INTRASUBJECT VARIABILITY OF THE KINEMATICS OF THE VERTICAL JUMP

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The variability of the kinematics of the vertical jump was studied in a sample of eight young adults. Six maximal effort vertical jumps from each subject were analyzed with the Peak Motus 2D videography (60 Hz) system. Kinematics of a seven segment model were calculated from the initiation of downward movement to five frames after take-off. The intrasubject variability was usually small but depended on the kinematic variable of interest. Discrete angular kinematic variables of key events had mean standard deviations between 2.7 and 6.5 degrees. Most displacement and velocity variables had coefficients of variation between 1 and 10 percent. These vertical jumpers used consistent movement patterns so single jumps would be representative of normative performance.

KEY WORDS: consistency, coefficient of variation, angle, velocity

INTRODUCTION: Movement variability is an important issue in biomechanics. Given the large number of degrees of freedom of the human musculoskeletal system, variability in the production of movement is a given. There has been considerable interest in this variability of movement from biomechanical (Hatze, 1995; Winter, 1984; Zehr and Sale, 1997) and motor control perspectives (Newell and Corcos, 1993). Studies of intrasubject variability are important in understanding the reliability and the size of meaningful changes in biomechanical signals (Salo and Grimshaw, 1998), as well as appropriate experimental designs to establish group differences in biomechanical variables (Bates, 1989; Bates, Dufek, & Davis, 1992; Dufek, Bates, Sterogiu, & James, 1995). Unfortunately, most studies of the variability of biomechanical signals have focused on continuous activities like walking and running, with fewer studies of discrete movements or skills.

The vertical jump is an important discrete skill in a variety of sports and activities. Most studies of vertical jumps have used between-subjects designs with single jumps from each subject because it is believed that there is an optimal kinematic structure in this movement and subjects are consistent in their performance (Bobbert et al., 1986; Bobbert and van Ingen Schenau, 1988; Bobbert and van Soest, 1994). Few studies, however, have documented the consistency of biomechanical variables in the vertical jump. Hudson (1986) noted that there were high intra-class correlation coefficients for selected discrete kinematic variables in three repeated vertical jumps of 20 subjects. Some studies have examined the variability and reliability of kinetic variables of the vertical jump (Cordova and Armstrong, 1996; Rodano, Squadrone, Rabuffetti, & Mingrino, 1996). A study was needed to document the intra-subject variability of the kinematics of vertical jumps in normal subjects. The data would be useful in establishing the consistency of kinematic variables that are typically qualitatively analysed by coaches and for suggesting the numbers of trials needed for stable intra-subject data. Kinematic variability data are also useful for interpreting changes in technique with training or comparisons with different subjects. The purpose of this study was to document the intra-subject variability of selected kinematics of the vertical jump.

METHOD: Eight physically active young adults gave informed consent and volunteered for the study. The group was a sample of skilled jumpers with intercollegiate or high school athletic experience. The subjects were seven males and one female with a mean (± SD) age of 25.6 ±5.4 years. After a warm-up and several practice jumps, subjects performed six maximal vertical jumps with approximately 5 to 10 seconds rest between trials. Spherical reflective markers (18 mm diameter) were taped to joint centre locations to define the endpoints of a seven segment model of the body. The model included the feet, legs, thighs, trunk, head/neck, arm, and forearm/hand segments. Symmetry of the opposite side of the body was assumed and anthropometric data (Plagenhoef, Evans, & Abdelnour, 1983) were used to calculate the whole body centre of gravity.

Sagittal plane images (60 Hz) of the vertical jumps were collected with a Panasonic N5100 video camera. Video records of the jumps were digitised with the PEAK Motus analysis system from the initiation of the countermovement to five frames after take-off. Data were smoothed with a recursive Butterworth digital filter with cut-off frequency selected by the Jackson (1979) method. Five potentially observable jumping technique kinematic variables were calculated - knee angle, hip angle, trunk inclination, vertical position and velocity of the centre of mass. Joint angular velocities were also calculated to examine the variability of higher order kinematic variables. Intra-subject variability of these variables was documented by calculating the standard deviations (SD) and coefficients of variation (CV). Typical variability of each kinematic variable was documented by calculating the mean variability across subjects. Normative kinematics of the vertical jumps were calculated from subject mean and best jump data, and the pattern of movement was examined by calculating mean curves for each variable.

RESULTS: Most vertical jump kinematic variables were highly consistent, while some were slightly more variable. Table 1 presents mean intra-subject coefficients of variation for angular and linear kinematic variables at key points in the jump. Note that there was a trend of less variability at take-off when joint extension (hip and knee) was nearing its anatomical constraints. The trunk angle at take-off appears more variable, but this is an artifact of the very small mean angle of trunk lean at take-off. The mean intra-subject SD for trunk lean at take-off and at maximum countermovement were 4.1 and 2.7 degrees, respectively. The mean intra-subject SDs of all discrete angular kinematic variables were between 2.7 to 6.5 degrees. The intra-subject variability of higher order kinematic variables are presented in Table 2. Note that vertical take-off velocity is very consistent with a mean CV of 2.5 percent. This was similar to exemplar results presented by Aragon-Vargas and Gross (1997).

Table 1 **Mean (SD) Intra-subject Coefficients of Variation of Discrete Kinematics**

	Max Countermovement	Take-off
Knee Angle	4.5 (2.0)	2.2 (1.0)
Hip Angle	9.2 (5.3)	1.8 (0.5)
Trunk Inclination	7.4 (4.3)	33.9 (18.9)
Vertical Position$_{CM}$	2.0 (1.4)	0.8 (0.4)

* CM = centre of mass, Coefficient of variation (%) = (SD/mean)*100

DISCUSSION: Intrasubject variabilities of the kinematics of the vertical jump in these subjects were very small. Skilled vertical jumpers can be expected to create highly consistent linear and angular displacements and velocities across jumps. Coaches qualitatively analysing the vertical jumps of skilled performers will only need to observe multiple trials based on their ability to observe the relevant components of the jump. The patterns and peak values of mean curves for each subject were similar to curves from the trial with the highest take-off velocity. This is in contrast to the differences observed in a more open task like the tennis forehand (Knudson, 1990). The greater variability of mean angular velocity curves compared to angular position reported by Knudson (1990) was not observed in the vertical jump. If displacement and velocity variables in skilled vertical jumps are highly consistent, coaches and researchers can assume a single, full-effort vertical jump of a skilled performer will be representative of their performance. This simplifies the qualitative or quantitative analysis of the individual over time. It is likely that higher order variables like acceleration and derived kinetics require multiple trials to establish stable normative data because of their greater variability (Rodano et al., 1996; Winter, 1984).

Table 2 **Mean (SD) Intra-subject Variability of Vertical Jump Kinematics**

	Mean Standard Deviation	CV (%)
Eccentric Phase		
VDCM$_{CM}$ (cm)	3.0 (1.5)	9.0 (3.9)
MAXKEAV (deg/s)	21.2 (11.1)	10.6 (6.1)
Concentric Phase		
VVTO$_{CM}$ (m/s)	0.06 (0.02)	2.5 (1.2)
MAXKCAV (deg/s)	31.7 (19.7)	4.0 (2.4)
MAXTCAV (deg/s)	14.1 (9.5)	10.1 (5.5)

* VDCM$_{CM}$ = vertical displacement of centre of mass (magnitude of countermovement), MAXKEAV = maximum knee eccentric angular velocity, VVTO$_{CM}$ = vertical velocity at take-off of center of mass, MAXKCAV = maximum knee concentric angular velocity, MAXTCAV = maximum trunk concentric angular velocity.

Table 3 compares the mean kinematic data across the subjects calculated from mean subject data versus the jumps with the greatest take-off velocity. These data indicate that the analysis of single maximal jumps yield similar mean and variability measures across subjects compared to averaging subject mean data. When comparing the movement of different jumpers, the between subject differences in jumping motion are usually large (Hubley & Wells, 1983) compared to within subject variation. In the present study intersubject standard deviations were two to three times larger than intra-subject standard deviations. Several biomechanical factors like coordination (Hudson, 1986) and rate of force development (Jaric, Ristanovic, & Corcos, 1989) are likely to be related to the larger kinematic differences in vertical jumps across rather than within subjects. More data are needed to document the variability of less skilled subjects who could be expected to have greater intra-subject and inter-subject variability in vertical jump kinematics.

Table 3 **Comparison of Between-Subject Mean (SD) Vertical Jump Kinematics**

	Mean of Six Jumps	Best Jump
Eccentric Phase		
MINKANGLE (deg)	83.4 (12.9)	85.9 (12.1)
MAXTLEAN (deg)	56.8 (13.3)	55.0 (11.5)
MAXKEAV (deg/s)	-213 (44)	-242 (48)
Concentric Phase		
VVTO$_{CM}$ (m/s)	9.02 (1.26)	9.31 (1.23)
MAXKCAV (deg/s)	775.8 (63.2)	776.8 (71.1)
MAXTCAV (deg/s)	139.9 (47.1)	130.7 (41.8)

- MINKANGLE= minimum knee angle, MAXTLEAN= maximum trunk lean, MAXKEAV = maximum knee eccentric angular velocity, VVTO$_{CM}$ = vertical velocity at take-off of center of mass, MAXKCAV = maximum knee concentric angular velocity, MAXTCAV = maximum trunk concentric angular velocity.

CONCLUSION: The consistency of position and velocity data of vertical jumps for skilled subjects is quite good. Coaches can expect observations of body motion in single vertical jumps to be close to typical and best performance in skilled subjects. Studies of the lower order kinematics of skilled vertical jumpers may be able to analyse one jump per subject. There is a need for data on the intra-subject and inter-subject variability of the kinematics of the vertical jump in lower skill levels.

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