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LOWERING VELOCITY OF THE CENTRE OF MASS DURING THE APPROACH AFFECTS JUMP HEIGHT IN VOLLEYBALL SPIKE JUMPS

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It is assumed that a high impact height and therefore a high jump height is a relevant factor for success in volleyball spikes. The purpose of the study was to investigate whether the speed of the vertical movement of the centre of mass during the approach phase affects the jump height or not. Therefore, spikes from position IV were analysed at a tournament of the European League. Results showed that the faster the COM can be lowered and the faster the direction of the COM movement can be turned into an upward movement, the higher the jump height can be. This should be addressed within the training process.

KEYWORDS: Volleyball, Spike, Motion analysis, Coordination

INTRODUCTION: In volleyball the impact height in spike jumps is an important factor of success (Neef & Heuchert, 1978, Tilmann et al., 2004). The optional target area at the opponents court increases with rising impact height of a volleyball spike jump. It is possible to raise the impact height by increasing the jump height. Hence, the aim of this study was to find parameters during the approach phase affecting the jump height in spike jumps from position IV.
The knee angles and their time histories describe the amount of the lowering movement of the centre of mass (COM) during the approach. Together with the closing time and step length these parameters characterises the execution of the approach. It is anticipated that COM height decreases together with a lower knee angle in the last step. For storing energy in the elastic elements, the amount and velocity of the knee bending and therefore, the elongation of the knee extensor muscles and the time history of these variables are important describing parameters. Komi & Bosco (1978) suggested that the power output of extensor muscles could be increased by a lengthening movement previous to the concentric phase. Komi & Bosco (1978) explained this with the storing of elastic energy in the elastic elements of a muscle. It is of deeper interest to investigate whether an optimum range of this extension movement could be found for the approach of the volleyball spike, only using 3D-data of a motion analysis during competition or not.

METHODS: The database included spike movements performed by male outside hitters of the national teams of Croatia, Estonia, Germany and the Netherlands. The data were recorded during a European League tournament. Since the most important spike position used by international top level teams is position IV (Kuhlmann et al., 2008), only spikes from this position were considered. Position IV is the position of the outside hitter at the left side of the court in front of the net. The pass was always played half high and without combination. Fast or unscheduled actions due to a bad pass were excluded. Therefore, only actions were accepted when the outside hitters always had enough time to prepare themselves for an optimal spike jump, including the approach and the takeoff. All subjects performed a step-close technique, identified by Coutts (1982). The flight angle of the ball after impact had to be 110° to 145° to the net to improve the standardisation of the boundary conditions.
Ten elite outside hitters of different national teams of the highest order were analysed. This is equivalent to approximately 10% of the outside hitters playing in national teams on highest

international level. The sample had a mean body height of 198.8 $\pm$ 4.4cm and a mean body mass of 92.0 $\pm$ 5.3kg. From each player one spike jump was analysed. The study concurred in the exigencies of the ethics committee for human research and in current local laws and regulations. Due to the camera positions, no effect on the players or on the results occurred.
Four digital cameras (BASLER A602fc-2) were positioned around the volleyball court capturing the spikes with a frame rate of 100 Hz. The cameras were activated and triggered externally. The frame rate was also externally controlled. The accuracy of the frequency controlling was previously tested. No relevant irregularity in the frequency was reported.
The calibration of the measurement setup and the methodology of the data-processing was described by Kuhlmann et al. (2007) in detail. A verification of this method by calculating points with known 3D coordinates showed an accuracy of 9.9 $\pm$ 7.7 mm (x-direction), 4.7 $\pm$ 1.4 mm (y-direction), 8.3 $\pm$ 4.4 mm (z-direction).
All digitisers had to digitise the same standardised test videos before they were allowed to start the original digitising process for this study. Inter-digitiser reliability was investigated by calculating differences of angles and changes in segment length of selected angles and segments of these test-videos. Inter-digitiser reliability was calculated as 0.07 ± 0.06° for angles and 1.3 ± 0.9mm for changes in segment length in the mentioned test videos.
17 anatomical landmarks were digitised in each frame of all four cameras to calculate the centre of mass (COM) using the HANAVAN-Model. The values of COM-height, maximum COM-lowering velocity (v_{COMlow}) and time differences were calculated from the 3D-coordinates, provided by the software SIMI-Motion. Jump height (JH) was calculated as the difference of COM-height at the last frame of ground contact and the highest COM in the flight phase. COM-vertical velocity at the last frame of ground contact (v_{COMvert}) was calculated, because this is the last moment to influence the jump height and jump direction of the COM. The flight characteristics of the COM cannot be influenced when airborne.
Kendall's correlation coefficient was calculated to detect coherence between those parameters. Statistical evaluation of the data was conducted using SPSS 16.0.

RESULTS: The mean values of jump height, v_{COMlow} and v_{COMvert} are presented in table 1. The time period from v_{COMlow} to the maximum vertical acceleration of the COM (a_{COMvert}) was calculated as 220 ± 37.4ms. Kendall's correlation coefficient between v_{COMlow} and jump height was calculated as r_T=-0.72. For the time period (Δt) between the moment of v_{COMlow} and the last frame of ground contact ($\Delta t_{v\mathrm{COMlow/LFGC}}$) and jump height r_T was calculated as -0.74. $\Delta t_{v\mathrm{COMlow}\,/\,a\mathrm{COMvert}}$ correlated with r_T= -0.75 with jump height. Kendall's correlation coefficient was calculated as r_T= 0.85 between jump height and v_{COMvert}. $\Delta t_{v\mathrm{COMlow}\,/\,\mathrm{LFGC}}$ was calculated as 312 ± 43.7ms.

Table 1
Selected mean values of the sample

Variable	Arithmetic Mean	Standard Deviation
Jump Height	63.2 cm	6.2 cm
v_{COMvert}	3.5 m/s	0.4 m/s
v_{COMlow}	-0.8 m/s	0.1 m/s

DISCUSSION: A high negative amount of v_{COMlow} correlates with a high amount of v_{COMvert} at the last frame of ground contact (LFGC) and with a high appendant jump height. Jump height depends directly on v_{COMvert}. Hence, a high correlation coefficient between jump height and v_{COMvert} is the logical consequence.
Results show that jump height increases when the time difference between v_{COMlow} and the last frame of ground contact is short. The reason for this effect could be the potentiation of power because of the mechanical properties of the muscle. The power output can be increased after lengthening the muscle because of the storage of elastic energy (Nicols, 1973; Stienen et al., 1978) in the muscle. The elastic energy can be stored for a short time.

Afterwards it can be utilised for power output. When not using the stored energy it dissipates and cannot be used for raising the power output anymore. That means the shorter the period of time between lengthening and shortening the less stored energy dissipates. This can be explained by the cross-bridge binding. The coupling time lasts from 15 ms (Stienen et al. 1978) to 120 ms (Nicols, 1973). After this time period the cross-bridges releases. The more cross-bridges exist, the more elastic energy can be stored in the muscle. After the coupling time expires, the cross-bridges releases and stored energy dissipates. The described data shows this effect of utilising stored energy by the negative correlation coefficient between $\Delta t_{vCOMlow\ /\ vCOMvert}$ and the jump height. The shorter the time difference between the storage of the elastic energy and reinstating it, the more stored energy can be used and the higher the jump height can be.
$\Delta t_{vCOMlow\ /\ LFGC}$ was calculated as 312 ± 43.7ms. The time period from v_{COMlow} to the maximum vertical acceleration of the COM ($a_{COMvert}$) was calculated as 220 ± 37.4ms. Both time intervals are longer than the coupling time described in the literature, but both describe the velocity of the movement in the stretch-shortening cycle (SSC). Because of the extended amplitude of this movement it is assumed that most cross-bridges releases during the movement.

CONCLUSION: It has to be an aim to raise the impact height in spike jumps of outside hitters in volleyball. The higher the impact height, the higher the chance for a successfull spike jump (Neef & Heuchert, 1978). There are several possibilities to increase the impact height. Kuhlmann et al. (2009) showed that the body posture during the flight phase and at the moment of impact might have an influence on the impact height. Another possibility is to increase the jump height. There are several parameters in the approach phase influencing the jump height. In this study it was shown that the time period between the maximum lowering velocity in vertical direction of the COM (v_{COMlow}) and the last frame of ground contact and also the time period between v_{COMlow} and $a_{COMvert}$ correlates with jump height. The shorter these time intervals the higher the jump height. In the same way the maximum value of v_{COMlow} influences the jump height. The faster the COM can be lowered and the faster the direction of the COM movement can be turned into an upward movement, the higher the jump height can be. It might be useful for coaches concentrate their attention on a fast and resolute performance of this part of the approach.

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