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ASSOCIATION OF IMPROVEMENTS IN SQUAT JUMP WITH IMPROVEMENTS IN COUNTERMOVEMENT JUMP WITHOUT AND WITH ARM SWING

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Abstract This study investigated the effects of an eight-week pre-season on-court volleyball along with strength and conditioning program on performance in squat jump (SJ) and countermovement jump without (CMJ) and with arm swing (CMJa); and whether the improvements in SJ contributed to improvements in CMJ and CMJa. Thirteen competitive female volleyball players completed an eight-week pre-season training program and their SJ, CMJ, and CMJa were assessed at the beginning and at the end of this period. Paired sample's t-test calculated the differences between two tests, while regression analysis investigated if an improvement or reduction in SJ was associated to improvements or reductions attained in CMJ and CMJa. In general, applied training significantly improved ($p<0.01$) SJ (10.2%), CMJ (10.2%), and CMJa (6.9%), with an exception to a few cases. Changes in SJ were moderately associated with changes in CMJ ($R^2=0.536$, $p=0.005$) and CMJa ($R^2=0.357$, $p=0.020$). On-court volleyball training followed by a strength and conditioning program significantly improved jumping performance, whereby contractile strength characteristics explained moderate amounts of improvement in CMJ and CMJa, which are the most common jumps in volleyball games. Analyzing to what degree certain elements explain components of performance such as ability to jump vertically adds to the precision of planning and reduces the possibility of error.

Key words: Team sports, plyometrics, jumping performance, strength and conditioning, power

INTRODUCTION

Volleyball is a sport where female athletes score by transferring the ball from their side of the court to the opponents side, whereby the ball need to cross over the 2.24 m high net and touch the floor or bounce off of the opponent's player out the bounds. Therefore, the most common way of pointing in volleyball is by spiking the ball very hard directly towards the empty space on the court. On the other hand, the players on the opposing side of the net are either trying to block the spike by vertically jumping as high as possible (i.e., high reach) or by reacting quickly in the direction of the ball in order to prevent it from dropping on the floor. In that regard, from the angle of physical performance, the success in volleyball depends on individual abilities of players to perform explosive effort jumps that would provide them with the vertical reach high enough to spike or block effectively [1–3].

Jumping performance is highly reliant on the proper activation and recruitment of the lower-extremity musculature [4–6]. For instance, volleyball players may need to jump from a relatively static squat (SJ) position relying on concentric muscle contraction, or by actively engaging in a countermovement jump (CMJ) which utilizes the contribution of elastic energy to jump higher [6]. Effective SJ requires lower-body muscles to be able to generate large forces in a short time in order to accelerate the centre of body mass as much as possible purely by muscle contraction. During CMJ, players perform a quick squat first that activates the muscles and extends the tendons, and then they jump using the forces generated by muscle contraction and elastic energy generated in the muscle tendons. In addition, volleyball players use the arm swing (i.e., CMJ with arm swing – CMJa) to help them jump even higher in order to perform technical elements such as spiking and blocking that require hands to be as high as possible.

Considering this, strength and conditioning programs for volleyball players normally focus on development of lower-body strength and power, aiming to improve jumping performance of volleyball plays [7–9]. In that regard, Häkkinen [8] investigated the changes in physical fitness profiles of female volleyball players during a competitive season and found significant improvements in the height of SJ and CMJ. Players performed two-three weekly sessions for physical conditioning which focused on strength and explosive strength training. Marques et al. [9] implemented a 12-week in-season resistance and plyometric training program twice a week and found significant improvements in one-repetition maximum parallel squat and CMJ height. Thus, strength and explosiveness were found to improve in female volleyball players as an adaptation to strength and power training.

The association between strength characteristics and explosive jumps has been well documented in literature, whereby optimal contractile and recruitment characteristics from maximal squat and SJ positively influence CMJ [4,10–12]. Moreover, longitudinal studies on volleyball players showed significant improvements in jumping performance after applied strength and plyometric training. However, the evidence examining the degree to which improvements in SJ are associated with improvements in CMJ and CMJa in volleyball players is scarce. Therefore, the aim of this study was to investigate the effects of an eight-week pre-season program on jumping performance, and whether improvements attained in SJ are associated with those attained in CMJ and CMJa in competitive level volleyball players. It was hypothesized that applied training will improve jumping performance, and that improvements attained in SJ will be associated with improvements in CMJ and CMJa.

METHODS AND MATERIALS

This experimental study examined the associations of improvements obtained in SJ to improvements obtained in CMJ and CMJa after eight-weeks of on-court volleyball training and off-court strength and conditioning training were applied (Table 1). Lower-body power was tested at the beginning of the study (pre-test) and at the end of the study (post-test). Three tests were used, SJ for contractile abilities of legs, CMJ for stretch-shortening cycle of leg muscles, CMJa for the stretch-shortening cycle coupled with the arm swing. The results obtained at post-test were compared to those from pre-test and the obtained differences were further analysed to determine the association between different muscle properties. Pre- and post- testing sessions were completed for all subjects during the same training sessions. The same strength and conditioning trainer conducted all testing and training sessions.

SUBJECTS

The sample consisted of 13 female volleyball players (n = 13) that played in the highest Serbian national league for the minimum of two seasons. The main characteristics of the sample were age = 20.02 ± 3.95 years, body height (BH) = 181.08 ± 8.17 cm, body mass (BM) = 69.55 ± 10.07 kg, and percent body fat = 19.38 ± 3.05 %. Body fat percent was assessed by an eight-channel bioelectric impedance analyzer (InBody 370, Biospace Co. Ltd, Seoul, Korea), following previously reported procedures [13,14]. All players were familiar with the basics of strength and plyometric training and were injury free for a minimum of one year. Subjects were informed about the possible utilization of the data in research purposes and their data were included in analysis upon agreeing to do so. The research was carried out in accordance with the conditions of Declaration of Helsinki, recommendations guiding physicians in biomedical research involving human subjects [15], and with the ethical approval number 484-2 of the ethical board of the Faculty of Sport and Physical Education, University of Belgrade.

TRAINING PROCEDURES

Overall, the strength and conditioning part of this eight-week training program followed a linear program design starting with muscular endurance and hypertrophy-based training, then later progressing to strength and power-based training. For the first 4-weeks, power-endurance and hypertrophy-based training were utilized to establish and improve the functional capacity of the muscular, skeletal, and respiratory systems at lower intensities. For the second 4-weeks, maximal strength and power-based training were utilized as mechanisms to better develop muscular and skeletal system functioning at higher intensities [16]. On-court volleyball training focused on volleyball skill development, as well as learning and improving tactical elements of the game. This was further situationally practiced at friendly games.

TESTING PROCEDURES

Prior to performing the jump assessments, participants performed a standardized 10-minute warm-up including low aerobic intensity jogging and sport-specific dynamic drills such as short changes of direction, short and quick jumps (bouncing) and few maximal jumps. Lower-body muscular power was assessed using SJ, CMJ and CMJa. Each test was performed three times and the highest value was used for final analysis. The order of testing was randomized. Participants were allowed about 30-60 seconds between jumps within one test (or more if necessary). After completion of each test, and prior to beginning the next, participants rested 3-5 minutes. Each assessment was conducted according to the procedures explained in Markovic et al. [17]. A resistive contact platform (Chronojump, Boscosystem®, Barcelona, Spain) was utilized to measure the jump height from flight time [18,19]. Additionally, all three tests have been reported to be reliable (ICC = 0.93 – 0.98) and valid (*r* = 0.80 – 0.87) [19].

Table 1. Training log showing the schedule and summary of the applied trainings and games

Jul/Aug	Day	Morning	Afternoon	Sep	Day	Morning	Afternoon
30	Monday	Pre-test	Off	1	Saturday	Day off	
31	Tuesday	Gym	Off	2	Sunday	Gym	Court
1	Wednesday	Court	Off	3	Monday	Off	Court
2	Thursday	Gym	master	4	Tuesday	Gym	Game
3	Friday	Court	master	5	Wednesday	Gym	Court
4	Saturday	Gym	Off	6	Thursday	Gym	Court
5	Sunday	Day off		7	Friday	Off	Game
6	Monday	Gym	Court	8	Saturday	Gym	Game
7	Tuesday	Court	Court	9	Sunday	Off	Game
8	Wednesday	Off	Court	10	Monday	Day off	
9	Thursday	Gym	Court	11	Tuesday	Gym	Court
10	Friday	Off	Court	12	Wednesday	Off	Game
11	Saturday	Gym	Court	13	Thursday	Gym	Game
12	Sunday	Day off		14	Friday	Off	Court
13	Monday	Gym	Court	15	Saturday	Gym	Game
14	Tuesday	Court	Court	16	Sunday	Day off	
15	Wednesday	Off	Court	17	Monday	Gym	Court
16	Thursday	Gym	Court	18	Tuesday	Off	Court
17	Friday		Court	19	Wednesday	Gym	Court
18	Saturday	Gym	Court	20	Thursday	Off	Game
19	Sunday	Day off		21	Friday	Off	Court
20	Monday	Gym	Court	22	Saturday	Game	
21	Tuesday	Gym	Court	23	Sunday	Day off	
22	Wednesday	Off	Court	24	Monday	Post-test	Off
23	Thursday	Gym	Court				
24	Friday	Gym	Off				
25	Saturday	Day off					
26	Sunday	Day off					
27	Monday	Gym	Court	**Summary:**			
28	Tuesday	Gym	Game	Overall number sessions = 71			
29	Wednesday	Off	Court	Gym = 27 sessions (38%),			
30	Thursday	Gym	Court	Court = 33 Sessions (46%)			
31	Friday	Gym	Game	Games = 11 (15%)			

SQUAT JUMP (SJ)

The SJ was utilized to assess the contractile ability of the lower extremities. SJs were performed with the participant flexing the knee to approximately 90 degrees with the hands on the hips to reduce upper extremity contribution to power production. Participants remained stabilized in the 90 degree position for 3-seconds prior to performing the jump. The stabilization in the 90 degree position restricted the use of elastic energy of the muscles.

COUNTERMOVEMENT JUMP (CMJ)

The CMJ was utilized to assess the stretch-shortening cycle of lower extremity muscles while the CMJa was utilized to assess the stretch-shortening cycle during the coordinated whole-body locomotion related to volleyball. With their hands on their hips, participants began the CMJ test by performing a fast countermovement of their lower limbs to the 90 degree position and then jumping as high as possible.

COUNTERMOVEMENT JUMP WITH ARM SWING (CMJA)

The CMJa test was identical to the CMJ test, except participants were allowed to use an arm swing backward as they flexed their knees to the 90 degree position and forward as they extended their knees into the jump. In both the SJ and CMJ tests, the subjects were required to land in the same point of takeoff and rebound with straight legs when landing in order to avoid knee bending and alteration of measurements.

STATISTICAL ANALYSIS

All data was collected and exported to Microsoft Excel for further analysis. All statistical procedures were conducted using a Statistical Package for Social Sciences (IBM, SPSS Statistics 20). All data were analysed descriptively for mean, standard deviation (SD), minimum (Min), and maximum (Max). A paired sample t-test was used to determine the differences between the pre- and post-test. A linear regression analysis was conducted to determine the association between the differences obtained in SJ and those obtained in CMJ and CMJa. The magnitude of between-test difference was calculated using a Cohen's effect size (ES) formula: $ES = (M_2 - M_1)/S_1$, where M_1 and M_2 are the means at test and retest and S_1 is a standard deviation related to M_1. The ES were defined as small = 0.2, moderate = 0.5, large = 0.8 and very large = 1.3. The effect size of the regression analysis was defined as small = 0.04-0.25, moderate = 0.25-0.64, and large ≥ 0.64 [20].

RESULTS

Descriptive statistics for pre- and post- test and paired sample t-test are shown in Table 2. On a general level, improvements occurred in all three tests. The effect of applied training on SJ, CMJ and CMJa were the same, with relative change in CMJa being 3.3% smaller than in other two tests (Figure 1).

Table 2. Descriptive statistics and t-test with presented mean difference and 95% confidence interval

Variables	Mean±SD Min-Max	Mean±SD Min-Max	Mean diff.	95% CI Lower-Upper		t	p
SJ (cm)	30.23±3.30 25.8-35.5	33.31±3.97 27.3-41.2	-3.08	-5.08	-1.08	-3.36	.006
CMJ (cm)	31.99±3.40 26.5-37.8	35.25±4.00 28.1-42.5	-3.26	-5.42	-1.10	-3.28	.007
CMJa (cm)	36.53±4.57 31.7-44.3	39.06±4.37 32.7-46.4	-2.53	-4.78	-0.28	-2.45	.031

SJ – squat jump, CMJ – countermovement jump, CMJa – countermovement jump with arm swing, SD – standard deviation, Min – minimum, Max – maximum, Mean diff. – mean difference.

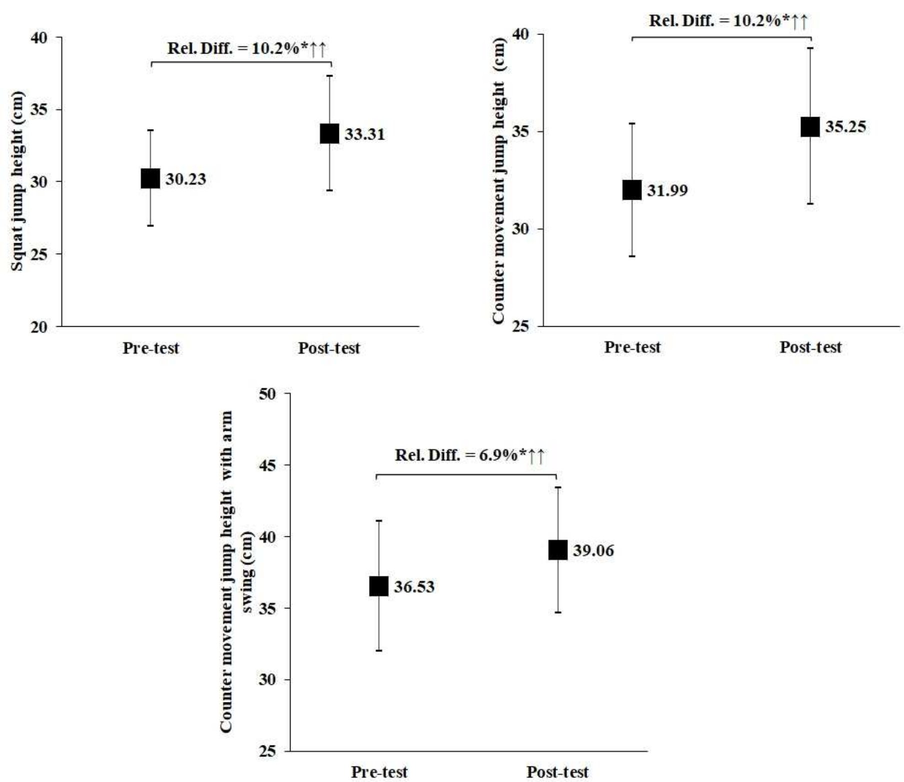

Figure 1. Relative differences and effect sizes. * Significant at $p < 0.05$, ↑↑ - moderate effect size.

However, the analysis on an individual level of each player revealed that three players did not improve in SJ, four did not improve in CMJ, and two did not improve CMJa (Figure 2).

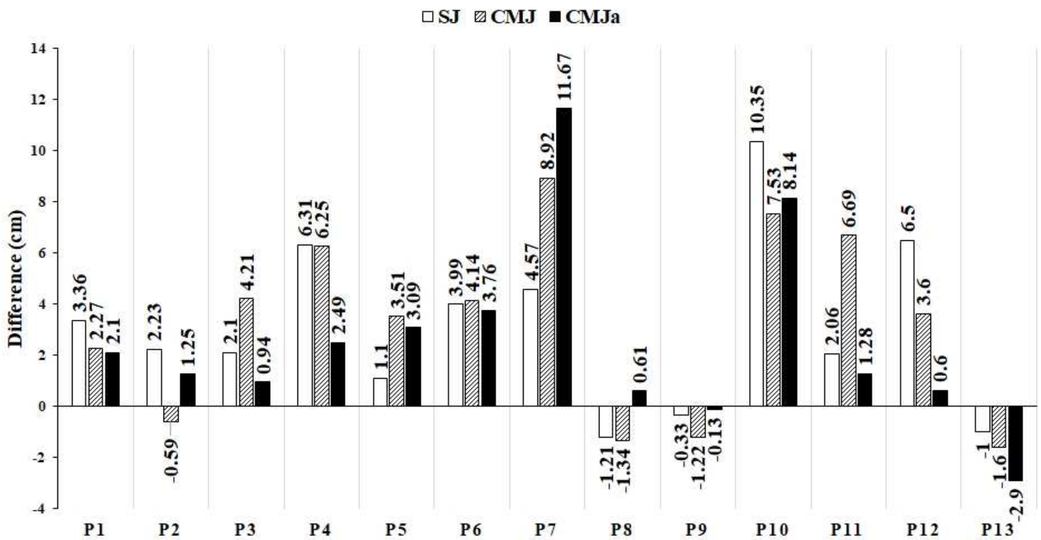

Figure 2. Individual changes in SJ, CMJ and CMJa

The regression analysis revealed that about 53.6% of the variance in improvement in CMJ and 37.7% of improvement in CMJa could be explained by the improvements attained in SJ (Figure 3).

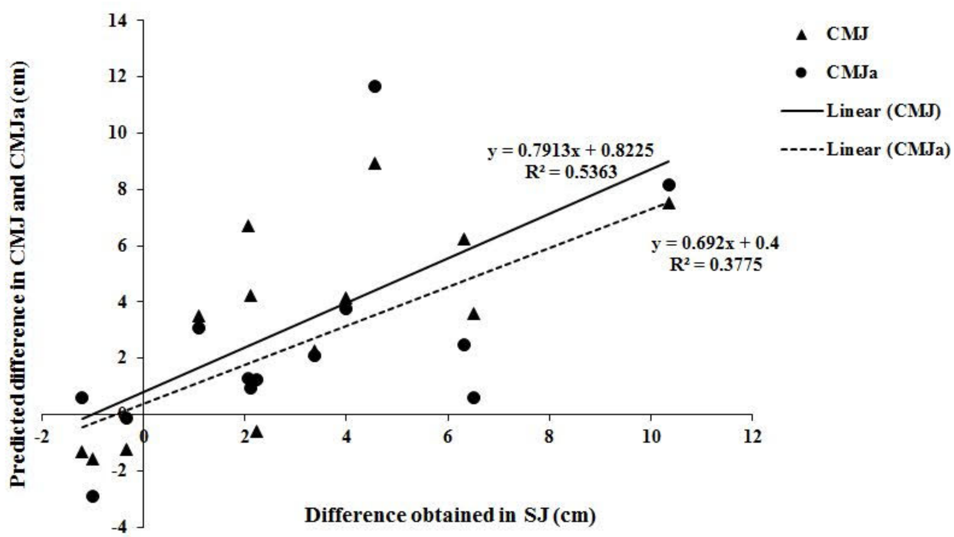

Figure 3. Regression analysis scatterplot for CMJ and CMJa

Table 3. Regression analysis and regression coefficients

Predicted variable	Adj. R^2	SEE	F	p	Const.	B	ß	p
CMJ difference	.476	2.59	11.89	.005	-20.5	0.215	0.721	0.005
CMJa difference	.347	3.01	7.37	.020	-19.3	0.197	0.633	0.020

Note: Predictor variable was the differences attained in SJ.
Adj. R2 – adjusted R^2, SEE – standard error of the estimate. Const. – constant, B – unstandardized coefficient, ß – standardized coefficient. CMJ – countermovement jump. CMJa- countermovement jump with arm swing.

DISCUSION

The main findings of this study showed that the majority of players improved jumping performance in all three tests, whereby moderate improvement of about 10% in SJ followed by the same improvement in CMJ suggests that players improved contractile abilities of leg muscles. In contrast, two out of three players whose SJ reduced performed lower in CMJ and CMJa as well. Accordingly, the regression analysis established moderate causal associations between the improvements (decrease) in SJ and CMJ and CMJa, additionally reinforcing the notion of the importance of contractile components for jumping performance.

Häkkinen [8] investigated the changes in physical fitness profiles of female volleyball players during the competitive season. He followed a group of players who had 4-5 weekly sessions of playing drills and competitive games and 2-3 weekly sessions for physical conditioning. Author reported significant improvements in SJ (1.3 cm or 4.3%) and CMJ (1.5 cm or 4.6%). Kavanaugh et al. [7] investigated the long-term changes in jumping performance of NCAA division I female volleyball players. The authors formed three groups based on the duration that the players were observed, with group 1 being followed the shortest (0.7 years), and group 3 the longest (2.4 years). They reported that SJ and CMJ improved in all three groups, with group 3 having the highest improvements, followed by group 2 and group 1. Mean relative improvements in SJ were 6.8% in group 1, 10.8% in group 2, and 19.7% n group three, while mean relative improvements in CMJ were 6.2, 6.6, and 16.6%, respectively. In contrast, after six weeks of preseason skill-based conditioning on physical performance of volleyball players Trajković et al. [3] did not find significant differences in vertical jump performance measured by CMJa and spike jump testing. Authors concluded that pre-season skilled based conditioning alone is not sufficient for improvements in jumping performance and that for that purpose, strength and conditioning training is needed. Considering this, the effects attained in our study are similar to those of studies that included volleyball and strength and conditioning training together. Therefore, the addition of strength and conditioning should be included into volleyball training of females in order to improve vertical jump performance.

The authors would posit the reasons for this as significant improvements in muscle functioning and expression, or strength and coordination, during the first four-to-six weeks of a training program being attributable to neural adaptations [4,16]. After introducing novel forms of training attributed to strength and power-based training, athletes typically experience neural adaptations. The amount of motor units recruited increases along with the speed and efficiency of their recruitment during specific tasks, which are coupled with the activation of adjoining musculature. This could be the reason for significant improvements in SJ, CMJ, and CMJa performance. Moreover, it seems that these muscular adaptations (i.e., recruitment and firing rate of motor units) explained a moderate amount of improvements in CMJ (53.6%) and CMJa (37.8%). It is possible that muscle attributes needed for SJ can help the athlete express greater explosive strength and higher jump height, which altogether may lead to improved on-court performance. Somewhat smaller degrees of association with CMJa could be attributed to the fact that arm swing is related to multi-movement coordination and skill, and that it also contributes to more technical elements. Thus, the arm swing in those more skilled (i.e., opposite and right side hitter) could contribute more than in those less skilled (i.e., middle blocker). Considering this, our results support the improvement in strengthening of muscle contraction of lower-extremities in an effort to increase power and volleyball-specific performance.

CONCLUSION

This research illustrated that on-court volleyball training followed by a strength and conditioning program significantly improves jumping performance. It seems that strength and conditioning improved the contractile strength characteristics in a majority of the players. Moreover, this explained a considerable amount of improvement in CMJ and CMJa, which are the most common jumps in volleyball games. This study, in addition to established literature, showed that strength and conditioning should be integrated into volleyball clubs in order to optimize performance. Additionally, head coaches should work collaboratively with strength and conditioning coaches in order to improve their players technically, tactically, and physically, as high levels of physical preparedness constitutes the potential for performing all technical skills and tactical knowledge on the highest level, and reduces the risk of injuries.

PRACTICAL APPLICATION

Holistic approaches to volleyball performance allows teams to optimize individual components of performance, ultimately improving overall performance. The presented analysis showed group and individual differences, emphasizing the importance of each player within the system. Understanding how to plan and apply strength and conditioning programs within complex long- and short-term volleyball training is of high importance for performance and reduction of injury risk. More importantly, analyzing and writing the diagnosis of specific approaches and to what degree certain elements explain components of performance such as ability to jump vertically adds to the precision of planning and reduces the possibility of error.

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