ORIGINAL ARTICLE

The contribution of plyometric exercises assisted by sensory technology on vertical jump parameters in U15 female volleyball players

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim Volleyball requires high vertical jump skills for crucial actions like attacking and blocking, making jump training a focus for players, especially in youth categories. The main goal of the study was to highlight (with some specific data) the strengths and weaknesses of integrating sensory technology into the physical training program, during the entire competitive period.

Material and Methods The study included both an experimental and a control group, each consisting of 16 female athletes from the volleyball section of the Cetate Sports High School in Deva. During the competitive season of 2022/2023, both groups underwent daily training sessions from Monday to Saturday, totaling 120 minutes per day. The BlazePod Flash Reflex Training system was employed in this research. It integrates cognitive training to enhance thinking speed and clarity with physical exercises aimed at maximizing motor skills. Performance evaluations of the athletes utilized eight predefined tests from the OptoJump Next optical measuring system and the Myotest accelerometric system. To analyze the data, paired (dependent) sample t-tests were conducted to compare average parameters between matched samples. Repeated measures ANOVA was utilized to compare the average outcomes, ensuring the participants were consistent across the evaluated conditions.

Results The experimental group showed significant improvements in the height reached from the center of gravity and flight time for the following tests: Countermovement Jump, Countermovement Jump with Arm Swing, Squat Jump, Squat Jump with Arm Swing, and Drop Jump from 30 cm. All improvements reached statistical significance: $p<0.05$. Significant enhancements were also observed in average jump height, jump power, force of jumps, and ascensional speed, demonstrating statistical significance ($p<0.05$). Furthermore, the use of an arm swing during jumps notably improved performance compared to when jumps were performed with hands on hips. This indicates that an arm swing can significantly increase the height of the vertical jump ($p<0.05$).

Conclusions The study confirms that the integration of sensory technology into the training programs for junior volleyball teams is effective in enhancing training outcomes. This approach not only improves the vertical jump capabilities of young athletes but also positively affects their ability to perform technical moves that require elevation from the ground. It underscores the potential of innovative training methods in advancing athletic performance in youth sports.

Keywords: volleyball, plyometrics, sensory technology, vertical jump

Introduction

Volleyball, a dynamic and complex sport, is rooted in natural human movements and carries significant instructional and educational values. Its popularity has surged globally, especially among younger athletes, marking it as one of the world's most favored sports [1]. With its explosive growth, the sport presents unique challenges and opportunities for athletic development.

The success in volleyball is heavily dependent on the athlete's physical capabilities, particularly in performing vertical jumps that are crucial for executing key actions like attacking, setting, serving, and blocking [2, 3]. These skills highlight the importance of specialized physical training within the sport's competitive framework [4, 5]. This emphasis on athleticism bridges to the sport's physiological demands.

Traditionally considered a high-power, predominantly anaerobic activity, volleyball requires athletes to engage in intense bursts of activity with short recovery periods between points [6,7,8]. This structure of play necessitates a comprehensive physical conditioning program that balances both aerobic and anaerobic capacities for sustained performance [9, 10]. The integration of such conditioning within training regimens poses a challenge yet is critical for reaching peak performance levels.

While the significance of physical training in

doi:10.15561/26649837.2024.0210

enhancing athletic performance is universally acknowledged [11], achieving excellence in volleyball is particularly challenging due to the need for a harmonious blend of physical training with other training components [12]. However, there is often a gap in applying a scientific basis to physical training, especially at the youth level, which can limit athletes' potential [13]. Addressing this gap requires a detailed understanding of the sport's demands and the strategic application of training methodologies.

Against this backdrop, the introduction of sensory technology into volleyball training presents a promising avenue for enhancing physical training outcomes. The study by Vuorinen [14] systematically incorporates sensory technology into the training regimen to explore its potential in optimizing vertical jump performance and related skills. This approach not only aims to elevate the athletes' physical capabilities but also integrates innovative training methods that support their overall development in the sport.

This strategic incorporation is expected to significantly improve vertical jump capabilities and the performance of skills requiring ground detachment, thereby illustrating the tangible benefits of incorporating advanced sensory technologies into sports training.

The main goal of the study was to highlight (with some specific data) the strengths and weaknesses of integrating sensory technology into the physical training program, during the entire competitive period.

Materials and Methods

Participants

The study involved two groups: an experimental group and a control group, each consisting of 16 female athletes from the volleyball section of Cetate Sports High School in Deva. The composition of each group was evenly divided between athletes: 8 athletes were 15 years old (born in 2009), and the other 8 were 14 years old (born in 2010). Detailed characteristics of the athletes are provided in Table 1.

Prior to the commencement of the study, informed consent was obtained from the parents of all participating athletes. Additionally, the study protocol was thoroughly reviewed and approved by the Ethics Committee of the University.

Research Design

During the competitive season of 2022/2023, both the experimental and control groups engaged in daily training sessions from Monday to Saturday, each lasting 120 minutes. The evaluation of the athletes involved eight predefined tests. These assessments were facilitated by two distinct systems: the optical measuring system, OptoJump Next (Table 2), and the accelerometric system, Myotest (Table 3).

Additionally, the study utilized the BlazePod Flash Reflex Training system. This innovative equipment combines cognitive exercises aimed at enhancing mental processing speed with physical training activities designed to maximize motor skills (Table 4).

Table 1. Characteristics of the athletes.

Characteristics	EG		CG	
	14.11.2022	**15.05.2023**	**14.11.2022**	**15.05.2023**
Height (cm)	1.67 ± 0.04	1.69 ± 0.05	1.68 ± 0.03	1.70 ± 0.03
Weight (kg)	53.68 ± 3.15	55.12 ± 3.22	54.87 ± 3.11	55.93 ± 2.88

Values are expressed as means ± standard deviations. EG = experimental group, CG = control group.

Table 2. Tests performed with the Optojump optical measurement system.

Test	Purpose	Measured parameters
Countermovement jump with arm swing (CMJAS)	Evaluation of explosive force of lower limbs	Flight time (FT), height reached from center of gravity (JH)
Squat jump with arm swing (SJAS)	Evaluation of explosive force of lower limbs	Flight time (FT), height reached from center of gravity (JH)
Successive vertical jumps for 10 seconds (10 s)	Analysis of anaerobic power	Average: contact time (AVCT), flight time (AVFT), height of jumps (AVJH), power of each jump (AVP)
Countermovement jump (CMJ)	Evaluation of explosive force of lower limbs	Flight time (FT), height reached from center of gravity (JH)
Squat jump (SJ)	Evaluation of explosive force of lower limbs	Flight time (FT), height reached from center of gravity (JH)
Drop jump 30 cm (DJ30)	Evaluation of explosive force of lower limbs	Contact time (CT), flight time (FT), height reached from center of gravity (JH), power of each jump (P)

During the competitive season of 2022/2023, both the experimental and control groups engaged in daily training sessions from Monday to Saturday, each lasting 120 minutes. The athletes were evaluated using eight predefined tests, facilitated by two distinct systems: the optical measuring system, OptoJump Next (Table 2), and the accelerometric system, Myotest (Table 3).

Additionally, the BlazePod Flash Reflex Training system was utilized in this study. This cutting-edge equipment merges cognitive exercises, designed to enhance mental processing speed, with physical training activities aimed at optimizing motor skills (Table 4).

Throughout the competition period, from November 2022 to May 2023, physical training sessions were conducted weekly from Monday to Thursday. Exercises targeting the development of muscles in the lower and upper limbs, shoulders, chest, and back were exclusively performed using elastic cords/tubes. Both groups participated in the same exercises for the duration of the study.

Blazepod: Plyo Box

Placement of Light Capsules: Three light capsules are positioned atop three plyometric boxes of different heights: 20 cm, 30 cm, and 40 cm. These boxes are aligned in a straight line.

Table 3. Tests performed with the Myotest accelerometric system.

Test	Purpose	Measured parameters
3 consecutive countermovement jumps (My-CMJ)	Evaluation of explosive force of lower limbs	Average: jump height (AVJH), jump power (AVP), force of jumps (AVF), ascensional speed (AVS)
3 consecutive squat jumps (My-SJ)	Evaluation of static dynamic explosiveness of the lower limbs	Average: jump height (AVJH), jump power (AVP), force of jumps (AVF), ascensional speed (AVS) Maximum power (PMAX)

Table 4. Intervention program.

Day	Type of training	Training content EG	Training content CG
Monday	Aerobic	Blazepod: Run pacer drill 6 min/km	Run at 2/4 tempo around the hall or the length of it for 6 minutes
Tuesday	Anaerobic	1. Blazepod cognitive agility - 2 rep.	1. 6 x 15/18 m (Intensity 100%)
		2. Blazepod speed trap - 2 rep.	2. 6 x 10/12 m
		3. Blazepod speed competition - 2 rep.	3. 6 x 5/8 m
	Plyometric	1. Blazepod: Plyo box - 1 set	1. Plyo box jumps (30 cm) x 10 rep.
		2. Blazepod: Lateral jumps over hurdles + 3-step spike approach - 1 set	2. Lateral jumps over hurdles + 3-step spike approach x 6 rep.
		3. Blazepod: Lateral hurdle jumps - 1 set	3. Lateral hurdle jumps 45 s
		4. Blazepod: Block jumps with added steps- 1 set	4. Side step block jumps 30 s
		5. Blazepod: Plyo codes - 1 set	5. Plyo jumps 30 s
Wednesday	Aerobic	Blazepod: Run pacer drill 6 min/km	Run at 2/4 tempo around the hall or the length of it for 6 minutes
Thursday	Anaerobic	1. Blazepod cognitive agility 2 rep.	1. 6 x 15/18 m (Intensity 100%)
		2. Agility star 2 rep.	2. 6 x 10/12 m
		3. Blazepod speed box 2 rep.	3. 6 x 5/8 m
	Plyometric	1. Blazepod: Plyo box - 1 set	1. Plyo box jumps (30 cm) x 10 rep.
		2. Blazepod: Lateral jumps over hurdles + 3-step spike approach - 1 set	2. Lateral jumps over hurdles + 3-step spike approach x 6 rep.
		3. Blazepod: Lateral hurdle jumps - 1 set	3. Lateral hurdle jumps 45 s
		4. Blazepod: Block jumps with crossed steps - 1 set	4. Cross step block jumps 30 s
		5. Blazepod: Plyo codes - 1 set	5. Plyo jumps 30 s

Distance: There is a 1-meter gap between each of the plyometric boxes to ensure adequate space for movement.

Starting Position: Participants begin standing one meter behind the middle plyometric box. They are required to observe and react to the capsule that illuminates.

Exercise Structure: Upon illumination of a light capsule on a box, the participant swiftly moves to the indicated box and performs a jump onto it with an arm swing. After landing on the box, they jump back down to the ground and prepare to react to the next capsule lighting up, thus continuing the jumping sequence. Movement between the boxes involves either added steps or cross steps to maintain agility and coordination.

Accessories Required: Three plyometric boxes are utilized in this exercise setup.

Duration: The exercise consists of making 10 contacts with the luminous capsules, with participants responding to the lights by performing jumps onto the corresponding boxes.

Blazepod: Lateral jumps over hurdles + 3-step spike approach

Placement of Light Capsules: Two small hurdles, each 15 cm in height, are positioned in a straight line on the ground. Light capsules are placed at the end of this line.

Distance: There is a 1-meter gap between the hurdles and the capsules.

Starting Position: Participants begin the exercise standing midway between the hurdles and the capsules.

Exercise Structure: Participants execute a lateral jump from a two-footed stance over the hurdle towards the end where the light capsule illuminates. They then return to the starting position by performing a lateral jump from two feet. After completing 3 jumps over the hurdles and returning to the starting position, the subject performs a 3-step spike approach toward the net, concluding with a landing on mats or a plyometric box.

Duration: Participants are required to perform 6 complete jumping cycles. There is a 20-second rest period between each cycle to allow for recovery.

Accessories Required: Two hurdles, each 15 centimeters in height, are used in this exercise.

Blazepod: Lateral Hurdle Jumps

Placement of Light Capsules: Five hurdles, each 25 centimeters high, are aligned in a row on the ground. Four light capsules are positioned between these hurdles.

Distance: There is a 50-centimeter gap between each of the hurdles. The light capsules are situated 50 centimeters in front of the line of hurdles.

Starting Position: Participants start the exercise positioned equidistantly between two hurdles, facing the direction of the light capsules.

Exercise Structure: Upon the activation of a light capsule, the participant executes lateral jumps over the hurdles towards the illuminated capsule. Upon reaching it, the participant touches the capsule, then visually locates the next lighting capsule and repeats the jumping process towards it, continuing until the end of the activity sequence.

Duration: Each touch triggers a change in capsule color, with the total duration of the activity set at 45 seconds.

Accessories Required: Five hurdles, each 25 centimeters in height, are used for this exercise.

Blazepod: Plyo Codes

Placement of Light Capsules: Four light capsules are positioned on the ground in a single row.

Distance: A 20 cm gap is maintained between each of the light capsules.

Starting Position: Participants begin the exercise standing 2 meters behind the row of light capsules, centrally within a square delineated by 15 cm hurdles.

Exercise Structure: Upon the illumination of a capsule, the participant undertakes the exercise designated for that specific color, continuing with that activity until the next capsule lights up. The designated exercises are as follows:

a. First Color: The participant executes two-legged jumps forwards or backwards over the hurdle located at the front or back of the square.

b. Second Color: The participant performs lateral two-legged jumps to the left or right, going over the hurdle on the respective side.

c. Third Color: Engaging in bouncing movements on two legs, akin to a ball, within the center of the square.

Duration: Capsule color changes occur every 4-6 seconds, with the overall activity lasting for 30 seconds.

Blazepod: Block Jumps with Side or Cross Step

Placement of Light Capsules: Two light capsules are positioned at an elevated level.

Distance: The capsules are affixed to the volleyball net, set at a height tailored to the athlete performing the exercise, ranging from 2.24 to 2.60 meters. They are spaced 3 to 4 meters apart.

Starting Position: Participants start positioned equidistantly between the two capsules, standing wide apart.

Exercise Structure: Upon the activation of one capsule, the participant advances towards it using side steps or cross steps, makes contact with the capsule, and then lands securely on both feet. Following the landing, the participant awaits the lighting of the opposite capsule before moving towards it, again utilizing side steps, cross steps, or huddled steps for movement.

Duration: The exercise is performed continuously for 30 seconds, focusing on the dynamic transition between capsules.

Statistical Analysis

Statistical processing of the research data was carried out using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY). Continuous variables were expressed as mean values and standard deviations, while categorical variables were presented in terms of absolute frequencies and percentages. Paired (dependent) sample t-tests were employed to compare mean values between paired samples. For comparing the means across groups, where participants remained the same in each group, repeated measures ANOVA was utilized. To assess mean differences according to dichotomous variables within the study, the t-test for independent samples was applied. A p-value of less than 0.05 was considered to indicate statistical significance.

Results

In the Countermovement Jump (CMJ), the experimental group showed an increase in Jump Height (JH) of 27.37% ($p<0.05$) and Flight Time (FT) of 12.92% ($p<0.05$). The control group also exhibited an upward trend in both parameters: a 24.1% increase in JH and an 11.26% rise in FT (Table 5).

Significant improvements were observed in the Countermovement Jump with Arm Swing (CMJAS) during the experimental program. The average JH increased by 28.25% ($p<0.05$), and the FT by 13.7% ($p<0.05$). Similarly, the control group demonstrated notable advancements in this test; FT increased from an average of 0.444 seconds to 0.496 seconds, marking a 12.73% increase in the final test compared to the initial one. An approximate 25% increase in the average JH was observed in the control group during the competitive period of the annual training plan.

For the Squat Jump (SJ), specific training proved crucial, leading to an increase in Jump Height (JH) of 25.18% ($p<0.05$) in the experimental group and 21.77% in the control group. The Flight Time (FT) improvements were approximately half of those observed for JH: 11.86% ($p<0.05$) in the experimental group and 10.72% in the control group.

The Squat Jump with Arm Swing (SJAS) yielded similar outcomes to the previous test. Specifically, JH and FT increased by 29.43% ($p<0.05$) and 13.79% in the experimental group, respectively, and by 25.26% ($p<0.05$) and 11.85% in the control group.

Employing an arm swing enabled the athletes to perform significantly better than in similar tests conducted with hands on hips. These results suggest that the use of an arm swing can contribute to an approximate 4% increase ($p<0.05$) in the height of the vertical jump, as opposed to jumps executed with the subject's hands on their hips (Table 6, Table 7).

The Drop Jump from 30 cm (DJ30) report included four parameters: jump height (JH), flight time (FT), power (P in W/kg), and contact time (CT in seconds). In the DJ30, the experimental group exhibited an average increase in JH of 26.44% ($p<0.05$), while the control group showed a slightly lower improvement, at 8.23% less than the DJ30 results. FT enhancements were observed at about 11.65% ($p<0.05$) for the experimental group and approximately 9% for the control group. Notably, power (P) measured during the DJ30 increased by 44% in both groups. Additionally, the experimental group demonstrated a significant reduction in CT by 27.79% during the DJ30, with the control group also showing a notable decrease of 33.33% in this parameter.

In the Myotest device's 3 consecutive Countermovement Jumps (My-CMJ), the experimental group demonstrated substantial improvements from the initial to the final testing, with an 18.12% ($p<0.05$) increase in Average Jump Height (AVJH), a 25.49% rise in Average Jump Power (AVP), a 6.34% ($p<0.05$) enhancement in Average Force (AVF), and an 11.82% ($p<0.05$) uplift in Average Ascensional Speed (AVS). The control group also noted improvements, with an 11.25% increase in AVJH, a 25.49% rise in AVP, an 8.82% increase in AVF, and a 7.96% enhancement in AVS.

The assessment of the lower limbs' static-dynamic explosiveness utilized the Myotest device, wherein participants were required to execute three successive squat jumps (My-SJ). The outcomes of this particular test indicated a discernible advantage for the experimental group, with an improvement margin of 2-4% over the control group.

A consistent parameter across all conducted tests was jump height. Analyzing the outcomes associated with this parameter reveals that, by the conclusion of the 26-week competitive period, the experimental group demonstrated enhancements ranging from 3% to 7% in comparison to the control group, as detailed in Figure 1.

Discussion

Is Plyometric Training Safe for Children?

This question is paramount in performance sports, especially considering the associated risks of injury, potential muscle soreness, overtraining, or even frustration when involving young athletes [15].

Faigenbaum and Yap [16] argue that plyometrics are inherently part of many natural movements, as demonstrated by the variety of jumps seen in children's play activities. Even walking, a fundamental voluntary motor action, embodies a form of plyometric exercise since each step initiates a stretch-shortening cycle in the quadriceps.

To mitigate the potential negative outcomes of plyometric training, it is imperative for coaches to have a thorough understanding of the neurophysiological, musculoskeletal, and mechanical principles underpinning plyometric

Table 5. Results & Corelations.

Test & parameter	Experimental group		Control group		Correlations between EG & CG			
	Pre test	Post test	Pre test	Post test	Pre test	Post test	Pre test	Post test
					t	t	Sig. (2-tailed)	Sig. (2-tailed)
CMJ - JH (cm)	24.86 ± 2.3	31.64 ± 3.05	23.24 ± 2.47	28.84 ± 2.01	1.9	3.6	0.066	0.005
CMJ - FT (s)	0.45 ± 0.02	0.51 ± 0.03	0.44 ± 0.03	0.48 ± 0.02	1.9	2.99	0.067	0.006
CMJAS - JH (cm)	26.26 ± 2.5	33.73 ± 3.71	24.24 ± 2.53	30.23 ± 1.96	2.28	3.32	0.030	0.002
CMJAS - FT (s)	0.46 ± 0.02	0.44 ± 0.01	0.52 ± 0.02	0.49 ± 0.01	2.15	3.26	0.390	0.003
SJ - JH (cm)	24.62 ± 2.22	30.82 ± 2.91	22.69 ± 2.31	27.63 ± 1.64	2.4	3.81	0.022	0.001
SJ - FT (s)	0.44 ± 0.02	0.5 ± 0.02	0.42 ± 0.02	0.47 ± 0.01	2.4	3.75	0.023	0.001
SJAS - JH (cm)	25.69 ± 2.36	33.25 ± 3.54	23.67 ± 2.32	29.65 ± 1.97	2.43	3.54	0.021	0.001
SJAS - FT (s)	0.45 ± 0.02	0.52 ± 0.02	0.43 ± 0.02	0.49 ± 0.01	2.42	3.47	0.021	0.002
DJ30 - JH (cm)	25.95 ± 2.73	32.81 ± 4.20	24.22 ± 28.63	28.63 ± 1.76	2.02	3.66	0.052	0.001
DJ30 - P (W/kg)	24.53 ± 3.29	35.41 ± 4.60	23.59 ± 3.48	34.16 ± 3.9	0.785	0.829	0.439	0.414
DJ 30 - FT (s)	0.45 ± 0.02	0.51 ± 0.03	0.44 ± 0.01	0.48 ± 0.01	1.96	3.67	0.059	0.001
DJ30 – CT (s)	0.38 ± 0.04	0.27 ± 0.03	0.39 ± 0.07	0.26 ± 0.04	- 0.215	1.36	0.831	0.182
10 s - AVJH (cm)	24.20 ± 2.68	27.21 ± 4.15	22.95 ± 2.41	24.63 ± 2.37	1.38	2.15	0.177	0.039
10 s - AVCT (s)	0.37 ± 0.07	0.23 ± 0.05	0.33 ± 0.05	0.25 ± 0.03	1.67	-1.18	0.105	0.244
10 s - AVFT (s)	0.44 ± 0.02	0.46 ± 0.03	0.43 ± 0.02	0.44 ± 0.02	1.37	2.14	0.179	0.040
10 s - AVP (W/kg)	24.86 ± 5.19	35.33 ± 6.91	23.91 ± 2.96	30.75 ± 4.29	0.635	2.25	0.530	0.032
MY-CMJ AVJH (cm)	24.83 ± 2.53	29.33 ± 3.57	24.35 ± 1.8	27.09 ±1.46	0.618	2.32	0.541	0.027
MY-CMJ AVP (W/kg)	34.36 ± 4.78	41.99 ± 5.37	33.39 ± 2.71	36 ± 3.9	0.704	0.487	0.487	0.001
MY-CMJ AVF (N/kg)	21.75 ± 2.37	23.13 ± 2.71	22.21 ± 2.02	22.83 ± 2.56	- 0.601	0.321	0.552	0.750
MY-CMJ AVS (cm/s)	202.75 ± 15.6	227.13 ± 16.6	201.19 ± 6.1	216.88 ± 7.46	0.372	2.24	0.712	0.032
MY-SJ AVJH (cm)	24.41 ± 2.47	28.17 ± 3.10	23.78 ± 1.91	26.54 ± 1.37	0.806	1.924	0.426	0.064
MY-SJ AVP (W/kg)	36.15 ± 2.53	39.36 ± 4.11	35.53 ± 2.43	38 ± 2.59	0.697	1.121	0.491	0.271
MY-SJ PMax (W/kg)	37.73 ± 2.82	40.62 ± 4.16	36.75 ± 2.01	38.72 ± 2.83	1.14	1.509	0.271	0.263
MY-SJ AVF (N/kg)	22.30 ± 2.02	23.82 ± 1.92	23.02 ± 2.27	23.88 ± 3.08	- 0.951	- 0.062	0.349	0.951
MY-SJ AVS (cm/s)	207.38 ± 13.6	223.13 ± 11.4	209.13 ± 21.3	219.69 ± 6.6	- 0.276	1.04	0.784	0.305

EG = experimental group, CG = control group, CMJ = countermovement jump, CMJAS = countermovement jump with arm swing, SJ = squat jump, SJAS = squat jump with arm swing, 10 s = successive vertical jumps for 10 seconds, DJ30 = drop jump 30 cm, MY-CMJ = 3 consecutive countermovement jumps, MY-SJ = 3 consecutive squat jumps, FT = flight time, JH = height reached from center of gravity, AVCT = average contact time, AVFT = average flight time, AVJH = average height of jumps, AVP = average power of each jump CT = contact time, P = power of each jump, AVF = average force of jumps, AVS = average ascensional speed, PMAX = maximum power.

Table 6. Statistical indicators of CMJ & CMJAS.

Group		Pair	t	p (2-tailed)
EG	1	CMJ JH (cm) IT - CMJAS JH (cm) - IT	-5.144	0.000
	2	CMJ FT(s) IT - CMJAS FT (s) - IT	-4.145	0.001
	3	CMJ JH (cm) FT – CMJAS JH (cm) FT	-6.883	0.000
	4	CMJ FT (s) FT - CMJAS FT (s) FT	-7.297	0.000
CG	1	CMJ JH (cm) IT - CMJAS JH (cm) - IT	-10.651	0.000
	2	CMJ FT(s) IT - CMJAS FT (s) - IT	-10.787	0.000
	3	CMJ JH (cm) FT – CMJAS JH (cm) FT	-10.377	0.000
	4	CMJ FT (s) FT - CMJAS FT (s) FT	-10.233	0.000

EG = experimental group, CG = control group, CMJ= countermovement jump, JH= height reached from center of gravity, FT= flight time, IT= initial test, FT= final test.

Table 7. Statistical indicators of SJ & SJAS.

Group		Pair	t	p (2-tailed)
EG	1	SJ JH (cm) IT - SJAS JH (cm) - IT	-6.467	0.000
	2	SJ FT(s) IT - SJAS FT (s) - IT	-6.357	0.000
	3	SJ JH (cm) FT – SJAS JH (cm) FT	-8.979	0.000
	4	SJ FT (s) FT - SJAS FT (s) FT	-9.446	0.000
CG	1	SJ JH (cm) IT - SJAS JH (cm) - IT	-5.435	0.000
	2	SJ FT(s) IT - SJAS FT (s) - IT	-5.436	0.000
	3	SJ JH (cm) FT – SJAS JH (cm) FT	-7.875	0.000
	4	SJ FT (s) FT - SJAS FT (s) FT	-7.832	0.000

EG = experimental group, CG = control group, SJ= squat jump, JH= height reached from center of gravity, FT= flight time, IT= initial test, FT= final test.

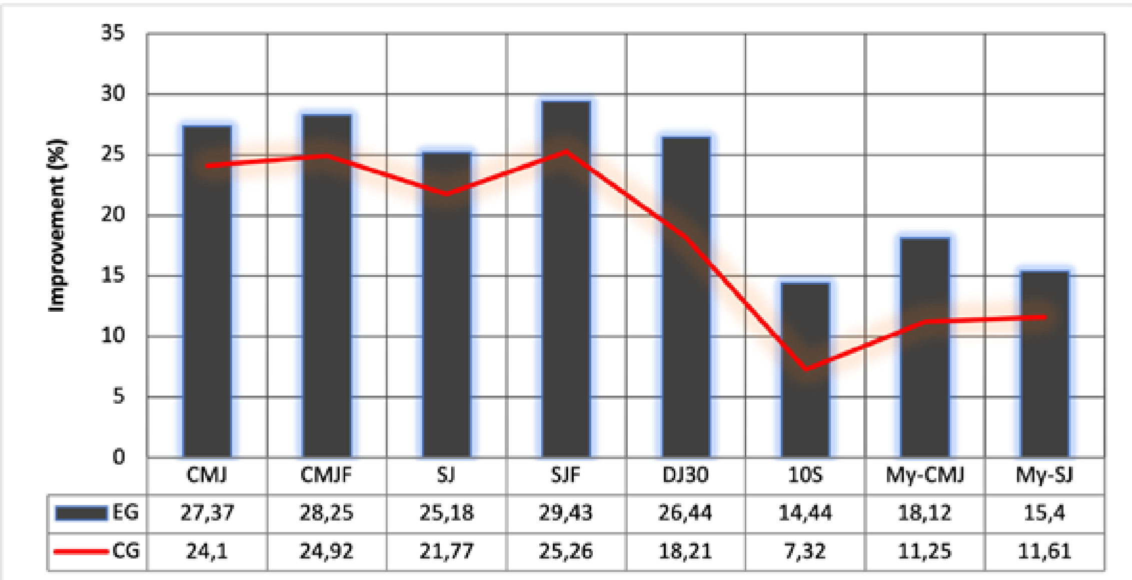

Figure 1. Jump height improvements. EG = experimental group, CG = control group.

exercises [17]. Properly structured plyometric training, developed with careful consideration, can enhance the contractile characteristics of children's muscles and augment the neural mechanisms involved in muscle contraction [18].

Strength Training in the Youth Sector

Historically, performance sports specialists were hesitant to endorse strength training for young athletes, citing concerns over potential damage to children's growing bones. However, this viewpoint has evolved significantly, thanks in large part to research showing that properly designed and supervised strength training programs do not cause cracks or fractures in cartilage growth plates.

Over the last three decades, extensive research has underscored the benefits of strength training for children, provided that such training is carefully supervised and involves lifting appropriate weights [19, 20, 21]. The Department of Pediatrics at Stanford University School of Medicine in the USA [22] has endorsed strength training for young athletes, highlighting its correct application's numerous advantages. When executed properly, strength training can increase muscle strength, enhance bone density, strengthen ligaments and tendons, boost athletic performance, and potentially prevent injuries among youth athletes.

Stanford specialists advocate that children engaged in strength training can utilize a variety of methods, including free weights, body weight exercises, fitness machines, and other apparatus like elastic bands. Reflecting on this guidance, our research has similarly embraced the use of exercises with elastic tubes/bands. The beneficial outcomes of such training modalities have been well-documented across multiple studies [23, 24, 25].

The Validity of the Testing Equipment

In our research, assessments were conducted using the OptoJump Next optical measurement system and the Myotest system. The OptoJump Next is adept at facilitating movement tests requiring precise time measurements, while the Myotest system employs three-dimensional accelerometry to accurately measure specific athletic parameters.

The reliability and validity of the OptoJump system, based on its photocell technology, have been well-established over time. Numerous studies have validated its significant utility in sports science research, especially for analyzing various athletic skills in scenarios where a force plate is not accessible [26, 27, 28].

Similarly, the Myotest system's effectiveness in capturing various parameters through three-dimensional accelerometry has been rigorously evaluated. The findings from multiple studies confirm that Myotest delivers valid and highly reproducible data. It stands out as a reliable method for assessing vertical jumps, validating its use in field evaluations [29, 30, 31].

The Effects of Plyometrics on the Vertical Jump

The 26-week training program significantly enhanced the metrics assessed across all nine tests administered to the participants. When comparing the groups—specifically in the Countermovement Jump (CMJ), Drop Jump from 30 cm (DJ30), 10-second test (10 s), and Myotest CMJ (My-CMJ)—the findings suggest that the specialized physical training program, designed to maximize and develop vertical jump capabilities, was more effective than a conventional training regimen, with a statistical significance threshold of $p<0.05$.

This observation is consistent with the conclusions of prior research, which have underscored the beneficial effects of plyometric training on vertical jump performance among adolescent athletes [32, 33, 34]. By the conclusion of the competition period, the experimental group, which underwent our targeted intervention program, exhibited improvements in performance parameters ranging from 12% to 29%.

Comparatively, literature reviews indicate that plyometric training can enhance vertical jump height by 5% to 35% in untrained individuals and by 6% to 13% in those who are already trained [35, 36, 37].

The Effects of Sensory Technology

The utilization of reactive training lights in performance sports has a long history, yet recent advancements, such as BlazePod, have made this technology accessible to a broader audience. BlazePod's "flash reflex" light capsules illuminate in various colors, providing visual stimuli for exercises aimed at enhancing an athlete's reaction time, coordination, balance, and strength.

Hoffmann [38] discusses the application of sensory technology in training, highlighting its efficacy in improving hand-eye coordination, agility, speed, stability, and strength. Despite the recognized benefits of reactive training lights, there remains a gap in the literature concerning the integration of plyometrics with sensory technology. Thus, our research pioneers a novel approach, merging these two methodologies to potentially revolutionize the physical training landscape for athletes.

The Arm Swing Effects

Volleyball players frequently employ a comprehensive arm swing technique, where arms are initially drawn back and then propelled forward with elbows fully extended during the counter-movement vertical jump [39]. This technique is crucial in volleyball for executing jump serves, passes, blocks, and attacks, contributing to increased vertical jump height by enhancing hip joint muscle activity [40]. The arm swing is particularly effective in augmenting the height of the counter-movement vertical jump, a pivotal element in volleyball [41].

The vigorous upward acceleration of the arms generates a counteractive downward force on the body, consequently amplifying the vertical force exerted on the ground. It has been theorized that this downward force results in a pre-loading effect on the lower limbs, which moderates the velocity of knee extension. This moderation allows for an increased force output by the quadriceps muscles, in accordance with the force-velocity relationship [42].

Harman et al. [43] argue that the optimal method to maximize standing jump height includes incorporating a counter-movement with a controlled arm swing. This approach underscores the importance of the arm swing in enhancing vertical jump efficiency.

In a study focusing on eighteen high-performance volleyball players from the Czech first league, Vaverka et al. [44] discovered that the counter-movement jump with an arm swing resulted in an average vertical jump height that was 0.143 meters (37.7%) higher than the counter-movement jump without the arm swing. Utilizing force platforms, Payne et al. [45] observed a 5% increase in vertical jump height attributable to the arm swing. Additionally, Ramey [46] reported increases in maximal force generation from 2.5 times the body weight without an arm swing to 3.7 times the body weight with an arm swing, suggesting the arm swing's contribution to vertical jump height ranges from 0 to 40%. Shetty and Etnyre [47] found that the arm swing contributed to increases in peak force (6%), power (15%), and breakaway speed (6%), while also aiding in the reduction of peak landing force by 12%.

In an examination of eleven Canadian national female volleyball players' vertical jumps, Coutts [48] affirmed that the arm swing enhances jump performance, noting a 10% increase in vertical breakaway speed due to the arm swing [49]. After implementing the intervention program on female athletes in the experimental group at the end of the competitive period, significant differences were observed. The performances in tests allowing the use of an arm swing reached the threshold of statistical significance ($p<0.05$), with increases ranging between 3 and 16% in tests comparing the impact of the arm swing.

While this study has elucidated the considerable impact of arm swing on vertical jump performance, it is important to note its limitations. Specifically, the research was confined to a sample size of 32 female athletes from the volleyball section of Cetate Sports High School in Deva, which may affect the generalizability of the findings. This focus underscores the necessity for expanded research encompassing diverse age groups, genders, and competitive levels to comprehensively understand the arm swing's implications across a broader spectrum of athletes. Future investigations could delve into the biomechanical intricacies driving the enhancements in jump efficacy, adopting varied methodologies or longitudinal frameworks to gauge the sustained impact of combined plyometric and sensory technology-enhanced training regimens. Such explorations are crucial not only for corroborating these initial findings but also for advancing grasp of effective training methodologies for volleyball enthusiasts and athletes across other disciplines.

Conclusions

The implementation of a meticulously structured training regimen for junior volleyball players has proven to be a catalyst in strengthening technical-tactical skills related to vertical jumps. The duration of this intervention was well-suited to the developmental needs of this age group, allowing for the accumulation of the requisite motor skills.

The experimental intervention's methodologies were both effective and diverse, tailored to the proficiency levels of the participants. Over the course of the training, the athletes showcased significant motor potential, positioning them for enhanced tactical and technical performance.

The rapid advancement of modern technology in the realm of performance sports has introduced valuable tools for training enhancement. The incorporation of sensory technology in junior volleyball training aligns with the contemporary push for diversified and engaging motor activities, proving to be a pivotal element in elevating training efficacy.

Supported by robust statistical analysis, it is evident that utilizing a systematic approach incorporating sensory technology significantly boosts vertical jump capabilities and the execution of movements requiring ground detachment.

The intervention was well-received by the participants, with no injuries reported, underscoring the program's safety. Despite the perceived financial constraints associated with cutting-edge technology, its adoption is crucial for refining training programs and elevating the athletic prowess of junior volleyball players, emphasizing the necessity for coaches and sports administrators to invest in technologies that substantiate and augment training outcomes.

Acknowledgement

The authors are grateful to the volleyball players who have participated in this study, to Cetate Sports High School Deva and the Romanian Volleyball Federation for their support.

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Cite this article as:

Grădinaru L, Mergheş P, Oravițan M. The contribution of plyometric exercises assisted by sensory technology on vertical jump parameters in U15 female volleyball players. *Pedagogy of Physical Culture and Sports,* 2024;28(3):156–167.
https://doi.org/10.15561/26649837.2024.0210

Received: 24.03.2024
Accepted: 25.04.2024; Published: 30.06.2024