The autoregulation method on the jumping ability of college badminton athletes

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Objectives: Jumping ability has been identified as a key factor that influences the performance of badminton athletes. Autoregulatory progressive resistance exercise (APRE) and velocity-based resistance training (VBRT) are commonly used to develop athletes' muscle strength and have been proven to accurately monitor the development of muscle explosive power. Therefore, this study aims to investigate the effects of APRE and VBRT on athletes' vertical jumping ability, providing practical implications for improving the jumping ability of athletes during competitions.

Methods: Upon completing familiarization and pretesting, 18 badminton athletes were included and completed the training intervention (age, 21.4 ± 1.4 years; stature, 170.1 ± 7.3 cm; body mass, 65.9 ± 12 kg); they were randomly divided into the APRE group ($n = 9$) and VBRT group ($n = 9$). Jumping performance was assessed during the countermovement jump (CMJ), squat jump (SJ), and drop jump (DJ) via SmartJump, with CMJ 's and SJ's jump height and eccentric utilization ratio (EUR) and reactive strength index (RSI). All participants then completed a 4-week in-season resistance training intervention.

Results: 1) The results of the within-group indicated that only the CMJ (pre: 41.56 ± 7.84 vs. post: 43.57 ± 7.85, $p < 0.05$) of the APRE group had significant differences, whereas the SJ, EUR, and RSI were not significantly different ($p > 0.05$). 2) The results of the intergroups revealed that all indicators had no significant differences ($p > 0.05$), but APRE had a moderate effect size on the improvement of the CMJ ($\eta^2 = 0.244$) and EUR ($\eta^2 = 0.068$) when compared with VBRT.

Conclusions: It is concluded that APRE was associated with greater power and neuroadaptation to improve the CMJ height of badminton athletes, as well as similar repetitions and total training volume, throughout a 4-week training when compared with VBRT. Therefore, APRE may assist coaches in enhancing athletes' CMJ's height in the short term, whereas improvements in SJ's height, EUR, and RSI may require longer-term training intervention to manifest.

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Abstract

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Introduction

Badminton is a type of racquet sport that involves various explosive movements, such as jumping, quick changes of direction, net shots, and fast arm movements. It requires specific physical and physiological attributes, court performance, and technical and tactical requirements [1, 2]. Among these, jumping ability has been identified as a key factor that influences the performance of badminton athletes, and athletes often need to transform their daily muscle strength into explosive power before competition [3]. It is well understood that muscle strength plays a key role in improving and maintaining sports performance, including speed [4], agility [5], and explosive strength [4, 6], and it even contributes to the development of motor skills [7]. Resistance training is recognized as an effective method for improving explosive power [8]. In recent years, the autoregulatory resistance training (ART) method has been proposed and applied to strength training to overcome the shortcomings of percentage-based resistance training (PBT) [9, 10], whose main purpose is to monitor and evaluate whether the exercise load is appropriate according to the motor skills of the athlete's real-time dynamics and, at the same time, to adjust the training load (including training volume and intensity) so that the athlete can train with a more appropriate load that is suitable for his/her immediate state, thereby achieving a greater effect and reducing the onset of fatigue [11].

Autoregulatory progressive resistance exercise (APRE), rating of perceived exertion, and velocity-based resistance training (VBRT) are three common methods of ART [12]. The three methods are effective in controlling the intensity of resistance training [12]. VBRT is an emerging and popular method of monitoring and designing prescription training that uses various advanced speed measurement devices during strength training, purposefully tracks the speed of moving loads, and provides feedback [13]. APRE is a daily adjustable progressive resistance exercise [14], similar to nonlinear programming resistance training, which allows athletes to improve performance in training sessions when they are physiologically recovered [15]. Among them, APRE's 6RM program [16] and VBRT's 10% velocity loss [17] are commonly used to develop athletes' explosive power and have been proven to accurately monitor the development of muscle explosive power.

In the field of ART, attention has been focused on comparing APRE with PBT (here, PBT refers to linear periodized percentage-based resistance training, and all studies on APRE in this paper used this definition of PBT), VBRT with PBT, VBRT with rating of perceived exertion, and different velocity losses [18]. In addition, no studies have compared APRE with VBRT, and the advantages of these two methods for developing muscle strength remain to be elucidated. Therefore, the purpose of this study was to compare the effects of APRE and VBRT on explosive power in a medium cycle, which could provide a practical basis for selecting a more appropriate method of autoregulatory resistance training.

Materials and methods

Experimental approach to the problem

A randomized controlled trial was conducted to investigate the effects of APRE and VBRT on the explosive power of the lower limbs in athletes. After familiarization with the program and pretesting, participants were randomly assigned to the VBRT or APRE group. The experimental period lasted for 6 weeks, including the first and last weeks of testing, in which all participants completed two training sessions per week for 4 weeks. Testing consisted of countermovement jump (CMJ), squat jump (SJ), and drop jump (DJ) tests. All tests were performed at least 48 hours before/after the most recent training session. All testing and training sessions took place at the same venue under the direct supervision of the lead investigator.

Participants

Twenty-one participants (male = 11, female = 10) were originally recruited to take part in the research study. The inclusion criteria of the recruited athletes for the study were as follows: 1) absence of any significant physical health issues, 2) older than 18 years, 3) a minimum of 3 years of prior experience in playing badminton, and 4) absence of any injury or illness in the past 6 months. However, three participants were excluded due to injury, so only 18 badminton athletes were included and completed the training intervention (age, 21.4 ± 1.4 years; stature, 170.1 ± 7.3 cm; body mass, 65.9 ± 12 kg). The participants were randomly distributed into two groups: VBRT ($n = 9$) and APRE ($n = 9$). The participants' characteristics are presented in Table 1. There was no statistically significant difference between the two groups in terms of baseline ($p > 0.05$), and the grouping was reasonable. All of the included athletes were free of injury and sleep disorders and were nonsmokers. They volunteered to participate in this study and provided signed informed consent after being informed of the testing procedure and potential risks. This study was approved by the Ethics Committee forHuman Experiments (approval number 2022LCLL-38).

Procedures

Participants completed jumping performance testing in 1 day, including the CMJ, SJ, and DJ. Before all testing and training sessions, participants were supervised during a standardized warm-up, consisting of 5 minutes of jogging and dynamic stretching. After the completion of the final resistance training, testing for outcome measures was repeated after 48 hours of recovery.

Outcome measures

CMJ, SJ, and DJ tests were administered indoors using the SmartJump wireless portable jump test mat, which consists of a wireless mobile device terminal and a SmartJump vertical jump mat. The jumping test mat analyzes the jumping motion by pressure sensing. All the tests required participants to place their arms around their waist and not bend their hips and knees during the lift-off process. For the CMJ, participants kept their torso as immobile as possible while simply completing a coherent and rapid squat jump to the maximum height. For the SJ, participants listened to the experimenter’s command; after the participants hear “squat,” they perform a half squat; the experimenter says “1, 2,” and then “jump,” and the participants quickly jump to their maximum height. For the DJ, participants stepped off a box (height, 30 cm) with their preferred leg, landed on the floor with both feet, and immediately jumped as high as possible. Participants were instructed to jump to the highest height as fast as possible. The CMJ, SJ, and DJ were performed three times with 20-second rests between each jump, with the highest jump (in centimeters), eccentric utilization ratio (CMJ’s jump height [in centimeters]/SJ’s jump height [in centimeters]), and reactive strength index (jump height [in meters]/contact time [in seconds]) used for analysis.

Training routine

Resistance training started at 3:00 PM on Mondays, Wednesdays, and Fridays and ended by 5:00 PM. This study used GymAware, a jump box, a barbell, and other equipment. Each resistance training session began with a standardized warm-up followed by two sets of 10 free-weight back squat repetitions, separated by 2 to 3 minutes of active rest periods. The APRE group performed back squats with a 6RM session based on their baseline one-repetition maximum (1RM), whereas the VBRT group performed back squats with a modifiable load based on a target velocity threshold established from the standardized load–velocity relationships.

Autoregulatory progressive resistance exercise. Participants in the APRE group performed with a set number of repetitions at a certain percentage of the 6RM based on Delorme’s PRE program. The 6RM resistance training protocol consisted of four sets. Set 1 used 50% 6RM for 10 squats, and Set 2 used 75%

6RM for 6 squats. In Set 3, participants were required to squat with 100% 6RM load until failure, and then the squat weight of Set 4 was determined according to the load adjustment table (refer to Table 2). In Set 4, participants were required to perform repetitions as hard as possible until exhaustion, and the number of repetitions was used to specify the starting load for the next training session [43].

Velocity-based resistance training. Participants in the VBRT group performed with a load that corresponded to mean concentric velocity (MCV) at 80% 1RM established from a standardized load–velocity relationship. MCV monitoring was used to dictate changes in load lifted and the number of repetitions completed on a real-time, set-by-set basis. Velocity stops were integrated into each set at 10% below the target velocity of each specific zone [19]. Thereafter, if the maximum MCV in a set of repetitions was ±0.06 m/s outside of the target movement velocity, the barbell load was then adjusted by ±5% 1RM for the subsequent set [20].

Statistical analyses

Data analysis was completed using Jamovi 2.3.26. Mean and standard deviation (SD) values were calculated using standard statistical methods. The normality of all variables was tested using the Shapiro–Wilk test procedure. Levene's test was used to determine the homogeneity of variance. Subsequently, repeated measures analysis of variance was performed. The differences between the groups before and after training and the differences in change scores between the two groups before and after training were compared. The Bonferroni adjustment was performed to determine the p value of the comparisons, and $p < 0.05$ was considered statistically significant. The partial squares eta (η^2) is a measure of effect size for between-group differences in intervention effects that were calculated and considered small ($0.01 \leq \eta^2 \leq 0.06$), moderate ($0.06 \leq \eta^2 < 0.14$), or large ($\eta^2 \geq 0.14$) [21].

Results

All data are expressed as means ± SD. The subject's characteristics including age, weight, and height are listed in Table 1. There were no significant differences between groups for any of the participants' characteristics and performance outcomes at the baseline ($p > 0.05$). Likewise, repetitions and total training volume had the same results.

After 4 weeks of training, only the APRE group demonstrated greater improvement in the CMJ (pre: 41.56 ± 7.84 vs. post: 43.57 ± 7.85; $p = 0.04$) when compared with the baseline. Pre- to post-training changes in the CMJ, SJ, eccentric utilization ratio (EUR), and reactive strength index (RSI) were compared between the APRE- and VBRT-trained groups. There were no significant differences between groups for all measures ($p > 0.05$) (Figure 1). The effect size indicates that APRE is better than VBRT in the CMJ ($\eta^2 = 0.244$) and EUR ($\eta^2 = 0.068$), relatively (Table 3).

Discussion

In this study, APRE was found to be effective in improving the CMJ's jump height of college badminton athletes over a 4-week period. However, the between-group comparison between APRE and VBRT indicated no significant difference in the improvement of the jumping ability of the athletes. Despite this finding, considering the large and moderate effect sizes [21] of APRE on improving the CMJ and EUR of athletes compared with VBRT, a previous study suggested that APRE is more effective than PBT for short-term gains [16]. It can be concluded that APRE has a positive effect on improving the pre-competition jumping ability of college badminton athletes.

The three most popular methods for assessing vertical jump are the CMJ, SJ, and DJ [22], and it is well-known that participants can achieve higher jump heights and greater output power in the CMJ compared with the SJ [23]. A study suggested that 4 weeks of PBT did not significantly improve the CMJ and SJ of athletes [24]. However, the results of the present study were different, and Mann also highlighted that APRE is more applicable to athletes than PBT [25]. After 4 weeks of training, the participants' CMJ in the APRE group was significantly improved. PBT prescribes the weight, the number of repetitions, and sets for each squat [13]; VBRT sets a speed range for squats, and training is immediately stopped once the speed falls out of the range [13]; APRE aims to maximize the number of repetitions [25]. Specifically, APRE sets the overall number of sets and the number of repetitions for the first two sets, whereas the third and fourth sets require the subject to reach exhaustion, but the maximum number of repetitions varies with the subject's exercise status [25]. The third and fourth sets of APRE required participants to perform repetitions until failure, and the rationale for performing resistance exercises until failure is to maximize motor unit recruitment [26]. Type IIa muscle fibers are maximally mobilized during force training under moderate-to-high intensity loads. Because of its greater aerobic metabolic capacity and fatigue resistance [27, 28], fatigue resistance is more conducive to the development of muscle strength and muscle hypertrophy [29]. As the improvement of the CMJ in adult athletes largely depends on the increase in individual muscle strength, and the training mechanism of APRE is more conducive to inducing the development of maximum strength [30], it is plausible that APRE is better than VBRT for improving the CMJ after 4 weeks of training.

The ratio of the CMJ to the SJ is known as the EUR [31] and is often used to examine the effect of reversal on generating greater jump height and the effect of the neuromuscular system on rapid force generation [32]. After 4 weeks of resistance training, the EUR of VBRT remained stable, and its CMJ and SJ did not change significantly before and after the intervention training. The EUR of APRE was improved to 1.08 (1.1 was the best optimum) [33], whereas its SJ did not significantly change after the training (pre: 40.83 ± 7.69, post: 40.61 ± 8.37). However, the CMJ (pre: 41.56 ± 7.84, post: 43.57 ± 7.85) indicated significant improvement after the training. According to the EUR standard calculation formula, it was found that the improvement in APRE's EUR was mainly caused by the increase in the CMJ. The exhaustion training of the last two groups in the APRE training mechanism appears to be an important factor in improving EUR to a high level. As mentioned earlier, exhaustion training in APRE can maximize the recruitment of motor units to increase muscle strength and improve the CMJ. Therefore, the improvement in EUR can be attributed to the increase in the recruitment ability of motor units. The improvement of EUR indicates an increase in the storage and utilization of elastic energy in the stretch-shortening cycle, which means that athletes can better perform muscle pre-activation, the stretch reflex, and the release of stored passive elastic energy in the muscle tendinous tissue [34]. However, there was no significant difference in EUR between the two groups in the pretest of this study, the EUR of APRE (1.04) was lower than that of VBRT (1.09), and the difference between the two was 0.05, with VBRT's EUR being close to 1.1. Therefore, this result only indicates that APRE can improve the EUR of athletes.

Young proposed the RSI as a measure of the ability to quickly transition from eccentric to concentric muscle contractions during jumping [35]. The RSI is calculated as the jump height during a DJ divided by the contact time [36]. Improvement of the RSI can be achieved by increasing jump height and decreasing contact time. Rebelo's meta-analysis found [30] that both long-term [37] and short-term [20, 38] resistance training can increase the RSI in adolescents, but the effect on trained adult athletes is smaller. Additionally, 4 weeks of both high- and low-intensity resistance training failed to significantly improve explosive strength in adult athletes [39]. Resistance training typically involves moderate-to-high loads [40], which results in relatively slow movement speeds that may not be conducive to rapid force generation. The improvement in the RSI in adolescents is attributed to two factors: 1) an increase in muscle strength through resistance training leading to an increase in jump height while contact time remains constant [36] and 2) an increase in activated muscle units, where resistance training can activate 10% more muscle units in adolescents than in adults [41]. However, for adult athletes, it is challenging to significantly improve the RSI through resistance training once muscle strength has reached a certain level, but reducing contact time may improve the RSI. Research has suggested that post-activation potentiation can have an acute effect on the RSI in adult athletes. After heavy squats at 93% of one-repetition maximum, the RSI was slightly improved but not significantly, contact time decreased significantly (7.8%), and leg stiffness improved significantly (10.9%) possibly due to increased neural-muscular activation, allowing athletes to better control the stiffness of their leg muscles and thereby reduce contact time [42]. Similarly, plyometric training can improve the RSI in adult athletes by reducing contact time during jumping (0.84, 95% CI: 0.37–1.32) [30]. Therefore, resistance training can improve the RSI in adolescents by increasing muscle strength, but improving the RSI in adult athletes through resistance training is challenging. Post-activation potentiation and fast stretch-shortening combined training can improve the RSI in adult athletes by reducing contact time.

Limitations

This study has several limitations that should be mentioned: a) a control group was not used to compare the effect of the current experimental protocols, b) the number of participants was not sufficient, and c) a relatively short training intervention was used. Although the results of this study may be limited to specific contexts of sample selection and intervention duration, they still have practical significance by providing insights into the effects of APRE and VBRT on lower limb explosive power and can serve as a reference for future related research. Future studies may consider increasing the sample size and intervention duration and controlling for other factors that may influence the results to more comprehensively and accurately evaluate the effects of intervention methods.

Conclusion

Improving the jumping ability of badminton athletes is crucial for achieving excellent athletic performance and competition results. Therefore, coaches need to understand methods for enhancing the jumping ability of athletes during the season. This study found that using APRE can effectively improve the CMJ performance of badminton athletes in a shorter period and that APRE is superior to VBRT in terms of CMJ performance and EUR testing. From a practical perspective, APRE was associated with greater power and neuroadaptation, as well as similar repetitions and total training volume, throughout a 4-week training cycle when compared with VBRT. Therefore, APRE may assist coaches in enhancing the CMJ performance of athletes in the short term, whereas improvements in the SJ performance, EUR, and RSI may require longer-term training intervention to manifest.

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Table 1(on next page)

Physical characteristics of the participants(M±SD)

Table 1 Physical characteristics of the participants（M±SD）

	APRE（n=9）	**VBRT（n=9）**	**p**
Age(years)	21.2±1.39	22.1±1.52	0.468
Hight(cm)	172.4±7.18	168.9±7.93	0.842
Weight(kg)	66.46±10.74	63.99±13.27	0.787

Table 2(on next page)

APRE protocol for 6RM and set 4 adjustment

Table 2 APRE protocol for 6RM and set 4 adjustment.

Repetitions	Intensity (% of 6RM)
APRE protocol for 6RM	
10×	50%
6×	75%
Maximum	6RM
Maximum	Adjusted weight
Repetitions for set 3 6RM routine adjustment	Set 4 adjustment
0-2	-2.5 to 5kg
3-4	-0 to 2.5kg
5-7	keep
8-12	+2.5 to 5kg
13+	+5 to 10kg

Tips：APRE—autoregulatory progressive resistance exercise；6RM—6 Repetition Maximum；

Table 3(on next page)

Changes in the variables of CMJ, SJ, EUR, and RSI between pre- and post-test after training in each of groups.

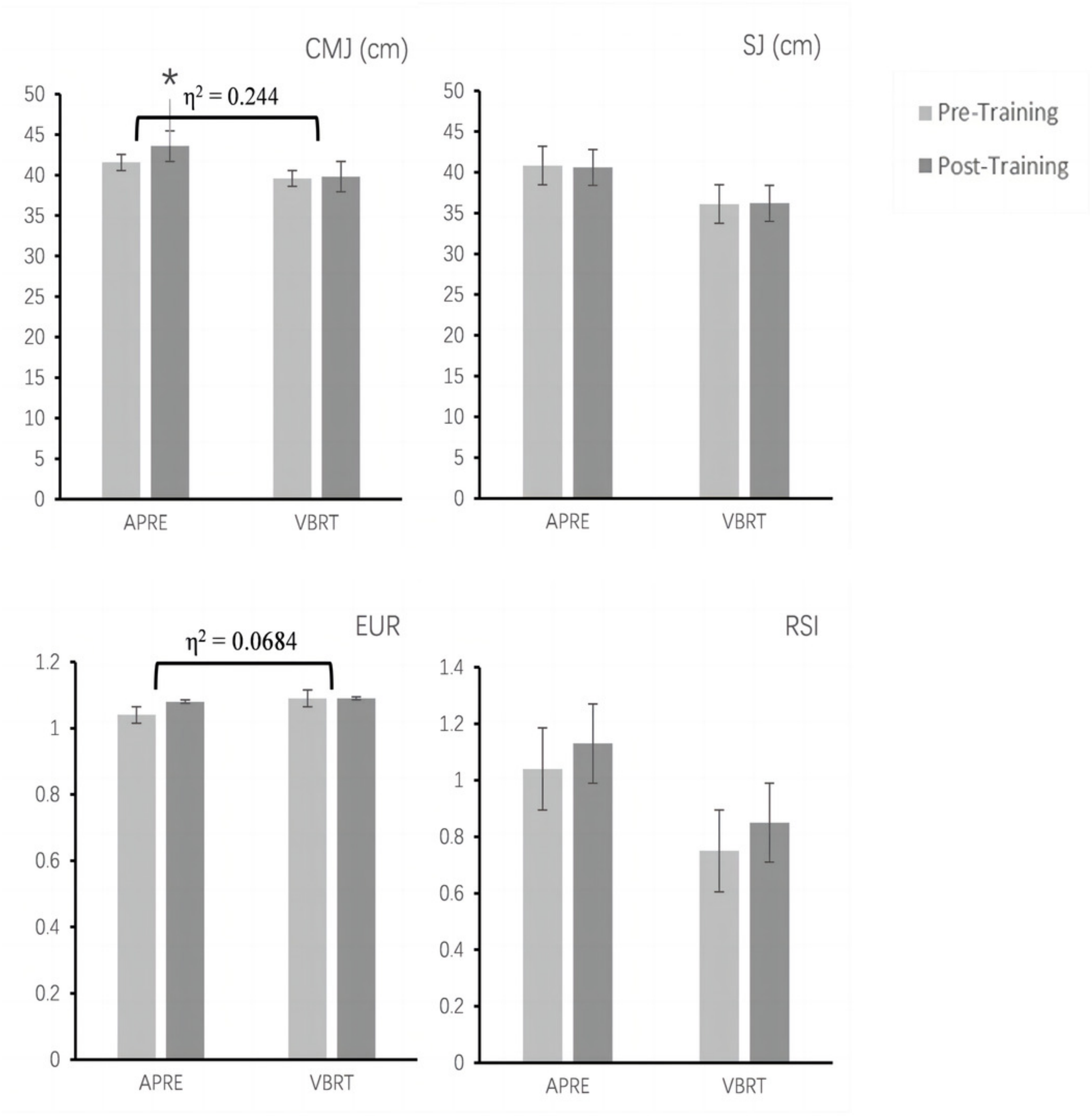
Table 3 Changes in the variables of CMJ, SJ, EUR, and RSI between pre- and post-test after training in each of groups

Variables	APRE(n=9)			VBRT(n=9)			Effect sizes (η²)
	Pre	Post	P value	Pre	Post	P value	
CMJ (cm)	41.56±7.84	43.57±7.85	0.04	39.59±7.97	39.81±7.08	1	0.244
SJ (cm)	40.83±7.69	40.61±8.37	1	36.1±7.35	36.2±6.33	1	0.003
EUR	1.04±0.06	1.08±0.04	0.986	1.09±0.07	1.09±0.05	1	0.068
RSI	1.04±0.27	1.04±0.36	1	0.75±0.21	0.85±0.26	1	0.000

Figure 1

Intra-group and inter-group change in CMJ, SJ, EUR, and RSI from 4 week for APRE and VBRT groups

All data are presented as Mean ± SD. *Significant differences between pre- and post- for APRE or VBRT at the p less than 0.05 level.


CMJ (cm)
*
$\eta^2 = 0.244$
SJ (cm)
Pre-Training
Post-Training
EUR
$\eta^2 = 0.0684$
RSI
APRE
VBRT
0
5
10
15
20
25
30
35
40
45
50
0.2
0.4
0.6
0.8
1
1.2
1.4