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Kinematic Factors in Countermovement Jump for Female Volleyball Players with Different Skill Levels

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Abstract The focus of this paper was to identify crucial kinematic factors that contribute to the countermovement jump (CMJ) height between different skilled levels of female volleyball players. A total of 20 female volleyball players were recruited. The results of standard multiple regression indicated that the best model accounted 64% and 45% of the variance in the jump height for skilled and non-skilled group, respectively, with different combinations of variables during the preparation phase. A small portion of variance in jump height (11% and 22%) was accounted for during the propulsive phase for both groups. The skilled group exhibited more contributors from the preparation phase of the countermovement jump which indicated that skilled female volleyball players better utilize stretch-shortening cycle in jumping performance resulting in higher jump height than non-skilled female volleyball players. This also confirms the importance of storing and re-utilizing energy for jumping performance. Additionally, hip extension velocity and trunk angular displacement were essential for jump height during propulsive phase. Several pedagogical guidelines are provided to improve female volleyball players' CMJ performance.

Keywords Countermovement jump, Kinematics, Skill levels, Techniques, Volleyball

1. Introduction

The ability to jump is so crucial that it has been studied extensively over the last few decades. In particular, the countermovement jump (CMJ) is a fundamental movement for athletes in multiple sports. In volleyball, CMJ is essential for both defensive and offensive performances such as jump setting, standing (in-place) blocking, and jousting. In fact, all three are important for winning in elite competitions [28].

There are many studies which have investigated a variety of contributors to jump height [e.g., 1, 3, 4, 6, 7, 12, 13, 20]. Argón-Vargas and Gross [6, 7] and Dowling and Vamos [1] identified multiple contributors to jump height in different mechanical levels among and within subjects. Both studies concluded that the best model for jump height was peak and average mechanical power (accounted 83-88% of the variance). Argón-Vargas and Gross[6] as well as McErlain-Naylor et al. [13] identified takeoff velocity as the most influential factor to CMJ height accounting for nearly 60% of variance. Vanezis and Lees [12] (2005) concluded that muscle capability was the main factor that differentiated good and poor jumpers.

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These studies identified kinetic factors as being most influential for CMJ. Although power, force, and takeoff velocity are the strongest predictors of jump height, they are not practical instructional variables to enhance sport performance outside of a laboratory setting. For example, force and power are not directly observable traits without equipment and subject to bias based on outcome. Finally, takeoff velocity and gravity dictate the vertical displacement of CoM after takeoff and is actually the outcome of jumping performance. Thus, without fully understanding the specific precursor factors influencing takeoff velocity, coaches and athletes are unable to accurately and efficiently effect skill instruction and/or development.

The literature has revealed strong relationships among several kinetic factors and CMJ performance or jump height. However, there are several other limitations (besides the lack of practical pedagogical application) in the literature that need to be addressed. The applicability of the current literature is limited in several major ways. First, studies identified men and women have different biomechanical parameters for the same movement [5, 8, 9]. Second, studies have shown that similar performance outcomes can be achieved with different biomechanical variables by different athletes at comparable levels of skill (i.e., elite athletes). The generalizability of these studies is limited to individuals or groups that match the study's sample (e.g., healthy active males) and results cannot be applied to athletes of different skill levels [10]. Finally, despite the similarity of the term

CMJ, the performance outcome and the related biomechanical contributors would most likely differ according to specific background training of athletes and the particular sport.

The heterogeneous samples of the previous studies including sample population and sport type fail to provide sport-specific and pedagogically significant information for female volleyball players. Therefore, the purpose of the present study is twofold. The first goal is to investigate the important kinematic variables for the CMJ jump height and identify the differences of the CMJ kinematic variables in different skill level of female volleyball players. Furthermore, the second aim of this current study is to provide useful and effective pedagogical information to improve female volleyball players' jumping performance.

2. Methods

Ten female volleyball players (mean body height = 1.78 ± 0.09 m; mean body mass = 66.4 ± 7.4 kg) were recruited from a highly competitive team and another ten recreational female volleyball players were recruited from the local recreation center (mean body height = 1.74 ± 0.03 m; mean body mass = 66.05 ± 8.23 kg). All 20 participants had no injury during and prior to the data collection that could interfere the jumping performance. All policies and procedures for the use of human subjects were followed and approved by the university Institutional Review Board.

Each subject wore their own volleyball shoes for the study. Every player was required to warm-up for at least five minutes by stretching all major muscle groups for jump performance and practicing several CMJ jumps in front of the cameras in the university biomechanics lab. All subjects performed a maximum of five countermovement jumps with arms akimbo. Each subject took a half minute break between each trial. A cooling down procedure was provided for all participants.

Three-dimensional coordinate data of the body were obtained with three 60-Hz digital video cameras in conjunction with a motion analysis system (Vicon Motus: 9.2). Each camera was setup 120 degrees apart around subjects. A model using 19 points that composed 14 segments was used. Anthropometric parameters from deLeva [17] were adapted for CoM calculation. The coordinate data were filtered using quantic spline processing [18, 19]. Data were collected from the tenth frame before the movement onset until the tenth frame after the peak of the jump. Jump height was determined from the height of CoM at instant of takeoff to the peak of the jump. The linear and angular kinematics variables of preparation and propulsive phases for CMJ were calculated. The preparation phase started from the beginning of downward movement to the lowest position of CoM. The propulsive phase started from the lowest position of CoM to the instant of takeoff. Kinematic variables (see Table 1) were obtained to describe the CMJ performance.

Table 1. Means and SDs of Kinematic Variables (bolded numbers: $P < 0.05$; bolded numbers with * represent $P < 0.01$)

	Kinematic Variables	Skilled	Non-Skilled
	Jump Height [y]	**0.32 ± 0.03 m**	**0.24 ± 0.04 m***
Phases			
Preparation	Time [*X1*]	0.50 ± 0.07 s	0.48 ± 0.11 s
	Max. velocity at CoM [*X2*]	**-1.28 ± 0.2 m/s**	**-1.17 ± 0.19 m/s***
	Max. vertical displacement at CoM [*X3*]	**-0.37 ± 0.06 m**	**-0.30 ± 0.06 m***
	Trunk segmental angular displacement [*X4*]	**56.01 ± 6.72º**	**46.91 ± 11.32º***
	Thigh segmental angular displacement [*X5*]	**58.07 ± 5.63º**	**53.54 ± 5.91º***
	Shank segmental angular displacement [*X6*]	34.19 ± 6.06º	32.10 ± 5.42º
	Max. Hip joint angular velocity [*X7*]	**-340.05 ± 34.69º/s**	**-315.85 ± 54.00º/s***
	Max. Knee joint angular velocity [*X8*]	**-362.87 ± 122.76º/s**	**-307.42 ± 88.44º/s**
	Max. Ankle joint angular velocity [*X9*]	-158.07 ± 71.04º/s	-190.16 ± 91.37º/s
	Min. Hip joint angle [*X10*]	**51.65 ± 8.10º**	**70.36 ± 13.31º***
	Min. Knee joint angle [*X11*]	**70.60 ± 5.75º**	**78.89 ± 7.83º***
	Min. Ankle joint angle [*X12*]	**66.62 ± 3.49º**	**68.64 ± 4.96º***
Propulsive	Time [*X13*]	0.31 ± 0.05 s	0.30 ± 0.05 s
	Trunk segmental angular displacement [*X14*]	**52.99 ± 7.91º**	**42.87 ± 9.76º***
	Thigh segmental angular displacement [*X15*]	**57.75 ± 6.51º**	**53.5 ± 7.38º***
	Shank segmental angular displacement [*X16*]	**38.96 ± 3.94º**	**42.7 ± 6.09º***
	Max. Hip joint angular velocity [*X17*]	**706.00 ± 73.53º/s**	**604.43 ± 72.04º/s***
	Max. Knee joint angular velocity [*X18*]	**905.49 ± 112.29º/s**	**792.61 ± 76.17º/s***
	Max. Ankle joint angular velocity [*X19*]	680.09 ± 107.55º/s	645.95 ± 77.84º/s

Table 2. Correlations during preparation phase (bolded numbers: $P < 0.05$; numbers with * represent $P < 0.01$)

	X1	*X2*	*X3*	*X4*	*X5*	*X6*	*X7*	*X8*	*X9*	*X10*	*X11*	*X12*
Skilled	.17	**-.32**	**-.41***	**.35**	**.55***	-.23	-.26	-.02	-.24	**-.63***	**-.64***	**.50***
Non-Skilled	-.02	-.20	**-.57***	.19	-.11	.27	.16	-.04	.05	-.24	-.18	**-.49***

Zero-order correlation and stepwise multiple regression were performed to examine the association between the jump height and the kinematic variables. However, zero-order correlations can be somewhat misleading. Thus, in an effort to accurately identify the combination of factors contributing to jump height for preparation and propulsive phases, respectively, standard multiple regression was applied. Variance Inflation Factors (VIFs) values were analyzed and values exceeding 10 signified the presence of multicollinearity. In addition, visual inspection of scatterplots was completed to ensure linearity. Standard t-test was used to determine the difference of the selected kinematics variables between these two groups. Statistical significance was set at the $P < 0.05$ level.

3. Results

Skilled female volleyball players had significant higher jump height than non-skilled female volleyball players ($P < 0.01$) with significant differences in fourteen variables (Table 1). The association between jump height and kinematics variables were listed in Tables 2 and 3. The variables that were significantly associated with jump height for skilled volleyball players in the preparation phase (downward) were maximum vertical velocity at CoM ($r = -0.32$, $P < 0.05$), maximum vertical displacement at CoM ($r = -0.41$, $P < 0.01$), segmental angular displacement for trunk ($r = 0.35$, $P < 0.05$) and thigh ($r = 0.55$, $P < 0.01$), and minimum joint angle of hip ($r = -0.63$, $P < 0.01$), knee ($r = -0.64$, $P < 0.01$), and ankle ($r = 0.50$, $P < 0.01$). The only variable significantly associated with jump height for skilled female volleyball players during propulsive phase was trunk segmental angular displacement ($r = 0.34$, $P < 0.05$).

The standard multiple regression showed the best factors which contributed to jump height for skilled volleyball players during the preparation phase were minimum knee and ankle joint angles, trunk angular displacement, and maximum vertical velocity at CoM. Together these variables accounted 64% of variance in jump height for the skilled group. The standard multiple regression identified only one variable that significantly contributed to jump height during the propulsive phase of the skilled group, trunk angular displacement, which accounted for only 11% of jump height. For non-skilled female volleyball players, the best two variables during preparation phase contributed to jump height were thigh segment range of motion and CoM displacement which accounted 45% of variance of jump height. During the propulsive phase, only one variable was identified, maximum hip angular velocity, to have significant contribution to jump height. This variable accounted 22% of variance in jump height. All values of the VIFs were less than 10 with the highest of 3.1, indicating no problems with multicollinearity.

Table 3. Correlations during propulsive phase

	X13	*X14*	*X15*	*X16*	*X17*	*X18*	*X19*
Skilled	.23	**.34**	.24	-.10	.08	.10	-.14
Non-Skilled	-.14	.10	.21	.16	**.48***	**.32**	.16

Note: bold numbers: $P < 0.05$; numbers with * represent $P < 0.01$.

4. Discussion

As expected, skilled (0.32 ± 0.03 m) players had significantly greater jump height than non-skilled (0.24 ± 0.04m) female performers ($P < 0.01$). A total of eight variables were significantly associated with the jump height in the skilled group while only four variables correlated to the jump height in the non-skilled group (Tables 2 and 3). Furthermore, seven and two variables were associated with jump height during the preparation phase for skilled and non-skilled female volleyball players, respectively. The best model accounted 64% and 45% of the variance in the jump height for skilled and non-skilled group in preparation phase, respectively, with different combination of variables. This percentage of variance for skilled female performers was similar to studies of Argón-Vargas and Gross [6] and Mcerlain-Naylor et al. [13]. Interestingly, there are very few variables that associated with jump height for both groups during propulsive phase. During propulsive phase, the best variables that contributed to jump height accounted for 11% and 45% in the jump height for skilled and non-skilled players, respectively. The variables that significantly contributed to jump height for both groups are different in both phases. This indicates that a fundamental movement like CMJ can be performed differently due to skill level of the performers which results in different jump heights [10].

There are more variables that are associated with jump height in the preparation phase in the skilled group than in the non-skilled group. This implies that skilled players are better at coordinating these variables which resulted in higher jump heights than non-skilled players during the preparation phase. Among these variables, skilled players moved downward significantly faster than non-skilled players [1, 13] with greater range of motion of CoM vertical displacement, trunk and thigh angular displacements, and minimum joint angles at hip, knee and ankle joints [27] (Table 1). Additionally, skilled players exhibited greater hip and knee maximum flexion angular velocities (Table 1). All these imply that skilled players are able to move farther and faster to store more energy in musculoskeletal system than non-skilled players during preparation phase.

One interesting finding during the preparation phase was that the minimum ankle joint angle had significant association with jump height in both groups but one is positive and another is negative. This could be due to skilled athletes having greater hip and knee flexion where the body segments appear to be in a sitting posture with less ankle dorsiflexion during the preparation phase. During propulsive phase, only the trunk segment range of motion had a significant association with jump height in the skilled group. In the non-skilled group, there were two variables, maximum hip and knee angular velocities, that was significantly associated with jump height (Table 2). There were very few variables associated with jump height and identified as contributors for jump height during propulsive phase in the current study. This could be due to the homogeneous groups of performers in which less variability can be observed during the concentric phase of maximal performance.

Different variables were identified as crucial contributors to jump height for both groups according to multiple regression analysis. During the preparation phase, the minimum knee [27] and ankle joint angles, trunk angular displacement, and maximum velocity at CoM were identified as fundamental contributors in the skilled group while range of motion for thigh segment and CoM displacement were identified as significant contributors in the non-skilled group. This confirms the importance of preparation phase to jump height since more variables were identified in the skilled group. On the other hand, the standard multiple regression identified one variable, trunk angular displacement, as crucial factor to jump height for skilled group during the propulsive phase. For the non-skilled groups during the propulsive phase maximum hip angular velocity was identified as a crucial contributor. Both of these variables point out the importance of hip extensors to jump height for different skilled levels of performers when upper body (hip and above) has greater percentage of the body mass [17] (about 60%) while arm (arm swing) was not allowed to assist the jumping performance.

Studies have examined the methods to enhance an athlete’s jumping ability through many different approaches based on the knowledge of stretch-shortening cycle (SSC) such as strength and conditioning. In this study, the biomechanical model for CMJ exhibited by skilled female volleyball athletes should be taught to unskilled athletes. Performers need to be able to move downward farther and faster to jump higher during the preparation phase. This phase is an important part of SSC which represents high-intensity of eccentric muscle action and results in high power output during concentric phase of a CMJ [20, 25-27]. Multiple studies showed that plyometric training is an effective method to improve countermovement jump height about 8.7% [15, 21-24] and thus, is recommended to be integrated as part of the practice regimen for individuals or teams. To move downward further, it is suggested that performers rotate trunk and thigh angles more to minimize hip and knee joint angles. Finally, during the propulsive phase, both skilled and unskilled performers should be encouraged to extend their hip joint further and faster.

In summary, the preparation phase for countermovement jump appears to be important to enhance jump height based on the findings of this study. In addition, hip extension is also important for jumping performance during the propulsive phase of performance. However, the transition from preparation to propulsive phase was not in the scope of this study which may clarify the utilization of stored energy. Furthermore, jump height in this current study was defined as the vertical displacement of CoM from the instant of takeoff to the peak of the jump. This is merely a part of overall performance such as volleyball block height, spike height, basketball rebound height, etc. since there are other components that consist of the overall height of performance. The limitations of current study were: 1) homogeneous groups of performers, 2) the maximum effort of each attempts during data collection, 3) subjective selection of kinematic variables for analysis, 4) only female volleyball players with different skill levels were examined, and 5) kinetic variables were excluded in the analysis.

5. Conclusions

Skilled female volleyball players were better able to coordinate more variables in the preparation phase to enhance jump height where there were very few variables were identified in non-skilled group. In order to jump higher, moving farther and faster during the preparation phase is essential and the minimum knee and ankle joint angles, trunk angular displacement, and maximum downward velocity at CoM were crucial factors. During the propulsive phase, hip extensors were important for trunk angular displacement and hip extension angular velocity. This study confirms the ability to utilize SSC to enhance jump height is essential between different skill levels of female volleyball players.

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