RESISTED PLYOMETRIC EXERCISES INCREASE MUSCLE STRENGTH IN YOUNG BASKETBALL PLAYERS

EXERCÍCIOS PLIOMÉTRICOS RESISTIDOS AUMENTAM A FORÇA MUSCULAR EM JOVENS JOGADORES DE BASQUETEBOL

LOS EJERCICIOS PLIOMÉTRICOS RESISTIDOS AUMENTAN LA FUERZA MUSCULAR EN JÓVENES JUGADORES DE BALONCESTO

ORIGINAL ARTICLE
ARTIGO ORIGINAL
ARTÍCULO ORIGINAL

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ABSTRACT

Introduction: Training methods that increase muscle strength have an important effect on basketball. Objectives: This study was planned to investigate the effect of a 12-week resisted plyometric training program for isokinetic muscle strength in young basketball players. Methods: Thirty-five male athletes who participate in regular basketball training were randomly assigned to one of three groups: the control group (C), the plyometric exercise group (P), and the resisted plyometric exercise group (RP). All the players participated in the standard basketball training program 5 days a week for 12 weeks. While the control group performed only standard basketball training, the P group and the RP group participated in plyometric and resisted plyometric exercise programs, respectively, 3 days a week. Vertical jump height and isokinetic muscle strength at 60, 180 and 300°s^{-1} were measured at the beginning and end of the study. Results: The plyometric and resisted plyometric training programs did not alter vertical jump performance. However, isokinetic muscle strength increased at all angles in the P and RP groups. Conclusion: Plyometric and resisted plyometric training programs applied for 12 weeks have a positive effect on muscle strength in young basketball players. ***Level of evidence II; Therapeutic studies - investigation of treatment results.***

Keywords: Basketball; Muscle strength dynamometer; Training; Athletic performance; Adolescent.

RESUMO

Introdução: Os métodos de treinamento que aumentam a força muscular têm importante efeito no basquete. Objetivos: Este estudo foi planejado para investigar o efeito de um programa de treinamento pliométrico resistido de 12 semanas sobre a força muscular isocinética em jovens jogadores de basquete. Métodos: Trinta e cinco atletas do sexo masculino que faziam treinamento regular de basquete foram designados randomicamente a um de três grupos: grupo controle (C), grupo exercícios pliométricos (P) e grupo exercícios pliométricos resistidos (PR). Todos os jogadores participavam do programa de treinamento de basquete padrão 5 dias por semana durante 12 semanas. Enquanto o grupo controle realizou apenas o treinamento de basquete padrão, o grupo P teve pliometria e o grupo PR teve um programa de exercícios pliométricos resistidos 3 dias por semana. A altura do salto vertical e a força muscular isocinética a 60º/s, 180º/s e 300º/s foram medidas no início e no final do estudo. Resultados: Os programas de treinamento pliométrico e pliométrico resistido não alteraram o desempenho do salto vertical. No entanto, a força muscular isocinética aumentou em todos os ângulos nos grupos P e PR. Conclusão: Os programas de treinamento pliométrico e pliométrico resistido aplicado por 12 semanas têm efeito positivo sobre a força muscular de jovens jogadores de basquete. ***Nível de evidência II; Estudos terapêuticos - Investigação de resultados de tratamento.***

Descritores: *Basquete; Dinamômetro de força muscular; Treinamento; Performance atlética; Adolescente.*

RESUMEN

Introducción: Los métodos de entrenamiento que aumentan la fuerza muscular tienen un efecto importante en el baloncesto. Objetivos: Este estudio se planificó para investigar el efecto de un programa de entrenamiento pliométrico resistido de 12 semanas sobre la fuerza muscular isocinética en jóvenes jugadores de baloncesto. Métodos: Treinta y cinco atletas masculinos que entrenaban baloncesto de forma regular fueron asignados aleatoriamente a uno de los tres grupos: grupo de control (C), grupo de ejercicio pliométrico (P) y grupo de ejercicio pliométrico resistido (PR). Todos los jugadores participaron en el programa estándar de entrenamiento de baloncesto 5 días a la semana durante 12 semanas. Mientras que el grupo de control solo realizaba el entrenamiento estándar de baloncesto, el grupo P la técnica de pliometría y el grupo PR un programa de ejercicios pliométricos resistidos 3 días a la semana. Se midieron la altura del salto vertical y la fuerza muscular isocinética a 60o/s, 180o/s y 300o/s al inicio y al final del estudio. Resultados: Los programas de entrenamiento pliométrico y pliométrico resistido no alteraron el rendimiento del salto

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Editor responsible for the review process: Julia Maria D'andrea Greve

vertical. Sin embargo, la fuerza muscular isocinética aumentó en todos los ángulos en los grupos P y PR conclusıón: Los programas de entrenamiento pliométrico y pliométrico resistido aplicados durante 12 semanas tienen un efecto positivo en la fuerza muscular de jóvenes jugadores de baloncesto. ***Nivel de evidencia II; Estudios terapéuticos: investigación de los resultados del tratamiento.***

Descriptores: *Baloncesto;* Dinamómetro de fuerza muscular; *Entrenamiento; Rendimiento atlético; Adolescente.*

DOI: http://dx.doi.org/10.1590/1517-8692202228042020_0125 Article received on 11/17/2020 accepted on 10/04/2021

INTRODUCTION

Basketball is a high-intensity team sport that requires agility, the ability to jump, sprint, and change direction, as well as technical and tactical skills.[1–3] Accordingly, the ability to produce strength, power, and speed are important physical performance characteristics for basketball players.[4] Due to these demands, both aerobic and anaerobic mechanisms are highly activated to provide energy during basketball.[4]

Explosive strength levels are essential for basketball performance, mainly for the improvement of vertical jumping.[4] Two training methods, namely resisted plyometrics and plyometric training, are usually employed for improving explosive strength in basketball players.[5,6]

Plyometric training (PM) constitutes a natural part of the movements in basketball because they involve jumping, hopping, and skipping,[7] and a combination of eccentric and concentric contractions by which to engage muscles.[8] Therefore, PM has consistently been shown to improve the development of muscle force and power.[9] Thus, it is of value to include specific PM activities in training programs to improve the most important athletic abilities.

Resistance training is implemented in PM training by coaches as it may provide to enhance jumping ability in athletes.[10] There are a variety of resisted training methods coaches use, along with plyometric exercises such as water exercises,[11] training with dumbbells[12] or weight vest.[13.] Alemdaroglu et al. investigated the effects of plyometric training following a resistance pair sets in students and found an increase in vertical jump performance and muscle strength.[14] The effect of plyometric and resisted plyometric training on physical performance parameters will result in the optimization of the athlete's individual development and athletic skills. Therefore, athletic programs including PM and resisted PM would be effective for developing and maintaining the athlete's physical parameters throughout a season.

In the literature, relatively few studies have investigated the effects of resisted PM using a device manufactured for this purpose such as Vertimax on physical performance parameters in athletes. Rhea et al. showed that resisted training using Vertimax resulted in an increase in vertical jumping performance in a comparison with classical training in athletes from different sports such as baseball, gymnastics, soccer, and basketball.[15] Other studies found greater jumping effects for the traditional plyometric method relative to resisted plyometrics in recreationally trained students.[16] The results from recreational active volunteers or athletes from different sports cannot be generalized to distinctive groups such as basketball players which requires highly specific skills and demands. In their recent review, Makaruk et al. have pointed out the scarcity of studies on mechanisms to explain the specific effects of resisted plyometric training on the needs of different sport types.[17]

This study aimed to investigate the effect of PM and resisted PM by using a standard Vertimax device on vertical jump performance and isokinetic muscle strength in young athletes who perform regular basketball training.

MATERIALS AND METHODS

Participants

This study is approved by Ethics Committee of Clinical Research of Faculty of Medicine of Akdeniz University (approval number is 09.03.2016/177) in accordance by the latest version of the Declaration of Helsinki. All participants have signed an informed consent form before the testing and subsequent training programs. The athletes were evaluated in terms of chronic diseases such as heart disease, diabetes, stroke, hypertension, drug usage, allergy history, and sports injury. Participants who decided to withdraw from the study were excluded from the analysis.

Sixty male basketball players who were between the ages of 15–16 and who had been performing at a professional sports club for at least four years participated in the study. Athletes who could not join the study for more than a week because of injury during field training, giving up sports, being transferred, or illness were exempted from evaluation. Finally, data from 35 athletes (avg: 4 ± 1.8 years training experience) were analyzed.

Participants were divided into three groups randomly: a control group, which underwent the standard basketball training (C); a group that participated in PM in addition to standard basketball training (P); and a group that underwent resisted plyometric training (RP) using a Vertimax (Vertimax LLC, Model V8, Tampa, Florida, US) device in addition to standard basketball training. Initially, 60 athletes — 20 from group RP, 20 from group P, and 20 from group C — were recruited. However, 25 participants were excluded and data from 35 athletes — 12 from group C, 11 from group P, and 12 from group RP — were analyzed. Before the experiment took place, a sports medicine doctor examined all athletes; laboratory tests indicated that no athlete had any medical problems that would prevent them from participating in the study.

Training program

The training program was conducted for 12 weeks for all three groups. Accordingly, group C did standard basketball training for 12 weeks (Table 1), while groups P and RP underwent a plyometric, and resisted plyometric training, respectively, three times a week in addition to the standard basketball training for 12 weeks (Figure 1) (Table 2 and 3). The parameters stated below were measured at the onset and end of the training program.

Procedure

Baseline testing

The subjects' heights were measured using a sensitive height gauge (Soehnle-Waagen GmbH & Co. KG). Body composition parameters were measured using a bioelectric impedance device (TANITA, TBF-300, Tokyo, Japan) while athletes were barefoot and wearing light clothes.

Vertical jump test protocol

The vertical jump test was performed using the Newtest 2000 (Jumpmeter) test battery. The athlete jumped vertically as high as possible bending his knees and receiving support from the arms and the knees. Athletes performed three jumps; the highest jumping height was recorded. Anaerobic power (watts) was calculated using the following formula:

$$\text{Anaerobic Power} = \text{Body mass (kg)} \times \text{Distance (m)}^2 / \text{Time (sec)}^3$$

Isokinetic dynamometer test protocol

Force measurements of extensor and flexor muscles of both knees were obtained using an isokinetic dynamometer (CSMI Humac Norm, Stoughton, USA). After the 15 minutes of warm up and stretching exercises

Table 1. Body composition characteristics of the study groups.

	Pre-training			Post-training		
Variables	**C**	**P**	**RP**	**C**	**P**	**RP**
Age (Year)	15.50±0.52	15.46±0.82	15.75±0.75	15.75±0.52	15.71±0.82	16.00±0.75
Height (cm)	183.5±4.66	179.09±9.13	184.08±11.8	186±6.16	179.73±9.61	184.75±11.26
Body Mass (Kg)	70.21±7.71	68.56±14.75	73.90±14.93	71.17±8.05	70.36±14.02	75.17±14.69
BMI (kg.m^{-2})	21.55±2.07	20.86±3.01	2.77±2.62	21.54±2.06	21.74±2.76	22.48±2.44
% Fat	18.08±3.87	15.78±3.85	16.84±3.57	18.07±3.89	16.35±4.17	17.32±3.86
Fat Mass (kg)	13.41±4.16	11.29±5.25	12.83±4.33	13.69±4.21	12.15±5.47	13.62±4.78
LBM (kg)	59.15±6.14	57.25±10.41	61.45±11.58	59.10±6.13	59.18±9.84	63.17±11.37
Skeletal Muscle Mass						
Total	56.03±5.91	54.36±9.93	58.37±11.04	56.16±5.85	56.23±9.40	60.04±10.88
Lower Extremity	19.93±2.52	19.83±4.04	20.99±4.27	20.02±2.46	20.02±3.72	21.15±4.19
Upper Extremity	5.38±0.55	5.45±0.98	5.80±1.17	5.45±0.57	5.72±0.96	5.98±1.13
Trunk	30.54±3.09	29.09±5.13	30.95±4.91	30.98±3.52	30.49±4.98	32.33±4.99

BMI: Body Mass Index. LBM: Lean Body Mass. C: Control Group. P: Plyometric Group. RP: Resisted Plyometric Group.

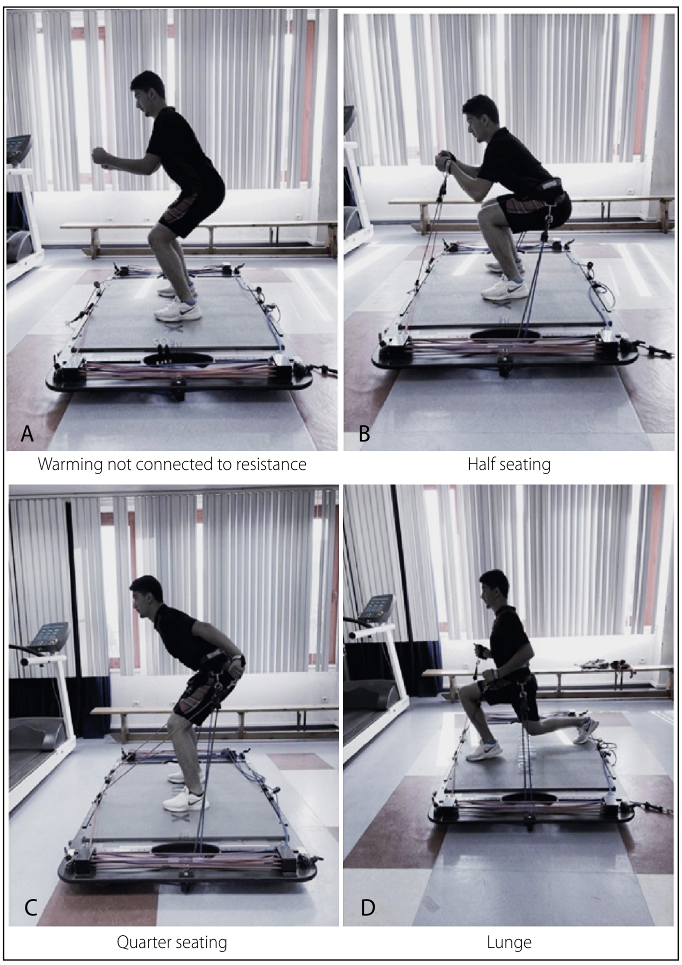

Figure 1. Demonstrations of the resisted plyometric exercises on the Vertimax platform .

for flexor and extensor muscle groups for both knees, the calibration of the device for each participant took place before the measurement.

The isokinetic concentric muscle strength of the subjects was tested using a protocol that included 4, 4, and 20 repetitions at 60 °s^{-1}, 180 °s^{-1}, and 300 °s^{-1} angular velocities, respectively. There were three repetitions at each angular velocity, to increase the orientation of the subjects to the test application. In order to prevent fatigue development, a two-minute rest period was provided between dominant and non-dominant extremity force measurements and a 20-second rest period between angular velocities. The subjects were encouraged verbally to perform at their maximum ability during the tests. Muscular force values of the subjects were obtained via the isokinetic dynamometer software. Peak moment values were used as the force parameter.

Table 2. Standard training program of all study groups.

Week	Number of Training/ Week	Content	Week	Number of Training/ Week	Content
1	4	Endurance run	7	10	Tra Mixed training + tactical
		Overall condition + fundamental training			Training for competition
2	7	Overall condition + fundamental training	8	10	Combined training
		Technical + mixed training			Combined training
3	10	Overall condition + technical	9	6	Combined training
		Technical + tactical			Combined training
4	10	Technical training + overall condition	10	6	Tactical + shooting
		Technical training +shooting			Tactical + shooting
5	10	Technical training + shooting	11	6	Preparation for the matches
		Technical + tactical + overall condition training			Overall condition + shooting
6	10	Technical + shooting	12	6	Preparation for the matches
		Technical + tactical			Preparation for the matches

Statistical analysis

The SPSS 23.0 software package (IBM, USA) was used for statistical analyses of the data. The results are presented as ± standard deviation (SD). The Shapiro-Wilk test was applied to determine the distribution of the parameters. One-way analysis of variance (ANOVA) was used for analysis of the parameters with homogeneous distributions, while the Kruskal Wallis test was used for intergroup analysis of parameters that did not exhibit a normal distribution. Comparison between the initial and final measurements was evaluated with a paired *t*-test; $p<0.05$ was used as the statistical significance level. Effect sizes (ES) were calculated as the mean difference between the initial and final measurements divided by the SD of the baseline measurement for each group. ES values of 0.01 to 0.19 were considered as very small, 0.2 to 0.49 as small, 0.5 to 0.79 as moderate, and >0.80 as large.

RESULTS

The body composition characteristics among the groups are presented in Table 1. The results of the statistical analysis showed that the individuals in the three groups had similar demographic characteristics.

No significant differences were observed between their initial and final measurements (p > 0.05).

The initial and final (post-experiment) measurements of anaerobic power among the study groups are presented in Table 4. Although participants in all groups exhibited an increase in jumping height scores post-experiment, a moderate increase was observed only in the control group ($p < 0.05$; ES: 0.5). Anaerobic power values from the vertical jump test slightly increased following plyometrics or resisted plyometrics exercises.

The pre- and post-experiment results of isokinetic peak moment at 60 $°s^{-1}$ of the right and left knee during extension and flexion among the study groups are presented in Table 5. No significant differences were found in isokinetic extensor peak moment results among the groups. However, an increase in isokinetic peak moment during flexion was found in C, P, and RP groups. The ES of the increase was found to be small, moderate, and large for C, P, and RP groups, respectively.

The isokinetic peak moment at 180 $°s^{-1}$ of the right and left knee during extension and flexion among the study groups is presented in Table 6. A statistically significant increase was found in the P and RP groups during knee flexion and extension. The ES values of the peak moment during knee extension were moderate for both groups, whereas the ES was moderate for the P group and large for the RP group during knee flexion.

The pre- and post-experiment results of isokinetic peak moment at 300 $°s^{-1}$ of the right and left knee during extension and flexion among the study groups are presented in Table 7. An increase in peak moment values were found in the C and P groups during knee extension; however, the ES values were notably large in the P and RP groups during knee flexion.

DISCUSSION

In the present study, we explored the impact of plyometric and resisted plyometric training on physical performance parameters in young athletes who participate in regular basketball training. The results of the study revealed the distinct impact of resisted plyometric training on leg power.

The PM method used in the study has become popular in the recent years and it is used safely in athletes of all ages.[15,16] Especially young athletes who are still developing physically, attempt to improve their physical capacity and athletic skills through training. Implementing the best training method available will improve the performances of athletes in this age group.

In this study, the age, physical characteristics and physical performance capacities of the athletes were found to be similar across the study groups. Importantly in our study, no injuries that would have impacted the final measurements were caused by the training.

Table 3. Training program of P and RP groups.

Weeks	Training Schedule		Sets x Repeats		Rest				BN and RG*		Training Number/ Week	
					Repeats		Between Sets (min)					
	P (jump)	RP (jump)	P	RP	P	RP	P	RP	P	RP	P	RP
1. 2.	Warming	Warming	1x10	1x10	1	1	3	3	0	ZR	3	3
	Half seating	Half seating	2x10	2x10	1	1	3	3	0	FL; **2***		
	Quarter seating	Quarter seating	2x10	2x10	1	1	3	3	0	FL; **2***		
	Lunge	Lunge	1x10	1x10	1	1	3	3	0	ZR		
3.4.	Warming	Warming	1x10	1x10	1	1	3	3	0	ZR	3	3
	Half seating	Half seating	2x12	2x12	1	1	3	3	0	FL; **2**		
	Quarter seating	Quarter seating	2x12	2x12	1	1	3	3	0	FL; **2***		
	Lunge	Lunge	1x6	1x10	1	1	3	3	0	ZR		
5.6.	Warming	Warming	1x10	1x10	1	1	3	3	0	ZR	3	3
	Quarter Seating Jump	Quarter Seating Jump	2x12	2x10	1	2	3	3	0	FL; **3***		
	Lunge Jump	Lunge Jump	1x10	1x10	1	1	3	3	0	ZR		
	Half seating	Half seating	2x12	2x10	1	2	3	3	0	FL; **3***		
7.8.	Warming	Warming	1x10	1x10	1	1	3	3	0	ZR	3	3
	Half seating	Half seating	3x10	2x12	2	2	3	3	0	FL; **3***		
	Quarter seating	Quarter seating	3x10	2x12	2	2	3	3	0	FL; **3***		
	Lunge	Lunge	1x10	1x10	1	1	3	3	0	ZR		
9.10	Warming	Warming	1x10	1x10	1	1	3	3	0	ZR	3	3
	Half seating	Half seating	3x12	2x10	2	2	3	3	0	FL; **4***		
	Quarter seating	Quarter seating	3x12	2x10	2	2	3	3	0	FL; **4***		
	Lunge	Lunge	1x10	1x10	1	1	3	3	0	ZR		
11.12	Warming	Warming	1x10	1x10	1	1	3	3	0	ZR	3	3
	Half seating	Half seating	4x10	2x12	2	2	3	3	0	FL; **4***		
	Quarter seating	Quarter seating	4x10	2x12	2	2	3	3	0	FL; **4***		
	Lunge	Lunge	1x10	1x10	1	1	3	3	0	ZR		

P: Plyometric Group, RP: Resisted Plyometric Group, BN: Binding Number, RG*: Resistance Grade, ZR: Zero resistance, FL: Four-location.

Table 4. Anaerobic power results of all study groups (watts) (Mean+SD).

Groups	Anaerobic power (Watts) Pre-training	Anaerobic power (Watts) Post-training	ES (Effect size)	Jumping height (cm) Pre-training	Jumping height (cm) Post-training	ES (Effect size)
C (n=12)	4946.51±761.75	5201.34±710.12	0.3	58.17±7.64	62.00±6.72*	0.5
P (n=11)	4555.26±749.64	4732.25±775.86	0.2	54.64±6.76	55.55±10.09	0.1
RP (n=12)	4936.79±714.04	5158.04±648.38	0.3	56.83±6.91	58.58±7.01	0.2

Control Group. P: Plyometric Group. RP: Resisted Plyometric Group. *p<05, difference from pre-training measurement.

Table 5. Isokinetic peak moment results of the knee during flexion and extension at $60°.s^{-1}$(Nm).

	Group	Right / Left	Pre-training	Post-training	Effect size (Pre-Post)
			X	X	
Extension	C	Right	192.67±33.44	200.17±27.83	0.24
		Left	185.08±27.29	184.42±28.37	-0.02
	P	Right	189.45±32.56	194.73±38.42	0.15
		Left	175.91±38.47	190.00±33.68	0.39
	RP	Right	198.50±47.49	209.25±50.19	0.22
		Left	192.17±43.08	200.33±46.98	0.18
Flexion	C	Right	110.17±13.29	112.75±16.40	0.17
		Left	112.50±21.49	120.25±17.9*	0.39
	P	Right	106.18±26.20	122.36±28.54*	0.59
		Left	108.18±23.36	118.64±20.67	0.48
	RP	Right	125.67±25.45	148.33±32.71*♯	0.78
		Left	119.17±25.07	134.25±30.74	0.54

C: Control Group. P: Plyometric Group. RP: Resisted Plyometric Group. *p<05, difference from pre-training measurement, ♯P<0.05, difference from cprresponding measurement of P group.

Table 6. Isokinetic peak moment results of the knee during flexion and extension at $180°.s^{-1}$(Nm).

	Group	Right / Left	Pre-training (Nm)	Post-training (Nm)	Effect size (Pre-Post)
			X	X	
Extension	C	Right	122.2±18.17	133.6±14.22	0.70
		Left	120.9±16.45	122.4±17.15	0.09
	P	Right	122.27±23.58	132.64±26.96*	0.41
		Left	117.91±21.94	130±22.57*	0.54
	RP	Right	132.22±15.01	143.56±16.71*	0.72
		Left	135.44±16.69	141.89±20.62	0.35
Flexion	C	Right	81.8±9.61	84.2±8.94	0.26
		Left	84.2±15.06	84.2±14.51	0.00
	P	Right	82.82±19.91	94.73±21.58*	0.57
		Left	83.18±19.63	92.64±16.87*	0.52
	RP	Right	91.22±14.69	116±16.35*♯	1.60
		Left	93.11±9.73	103.56±13.95*	0.88

C: Control Group. P: Plyometric Group. RP: Resisted Plyometric Group. *p<05, difference from pre-training measureament. ♯p<0.05, difference from cprresponding measurement of P group.

Table 7. Isokinetic peak moment results of the knee during flexion and extension at $300°.s^{-1}$(Nm).

	Group	Right / Left	Pre-training (Nm)	Post-training (Nm)	Effect size
			X	X	
Extension	C	Right	86.3±11.33	91±19.06	0.31
		Left	79.5±9.56	93±12.05*	1.25
	P	Right	85.91±15.1	96.55±17.94*	0.64
		Left	77.55±18.36	94.18±18.33*	0.91
	RP	Right	96±15.54	95.11±12.54	0.06
		Left	87.67±20.02	98.89±18.75	0.58
Flexion	C	Right	60.6±8.5	62.55±9.83	0.21
		Left	61±12.22	68.64±10.17	0.68
	P	Right	64.64±11.97	74.27±15.03	0.71
		Left	61.82±19.24	73.82±13.11*	0.74
	RP	Right	72±12.61	84±9.71*♯	1.08
		Left	63.67±16.24	73.89±7.47	0.86

C: Control Group. P: Plyometric Group. RP: Resisted Plyometric Group. *p<05, difference from pre-training measureament, ♯ p<0.05, difference from corresponding measurement of P group.

Vertimax© is a device that enables resisted combined training with the help of elastic ropes that have different resistance levels and can be applied to the arms and legs. Initially, the device was used three days a week with lower resistance levels and with submaximal exercises; resistance and repetitions were increased gradually over time. Due to the athletes were adolescents in the present study, three days a week with submaximal training was preferred.

A prominent increase in power expenditure (watts) was not found in P, or RP groups. In the literature, relatively few studies have used the Vertimax© device over different periods. McClinton et al.[16] compared acute resisted exercise using Vertimax© with deep vertical jump training and found that deep jump training twice a week for six weeks yielded more improvement in vertical jump performance in a comparison with resisted jump training with the same period of training time and frequency. Different results likely arose due to the duration of the training programs and methodological differences between the two studies. In contrast, in the present study, a significant and prominent increase in muscular force in the RP group was observed. This finding necessitates future studies that assess the impact and participation of muscles of the upper body and arm, which impact vertical jump performance.

Carlson et al.[19] argued that vertical jump performance is equally affected by six-week force training programs, plyometric training programs, and force training programs applied together with Vertimax©. In his meta-analysis, Markovicz[20] argued that PM increased vertical jump performance by 4.7–8.7% in healthy individuals. However, the researcher drew attention to the different methods used to measure vertical jump performance (test methods that include support from the arms or not, or differences in test speed) across studies on this topic, scarcity of research in which athletes and non-athletes were evaluated differently, sport-specific (basketball, cycling, long-distance running) differences, and relatively small effects of interventions.

Although the current study employed the training model that the vendor advises and that has been applied before, there were no significant differences, likely because of the method applied, the time and intensity of the training, and the characteristics of the participants such as genetic factors, age, weight, gender, or physical condition level. We suggest that studies conducted with different resistance levels will provide clearer information on this topic. We also consider the fact that the control group consisted of elite athletes and the vertical jump performance of C group was not poor in a comparison with the other groups.

In this study, contraction force of the knee flexor and extensor muscles of the athletes were found to be increased in P and RP groups. Increasing the force in the lower extremities is very important in sports activities, especially those in which jumping and sprinting activities are frequently used.[21–24] Plyometric training increases the stretch-shortening cycle of the muscles.[18] There is evidence that resisted plyometric training programs result in increases in the muscular force developed by the upper extremities, thus improving vertical jump performance.[25] In this study, no significant differences were observed in the 60 $°s^{-1}$ right and left leg extensor peak power results among the groups; however, an increase was detected in the 60 $°s^{-1}$ right leg flexor peak power values in the P and RP groups. An increase was also observed in the 180 $°s^{-1}$ right flexor and extensor measurement in the P and RP groups. Moreover, flexor and extensor power measurements at 300 $°s^{-1}$ increased notably in the P group. No significant differences in peak moment values were found among the groups at all three angular velocities. Plyometric and resisted plyometric training programs yielded significant changes in dominant leg power, especially in the 60 $°s^{-1}$ and 180 $°s^{-1}$ flexor muscle peak power measurements. The fact that no significant differences were observed in extensor muscle peak power data shows that the training programs used in the study did not train extensors to the same extent as flexor muscles. Consistent with this observation, Rhea et al. argued that higher muscular strength is obtained with Vertimax© application compared to traditional strength-training programs.[15,19]

In the P and RP groups, significant increases were observed in isokinetic peak moment during knee flexion and extension at 60 $°s^{-1}$, 180 $°s^{-1}$, and 300 $°s^{-1}$; however, improvements were not seen in anaerobic power. To our knowledge, the present study has original design since the resistive exercise (Vertimax©) was performed by adolescent basketball players for the first time, and also showing statistically significant results in isokinetic peak moment at 180 and 300 ºs-1.

CONCLUSION

In conclusion, the results of the present study clearly showed that although the effect of the anaerobic power is less pronounced, resisted plyometric training program on the Vertimax platform results an increase in muscle strength in young basketball players. Future studies using the Vertimax© device with different protocols would elucidate the impact of duration, frequency, or intensity on basketball-specific parameters more precisely.

ACKNOWLEDGEMENTS

This study was supported by The Scientific Research Projects Coordination Unit of Akdeniz University (Project number: TYL 2016-1574).

All authors declare no potential conflict of interest related to this article

AUTHORS' CONTRIBUTIONS: Each author made significant individual contributions to this manuscript. OP: intellectual concept and preparation of the entire project, data acquisition, data analysis, statistical analysis, interpretation and writing; EH: intellectual concept, data acquisition and data analysis; NU: data acquisition and data analysis; NH: data acquisition and data analysis; AG: data acquisition and data analysis; YGO: intellectual concept and preparation of the entire project and data acquisition and interpretation. All authors approved the final version of the manuscript.

REFERENCES

1. Ferioli D, Bosio A, La Torre A, Carlomagno D, Connolly DR, Rampinini E. Different training loads partially influence physiological responses to preparation period in basketball. J Strength Cond Res. 2018;32(3):790–797.
2. Stojanovic E, Stojiljkovic N, Scanlan AT, Dalbo VJ, Berkelmans DM, Milanovic Z. The activity demands and physiological responses encountered during basketball match-play: A systematic review. Sports Med. 2018;48(1):111–135.
3. Taylor JB, Wright AA, Dischiavi SL, Townsend MA, Marmon AR. Activity demands during multidirectional team sports: A systematic review. Sports Med. 2017;47:2533–2551.
4. Ziv G, Lidor R. Physical attributes, physiological characteristics, on-court performances and nutritional strategies of female and male basketball players. Sports Med. 2009;39(7):547–568.
5. Santos EJAM, Janeira M. The effects of plyometric training followed by detraining and reduced training periods on explosive strength in adolescent male basketball players. J Strength Cond Res. 2011;25(2):441–452.
6. Santos EJ, Janeira MA. Effects of complex training on explosive strength in adolescent male basketball players. J Strength Cond Res. 2008;22(3):903-909.
7. Gonzalo-Skok O, Sánchez-Sabaté J, Izquierdo-Lupón L, Sáez de Villarreal E. Influence of force-vector and force application plyometric training in young elite basketball players. Eur J Sport Sci. 2019;19(3):305–314.
8. Komi PV. Stretch-shortening cycle: A powerful model to study normal and fatigued muscle. J Biomech. 2000;33(10):1197-1206.
9. Wagner DR, Kocak MS. A multivariate approach to assessing anaerobic power following a plyometric training program. J Strength Cond Res. 1997;11(4):251-255.
10. Argus CK, Gill ND, Keogh JWL, Blazevich AJ, Hopkins WJ. Kinetic and training comparisons between assisted, resisted, and free countermovement jumps. J Strength Cond Res. 2011;25:2219-2227.
11. Robinson LE, Devor ST, Merrick MA, Buckworth J. The effects of land vs. aquatic plyometrics on power, torque, velocity, and muscle soreness in women. J Strength Cond Res. 2004;18:84-91.
12. Markovic S, Mirkov DM, Knezevic OM, Jaric S. Jump training with different loads: Effects on jumping performance and power output. Eur J Appl Physiol. 2013;113(10):2511-2521.
13. Khlifa R, Aouadi R, Hermassi S, Chelly MS, Jlid MC, Hbacha H, et al. Effects of a plyometric training program with and without added load on jumping ability in basketball players. J Strength Cond Res. 2010;24(11):2955-2961.
14. Alemdaroğlu U, Dündar U, Köklü Y, Aşci A, Findikoğlu G. The effect of exercise order incorporating plyometric and resistance training on isokinetic leg strength and vertical jump performance: A comparative study. Isokinet Exerc Sci. 2013;21(3):211-217.
15. Rhea MR, Peterson MD, Lunt KT, Ayllon FN. The effectiveness of resisted jump training on the VertiMax in high school athletes. J Strength Cond Res. 2008;22(3):731-4.
16. McClenton LS, Brown LE, Coburn JW, Kersey RD. The effect of short-term VertiMax vs. dePMh jump training on vertical jump performance. J Strength Cond Res. 2008;22(2):321-5.
17. Makaruk H, Starzak M, Suchecki B, Czaplicki M, Stojiljković N. The Effects of Assisted and Resisted Plyometric Training Programs on Vertical Jump Performance in Adults: A Systematic Review and Meta-Analysis. J Sport Sci Med. 2020;19(2):347-357.
18. Harries SK, Lubans DR, Callister R. Resistance training to improve power and sports performance in adolescent athletes: A systematic review and meta-analysis. J Sci Med Sport. 2012;15(6):532–540.
19. Carlson K, Magnusen M, Walters P. Effect of various training modalities on vertical jump. Res Sports Med. 2009;17:84-94.
20. Markovic, G. Does plyometric training improve vertical jump height? A meta-analytical review. Br J Sports Med. 2007;41(6):349-355.
21. Baker, D. Selecting the appropriate exercises and loads for speed-strength development. Strength Cond Coach. 1995;3:8-15.
22. Cetin E, Hindistan IE, Ozkaya YG. Effect of different training methods on stride parameters in speed maintenance phase of 100-m sprint running. J Strength Cond Res. 2018;32(5):1263–1272.
23. Hindistan IE, Ozdogan EC, Bilgin G, Colak OH, Ozkaya YG. Effects of sprint interval training on sloping surfaces on aerobic and anaerobic power. Biomed Hum Kinet. 2020;12(1):41-50.
24. Haff GG, Whitley A, Potteiger JAA. A Brief Review: Explosive exercises and sports performance. Strength Cond J. 2001;23(3):13-20.
25. Harman EA, Rosenstein MT, Frykman PN, Rosenstein RM. The effects of arms and countermovement on vertical jumping. Med Sci Sports Exerc. 1990;22(6):825-33.