SUBJECT- AND JOINT-SPECIFIC STRATEGIES USED BY MALE BASKETBALL PLAYERS TO MAXIMIZE COUNTERMOVEMENT JUMP HEIGHT

Kristof Kipp, Michael Kiely, Matthew Giordanelli,
Philip Malloy, Christopher Geiser

Department of Physical Therapy, Marquette University, Milwaukee, USA

The purpose of this project was to study the subject- and joint-specific strategies that male basketball players use to increase countermovement jump (CMJ) height. Lower extremity joint kinematics and kinetics were recorded as 11 male, NCAA Division I basketball players performed 8-10 CMJ with increasing effort. Correlations between maximal potential energy of players' centre-of-mass (surrogate for CMJ height) and the amount of eccentric and concentric work done at the hip, knee, and ankle joint Single-subject and group-average analyses were used to study. The group-average analysis showed that all joint work variables predicted potential energy, whereas the single-subject analysis revealed varying levels of subject-specific correlations (i.e., joint-specific CMJ strategies) that did not necessarily reflect the group-average data.

KEY WORDS: biomechanics, single-subject analysis, mechanical work, sport.

INTRODUCTION: Vertical jumping is an integral aspect to high-level performance in the sport of basketball. Accordingly, a large part of the physical training and conditioning of basketball players focuses on increasing their jumping performance. In an effort to optimize training and enable a more objective use of exercise selection, researchers have investigated joint-specific contributions to vertical jumping (Lees, Vanrenterghem & De Clercq, 2004).

During maximal effort vertical jumps the work done by muscles that cross the hip joint appears to be the primary contributor to the total positive work performed (Hubley & Wells, 1983). Analysis of sub-maximal and maximal vertical jumps further indicates that hip joint mechanics are the primary driver associated with the differences in jump height between these types of jumps (Lees, Vanrenterghem & De Clercq, 2004; Vanrenterghem et al., 2004). In addition, peak hip joint torques and powers are greater in good jumpers compared to poor jumpers (Aragón-Vargas & Gross, 1997a). More specifically, the range of hip flexion motion during the countermovement increases with jump height (Vanrenterghem et al., 2004). In addition, the work done at the hip also markedly increases as jump height increases (Lees, Vanrenterghem & De Clercq, 2004).

Although previous studies have highlighted joint-specific contributions to sub-maximal and maximal vertical jump performance, far fewer studies have investigated subject-specific strategies during vertical jumping (Aragón-Vargas & Gross, 1997b). While these studies have provided interesting insights into subject-specific contributions to maximal effort vertical jumps, still relatively little is known about the joint-specific strategies that are used by individuals as they increase the height of their vertical jumps from sub-maximal to maximal effort levels. Interestingly, eccentric-phase mechanics appear more relevant in single-subject than group-average analyses of maximal effort jumps (Aragón-Vargas & Gross, 1997a; Aragón-Vargas & Gross, 1997b). Given that over half of the power delivered by the ankle joint comes from the return of energy stored in the muscle tendon unit during the eccentric phase (Bobbert, Huijing & van Ingen Schenau, 1986), it is thus surprising that eccentric-phase mechanics are rarely considered as part of the subject- or joint-specific analyses of vertical jump performance.

Given that a person's movement dynamics reflect joint- and subject-specific strategies across sub-maximal and maximal vertical jumps, full knowledge of these strategies would be required to optimize and individualize the exercise selection process during the program design phase of long-term physical training and conditioning for that person. The purpose of this study was to study subject-specific and joint-specific strategies used by high-level, male basketball players during sub-maximal and maximal effort vertical jumps in order to provide individualized insight into how they increase jump height and maximize performance.

METHODS: Eleven male, NCAA Division I basketball players (Mean±SD; Age: 21.6±1.8 years; Body Height: 193.3±10.2 cm; Body Mass: 80.5±10.5 kg) were recruited for this study. Each player provided written informed consent, which was approved by the local University's IRB. Each player performed a brief warm-up that included light calisthenics and several sub-maximal countermovement jumps (CMJ). After this brief warm-up each player performed 8-10 CMJ with increasing effort; two CMJ each at 25%, 50%, 75%, and 100%. Up to two additional CMJ were performed if players felt that they could jump higher during their maximal effort attempts. All CMJ were performed with arm swing.

Kinematic and kinetic data were collected during each CMJ. Kinematic data were collected with a 14-camera Vicon motion capture system at 100 Hz. Kinematic data were recorded from reflective markers that were attached to various anatomical landmarks and marker clusters that were attached bi-laterally to the thighs, shanks, and feet (Geiser, O'Connor & Earl, 2010). Kinetic data were collected at 1000 Hz from two AMTI force plates that were built into the floor.

Kinematic and kinetic data were both filtered at 15 Hz. Lower extremity biomechanics were calculated based on a four rigid-link model that included a foot, shank, thigh, and pelvis segment (Geiser, O'Connor & Earl, 2010). A standard inverse dynamics procedure that combined kinematic and kinetic data with anthropometric data was used to calculate the net internal joint torques of the hip, knee, and ankle joints (Winter, 2005). Joint powers were calculated as the product of joint torques and angular velocities, and were then in turn integrated to yield joint work.

The movement phase at each joint was broken down into eccentric and concentric phases, which were defined as periods when joint powers were negative and positive, respectively. Eccentric and concentric joint work of the left and right lower extremity were average by joint, so as to produce average values of hip, knee, and ankle joint work. Each of the joint work values were then normalized to body-mass. In addition, joint work was summed to provide an overall total of the amount of lower extremity work done (Flanagan & Salem, 2005). CMJ height was calculated from the displacement of one of the pelvis segment markers during the CMJ, and the gain in potential energy during the CMJ was subsequently calculated (Hubley & Wells, 1983).

Simple linear regression analyses were used to assess the correlations (Pearson's r) between the independent (CMJ effort) and dependent variables (joint and total work). Single-subject and group-average regression analyses were performed. In each case, the level of significance was set to 0.05.

RESULTS: The correlation coefficients and significance levels for the single-subject and group-average analyses are presented in Table 1.

DISCUSSION: The purpose of this study was to study subject- and joint-specific strategies used by high-level, male basketball players during sub-maximal and maximal effort CMJ. The practical application of such results should help provide insight into how each individual athlete increases vertical CMJ height, and maximizes performance.

With respect to joint-specific strategies, the correlation results between individual joint work and CMJ height indicated that in order to jump higher four players increased concentric work at the hip joint, five players increased work at the knee joint, and four players increased work at the ankle joint. It should be noted here, that several players increased work at multiple joints to increase CMJ height and that some did not exhibit any significant correlations between individual concentric joint work and CMJ height. In fact, for two players the only significant predictor of CMJ height was eccentric joint work. It is interesting to further note that these two players (Player 1 & 3) still exhibited significant correlations between total concentric joint work and CMJ height, which may suggest that these players absorb energy at primarily one joint and then distribute that energy to other joints during the concentric phase.

Table 1
Individual (Player 1-10) and team-average (AVG) correlations (Pearson's r) and significance levels (*p*-values – in brackets and *italics*) between COM potential energy and eccentric (Ecc) and concentric (Conc) total and individual lower extremity joint work during countermovement vertical jumps in male NCAA Division I basketball players.

	Hip		Knee		Ankle		Total	
Player	Ecc	Conc	Ecc	Conc	Ecc	Conc	Ecc	Conc
1	**0.919**	0.864	0.448	0.769	0.662	0.867	**0.881**	**0.919**
	(0.027)	*(0.059)*	*(0.449)*	*(0.129)*	*(0.223)*	*(0.057)*	***(0.048)***	***(0.027)***
2	0173	0.586	0.425	0.483	0.088	0.518	0.241	**0.829**
	(0.656)	*(0.097)*	*(0.255)*	*(0.188)*	*(0.822)*	*(0.153)*	*(0.533)*	***(0.006)***
3	0.620	0.607	**0.801**	0.424	0.196	0.082	0.590	**0.781**
	(0.075)	*(0.083)*	***(0.009)***	*(0.255)*	*(0.614)*	*(0.833)*	*(0.094)*	***(0.013)***
4	0.668	**0.777**	**0.813**	**0.782**	0.514	**0.816**	**0.746**	**0.795**
	(0.070)	***(0.023)***	***(0.014)***	***(0.022)***	*(0.193)*	***(0.014)***	***(0.034)***	***(0.018)***
5	0.501	0.793	0.554	**0.829**	0.762	0.564	0.640	0.798
	(0.311)	*(0.060)*	*(0.254)*	***(0.042)***	*(0.078)*	*(0.244)*	*(0.171)*	*(0.057)*
6	**0.952**	**0.916**	**0.944**	**0.782**	0.615	0.323	**0.944**	**0.782**
	(0.001)	**(0.001)**	**(0.001)**	**(0.008)**	(0.059)	(0.362)	***(0.001)***	***(0.008)***
7	0.522	**0.699**	0.614	0.554	0.607	0.520	0.614	**0.686**
	(0.149)	**(0.036)**	(0.079)	(0.122)	(0.083)	(0.151)	*(0.079)*	***(0.041)***
8	0.638	0.529	**0.759**	**0.831**	0.676	**0.768**	**0.823**	**0.837**
	(0.089)	(0.178)	**(0.029)**	**(0.011)**	(0.066)	**(0.026)**	***(0.012)***	***(0.010)***
9	0.182	0.338	0.044	0.525	0.025	0.545	0.414	0.185
	(0.696)	(0.458)	(0.925)	(0.226)	(0.958)	(0.206)	*(0.356)*	*(0.691)*
10	**0.832**	**0.705**	0.034	**0.898**	**0.708**	**0.918**	0.034	**0.958**
	(0.005)	**(0.034)**	(0.931)	**(0.001)**	**(0.033)**	**(0.001)**	*(0.931)*	***(0.001)***
11	0.796	0.684	0.382	0.612	0.364	**0.892**	0.695	**0.866**
	(0.058)	*(0.134)*	*(0.455)*	*(0.196)*	*(0.547)*	***(0.017)***	*(0.125)*	***(0.026)***
AVG	**0.924**	**0.900**	**0.776**	**0.756**	**0.831**	**0.917**	**0.961**	**0.937**
	(0.001)	***(0.001)***	***(0.024)***	***(0.030)***	***(0.011)***	***(0.001)***	***(0.001)***	***(0.001)***

Note: *p*-values < 0.05 are highlighted in **bold** font

The results showed that nine out of eleven players demonstrated significant positive correlations between total concentric joint work and CMJ height. In contrast, only four out of the eleven players demonstrated significant positive correlations between total eccentric joint work and CMJ height. These findings suggest that with regards to CMJ performance, concentric joint work is a better indicator than eccentric joint work. It could be speculated that these individuals did not demonstrate significant correlations between total eccentric joint work and CMJ height did not effectively use the stretch-shortening cycle or were unable to transfer joint work effectively between joints (Bobbert, Huijing & van Ingen Schenau, 1986).

Out of the two players that did not demonstrate any significant correlations between total joint work (either eccentric or concentric) and CMJ height, only one did not demonstrate any joint-specific correlations, which was surprising given the hypothetical association between joint energetics and CMJ height. The other player, however, did demonstrate a significant correlation between concentric joint work and CMJ height.

The group-average analysis showed that all joint work variables predicted CMJ height, which is in stark contrast to the above-mentioned discussion about the joint-specific strategies that players use to increase CMJ height. Given this discrepancy, these results underscore the disparity, and respective utility, of group-average and single-subject analyses in the field of sports biomechanics.

CONCLUSION: In summary, this study highlighted that out of a group of high-level (NCAA Division I) athletes, players used unique combinations of joint-specific strategies to increase

CMJ height across sub-maximal and maximal jump efforts. The practical implications of these results suggest that the strategies used by players to increase and maximize CMJ height are highly individualized. Therefore, future studies should investigate the effects of individualized exercise prescription and training programs that are based on a players' joint-specific CMJ strategy.

REFERENCES:

Aragón-Vargas, L. F., & Gross, M. M. (1997a). Kinesiological factors in vertical jump performance: differences among individuals. *Journal of applied Biomechanics*, 13, 24-44.

Aragón-Vargas, L. F., & Gross, M. M. (1997b). Kinesiological factors in vertical jump performance: differences within individuals. *Journal of applied Biomechanics*, 13, 45-65.

Bobbert, M. F., Huijing, P. A., & van Ingen Schenau, G. J. (1986). An estimation of power output and work done by the human triceps surae musle-tendon complex in jumping. *Journal of biomechanics*, 19, 899-906.

Flanagan, S. P., & Salem, G. J. (2005). The validity of summing lower extremity individual joint kinetic measures. *Journal of applied biomechanics*, 21, 181-188.

Geiser, C. F., O'Connor, K. M., & Earl, J. E. (2010). Effects of isolated hip abductor fatigue on frontal plane knee mechanics. *Medicine and science in sports and exercise*, 42, 535-545.

Hubley, C. L., & Wells, R. P. (1983). A work-energy approach to determine individual joint contributions to vertical jump performance. *European Journal of Applied Physiology and Occupational Physiology*, 50, 247-254.

Lees, A., Vanrenterghem, J., & De Clercq, D. (2004). The maximal and submaximal vertical jump: implications for strength and conditioning. *The Journal of Strength & Conditioning Research*, 18, 787-791.

Vanrenterghem, J., Lees, A., Lenoir, M., Aerts, P., & De Clercq, D. (2004). Performing the vertical jump: movement adaptations for submaximal jumping. *Human movement science*, 22, 713-727.

Winter, D.A. (2005). Biomechanics and motor control of human movement. New Jersey: John Wiley & Sons, Inc.

Acknowledgement

The authors would like to thank the Marquette University Sports Performance staff for their collaboration with this project.