PHYSICAL EDUCATION OF STUDENTS

ORIGINAL ARTICLE

Impact of arm technique and elastic force on vertical jump performance in physical education students: a convergent validation study

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Abstract

Background and Study Aim Vertical jump performance is crucial for athletes in many sports. However, the optimal techniques for maximizing jump height and efficiency for both students and professional soccer players require more effective solutions. This study aimed to investigate the influence of various vertical jump techniques, focusing on arm swing and elastic force utilization, and to evaluate the extent of the impact that each modification has on biomechanical characteristics and performance outcomes.

Material and Methods Ten first-grade Sport Science students and ten professional soccer players from F.C. Malisevo participated in the study. The participants performed a series of jumps, including the Countermovement Jump (CMJ), Squat Jump (SJ), and Abalakov jump (ABL), while being recorded on an iPhone 13 Pro at 240 frames per second. Data analysis was conducted using the My Jump 3 app and SPSS 26 software. Descriptive statistics and one-way ANOVA were employed for comparative analysis. The Independent Samples T-test was used to compare differences in jump performance between the groups.

Results Significant differences in jump performance and force production were observed between SP and PES, with professional athletes demonstrating superior neuromuscular capabilities and better utilization of elastic energy. However, within each group, no significant differences were found between the different jump techniques, suggesting that arm swing and elastic force contribute similarly to overall jump height. Arm swing contributed 11.0% to jump performance in PES and 12.0% in SP, while the influence of elastic force stored in tendons during the eccentric phase was 7.0% in PES and 6.0% in SP.

Conclusions Specialized training significantly enhances jump performance, as evidenced by differences in CMJ, SJ, and ABL between SP and PES. Arm swing and elastic force utilization play crucial roles in vertical jumping, with professional athletes potentially leveraging arm mechanics more effectively. The study validates the reliability of the My Jump 3 app for measuring jump performance across diverse athletic backgrounds.

Keywords: Abalakov, countermovement jump, squat jump, arms swing, proficiency, athletes, data validation

Introduction

Vertical jumping is a multi-joint movement that necessitates intricate motor coordination and is recognized as a cornerstone skill in movement proficiency [1]. Vertical jump tests are integral in sports as they serve as reliable indicators of lower body power, a crucial attribute for various athletic activities. Sports performance professionals frequently employ vertical jump height as a substitute for directly assessing power [2]. Coaches and athletic trainers can utilize assessments of vertical jumping ability to enhance performance and identify talent among athletes.

One common method to evaluate lower body mechanical capabilities is the Countermovement Jump (CMJ). The CMJ stands out as a widely adopted testing method for evaluating lower body mechanical capabilities. Its applications extend to monitoring sports performance, inter-limb asymmetries, neuromuscular fatigue, and the effectiveness of different training programs [3]. The CMJ is distinguished by the presence of an initial countermovement (CM) prior to the toe-off phase [4].

In contrast, the Squat Jump (SJ) entails maintaining a flexed, semi-squat position briefly before initiating the upward or concentric phase of the jump [5]. The SJ test primarily measures the capacity to generate explosive force, whereas the CMJ assesses the ability to express reactive elastic force [6]. Another variant is the Abalakov jump, named in honor of Vitaly Abalakov, who first described it in 1938. The Abalakov jump mirrors the mechanics of a CMJ, with the additional incorporation of an arm swing [7].

However, while the CMJ has been extensively studied and utilized, the role of arm swing technique

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in influencing jump performance and the utilization of elastic force stored in tendons remains a topic of growing interest and investigation. The incorporation of arm swing during vertical jumping has been recognized as a critical factor influencing jump height and efficiency [8]. Understanding the mechanics and impact of arm swing, in conjunction with lower body mechanics, is crucial for a comprehensive analysis of vertical jumping performance.

Besides this, as physical education students are not trained in jumping techniques, their arm swing and the speed of the eccentric contraction phase may not accurately reflect the percentage effect of the arm swing technique and elastic force stored in tendons during jumping. Therefore, data validation with professional athletes is crucial.

In the context of vertical jumping, understanding elastic force, also known as elastic energy, is crucial for optimizing performance and elucidating the mechanics underlying athletic proficiency. Elastic force refers to the energy stored within tendons, ligaments, and muscle fibers during the initial countermovement phase of jumps like the CMJ [9]. As an individual descends into the countermovement, these structures undergo stretching, accumulating potential energy. Upon transition to the upward phase of the jump, this stored energy is rapidly released, contributing to the propulsion and elevation of the body. This phenomenon, akin to a spring-like mechanism, enhances jump height and efficiency by augmenting the force generated by muscular contractions [10]. Understanding the dynamics of elastic force utilization is essential for coaches, athletic trainers, and sports scientists seeking to enhance athlete performance and prevent injuries.

This study aimed to investigate the influence of various vertical jump techniques, focusing on arm swing and elastic force utilization, and to evaluate the extent of the impact that each modification has on biomechanical characteristics and performance outcomes.

Materials and Methods

Participants

The study comprised ten first-grade Sport Science students, with an average height of 171.3 ± 8.1 centimeters and an average weight of 62.9 ± 6.5 kilograms. This selection criterion aimed to ensure uniformity in physical attributes and training backgrounds, thereby bolstering the study's validity and reliability. Additionally, to enable convergent validation, the study included ten professional soccer players from the F.C. Malisevo team. These players, with an average height of 179.8 ± 1.5 centimeters, an average weight of 75.0 ± 1.8 kilograms, and an average age of 23.7 ± 3.41 years, represent a high-performance standard, being ranked 4th in the AlbiMall Super League of Kosovo and participating in the Conference League in 2024.

My Jump 3 app

The methodology of this study began with the collection of crucial performance parameters using the My Jump 3 application. This data encompassed height, weight, height at 90°, lever length, and leg length, all vital for analyzing jump performance outcomes. Each participant executed a series of jumps, including the Countermovement Jump (CMJ), Squat Jump (SJ), and Abalakov jump, while being recorded on an iPhone 13 Pro at 240 frames per second, capturing high-definition video resolution.

Within the My Jump 3 app, jump recordings were loaded, and specific frames for take-off and landing were manually selected. Clear criteria were established beforehand to ensure accuracy: for take-off, the first frame where both feet were off the ground was chosen, free from motion blur or shoe deformation; for landing, the frame where one foot touched down without a visible gap between the shoe and the ground, and no motion blur, was selected. Utilizing these defined events, the app calculated jump height based on flight time [11].

It is noteworthy that the validity of the My Jump 3 app has been confirmed by numerous studies [12, 13, 14].

Statistical analysis

Following video analysis using the My Jump 3 app, the collected data underwent rigorous testing to ensure a comprehensive analysis of the results. Data collected from My Jump 3 was analyzed using the SPSS 26 package. Normality was assessed using Shapiro-Wilks tests to confirm that the data distribution met statistical assumptions. Descriptive statistics, including percentiles and percentages, were calculated to offer a clear overview of the data distribution and characteristics.

Moreover, One-way ANOVA tests were employed to scrutinize any significant differences between groups or conditions, facilitating a detailed comparison of jump performance across various parameters and conditions. The differences in jumps between Physical Education Students (PES) and Professional Soccer Players (SP) were examined using Independent Samples T-tests. Similarly, Independent Samples T-tests were used to assess percentage differences in arm technique and elastic force between PES and SP for data validation.

Consequently, the absence of statistically significant differences validated the findings as convergent.

Results

Based on the findings presented in Table 1, it is evident that both jumping performance (ABL, CMJ, SJ) and force (N) production are significantly higher in professional soccer players (SP) compared to physical education students (PES), with a p-value

< 0.05.

The results presented in Table 2 reveal statistically significant differences (p < 0.05) between ABL and SJ in both physical education students and professional soccer players. However, no statistically significant differences (p > 0.05) were observed between ABL and CMJ, or between CMJ and SJ in either group.

According to the data in Table 3, the impact of arm swing techniques on jumping performance was observed to be 11.0% in physical education students and 12.0% in professional soccer players. However, these discrepancies did not reach statistical significance between the two groups (p > 0.05). In contrast, the influence of elastic force stored in tendons during the eccentric phase on jumping performance was found to be 7.0% in PES and 6.0% in SP. Once again, these distinctions did not exhibit statistical significance (p > 0.05).

Discussion

This study aimed to investigate the impact of various vertical jump techniques, specifically focusing on arm swing and elastic force utilization, and to validate the findings from physical education students by comparing them with professional soccer players. The results demonstrated notable differences in jump performance and force production between the two groups, highlighting key insights into the mechanics of vertical jumping.

The higher jump performance and force production observed in professional soccer players compared to physical education students align with previous research indicating that trained athletes typically exhibit superior neuromuscular capabilities and better utilization of elastic energy stored in tendons and muscles [15]. The significant differences in the CMJ, SJ, and ABL between SP and PES (p < 0.05) underscore the influence of specialized training and physical conditioning in enhancing jump performance [16].

Table 1. Comparative Analysis of Height and Force Discrepancies Between PES and SP, Including Percentile Distribution

Tests	Groups	Height (cm)		Force (N)		Percentiles		
		X̄± SD	p	X̄± SD	p	25th (cm)	50th (cm)	75th (cm)
ABL	PES	36.87±5.23	.000	1434.8±269.2	.001	31.40	37.85	40.87
	SP	48.7±7.13		2225.0±280.4		44.60	47.40	56.97
CMJ	PES	32.99±5.81	.002	1352.9±268.1	.000	30.15	33.55	37.22
	SP	43.00±5.89		2019.7±213.9		39.52	41.90	47.97
SJ	PES	30.67±5.41	.004	1302.5±256.8	.000	27.27	31.45	34.20
	SP	40.21±6.41		1965.3±216.6		34.47	37.75	45.57

Note: PES - Physical education students, SP - Soccer Players, Significant differences - p<0.05, ABL - Abalakov (free arms countermovement jump), CMJ - Countermovement Jump, SJ - Squat Jump

Table 2. Comparative Analysis of Arm Swing Technique and Lower Extremities Elastic Force Effects on Jump Performance in PES and SP

Tests	Jumps	Groups	X̄ ± SD	F	Sig	Bonferroni (sig.)
Jumps (cm)	ABL	PES	36.99±4.98	4.270	.023	ABL>SJ (.021)
	CMJ		34.50±4.70			
	SJ		30.79±5.74			
	ABL	SP	48.77±7.13	4.509	.020	ABL>SJ (.020)
	CMJ		43.00±5.89			
	SJ		40.99±6.41			
Force (N)	ABL	PES	1469.0±279.4	1.476	.245	-
	CMJ		1466.8±228.8			
	SJ		1300.3±296.1			
	ABL	SP	2225.0±280.4	3.284	.053	-
	CMJ		2019.7±213.9			
	SJ		1965.3±216.6			

Note: PES - Physical education students, SP - Soccer Players, F - variation between sample means, Significant differences - p<0.05, ABL - Abalakov (free arms countermovement jump), CMJ - Countermovement Jump, SJ - Squat Jump, N - Newton

Table 3. Differences in Arm Swing Technique and Elastic Force Between PES and SP During Jump Performance

Groups	Measured features	$\bar{X} \pm SD$		Diff%	p
		Height (cm)	**Force (N)**		
PES	Arms swing technique (ABL vs CMJ diff)	3.88	81.85	11.0	.731
SP		5.77	205.3	12.0	
PES	Elastic force (CMJ vs SJ diff)	2.32	50.40	7.0	.827
SP		2.79	54.4	6.0	

Note: PES - Physical education students, SP - Soccer Players, Significant differences - $p<0.05$, ABL - Abalakov (free arms countermovement jump), CMJ - Countermovement Jump, SJ - Squat Jump, N - Newton

Interestingly, the lack of statistically significant differences between ABL and CMJ, and between CMJ and SJ within both groups ($p > 0.05$), suggests that while the arm swing and elastic force contribute to overall jump height, their relative impact may not differ drastically between these techniques. This finding is particularly relevant for sports performance professionals, as it indicates that focusing on one type of jump technique may suffice for evaluating an athlete's explosive power and reactive strength. However, it is generally better to include multiple jump type assessments. This multifaceted approach can provide a fuller picture of an athlete's capabilities and training needs [17].

Additionally, a larger difference between CMJ and SJ performances is not necessarily better. It may reflect not only the utilization of elastic energy in a small-amplitude CMJ due to a well-developed capability to co-activate muscles and quickly build up muscle stimulation but also a poor capability to reduce the degree of muscle slack and quickly build up stimulation in the SJ [18]. Therefore, analyzing both CMJ and SJ can provide more comprehensive insights into an athlete's explosive power and reactive strength.

The observed 11.0% impact of arm swing on jumping performance in PES and 12.0% in SP highlights the importance of arm mechanics in maximizing jump height [19]. Although the differences between the two groups were not statistically significant ($p > 0.05$), the slightly higher percentage in SP suggests that professional athletes may utilize arm swing more effectively due to better coordination and technique refinement [20].

Similarly, the influence of elastic force stored in tendons during the eccentric phase of the jump was found to be 7.0% in PES and 6.0% in SP, with no significant difference between the groups ($p > 0.05$). This indicates that both trained and untrained individuals benefit from the elastic energy stored during the countermovement phase [21]. It highlights the role of inherent biomechanical properties in jump performance, irrespective of the training level.

These findings support the importance of including both CMJ and SJ in assessments to provide a comprehensive evaluation of an athlete's explosive and reactive strength capabilities. Moreover, the study reinforces the validity of using the My Jump 3 app for accurately measuring jump performance, as indicated by the absence of significant differences in the validation data between PES and SP [12].

It is important to acknowledge that while this study provides valuable insights into vertical jump performance among soccer players and physical education students, the observed findings may vary when testing athletes from different sports. For instance, basketball players may have perfected distinct characteristics such as proficiency in arm swing technique, while track and field athletes may excel in elastic force utilization. Further exploration across a diverse range of sporting backgrounds would offer a more comprehensive understanding of the nuanced influences on jump mechanics and performance [22].

This study provides valuable insights into the mechanics of vertical jumping. It emphasizes the importance of specialized training in enhancing jump performance. Professional soccer players demonstrated superior neuromuscular capabilities and better utilization of elastic energy compared to physical education students. However, the lack of significant differences between the various jump techniques suggests that arm swing and elastic force contribute similarly across different types of jumps. These findings support the inclusion of both CMJ and SJ in assessments to provide a comprehensive evaluation of an athlete's explosive and reactive strength capabilities. Additionally, the study reinforces the validity of using the My Jump 3 app for accurately measuring jump performance. Future research should explore these dynamics across a broader range of sports to further understand the nuanced influences on jump mechanics and performance.

Conclusions

This study underscores the significant role of specialized training in enhancing vertical jump performance, as evidenced by the superior neuromuscular capabilities and efficient utilization of elastic energy in professional soccer players compared to physical education students. Despite the lack of statistically significant differences between various jump techniques, the consistent contribution of arm swing and elastic force across different types of jumps highlights the necessity of including both CMJ and SJ in performance assessments. The validation of the My Jump 3 app as an accurate tool for measuring jump performance further supports its use in diverse athletic contexts.

Future research should extend these findings by exploring vertical jump mechanics across a wider range of sports to provide a more comprehensive understanding of the factors influencing jump performance and to refine training programs accordingly.

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