sport-specific performance: Both groups significantly improved 20m sprint. For judo-specific anaerobic endurance (SJFT index), only experimental group improved significantly (P=0.009). No significant change in rapid throwing speed (sukashi speed) in either group. Conclusion: Six weeks of low-load BFRT can improves lower limb maximal strength as effectively as high-load training, with greater safety. It distinctly improves vertical jump power and judo-specific anaerobic endurance. Both methods equally enhance short-distance sprint speed. However, short-term isolated strength training has limited effects on technique-dependent movements; long-term technical training should be integrated.

Keywords: Blood Flow Restriction Training; Young Female Judo Athletes; Lower Limb Explosive Power; Specific Physical Fitness

1. Introduction

Athletic performance is composed of physical fitness, technique, tactics, psychology, and other factors, among which physical fitness serves as an important foundation for the execution of sport-specific skills [1]. Judo is characterized by high intensity, strong physical confrontation, and continuous offensive and defensive actions, placing extremely high demands on athletes' lower-limb strength and explosive power. Throwing techniques require rapid extension of the hip, knee, and ankle joints, as well as shifts in the center of gravity, to be completed within a very short period of time. Lower-limb explosive power directly determines the initiation speed of techniques, power output, and sport-specific performance [2]. This is particularly important for adolescent female judo athletes. Since their physical development is not yet fully mature, improving lower-limb strength and explosive power has significant training value. Traditional high-load resistance training can effectively improve maximal strength and neuromuscular adaptation, making it an important method for enhancing explosive power. However, the bones, joints, and soft tissues of adolescent female athletes are still developing. Long-term high-load training may easily lead to accumulated fatigue and an increased risk of sports injuries, and may also affect the effectiveness of sport-specific technical training. Therefore, while ensuring training benefits, reducing mechanical load and improving training efficiency have become important issues in current training practice.

Blood Flow Restriction Training (BFRT) involves applying a certain amount of pressure to the proximal part of a limb to partially restrict arterial blood flow and block venous return. This creates a hypoxic and metabolic stress environment in the muscles under low-load conditions, thereby inducing neuromuscular adaptations similar to those produced by high-load training [3]. Studies suggest that BFRT can promote lactate accumulation, growth hormone release, and the earlier recruitment of high-threshold type II fast-twitch muscle fibers, thereby improving motor unit recruitment capacity and neuromuscular output efficiency [4]. Existing research indicates that the factors affecting the training effects of BFRT mainly include age, sex, load intensity, pressure settings, cuff placement, and rest intervals [5]. Among these, a load of 20%–40% of one-repetition maximum (1RM) and a pressure range of 40%–80% of arterial occlusion pressure (AOP) are considered to provide favorable training benefits. A large number of studies and meta-analyses have found that BFRT can effectively improve lower-limb maximal strength, vertical jump performance, short-distance sprint ability, and power output [6]. In some cases, its training effects can reach the level of traditional high-load training, while also offering lower joint stress and higher safety.

At present, there has been considerable research on lower-limb explosive power in judo. However, studies focusing on adolescent female judo athletes remain limited. Existing research participants are mainly adult male athletes, and most studies focus on general physical fitness indicators, with insufficient attention paid to the transfer of training effects to sport-specific abilities and technical performance. In addition, no consensus has yet been reached regarding the long-term effects and optimal training protocols of BFRT in high-level athletic populations. In summary, research on the application of low-load BFRT to improve lower-limb explosive power and sport-specific abilities in adolescent female judo athletes is still relatively insufficient. Therefore, this study intends to examine the effects of a six-week low-load BFRT intervention on lower-limb explosive power and sport-specific performance, with the aim of providing a safer and more efficient training method for adolescent female judo athletes and offering a theoretical basis for judo physical conditioning practice.

2. Research Participants and Methods

2.1 Experimental Methods and Procedures

(1) Experimental Participants

This study recruited 16 adolescent female judo athletes as experimental participants. They were randomly divided into an experimental group (n = 8) and a traditional training group (n = 8) using a random number table method. The experimental group performed low-load blood flow restriction training throughout the training period, while the traditional training group performed conventional resistance training.

Independent-samples t-tests were conducted on the basic information and pre-test results of the two groups. No significant differences were found in any of the indicators between the two groups, indicating that the intervention experiment could be carried out. The basic information of the participants is shown in **Table 1**.

Table 1. Basic Information of the Participants

Group	Age (years)	Training Experience (years)	Height (m)	Body Weight (kg)	BMI (kg·m²)
Experimental Group(n= 8)	15.75 ± 1.04	5.12 ± 1.55	1.64 ± 0.04	61.63 ± 4.53	22.86 ± 0.89
Control Group (n = 8)	16.63 ± 1.41	4.88 ± 1.25	1.68 ± 0.05	64.88 ± 6.36	23.84 ± 1.42

(2) Experimental Instruments and Equipment

The experimental instruments and equipment included one laptop computer (MacBook Air, Apple, USA), a force plate/mat (Chronojump, Ergotech, Spain), blood flow restriction cuffs (T-bfr-0335, Theratools, China), a standard Olympic barbell bar (IRON-20KG, IRONMAN, China), weight plates (GF-50LB, Good Family, China), a judo dummy (HJ-G2095, Huijun, China), a stopwatch (S057, SEIKO, Japan), and a measuring tape (E8005A, Endura, China).

(3) Testing Procedures and Indicators

① Squat One-Repetition Maximum (1RM) Test

An indirect testing method was used to assess maximal squat strength. The testing procedure was as follows: participants first selected a light load for squat warm-up. After resting for 2 minutes, the load was increased by 10%–20%, and participants performed as many squat repetitions as possible. If more than 5 repetitions were completed, the load was increased by another 10%–20% based on the previous weight. After a 5-minute rest, the previous step was repeated until the number of repetitions was less than 5. During the test, designated personnel were positioned on both sides of the participant to provide protection and assistance [7].

② Countermovement Jump (CMJ)

Participants stood upright on the force platform. During the movement, the lowest body position was required to be a semi-squat. From the initial standing position, participants quickly squatted down to generate force and then jumped upward. After landing, they were allowed to flex their knees for cushioning until they returned to the initial standing posture. The lower-limb movement was performed with both feet, while the upper limbs were positioned with both hands on the hips. Each participant completed three valid jumps, with a 1-minute rest interval between trials, and the best result was recorded. After the test, the indicators recorded included maximum jump height, peak power, and ground contact time [8].

③ Squat Jump (SJ)

Participants placed both hands on their hips and maintained a semi-squat position, with the knee joint at approximately 90 degrees. From the starting position, participants performed a vertical jump as quickly and explosively as possible, aiming to reach the maximum height in the shortest possible time. Participants were instructed to avoid any countermovement before take-off, that is, to avoid any eccentric contraction of the lower-limb muscles. Each participant completed three valid jumps, with a 1-minute rest interval between trials, and the best result was recorded. After the test, the indicators recorded included maximum relative force, flight height, and flight time [9].

④ Drop Jump (DJ)

Participants stood still at the edge of an adjustable-height plyometric box. The initial position for the drop jump was standing on a 45-cm-high platform. With both hands on the hips, participants freely dropped from the initial position onto the force platform and then performed a push-off movement as quickly and explosively as possible, aiming to jump as high as possible in the shortest possible time. Each participant completed three valid jumps, with a 1-minute rest interval between trials, and the best result was recorded. After the test, the indicators recorded included maximum jump height, ground contact time, and reactive strength index (RSI).

⑤ 20-m Sprint

After a sufficient warm-up, participants prepared for the start after the timing began. All participants adopted a unified crouching start position and sprinted to the finish line immediately once ready. A total of three trials were conducted, with sufficient rest between each trial. The best result among the three trials was recorded as the final performance, and the completion time was measured and recorded.

⑥ Sport-Specific Physical Fitness Tests

1.SJFT Seoi-nage Test (10 repetitions)

This test was adapted from the classic Special Judo Fitness Test (SJFT), namely the alternating left-right seoi-nage test. Based on coaches' suggestions and the principle of easy operation, the testing procedure and method were adjusted. Technical requirements: participants were divided into groups of three with similar body mass and fixed group members. Each person served alternately as the participant and assistant. The participant stood between two assistants, 3 m away from each assistant. After the start signal, the participant ran to the first assistant and completed one seoi-nage uchikomi, then quickly ran to the second assistant and completed another seoi-nage uchikomi. Following the same procedure, the participant continuously completed 10 seoi-nage movements and then returned to the middle position to finish the test. The total time was recorded. The time required to complete the prescribed number of repetitions (10 repetitions) was used for calculation:SJFT index = (HR immediately after + HR at 1 min) × time for 10 repetitions / 60.That is, the shorter the time required to complete 10 seoi-nage movements and the lower the physiological load (HR immediately after + HR at 1 min), the stronger the judo-specific ability of the athlete [1].

2.Judo-Specific 10-Repetition Rapid O-goshi Uchikomi with a Dummy

A standard-weight judo throwing dummy was used, usually corresponding to the athlete's own body-weight category. During the test, the athlete stood ready at the starting position. After the command, the athlete was required to complete 10 repetitions as quickly as possible: throwing the dummy in front using a standard o-goshi technique, with the dummy's back required to land on the ground, and then rapidly returning to the original position for the next throw. The total completion time was recorded. Incomplete movements or non-standard landings were not counted in the final score.

(4) Training Program

Athletes in both groups received training three times per week for six weeks. The experimental group performed blood flow restriction training, while the traditional group performed conventional resistance training. Relevant lower-limb explosive power indicators were tested before and after the experiment for comparative analysis, in order to investigate the effects of BFRT on lower-limb explosive power in judo athletes. The experimental intervention program is shown in Table 2.

Table 2. Experimental Intervention Program

Group	Exercise	Load	Repetitions	Sets	Rest Interval
Blood Flow Restriction Group	Barbell Back Squat	180 mmHg + 40% RM load	8	4	1 min
	Power Clean	180 mmHg + 40% RM load	5	3	1 min
	Hex Bar Split Squat Jump	180 mmHg + 20 kg load	5 repetitions per leg	4	1 min
	Squat While Holding a Judo Dummy	30 kg	8	4	1 min
Resistance Training Group	Barbell Back Squat	75%–85% RM	8	4	1.5 min
	Power Clean	75%–85% RM	5	3	1.5 min
	Hex Bar Split Squat Jump	75%–85% RM	5 repetitions per leg	4	1.5 min
	Squat While Holding a Judo Dummy	75%–85% body weight	8	4	1.5 min

The BFRT group used Theratools BFR blood flow restriction cuffs with a width of 10 cm. The cuffs were worn on the upper one-third of the thigh, as close as possible to the groin. The wearing requirements for the cuffs were as follows:

Before wearing the cuffs, check whether there is any residual gas or air leakage in the cuffs.

The participant should stand naturally with the muscles relaxed, and the air valve of the cuff should face outward.

After wearing the cuffs, set the pressure to 20 mmHg and ask the participant to perform five squats. Observe the changes in the device values. If the difference between the left and right cuffs is within 10 mmHg, the pressure of the two cuffs is considered consistent.

Close attention should be paid during the training process. If the limb turns gray or blue, this indicates excessive pressure or overly tight binding, and timely adjustment should be made.

2.2 Statistical Analysis

Data collection and organization in this study were performed using Microsoft Excel 2021, and statistical analyses were conducted using SPSS 27.0. The data were expressed as mean ± standard deviation. To determine whether subsequent parametric tests were applicable, normality tests were conducted on the main indicators of the participants before data analysis. Due to the small sample size, the Shapiro–Wilk normality test was used to examine the pre-test and post-test data separately. A value of $p > 0.05$ indicated that the data were normally distributed. When the data did not conform to a normal distribution, non-parametric tests were used for analysis. Independent-samples t-tests were used to compare the data between the experimental group and the control/traditional group, as well as the pre- and post-intervention differences between the two groups. Paired-samples t-tests were used to compare the differences within the experimental group and the traditional group before and after the intervention. A value of $p < 0.05$ indicated a statistically significant difference, while $p > 0.05$ indicated no statistically significant difference.

3. Research Results

3.1 Intergroup Comparison of the Test Results of Various Evaluation Indicators Between the Two Groups Before the Intervention

Before the experimental intervention, baseline physical fitness tests were conducted on the participants in both groups. Independent-samples t-tests were then performed on the pre-test results of the experimental group and the traditional training group to examine whether the grouping of the participants was reasonable. The specific results are shown in Table 3.

As shown in the table, the results of the independent-samples t-test before the experiment indicated that, except for a significant difference in uchikomi time ($P < 0.01$), the p-values of all other indicators, including maximal squat strength, parameters of lower-limb explosive power, 20-m sprint performance, and the SJFT index, were greater than 0.05. This suggests that the two groups were at the same baseline level in terms of basic physical fitness at the beginning of the experiment. The grouping was balanced, and the influence of differences in the participants' initial abilities on the experimental results could be excluded. This provided a scientific comparative baseline for the subsequent objective verification of the effectiveness of the BFRT training program.

Table 3. Intergroup Comparison of Pre-Test Results Between the Experimental Group and the Traditional Training Group

Test Indicator	Experimental Group (Mean ± SD)	Traditional Training Group (Mean ± SD)	t-value	P-value
Squat 1RM (kg)	95.00 ± 11.02	84.38 ± 10.16	-2.005	0.065
CMJ Height (cm)	26.30 ± 3.16	26.24 ± 2.77	-0.040	0.969
CMJ Peak Power (W)	645.92 ± 73.09	727.11 ± 55.56	2.501	0.025
SJ Height (cm)	25.60 ± 3.07	26.97 ± 2.58	0.959	0.354
RSI Index	0.61 ± 0.094	0.63 ± 0.096	0.378	0.711
20-m Sprint (s)	4.04 ± 0.50	4.28 ± 0.41	1.086	0.296
SJFT Index	168.36 ± 21.88	163.59 ± 32.08	-0.348	0.733
Uchikomi Time (s)	36.67 ± 5.01	48.33 ± 7.41	3.686	0.002**

3.2 Intragroup Comparison of General Strength Results Before and After the Intervention

The experimental group and the traditional training group were tested before and after the intervention for general strength qualities, including squat one-repetition maximum (1RM), countermovement jump (CMJ) height, squat jump (SJ) height, CMJ peak power, and the reactive strength index (RSI), which is a derived indicator of the drop jump (DJ). Paired-samples t-tests were conducted on the pre- and post-intervention results of the two groups to determine whether significant improvements occurred after the intervention. The specific results are presented below.

3.2.1 Intragroup Comparison of Lower-Limb Maximal Strength Before and After the Intervention

The experimental group and the traditional training group were tested for squat one-repetition maximum (1RM) before and after the intervention. Paired-samples t-tests were conducted on the pre- and post-intervention results of both groups to determine whether significant improvements occurred after the intervention. The specific results are shown in Table 4.

Table 4. Intragroup Comparison of Squat 1RM Before and After the Intervention

Group	Indicator (kg)	Pre-Test	Post-Test	t-value	P-value
Experimental Group	Squat 1RM	95.00 ± 11.02	111.67 ± 8.31	-8.165	< 0.001**
Traditional Training Group	Squat 1RM	84.38 ± 10.16	110.83 ± 16.57	-5.086	0.001**

The data showed that after the six-week experimental intervention, both the experimental group and the traditional training group achieved highly significant improvements in lower-limb maximal strength. Specifically, squat 1RM improved significantly in the experimental group ($P < 0.001$) and in the traditional training group ($P = 0.001$). Under the low-load condition of 40% 1RM combined with 180 mmHg blood flow restriction, the squat performance of the experimental group increased to 111.67 ± 8.31 kg. In contrast, the traditional training group, which adopted high-load training at 75%–85% 1RM, increased to 110.83 ± 16.57 kg. This result strongly demonstrates that low-load blood flow restriction training has a training value comparable to traditional high-load resistance training in promoting the development of basic strength in adolescent female judo athletes.

3.2.2 Intragroup Comparison of Lower-Limb Explosive Power Indicators Before and After the Intervention

The experimental group and the traditional training group were tested before and after the intervention for lower-limb explosive power indicators, including countermovement jump (CMJ) height, squat jump (SJ) height, CMJ peak power, and the reactive strength index (RSI), which is a derived indicator of the drop jump (DJ). Paired-samples t-tests were conducted on the pre- and post-intervention results of both groups to determine whether significant improvements occurred after the intervention. The specific results are shown in Table 5.

Table 5. Intragroup Comparison of Lower-Limb Explosive Power Indicators Before and After the Intervention

Group	Indicator	Pre-Test	Post-Test	t-value	P-value
Experimental Group	CMJ Height (cm)	26.30 ± 3.16	26.98 ± 3.35	-2.486	0.042*

	CMJ Peak Power (W)	645.93 ± 73.09	669.31 ± 89.74	-2.753	0.028*
	SJ Height (cm)	25.60 ± 3.07	27.00 ± 3.58	-3.023	0.019*
	RSI Index	0.61 ± 0.09	0.70 ± 0.10	-3.893	0.006**
Traditional Training Group	CMJ Height (cm)	26.24 ± 2.77	25.36 ± 2.61	1.320	0.228
	CMJ Peak Power (W)	727.11 ± 55.56	703.82 ± 61.19	1.749	0.124
	SJ Height (cm)	26.97 ± 2.58	25.15 ± 2.86	2.000	0.086
	RSI Index	0.63 ± 0.10	0.52 ± 0.21	1.605	0.153

The data showed that after the six-week experimental intervention, the experimental group demonstrated significant improvements in CMJ height ($P = 0.042 < 0.05$), CMJ peak power ($P = 0.028 < 0.05$), SJ height ($P = 0.019 < 0.05$), and the RSI index ($P = 0.006 < 0.01$). Specifically, CMJ height in the experimental group increased from 26.30 ± 3.16 cm before the intervention to 26.98 ± 3.35 cm after the intervention; CMJ peak power increased from 645.93 ± 73.09 W to 669.31 ± 89.74 W; SJ height increased from 25.60 ± 3.07 cm to 27.00 ± 3.58 cm; and the RSI index increased from 0.61 ± 0.09 to 0.70 ± 0.10. All of the above indicators reached statistical significance, with the improvement in the RSI index being highly significant. In contrast, no statistically significant changes were observed in any explosive power indicators in the traditional training group. These results indicate that low-load blood flow restriction training has unique advantages in promoting the development of lower-limb explosive power in adolescent female judo athletes.

3.3 Intragroup Comparison of Sport-Specific Physical Fitness Results Before and After the Intervention

The experimental group and the traditional training group were tested before and after the intervention for sport-specific physical fitness indicators, including the 20-m sprint, the Special Judo Fitness Test (SJFT), namely the alternating left-right seoi-nage test, and the 10-repetition rapid o-goshi uchikomi with a dummy. Paired-samples t-tests were conducted on the pre- and post-intervention results of both groups to determine whether significant improvements occurred after the intervention. The specific results are presented below.

3.3.1 20-m Sprint

The data showed that after the six-week experimental intervention, both the experimental group and the traditional training group completed the 20-m sprint test before and after the intervention. Paired-samples t-tests were conducted on the pre- and post-intervention results of both groups. The specific results are shown in Table 6.

Table 6. Intragroup Comparison of 20-m Sprint Performance Before and After the Intervention

Group	Indicator	Pre-Test	Post-Test	t-value	P-value
Experimental Group	20-m Sprint (s)	4.04 ± 0.50	3.57 ± 0.15	3.425	0.011*
Traditional Training Group	20-m Sprint (s)	4.28 ± 0.41	3.88 ± 0.26	3.135	0.017*

The data showed that after the six-week experimental intervention, the 20-m sprint time of the experimental group decreased from 4.04 ± 0.50 s to 3.57 ± 0.15 s ($P = 0.011 < 0.05$), while that of the traditional training group decreased from 4.28 ± 0.41 s to 3.88 ± 0.26 s ($P = 0.017 < 0.05$). The results indicate that both low-load BFRT and traditional training can significantly improve short-distance sprint speed in adolescent female judo athletes. However, in terms of the magnitude of improvement, the experimental group showed a reduction of 0.47 s, representing an 11.6% decrease, whereas the traditional training group showed a reduction of 0.40 s, representing a 9.3% decrease. Numerically, the experimental group performed slightly better than the traditional training group.

3.3.2 SJFT Index

The SJFT is a sport-specific physical fitness test commonly used by the Chinese national judo team, and it can effectively reflect judo-specific anaerobic endurance and sustained explosive power. In competition, strength and explosive power are key factors for success in judo athletes. Therefore, the SJFT can be used as an effective method for evaluating the sport-specific performance of judo athletes. This test includes 10 consecutive two-person seoi-nage throws.

After the six-week intervention training, the experimental group and the traditional training group completed the SJFT before and after the intervention. Paired-samples t-tests were conducted on the pre- and post-intervention results of both groups. The two groups showed different trends after the intervention. The specific results are shown in Table 7.

Table 7. Intragroup Comparison of the SJFT Index Before and After the Intervention

Group	Indicator	Pre-Test	Post-Test	t-value	P-value
Experimental Group	SJFT Index	168.36 ± 21.88	145.29 ± 20.37	2.543	0.038*
Traditional Training Group	SJFT Index	163.59 ± 32.08	153.49 ± 26.19	0.686	0.515

The data showed that after the six-week experimental intervention, the SJFT index of the experimental group decreased significantly from 168.36 ± 21.88 before the intervention to 145.29 ± 20.37 after the intervention ($P = 0.038 < 0.05$), indicating a marked improvement in sport-specific physical fitness. In the traditional training group, the SJFT index decreased from 163.59 ± 32.08 before the intervention to 153.49 ± 26.19 after the intervention ($P = 0.515 > 0.05$), but this change did not reach the level of statistical significance. Therefore, it can be concluded that low-load blood flow restriction training has a better training effect than traditional high-load training in improving sport-specific anaerobic endurance and sustained explosive power in adolescent female judo athletes.

3.3.3 10-Repetition Rapid O-goshi Uchikomi with a Dummy

In the judo-specific test, "rapid o-goshi uchikomi with a dummy" refers to the participant repeatedly performing complete o-goshi uchikomi movements at maximal speed using a human-shaped training dummy. This test aims to evaluate the athlete's ability to maintain technical stability and explosive power output under high-intensity fatigue conditions. In the 10-repetition rapid o-goshi uchikomi with a dummy test, which is highly dependent on sport-specific technical proficiency, neither group showed statistically significant changes in performance before and after the intervention. The specific results are shown in Table 8.

Table 8. Intragroup Comparison of the 10-Repetition Rapid Uchikomi Test Before and After the Intervention

Group	Indicator	Pre-Test	Post-Test	t-value	P-value
Experimental Group	10-Repetition Rapid Uchikomi	36.67 ± 5.01	36.22 ± 5.33	0.242	0.816
Traditional Training Group	10-Repetition Rapid Uchikomi	48.33 ± 7.41	40.95 ± 6.76	2.226	0.061

The completion times of the experimental group before and after the intervention were 36.67 ± 5.01 s and 36.22 ± 5.33 s, respectively ($P = 0.816 > 0.05$), indicating that performance remained relatively stable. In the traditional training group, the completion time decreased from 48.33 ± 7.41 s before the intervention to 40.95 ± 6.76 s after the intervention, showing a trend toward improvement that approached statistical significance ($P = 0.061$). This suggests that traditional high-load resistance training may have certain positive transfer potential for o-goshi performance; however, this trend still needs to be verified through studies with a longer intervention period or a larger sample size. This result indicates that, because this indicator represents a highly complex sport-specific technical performance, a short-term intervention targeting a single strength quality is unlikely to directly lead to a significant reduction in the time required for a single technical movement. Future studies may consider reassessing sport-specific transfer effects after a longer intervention period.

3.4 Intergroup Differences in Test Indicators Between the Two Groups After the Intervention

After the six-week intervention experiment, independent-samples t-tests were conducted on various explosive power and sport-specific performance indicators in the traditional training group and the experimental group. The results showed that the experimental group performed significantly better than the traditional training group in the reactive strength index (RSI) and the 20-m sprint, as shown in Table 9.

Table 9. Intergroup Comparison of Test Indicators Between the Experimental Group and the Traditional Training Group After the Intervention

Test Indicator	Experimental Group (Mean ± SD)	Traditional Training Group (Mean ± SD)	t-value	P-value
Squat 1RM (kg)	111.67 ± 8.31	110.83 ± 16.57	-0.127	0.901
CMJ Height (cm)	26.98 ± 3.35	25.36 ± 2.61	-1.080	0.298
CMJ Peak Power (W)	669.31 ± 89.74	703.82 ± 61.19	0.899	0.384

SJ Height (cm)	27.00 ± 3.58	25.15 ± 2.86	-1.145	0.271
RSI Index	0.70 ± 0.10	0.52 ± 0.21	-2.150	0.050
20-m Sprint (s)	3.57 ± 0.15	3.86 ± 0.25	2.830	0.013*
SJFT Index	145.29 ± 20.37	153.49 ± 26.19	0.699	0.496
Uchikomi Time (s)	36.22 ± 5.33	40.95 ± 6.76	1.554	0.142

The data showed that after the six-week experimental intervention, in terms of maximal strength, the squat 1RM of the experimental group was 111.67 ± 8.31 kg, while that of the traditional training group was 110.83 ± 16.57 kg (P = 0.901 > 0.05). In terms of explosive power indicators, the CMJ height of the experimental group was 26.98 ± 3.35 cm, while that of the traditional training group was 25.36 ± 2.61 cm (P = 0.298 > 0.05). The CMJ peak power of the experimental group was 669.31 ± 89.74 W, while that of the traditional training group was 703.82 ± 61.19 W (P = 0.384 > 0.05). The SJ height of the experimental group was 27.00 ± 3.58 cm, while that of the traditional training group was 25.15 ± 2.86 cm (P = 0.271 > 0.05). None of these indicators showed statistically significant intergroup differences.In terms of sport-specific performance indicators, the SJFT index of the experimental group was 145.29 ± 20.37, while that of the traditional training group was 153.49 ± 26.19 (P = 0.496 > 0.05). The time for the 10-repetition rapid o-goshi uchikomi test was 36.22 ± 5.33 s in the experimental group and 40.95 ± 6.76 s in the traditional training group (P = 0.142 > 0.05), which also did not reach statistical significance. However, in the reactive strength index and 20-m sprint time, the experimental group demonstrated significantly better training effects than the traditional training group. The RSI of the experimental group was 0.70 ± 0.10, which was significantly higher than that of the traditional training group at 0.52 ± 0.21 (P = 0.050). The 20-m sprint time of the experimental group was 3.57 ± 0.15 s, which was significantly faster than that of the traditional training group at 3.86 ± 0.25 s (P = 0.013 < 0.05). These results indicate that low-load blood flow restriction training and traditional high-load resistance training have comparable effects in improving maximal strength and some explosive power indicators, while blood flow restriction training is superior to traditional high-load training in improving the reactive strength index (RSI) and short-distance sprint ability.

4. Discussion and Analysis

After the six-week intervention, both the experimental group, which performed low-load BFRT at 40% 1RM combined with blood flow restriction, and the traditional training group, which performed high-load training, showed significant improvements in squat 1RM, with no statistically significant difference between the two groups. This indicates that low-load BFRT has an effect similar to that of traditional high-load training in promoting the development of lower-limb maximal strength. For adolescent female judo athletes who are in the growth and development stage, have high sport-specific training loads, and relatively weak basic muscle strength, BFRT can induce strong neuromuscular adaptations and promote strength gains under low mechanical load through the combined effects of local ischemia, hypoxia, and metabolic stress [10]. Its core advantage does not lie in producing a greater absolute increase in maximal strength, but rather in achieving similar benefits with lower risks to the joints and soft tissues. Therefore, it can be used as an auxiliary or alternative training method during periods of high-intensity sport-specific training.

The experimental group showed significant improvements in explosive power indicators, including CMJ height, CMJ peak power, SJ height, and RSI, whereas the traditional training group showed no significant changes. In the intergroup comparison, the experimental group demonstrated a significant or marginally significant advantage in RSI. This suggests that BFRT not only improves basic strength but also enhances rapid force production, power output, and the efficiency of the stretch-shortening cycle [11]. Mechanistically, the hypoxia and accumulation of metabolites induced by blood flow restriction may preferentially fatigue slow-twitch muscle fibers, thereby enhancing the recruitment of high-threshold motor units and type II fast-twitch muscle fibers, and improving neuromuscular recruitment efficiency and firing frequency. The present training protocol, consisting of 40% 1RM, 180 mmHg pressure, three sessions per week, and a total duration of six weeks, was safe and provided strong metabolic stimulation. However, it should be noted that the intergroup differences in CMJ and SJ did not reach statistical significance, and there were baseline differences in power between the two groups. Therefore, the results still need to be verified in future studies with larger sample sizes.

Both the experimental group and the traditional training group showed significant improvements in 20-m sprint performance, indicating that both training methods can improve basic speed ability. The SJFT index of the experimental group decreased significantly, indicating improved sport-specific performance, while the traditional training group showed only a decreasing trend without statistical significance. In contrast, neither group showed significant changes in the 10-repetition rapid o-goshi uchikomi test. The sport-specific transfer effect of BFRT was mainly reflected in continuous explosive output and anaerobic endurance. The SJFT better reflects the high-intensity intermittent characteristics of judo competition. By improving athletes' adaptation to an acidic environment and repeated explosive movements, BFRT demonstrated advantages in this comprehensive sport-specific test [12]. The lack of significant change in uchikomi time may be due to the fact that this indicator is greatly influenced by technical proficiency, movement rhythm, coordination with partners, and other factors. Therefore, short-term physical conditioning intervention may not be sufficient to produce rapid technical performance improvements.

For adolescent female judo athletes in the later stage of growth and development who are exposed to heavy sport-specific training loads, low-load BFRT has high safety and strong practical value. It avoids excessive mechanical stress associated with traditional high-load training, such as increased risk of patellar tendon and anterior cruciate ligament injuries, while promoting growth hormone secretion through local hypoxia and metabolic stress. This allows athletes to obtain strength and explosive power adaptations while protecting the musculoskeletal system [13]. During the pre-competition tapering period or periods of high-intensity sport-specific sparring, BFRT can serve as a method for reducing training load while improving efficiency. It may reduce muscle damage and central fatigue, protect the joints, and contribute to the long-term development of young athletes.

Maximal strength, represented by squat 1RM, improved significantly in both groups because it is highly responsive to resistance training. Explosive power indicators, including CMJ, SJ, and RSI, require higher levels of neuromuscular coordination and rapid recruitment. BFRT may produce more obvious improvements in these indicators by promoting fast-twitch muscle recruitment through metabolic stress. Among the sport-specific indicators, the 20-m sprint reflects basic speed ability, whereas the SJFT reflects sustained explosive output and anaerobic metabolic adaptation. The latter is more consistent with the high metabolic stress characteristics of BFRT, which may explain the significant improvement observed in the experimental group. In contrast, uchikomi time is strongly influenced by technical factors, including movement pattern, rhythm, and coordination. The transfer of physical fitness improvements to sport-specific technical performance requires a longer period of time; therefore, the absence of significant change after a short-term intervention is a normal phenomenon [14].

5. Conclusions and Recommendations

Conclusions:

(1) Six weeks of low-load blood flow restriction training (30%–40% 1RM) can significantly improve lower-limb vertical explosive power in adolescent female judo athletes, and its effect is superior to that of traditional high-load resistance training over the same training period.

(2) BFRT not only improved linear sprint speed but also significantly optimized judo-specific physical fitness, as reflected by the SJFT index. This indicates that BFRT has unique advantages in improving anaerobic endurance and the ability to sustain repeated movement output.

(3) For adolescent female athletes in the later stage of growth and development who are exposed to relatively high sport-specific training loads, low-load BFRT is a safe and effective training method. It can reduce the risk of mechanical injury while producing favorable adaptations in explosive power.

Based on the results of this study and the related analysis, the following recommendations are proposed:

(1) Coaches are advised to use low-load BFRT as an effective supplement or alternative to traditional high-load resistance training during the preparation period, the pre-competition tapering period, or phases involving high sport-specific training loads.

(2) In sport-specific physical fitness training,

attention should be paid to the effect of blood flow restriction training on the development of sustained explosive power. It is recommended that BFRT be applied under fatigue conditions, as this may improve technical stability and sustained offensive ability. Combining BFRT with judo-specific movements may further enhance the practical application of training effects in competition.

(3) The standardization and safety of BFRT implementation should be strengthened. During implementation, it is recommended that the cuff placement be standardized. In addition, athletes' physical responses and subjective feelings should be closely monitored during training to ensure training safety.

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