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Molecular & Cellular Biomechanics 2024, 21(3), 148.
https://doi.org/10.62617/mcb148

Article

Effect of blood flow restriction training on the explosive power of lower limbs in taekwondo athletes during kicking

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CITATION

Xiao S, He J. Effect of blood flow restriction training on the explosive power of lower limbs in taekwondo athletes during kicking. Molecular & Cellular Biomechanics. 2024; 21(3): 148.
https://doi.org/10.62617/mcb148

ARTICLE INFO

Received: 20 May 2024
Accepted: 23 July 2024
Available online: 25 November 2024

Abstract: Objective: This paper aims to explore the effectiveness of blood flow restriction training (BFRT) on the lower extremity explosive power of Taekwondo athletes when they kick. **Methods:** Twenty Taekwondo athletes were randomly divided into BFRT and resistance training (RT) groups. The two groups underwent BFRT and RT for eight weeks, respectively. Indicators such as thigh and calf circumferences and countermovement jump (CMJ) performance were tested and compared. **Results:** In the pre-test, $p > 0.05$ was found between the two groups. In the post-test, the left/right thigh circumferences of the BFRT group were 54.56 ± 3.21 cm and 54.37 ± 3.37 cm, respectively, and $p < 0.05$ compared with the pre-test results and the RT group; however, no remarkable difference were observed between the RT group and pre-test results. The CMJ and static squat jump (SJ) scores in the BFRT group were 42.33 ± 7.84 m and 39.36 ± 7.52 m, respectively, and $p < 0.05$ compared with the pre-test and the RT group; however, there was no remarkable difference between the RT group and the pre-test results. In the BFRT group, the performance of 10 s in-situ double chop kick was 27.64 ± 1.51 times, and the performance of 10 s high turning kick was 19.87 ± 1.65 times ($p < 0.05$ compared with the pre-test results and the RT group); $p < 0.05$ when comparing the post-test results with the pre-test results in the RT group, but the increasing amplitude was lower than that in the BFRT group. The performance of the 10 s in-situ left/right middle turning kick was 16.12 ± 1.37 times and 18.09 ± 1.98 times in the BFRT group, and $p < 0.05$ compared with the pre-test results and the RT group; however, no remarkable difference were found between the RT group and the pre-test results. **Conclusion:** BFRT can effectively improve the lower extremity explosive power of taekwondo athletes during kicking, and the effect is superior to traditional RT.

Keywords: blood flow restriction training; taekwondo; kick; lower extremity explosive force

1. Introduction

Taekwondo is a highly competitive sport [1], and it is also one of the most injury-prone sports in the Olympic Games [2]. Taekwondo emphasizes limb-based attacking techniques [3]. Scoring is achieved through powerful strikes, such as kicks, to maximize force [4]. Therefore, the explosive force of athlete's lower limbs has high requirements [5]. Under the influence of increasingly fierce competition, the requirements for athletes' ability levels are also getting higher and higher. At the same time, while promoting the common development of theory and practice, taekwondo training methods are also constantly improving and innovating [6]. KAATSU training, or blood flow restriction training (BFRT), is a form of training that employs pressure intervention [7], which places the body in a state of pressure and restricts blood flow. It can ensure effective training results under low-load conditions [8]. It has been well applied in medical rehabilitation [9], sports training [10], and other fields. Yasuda et al. [11] analyzed the effect of 24-week KAATSU training on an 84-year-old woman. They found that her quadriceps cross-sectional area, one-repetition maximum (1RM) strength, and chair standing performance all improved, while body weight, hemodynamics, and other parameters did not change. The results suggested the effectiveness of KAATSU training in improving skeletal muscle mass in the elderly. Ishizaka et al. [12] analyzed the effectiveness of KAATSU training on the muscle activity of an elderly female patient with a weak body. They found through the observation of surface electromyography that appropriate KAATSU pressure could reduce the burden of subjects while increasing muscle activity. Mizushima et al. [13] analyzed the effects of KAATSU training on femoris rectus muscle activation, heart rate, and ratings of perceived exertion. The experiment on a healthy male found that exercise-induced fatigue perception was lower under KAATSU training, while muscle activation was similar. Noyes et al. [14] analyzed the impact of BFRT on the recovery of quadriceps and hamstring muscles in patients after knee surgery. They observed that 86% of patients experienced an increase in peak torque of quadriceps muscles by over 20% after undergoing 18 sessions of BFRT. Similarly, for hamstring muscles, the peak torque increased by more than 20% in 76% of patients. Hammert et al. [15] analyzed whether blood flow restriction (BFR) could enhance the adaptation of skeletal muscles to high-load resistance training and discovered that using BFR in low-repetition, high-load training did not increase adaptative response after an eight-week training period. Wong et al. [16] investigated the effectiveness of low-intensity BFRT by conducting a six-week study involving 179 participants, revealing that incorporating BFR into low-intensity isometric grip strength training yielded superior outcomes. By comparing BFRT with traditional training, this paper analyzed the influence of BFRT on lower limb explosive power, in order to provide some theoretical guidance for its further application in Taekwondo training. This paper offers a reliable method for enhancing the lower limb explosive power of athletes and makes some contributions to the improvement of the skills of taekwondo athletes.

2. Research subjects and methods

2.1. Subjects

Table 1. Basic information of subjects.

	BFRT group (*n* = 10)	**RT group (*n* = 10)**	***p***
Age/years	16.12 ± 0.56	15.67 ± 0.67	0.395
Height/cm	171.24 ± 4.56	169.84 ± 5.02	0.467
Weight/kg	54.12 ± 2.34	53.69 ± 2.16	0.526
Training time/years	4.12 ± 1.07	4.33 ± 0.86	0.625
1RM squat/kg	123.21 ± 7.12	122.87 ± 8.06	0.456

Twenty professional taekwondo athletes were selected as the study subjects. They had no major injuries, good health, and no joint damage within half a year. They all understood the purpose and process of the experiment and signed informed consent.

The subjects were randomly divided into two groups: one group underwent BFRT and was recorded as the BFRT group; the other group underwent traditional resistance training (RT) and was recorded as the RT group. The basic information of the two groups is shown in **Table 1**.

2.2. Research methods

2.2.1. Experimental procedure

The experimental procedure is shown in **Figure 1**. The athletes in the two groups received BFRT and RT for eight weeks, respectively, every Tuesday, Thursday, and Saturday from 15:00 to 17:00. Relevant lower limb explosive power indicators were tested before and after the experiment for comparative analysis to understand the influence of BFRT on the lower limb explosive power of Taekwondo athletes during kicking.

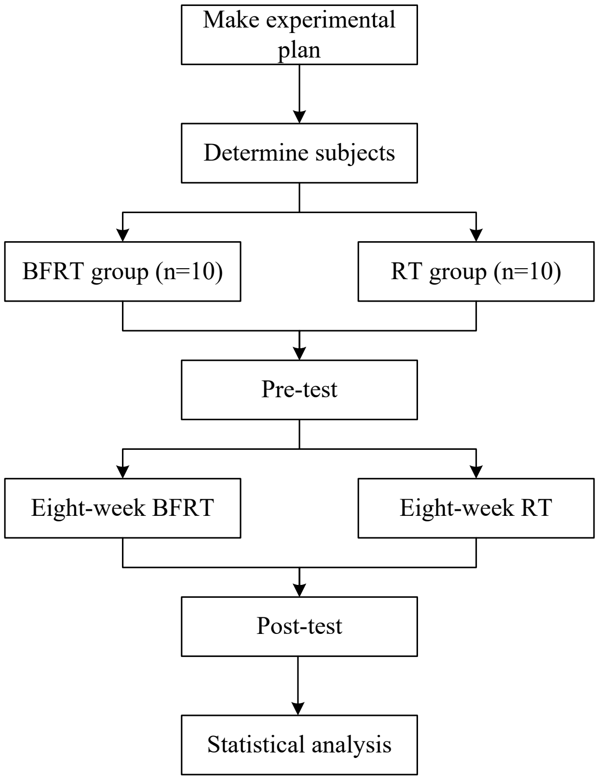

Figure 1. Experimental process.

2.2.2. Training scheme

Deep squat, deadlift, and kettlebell squat jump were used for training in both groups, while the Theratools pressure instrument (TheratoolsT-bfr-0335, the pressure belt is 109 cm long and 10 cm wide, the pressure displayed on the pressure gauge ranges from 0 to 300 mm/Hg) was used in the BFRT group. The pressure device was 10 cm wide, and the pressure straps were worn at the upper third of the thighs as close as possible to the thigh root. The wearing requirements of the strap are as follows.

1) Before wearing, whether there is other gas or gas leakage in the strap was checked.
2) The subject stood naturally with relaxed muscles, and the stomata of the strap faced outwards.

3) After wearing, the pressure of 20 mm/Hg was set, and the subjects were asked to squat with bare hands five times. The change in the instrument value was observed. If the difference between the left and right straps was within 10 mm/Hg, it was considered that the pressure of the two straps was consistent.
4) After checking the consistency in the pressure of the left and right straps, the gas was drained, and the pressure was reset by 200 mm/Hg. After the restart, the inflatable port was separated.
5) The training process was closely observed. If the limb turned gray or blue, it indicated that the pressure was too large or the binding was too tight, and it was adjusted in time.

Table 2 shows the training program in the two groups.

Table 2. Training regimen.

		Load	Times	Number of sets	Intergroup interval
BFRT group	Deep squat	25%–35% 1RM	30 × 15 × 15 × 15	4	1 min
	Deadlift	25%–35% 1RM	30 × 15 × 15 × 15	4	1 min
	Kettlebell squat jump	15 kg	20	4	1 min
RT group	Deep squat	70%–80% 1RM	10	4	3 min
	Deadlift	70%–80% 1RM	10	4	3 min
	Kettlebell squat jump	15 kg	20	4	3 min

Before the formal start of the experiment, the training movements were trained and corrected by professional coaches to avoid affecting the training effectiveness due to irregular movements. The training exercises for both groups in the formal training are shown in **Table 2**. For the BFRT group, the blood flow restriction pressure was maintained at 200 mm/Hg during exercise. Each BFRT training session consisted of four sets of deep squats and deadlifts with a load of 25%–35% 1RM. The progression was gradual, with the first set including 30 repetitions and the following three sets including 15 repetitions each. Finally, four sets of kettlebell squats were performed with a load of 15 kg, 20 repetitions per set, and the rest period between each set was one minute. The RT group did the same exercises, but only performed deep squats and deadlifts with a load of 70–80% 1RM. They also did four sets of kettlebell squats with a load of 15 kg, 20 repetitions per set, and the rest period between each set was three minutes. Before the training, they all warmed up by jogging and dynamic stretching and relaxed by foam rollers and static stretching after the training.

2.2.3. Test indicators

1) Thigh and calf circumference: A vernier caliper was used as the reference tool to calibrate the non-elastic tape measure. Any measurement size was taken, and then the vernier was fixed. A gauge block was taken to get close to the caliper claw. The zero point of the tape measure was attached to one end of the gauge block to pull it until it aligned with the vernier claw corresponding to the measurement size and compare it with the tape scale for calibration. The measurement started after calibration. During measurement, the subject stood with two legs apart. An inelastic tape was used to measure the circumference 3 cm below the thigh root

and the circumference at the fullest part of the calf. The measurements were repeated three times, and the average values were calculated.

2) Countermovement jump (CMJ) [17]: The subject stood on a force measuring pad with hands akimbo, listened to the command, and tried his best to do the CMJ movement. The jump was repeated three times, with a break of one minute between each jump. The optimal performance was considered as the ultimate outcome.
3) Static squat jump (SJ) [18]: The subject stood on a force measuring pad with hands akimbo, bent the knees until a 90° half squat, and tried his best to jump after hearing the command. The movement was repeated three times, with a break of one minute between each jump. The optimal performance was considered as the ultimate outcome.
4) The explosive power of kick: An electronic protection device was used to record the score, and the test movements are as follows.
    (1) 10 s in-situ double chop kick: The subject quickly hit the electronic protection device using the double chop kick in 10 s. Landing by two feet simultaneously was not allowed. The movement was repeated twice, with a break of 3 min between each movement. The best performance was recorded.
    (2) 10 s high turning kick: The subject hit the electronic helmet continuously within 10 s, repeated twice, and rested 3 min after the first kick. The optimal performance was considered as the ultimate outcome.
    (3) 10 s in-situ left/right middle turning kick: The subject hit the protective device continuously using the left/right middle turning kick in 10 s, repeated twice, and rested 3 min after the first set of kicks. The best performance was recorded.

2.2.4. Mathematical statistics and analysis

The experimental data were sorted in Excel, expressed as M + SD, and then statistically analyzed in SPSS 25.0 [19]. The pre-test and post-test results were compared using the paired sample *t*-test. The BFRT and RT groups were compared using the independent sample *t*-test [20]. $p < 0.05$ indicates a significant difference.

3. Research results

The thigh and calf circumferences of the two groups were compared in **Table 3**.

As can be seen from **Table 3**, in the comparison of thigh circumference, after eight weeks of training, the left and right thigh circumference of the BFRT and RT groups increased to a certain extent. Specifically, in the post-test, the left thigh circumference of the BFRT group was 54.56 ± 3.21 cm, which was 0.44 cm higher than the pre-test value and 0.29 cm higher than the RT group ($p < 0.05$); the right thigh circumference was 54.37 ± 3.37 cm, which was 0.39 cm higher than the pre-test value and 0.26 cm higher than the RT group ($p < 0.05$). However, the increase in thigh circumference in the RT group was not significant. Moreover, no significant differences in the left and right calves were observed between the pre-test and post-test values and between the BFRT and RT groups. These findings indicated that the influence of BFRT on limb circumference was mainly reflected in the thigh.

Table 3. Comparison of thigh and calf circumferences (unit: cm).

		BFRT group (*n* = 10)	RT group (*n* = 10)	*p*
Left thigh	Pre-test	54.12 ± 3.32	54.21 ± 3.84	0.425
	Post-test	54.56 ± 3.21	54.27 ± 3.77	0.021
	p	0.001	0.327	
Right thigh	Pre-test	53.98 ± 3.26	54.07 ± 3.34	0.355
	Post-test	54.37 ± 3.37	54.11 ± 3.06	0.032
	p	0.008	0.127	
Left calf	Pre-test	37.33 ± 2.87	37.41 ± 2.92	0.658
	Post-test	37.32 ± 2.64	37.43 ± 2.64	0.854
	p	0.785	0.854	
Right calf	Pre-test	37.41 ± 2.67	37.27 ± 2.37	0.748
	Post-test	37.45 ± 2.64	37.28 ± 2.38	0.825
	p	0.658	0.758	

The CMJ and SJ performance of the two groups is shown in **Table 4**.

Table 4. Comparison of CMJ and SJ performance (unit: m).

		BFRT group (*n* = 10)	RT group (*n* = 10)	*p*
CMJ	Pre-test	39.12 ± 8.78	38.84 ± 9.12	0.321
	Post-test	42.33 ± 7.84	39.56 ± 8.97	0.000
	p	0.000	0.456	
SJ	Pre-test	35.64 ± 7.88	36.01 ± 7.54	0.265
	Post-test	39.36 ± 7.52	37.89 ± 6.37	0.000
	p	0.000	0.127	

In the pre-test, the CMJ performance of the two groups was 39.12 ± 8.78 m and 38.84 ± 9.12 m, and the SJ performance was 35.64 ± 7.88 m and 36.01 ± 6.37 m, respectively ($p > 0.05$). In the post-test, the CMJ performance of the BFRT group was 42.33 ± 7.84 m, which was 8.21% higher than the pre-test value ($p < 0.05$) and 7% higher than the RT group (39.56 ± 8.97 m); the SJ performance of the BFRT group was 39.36 ± 7.52 m, which was 11% higher than the pre-test value and 3.88% higher than the RT group (37.89 ± 6.37 m). The performance of the CMJ and SJ in the RT group indicated no remarkable difference between the pre- and post-test periods ($p > 0.05$). It was concluded that eight weeks of RT improved CMJ and SJ performance to some extent, but the difference was not significant, and eight weeks of BFRT significantly improved CMJ and SJ performance.

Table 5 shows the performance of 10 s in-situ double chop kicks in the two groups.

Table 5. Comparison of 10 s in-situ double chop kick (unit: time).

	BFRT group (*n* = 10)	RT group (*n* = 10)	*p*
Pre-test	20.34 ± 1.77	20.22 ± 1.68	0.325
Post-test	27.64 ± 1.51	24.56 ± 1.39	0.000
p	0.000	0.000	

As seen from **Table 5**, in the pre-test, the performance of 10 s in-situ double chop kicks in the two groups was 20.34 ± 1.77 times and 20.22 ± 1.68 times, respectively ($p > 0.05$). In the post-test, the performance of the BFRT group was increased to 27.64 ± 1.51 times, and that of the RT group was increased to 24.56 ± 1.39 times, which was improved by 35.89% and 24.46% respectively compared to the pre-test performance ($p < 0.05$). These results suggested that after eight weeks of training, the performance of the two groups in in-situ double chop kicks was significantly improved. Moreover, there was an improvement of 12.54% in the BFRT group compared to the RT group ($p < 0.05$). This finding suggests that the effect of BFRT on performance optimization is significantly superior to that of RT.

Table 6 shows the performance of 10 s high turning kick in the two groups.

Table 6. Comparison of 10 s high turning kick performance (unit: time).

	BFRT group (*n* = 10)	RT group (*n* = 10)	*p*
Pre-test	15.36 ± 1.77	15.54 ± 1.67	0.267
Post-test	19.87 ± 1.65	17.84 ± 1.52	0.000
p	0.000	0.000	

As shown in **Table 6**, in the pre-test, the performance of 10 s high turning kicks was similar between the two groups ($p > 0.05$). In the post-test, the performance of the BFRT group was increased to 19.87 ± 1.65 times, and the performance of the RT group was increased to 17.84 ± 1.52 times, which was improved by 29.36% and 14.8% respectively compared to the pre-test performance ($p < 0.05$). These results suggested that the performance of the two groups was significantly improved after eight weeks of training. The post-test performance of the BFRT group showed an improvement of 11.38% compared to that of the RT group ($p < 0.05$), indicating that BFRT had a more obvious effect on the explosive power improvement of kicking.

Table 7. Comparison of the 10 s in-situ left/right middle turning kick performance (unit: time).

		BFRT group (n = 10)	RT group (n = 10)	*p*
Left leg	Pre-test	14.55 ± 1.16	14.48 ± 1.03	0.352
	Post-test	16.12 ± 1.37	14.87 ± 1.21	0.000
	p	0.000	0.745	
Right leg	Pre-test	16.12 ± 1.23	16.09 ± 1.31	0.365
	Post-test	18.09 ± 1.98	16.34 ± 1.23	0.000
	p	0.000	0.255	

Table 7 displays the performance of the 10 s in-situ left/right middle turning kick in the two groups.

As shown in **Table 7**, in the pre-test, the middle turning kick performance of the left leg was 14.55 ± 1.16 times and 14.48 ± 1.03 times, and the performance of the right leg was 16.12 ± 1.23 times and 16.09 ± 1.31 times, respectively, suggesting no remarkable difference between the two groups. In the post-test, the middle turning kick performance of the left leg in the two groups was 16.12 ± 1.37 times and 14.87 ± 1.21 times, respectively, which were improved by 10.79% and 2.69% compared with the pre-test, but only the p value in the BFRT group was< 0.05, and when comparing the BFRT group with the RT group, there was a difference of 8.41% ($p < 0.05$). The middle turning kick performance of the right leg in the two groups was 18.09 ± 1.98 times and 16.34 ± 1.23 times, respectively, which were improved by 12.22% and 1.55% compared with the pre-test, but $p < 0.05$ only in the BFRT group; there was a difference of 10.71% when comparing the BFRT group with the RT group. These outcomes suggested that eight weeks of RT had little effect on improving performance, while BFRT had a more significant effect.

4. Discussion

In taekwondo training, vibration training [21], aerobic exercise [22], and repeated high-intensity technical training [23] are used. BFRT has been proven to have certain effects on improving the aerobic capacity and muscle strength of the human body [24]. It is conducive to improving body function [25] and is a safe and effective training method [26]. Therefore, this paper mainly analyzed the influence of BFRT on Taekwondo athletes.

In the experiment, the pressure strap was worn on the thigh, and the selected training movements also focused on stimulating the thigh muscle group, so it may have a stronger impact on the thigh muscle group, which was also proved by the comparison of changes in limb circumference. In the post-test, the changes in the thigh circumference of the two groups were greater than that of the calf circumference. Comparing the BFRT group with the RT group, the left thigh circumference of the BFRT group was 54.56 ± 3.21 cm, which increased by 0.29 cm compared to the RT group ($p < 0.05$). The right thigh circumference was 54.37 ± 3.37 cm, which increased by 0.26 cm compared to the RT group ($p < 0.05$). The results proved the effectiveness of BFRT training on the growth of thigh muscle.

CMJ and SJ are commonly used indicators to test the explosive strength of lower limbs. According to the comparative results, there was no remarkable difference in CMJ and SJ performance between the two groups in the pre-test ($p > 0.05$). In the post-test, the CMJ performance of the BFRT group was 42.33 ± 7.84 m, which showed an increase of 8.21% compared with the pre-test performance and an improvement of 7% compared with 39.56 ± 8.97 m in the RT group ($p < 0.05$), and the SJ performance was 39.36 ± 7.52 m, which showed an increase of about 11% compared with the pre-test performance and an improvement of 3.88% compared with 37.89 ± 6.37 m in the RT group ($p < 0.05$). The CMJ performance of the RT group was 39.56 ± 8.97 m, which showed an increase of about 2% compared with the pre-test performance. The SJ performance was 37.89 ± 6.37 m, which showed an increase of about 5% compared with the pre-test value. It was found that the CMJ and SJ performance of the BFRT group was significantly different from that of the pre-test and the RT group ($p < 0.05$), which demonstrated that BFRT could achieve good training results under low load and was better than the traditional RT.

RT is a very commonly used method in various sports training. However, the results of several indicators of kick explosiveness revealed that the effect of RT was not as good as that of BFRT. This may be because under the long-term RT, the lower limb muscles already have a certain adaptability, so the improvement effect of some performance is not good. According to **Tables 5–7**, compared with the pre-test, the performance of the four kick explosiveness tests of the BFRT group was significantly improved in the post-test. The performance of the 10 s in-situ double chop kick was 20.34 ± 1.77 times, which was improved by 35.89% compared to the pre-test performance. The 10 s high turning kick performance was 19.87 ± 1.65 times, which was improved by 29.36% compared to the pre-test performance. The in-situ left/right middle turning kick performance was 16.1 ± 1.37 and 18.09 ± 1.98 times, which was improved by 10.79% and 12.22% compared to the pre-test performance. However, the RT group only demonstrated significant differences in the first two items. The 10 s in-situ double chop kick and high turning kick performance increased by 21.46% and 14.8%. Comparing the post-test 10 s in-situ left/right middle turning kick performance with the pre-test, $p > 0.05$.

Kick techniques in taekwondo require fast and powerful strikes. According to the results, after eight weeks of BFRT, the athletes' continuous starting ability, strength, and speed have been significantly improved, the storage and utilization of elastic potential energy were improved, the motion perception ability was enhanced, and the control ability and coordination ability of the limbs were improved. Therefore, they obtained higher results in various tests.

The greater improvement in lower limb explosive force observed in the BFRT group may be attributed to local metabolic stress and muscle fiber replenishment caused by BFR. Previous studies have shown that BFRT can enhance activation of type II muscle fibers by limiting blood flow and increasing fatigue rate, resulting in increased lactate concentration and decreased blood pH in the muscles [27], leading to increased secretion of growth hormone and insulin-like growth factor 1 [28]. This stimulates favorable changes in muscle structure, enhances phosphorylation of the mammalian target of rapamycin pathway [29], promotes S6K1 activity, and improves muscle protein synthesis [30]—all of which are important for developing muscular strength and explosiveness.

Based on the above results, it can be found that compared with the traditional RT, BFRT can achieve better training under low load, which is a scientific and effective method and can be applied in practical training. A limitation of the current study is the relatively small sample size, which may have reduced the statistical power to detect subtle between-group differences. Additionally, the eight-week training period, while sufficient to observe significant improvements, may not have been long enough to fully capture the longitudinal effects of BFRT on explosive power development in Taekwondo athletes. Therefore, in future work, it is necessary to further expand the sample size to verify the positive effect of BFRT on lower limb explosive power. It is also important to consider increasing training time in order to examine the impact of

BFRT training duration on lower limb explosive power and provide more reliable support for the further application of BFRT in practical sports training.

5. Conclusion

This paper studied the effectiveness of BFRT on lower limb explosive power. The experimental results showed that:

1) in the pre-test, no remarkable difference were found between the BFRT group and RT group in various indicators;
2) the post-test measurements of the left/right thigh circumference in the BFRT group showed a significant difference compared to both the pre-test value and RT group ($p < 0.05$);
3) the CMJ and SJ performance in the BFRT group in the post-test were significantly different compared with that in the pre-test and RT group ($p < 0.05$);
4) the performance of the CMJ and SJ in the RT group suggested no remarkable difference between the pre-test and post-test periods ($p < 0.05$).

The experimental results prove the positive effect of BFRT, which can be applied in taekwondo athletes' lower extremity explosive strength training during kicking.

Author contributions: Conceptualization, SX and JH; methodology, SX and JH; software, SX; validation, JH; formal analysis, SX and JH; investigation, JH; resources, SX; data curation, JH; writing—original draft preparation, JH; writing—review and editing, SX; visualization, SX; supervision, SX; project administration, SX. All authors have read and agreed to the published version of the manuscript.

Ethical approval: Not applicable.

Informed consent: Informed consent was obtained from all subjects involved in the study.

Conflict of interest: The authors declare no conflict of interest.

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